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ISGF
India Smart Grid Forum

SMART GRID HANDBOOK

FOR REGULATORS AND POLICY MAKERS

NOVEMBER 2017

India Smart Grid Forum

India Smart Grid Forum

India Smart Grid Forum (ISGF) is a Public Private Partnership initiative of Ministry of Power (MoP), Government of India for accelerated development of smart grid technologies in the Indian power sector. Mandate of ISGF is to advise government on policies and programs for promotion of Smart Grids in India, work with national and international agencies in standards development and to help utilities, regulators and the Industry in technology selection, training and capacity building.

SHAKTI SUSTAINABLE ENERGY FOUNDATION

Shakti Sustainable Energy Foundation

Shakti Sustainable Energy Foundation was established in 2009 to facilitate India's transition to a sustainable energy future by promoting policies that encourage energy efficiency as well as the increased generation of renewable energy. The energy choices that India makes in the coming years will be of profound importance. Meaningful policy action on India's energy challenges will strengthen national security, stimulate economic and social development and keep our environment clean.

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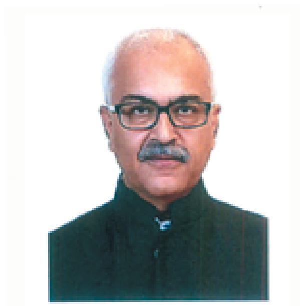

MESSAGE

I am pleased to learn that India Smart Grid Forum (ISGF) is publishing a Smart Grid Handbook for regulators and policymakers and is expected to provide insights on various aspects of smart grid.

Smart grid is an important step towards technology renovation and will require change in both business and operational strategies of the utilities. This handbook captures every aspect of smart grid components in detail and will serve as a good reference document for all concerned stakeholders in the domain.

I appreciate ISGF and its team of professional for their noteworthy efforts and wish them success in their future endeavors!

(A. K. Bhalla)

RIGHT TO INFORMATION

स्वच्छ भारत
एक कदम स्वच्छता की ओर

केन्द्रीय विद्युत विनियामक आयोग
CENTRAL ELECTRICITY REGULATORY COMMISSION

सत्यमेव जयते

के वि वि आयोग
CERC

Gireesh B. Pradhan
Chairperson

D.O.No. Chmn/Message/2017
Dated : 11.12.2017

Message

I am happy to learn that India Smart Grid Forum is bringing out this "Smart Grid Handbook for Regulators and Policy Makers". At the outset, I appreciate the initiative taken by ISGF to facilitate the Regulators and Policy makers with detailed information encompassing different aspects of smart grid and its components.

As we understand 'Smart Grid' facilitates the system to respond intelligently to changes in its environment, including demand, supply besides the changes in the connected external systems. Further, it is aimed at achieving improved performance besides facilitating the stakeholders to take informed decisions. The fundamental benefits include easy absorption of future technologies, removal of redundancies prevalent in the current systems, and more importantly substantial reduction of losses, thereby giving correct price signals to the consumers.

Most importantly, the 'Smart Grid' is likely to lead the utilities to change their business strategies and re-orient their business processes. As the policy makers and regulators are closely monitoring the developments in the sector and ready to take initiatives, this handbook is expected to give them insight into this emerging segment of electricity industry.

I appreciate ISGF and its team of professionals for their laudable efforts and wish them success.

(Gireesh B. Pradhan)

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NEW DELHI-110066, Dated : 12 December 2017

MESSAGE

I am pleased to note that India Smart Grid Forum (ISGF) has prepared a comprehensive Smart Grid Handbook which is the need of the hour in India. Utilities in India are rolling out smart grid projects for which we need large number of engineers who understand the topics. Also we require policy makers and regulators who approve smart grid projects, properly appraised of the subject. This handbook will serve as a good reference document for all stakeholders in the smart grid domain in India.

I congratulate ISGF for the good work they are doing and wish them success in their endeavors.

Rkverma
12/12/17

(RAVINDRA KUMAR VERMA)

Foreword

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To,
Mr Reji Kumar Pillai
President
India Smart Grid Forum
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India is spearheading large and aggressive energy transformation programmes that focus on technology interventions for building smart cities, mainstreaming renewable energy, modernizing the electricity grid and enabling rural and urban electrification at a faster pace. Smart Grids will play a key role in the success of these programmes and are also relevant to other key initiatives like the Electric Mobility Mission.

However, smart grids cannot evolve without dynamic and flexible regulations. Regulatory clarity and certainty is needed for obtaining approval for Smart Grid investments, recovery of these investments through different models, provision of incentives and penalties to promote adoption of innovative solutions by utilities, protection of consumer interest and value delivery. Recognizing this, the Forum of Regulators issued the Model Smart Grid Regulations in 2015 to facilitate the integration of smart technologies into the grid at the state level.

This, of course, was a positive measure, but much more needs to be done for Smart Grids to achieve larger scale and adoption. A key challenge is the lack of understanding of the basic tenets of Smart Grids, their potential implementation frameworks and value proposition by key stakeholders, particularly by state regulators and distribution companies. There is an urgent need to address this gap by educating State Regulators, distribution companies and other key stakeholders on the benefits, available technology options, costs, market players and implementation frameworks that are pertinent to the adoption of Smart Grids.

The 'Smart Grid Handbook for Regulators and Policy Makers', prepared by the India Smart Grid Forum (ISGF) with support from Shakti Sustainable Energy Foundation, is particularly relevant in this context. A first of its kind, the handbook contains 17 comprehensive research modules detailing themes relevant to Smart Grids such as business models, power quality and tariff structures. The handbook also provides insights on evolving trends in grid modernization, Microgrids and Electric Vehicles.

This handbook aims to provide wider knowledge to regulators, policy makers and distribution companies in the area of Smart Grids and the integration of renewable energy systems. I hope that it will prove to be a useful reference guide to stakeholders to effectively address the planning and operational needs of a Smart Grid environment.

Krishan Dhawan
Chief Executive Officer
Shakti Sustainable Energy Foundation

Preface

ISGF
India Smart Grid Forum

November 2017

In one of our meetings with Shri Gireesh B. Pradhan, Chairman, Central Electricity Regulatory Commission in early 2016, he expressed the need for a book explaining the basics of smart grid in the Indian context. He told that during his visits to different states in India he meets with engineers in utilities and his questions on "what is smart grid" and "what your company is doing in that direction", he gets different answers which indicated that most people had no clarity on the basics of smart grids. In that conversation we agreed to work on a handbook covering various aspects of smart grids which will explain the concepts and "how to" aspects of smart grid technologies and policies.

ISGF approached Shakti Sustainable Energy Foundation (SSEF) for a grant to undertake this assignment of preparing a Smart Grid Handbook primarily targeted for Regulators, Policy Makers and Utility Engineers. SSEF also expressed the same view that there is a need for such a handbook that will bring about common understanding for all stakeholders in the country on what is smart grid and what need to be done by policy makers, regulators and utilities to make the grid smarter. With the grant from SSEF and rich contributions from several experts in India and abroad who work closely with ISGF, we could compile this Smart Grid Handbook that has 17 Chapters. A Draft Version of the Handbook was released in March 2017 at India Smart Grid Week in New Delhi.

Subsequently in association with Central Electricity Authority (CEA), we conducted 3 days training program covering all the modules in Hyderabad on 10th to 13th April 2017 and in Kolkata on 31st May to 2nd June 2017 which were attended by large number of Regulators and Utility Officials from different states. The comments and feedback received from those training sessions and other stakeholders have been incorporated in the final version of this Handbook.

We have also added a section "Primer on Smart Grids" which is basically an executive summary covering all other chapters. There are some repetitions in the sections "Primer on Smart Grids", "21st Century Grids" and "Introduction to Smart Grids". This has been intentionally repeated so that if a reader skips any of these sections, still the fundamental concepts of smart grids is read and understood.

India Smart Grid Forum wish to thank Shri Gireesh B. Pradhan who initiated the idea for the Smart Grid Handbook, SSEF and CEA for their support and all the contributors for their rich contributions. We are sure this Handbook would add value to the learning of Smart Grid to all stakeholders.

Reji Kumar Pillai
President, India Smart Grid Forum
Chairman, Global Smart Grid Federation

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

India Smart Grid Forum (ISGF), Public Private Partnership initiative of Ministry of Power (MoP), Government of India with support from Shakti Sustainable Energy Foundation (SSEF) embarked on a monumental task of compiling the information related to smart grid concepts, technologies and implementation experiences in this ***Smart Grid Handbook for Regulators and Policy Makers***. This Smart Grid Handbook is by no means complete in itself as new concepts and technologies are continuously evolving; however, the Handbook aims to create an awareness about the challenges and opportunities of smart grid (including some actionable recommendations) while serving as a ready reference.

We suggest all readers to start with the **Appendix** which discusses electric power system basics. If you are familiar with the content, you will skim through it quickly; otherwise, please take your time to read the content as it will help you understand the smart grid fundamentals and technologies better as you navigate through various modules of this handbook – a total of 17 well written modules and a Primer that captures the essence of the Handbook in the beginning just after this Executive Summary. The last Module touches on smart cities, a topic in itself, as no discussion of smart grid is complete without covering smart cities.

The Handbook start with a **Primer on Smart Grids** which covers the essence of the entire Handbook in 25 pages. The Primer is actually the summary of the contents of the Handbook whereas this executive summary gives the readers a glimpse of what is in the Handbook.

Module 1 sets the tone of this Smart Grid Handbook by discussing 21st Century Electric Grids and the Evolving Trends in Grid Modernization. The module discusses the changing picture of the electric grid from a traditional grid where central generation dominates the power supply to an integrated grid where distributed energy resources (DERs), mostly Renewable Energy Resources (RESs), play an important role. Various new technologies are overviewed in this module including Electrical Energy Storage (ESS), New Generation Technologies related to RES, Solid State Transformer (SST), Electric Vehicle (EV) and Microgrid as a foundation to present the plurality of Smart Grid visions as embraced by many developed and developing countries around the world. The module concludes with the Smart Grid Vision and Roadmap for India.

Module 2 provides an Introduction to Smart Grids. The module starts with the elaboration of smart grid concept described in module 1. Smart Grid components and technologies at transmission systems are then described. This was followed by a description of the components and technologies at distribution level which is one of the focus of the smart grid evolution by engaging the consumer and transitioning them to a prosumer (producer as well as consumer).

Module 3 describes the Advanced Metering Infrastructure (AMI) – the component of the smart grid that interfaces with the consumer directly. Starting with the description and benefits of AMI, the module discusses various communication technologies available for AMI. The module then discusses various smart metering architectures which is followed by a discussion on interoperability, a key component for the success of any AMI or smart metering project. The module concludes with a discussion on various AMI initiatives in India including a discussion on business models for a successful AMI implementation.

Module 4 discusses key components of the smart grid related to communications and cybersecurity. The two way or bi-directional communication between the utility and the consumers enable both utility and customers to monitor power flows in real-time, predict, and manage energy usage. The module starts with the importance of Machine-to-Machine (M2M) communication for the automated operation of various systems that constitute the smart grid including data acquisition, pre-processing, transportation and analytics. It then follows up with the importance of M2M in the power sector. This module also covers various communication technologies and standards available along with the frequencies at which they operate including the communication network requirements in a smart grid. This module includes an interesting discussion on Global Frequency Spectrum Allocation Scenario which is followed by the related Indian Scenario. A separate discussion on PLC technologies is followed due to its importance. Conceptual description of M2M communications is followed with the applications of M2M/IOT in the power sector. This module also discusses cybersecurity as increased interconnection and integration also introduce cyber vulnerabilities into the grid. Starting with an introduction on cybersecurity, the module discusses various initiatives by Government of India. A discussion on how to build resilience in a utility's cyber space is followed by the infamous cyber-attack case study of STUXNET, which reintroduced the importance of cyber security in an electric power system.

Module 5 describes Architecture, Interoperability and Standards for smart grids. The module starts with the National Institute of Standards and Technology (NIST), USA smart grid conceptual model which is followed by a detailed discussion on the Smart Grid Architecture Model (SGAM). The Smart Grid Architecture Model (SGAM) is an outcome of the EU Mandate M/490's Reference Architecture working group. Interoperability, a key requirement of smart grid, is then discussed. The module concludes with a discussion on standards including the Indian scenario of standards for smart grids.

The focus of **Module 6** is Large Scale Renewable Integration. The module starts with the renewable energy technologies, India's RES targets and the mechanisms to promote renewable energy in India. A discussion on the challenges to large scale integration is followed comparing the characteristics of renewables with conventional generation. A separate section then discusses various aspects of large scale integration solutions including balancing approaches, power exchange market, demand response, storage. Three international case studies in Germany, Denmark and USA are then presented. The module concludes with a discussion on rooftop solar PV installation and government policies in this area.

Module 7 discusses Modern Load and Power Quality focusing on distribution network.

Microgrids are discussed in Module 8. The module starts with a discussion of mini- and micro- grid including the characteristics, components, benefits, Indian scenario and business opportunities. Details of Low voltage DC microgrids are then discussed. The module concludes with three case studies of microgrids in India, Scotland and USA.

The focus of **Module 9** is Energy Storage, a critical component to support integration of renewable energy resources in some scenarios. The module starts with a discussion on energy storage in India, specifically to support the capacity addition target of Government of India. The discussion on various energy storage technologies including mechanical, electrochemical, thermal, electrical and chemical and their comparison is a useful addition to this module. The application and role of energy storage in power system is then discussed. The module concludes with a discussion on market potential for energy storage systems.

Electric Vehicles (EVs) are discussed in **Module 10**. The module starts with a discussion on Electric Vehicle technologies, some of its components, and international and Indian standards along with international EV missions. Various aspects of Vehicle Grid Integration (VGI) are covered along with challenges and opportunities including motivations, business models, policies for EV rollouts and the role of smart grid in VGI. The module concludes with four interesting case studies from USA, Australia, Germany and Denmark.

Module 11 discusses two very important tools of smart grid – Energy Efficiency and Demand Response (DR). The module starts with the history of energy efficiency in India – the acts and regulations related to energy efficiency are discussed which is followed by the regulatory approach to promote energy efficiency while utilizing Demand Side Management (DSM) along with various energy efficiency initiatives undertaken. Next section of this module discusses in detail the demand response and various types of DR programs, technological components of DR programs, DR processes, DR pricing as an ancillary service, DR supporting renewable energy integration and DR for congestion management in transmission networks. This section concludes with the discussion on DR program in India and the US along with a discussion on DSM program to reduce peak load and energy consumption by March 2019. The module concludes with the recommendations related to the regulatory framework for demand response programs.

Module 12 describes some pilot smart grid projects and lessons learned from these projects. The discussion on smart grid projects covers 17 projects in various countries including the first smart microgrid village in Odisha, India – location, functionality, time period, brief description, background, implementation and outcomes of each project are described. Next section discusses exclusively projects in India – 10 of them with similar details as in the previous section. Some of the cancelled smart grid projects are also mentioned in this module. The module concludes with a brief information about four smart grid projects under National Smart Grid Mission (NSGM).

Module 13 discusses the Electricity Act 2003, Electricity (Amendment) Bill 2014 and Ujwal DISCOM Assurance Yojana (UDAY). First section of this module covers Electricity Act 1910, Electricity (Supply) Act 1948, Electricity Regulatory Commissions' (ERC) Act 1948 and the Electricity Act (EA) 2003. Next section discusses the necessity for amending the Electricity Act 2003 which is followed by a discussion on issues involving carriage and content separation. Following section discusses other suggested modifications including spinning reserve, renewable generation obligation, open access, regulatory commissions, appellate tribunal and tariff determination. UDAY scheme is discussed in detail in the following section. This module ends with a section on UDAY reform program and steps to be followed by DISCOMS.

Module 14 discusses the Model Smart Grid Regulations issued by the Forum of Regulators in India. The module starts with a discussion on the need for smart grid regulations in India. Next section includes a global review of regulatory practices in approvals. This is followed by brief description on tariff design for consumers participating in smart grid functionalities such as dynamic pricing, TOD/TOU tariff, critical peak pricing, extreme day pricing, extreme day critical peak pricing, real time pricing and surcharges on consumers benefited by smart grid etc. Next section of this module discusses on consumer awareness, participation and grievance redressal. Model smart grid regulations issued by the Forum of Regulators for India are discussed in the following section. The module concludes with a section discussing important issues in framing smart grid regulations.

Smart Grid Business Models are discussed in **Module 15**. The module opens with a discussion on the requirement of a new business models followed by new business models for utilities including a discussion on benefit sharing model and rollout strategies for AMI. Following section discusses new roles for utilities including using EVs as an asset, performing analytics to improve the business and exploration of various new opportunities. The module concludes with a discussion on cost benefit analysis.

Module 16 discusses the New Tariff Structures. The module starts with a discussion on tariff setting process, objective and methodology which was followed by a detailed discussion on Time of Day (TOD) tariff. Special tariff for EVs are discussed in the next section. Innovative tariff structure of several utilities in the US, Canada and Europe are described in this module. The module concludes with key recommendations for regulators on smart grid projects.

Smart Grid as an anchor infrastructure for a Smart City is discussed in **Module 17**. The module starts with a discussion on the Smart Cities Mission in India which was followed by a discussion on National Smart Grid Mission (NSGM). Following section discusses the paradigm shift with the smart grid. Urbanization in India is discussed in the next section. Smart grid resource sharing with smart cities are covered in the following sections along with a discussion on leveraging the smart grid assets as anchor infrastructure for smart city development. Smart cities standard framework is discussed in the following section. The module concludes with a discussion on Smart City Maturity Model (SCMM).

India Smart Grid Forum

A PRIMER ON SMART GRIDS

A PRIMER ON SMART GRIDS

1.0 INTRODUCTION

Electric grid is considered to be the biggest engineering achievement of the 20th century. We built large power plants that generate electricity which is transported over high voltage transmission networks to long distances and distribute the electricity at low voltage to millions of customers. The power system consisting of limited number of power stations injecting electricity in to the grid and millions of customers drawing electricity from the grid remained as the basic model of electrification for over a century. However in the past few years we see the emergence of a distinct trend with proliferation of distributed generation resources which has put the electric grids on the threshold of a paradigm shift. After 100 years of focus on centralized power generation, the shift is now towards de-centralized generation. In the recent past (from 2010), the picture of the grid has changed dramatically in many geographies. Some of the visible characteristics of this shift are:

- With the increasing share of generation resources being added at the distribution end, the traditional boundaries between generation, transmission and distribution are fast disappearing
- With consumers becoming "prosumers", the grid that is built for one-way flow of electricity is now experiencing bi-directional flow of electrons
- With decreasing cost of energy storage solutions, there is already a debate on whether to invest in transmission or in storage – the choice between "Generation + Transmission + Distribution" AND "Distributed Generation + Storage + Distribution" is becoming real. This is even more relevant in regions where T&D losses are very high as with distributed generation there are fewer network losses
- The nature of loads have changed – Incandescent lamps and induction motors that could accommodate frequency and voltage excursions comprised majority of the load on the grid in the past. The present day digital loads require quality power at constant frequency and voltage
- Power purchase is moving from Volumetric Tariffs to Transactive Tariffs as Inflexible Demand has become Price Responsive Demand

- The "Merit Order Dispatch" has graduated towards an " Energy Efficient and Environmentally Responsible Dispatch" regime
- Solar PV has already achieved grid parity in many parts of the globe which is about to unleash a rooftop PV revolution and with increasing quantum of wind power being added the power mix on the grid is changing more towards intermittent generation resources
- Large fleets of Electric Vehicles that can be aggregated as virtual power plants which could support short term supply-demand balancing will make the grid even more dynamic and complex

In the traditional electric grid, the ability to monitor power flows and control it in real-time is limited to high voltage networks which are equipped with automation systems. In the low voltage network, the power system operator has no visibility on who is consuming how much electricity when and where. In a smart grid equipped with sensors and smart meters which are connected to computers in the control room, it is possible to remotely monitor and control the flow of electricity in real time to every customer or even to every smart appliance inside a customer's premise. So the evolving smart grid of the 21st century will be drastically different – the grid will soon emerge as the "grid of things" like how the internet is evolving as "internet of everything".

2.0 CHANGING PICTURE OF THE ELECTRIC GRID

Some of the disruptive changes taking place in the power systems are described in detail below:

- **Integrated Grid**: Traditionally the power system was vertically divided in to three segments as Generation, Transmission and Distribution. In the recent years, increasingly larger share of new generation resources such as rooftop PV, micro-wind turbines, energy storage devices (batteries and electric cars etc) are being connected to the low voltage grid. This is leading to the fast dis-appearance of the traditional boundaries between generation, transmission and distribution. It is a very disruptive trend for electric utilities as their organizational structures and functions are also segregated in to Generation, Transmission and Distribution silos. Traditionally all generation from the power plants flowed in to the transmission department which accounted for total receipts from generation. With rooftop PVs connected at customer premises to the distribution grid on a net-metering scheme which department of the utility will account for the total monthly generation and energy inputs, energy balance etc? Similarly, the System Operations group forecast the demand and generation department will schedule the available plant capacity for next day. With distributed generation assuming larger share in the energy mix, there is a need for forecasting potential generation from the distributed resources connected to the grid at customer premises in order to accurately schedule and dispatch. But neither the customers who own these resources have any capability nor the distribution department of the utility which deal with this segment of the grid has any expertise and lastly but not the least the generation department has no visibility of distributed generation. In order to manage a grid with distributed generation resources connected at all voltage levels in the grid, utilities need to invent new organizational structures, new skills and operating rules which will require new investments. Management and operation of the evolving integrated grids are going to be major challenge in the transitional term.

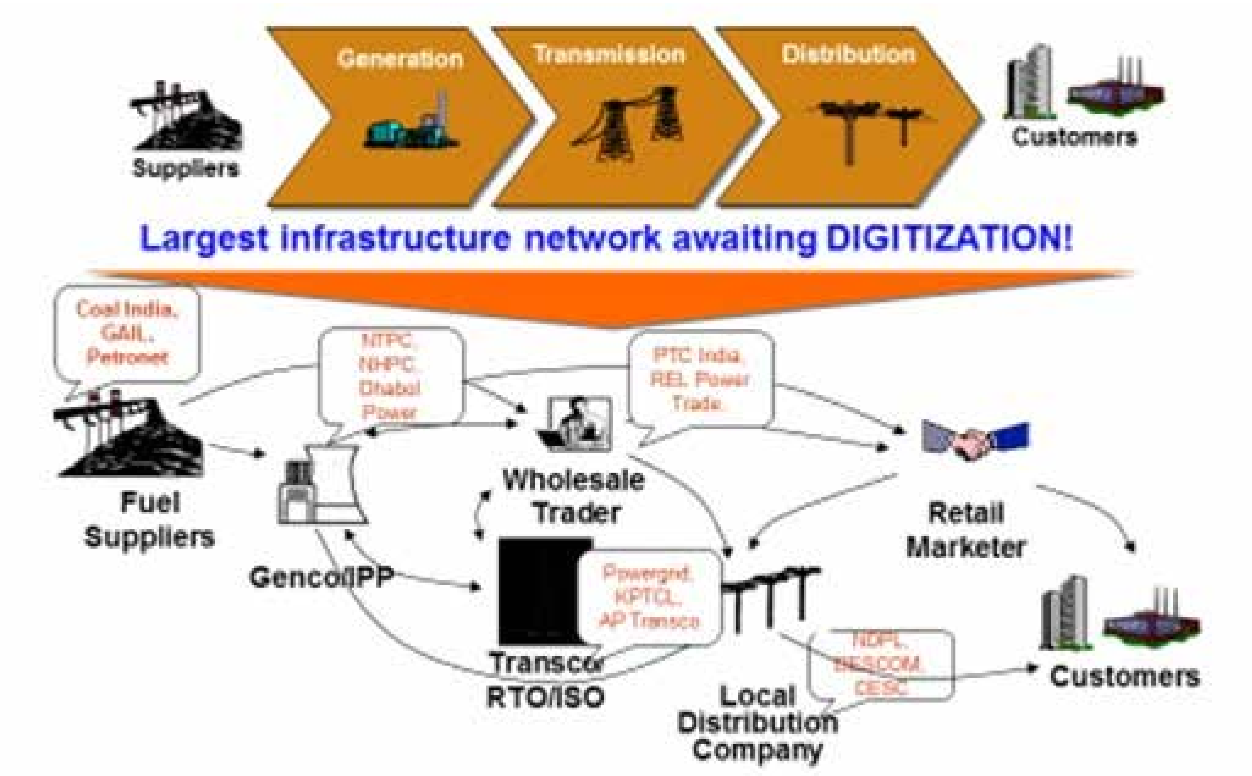


Figure 1: Structure of Traditional Grid

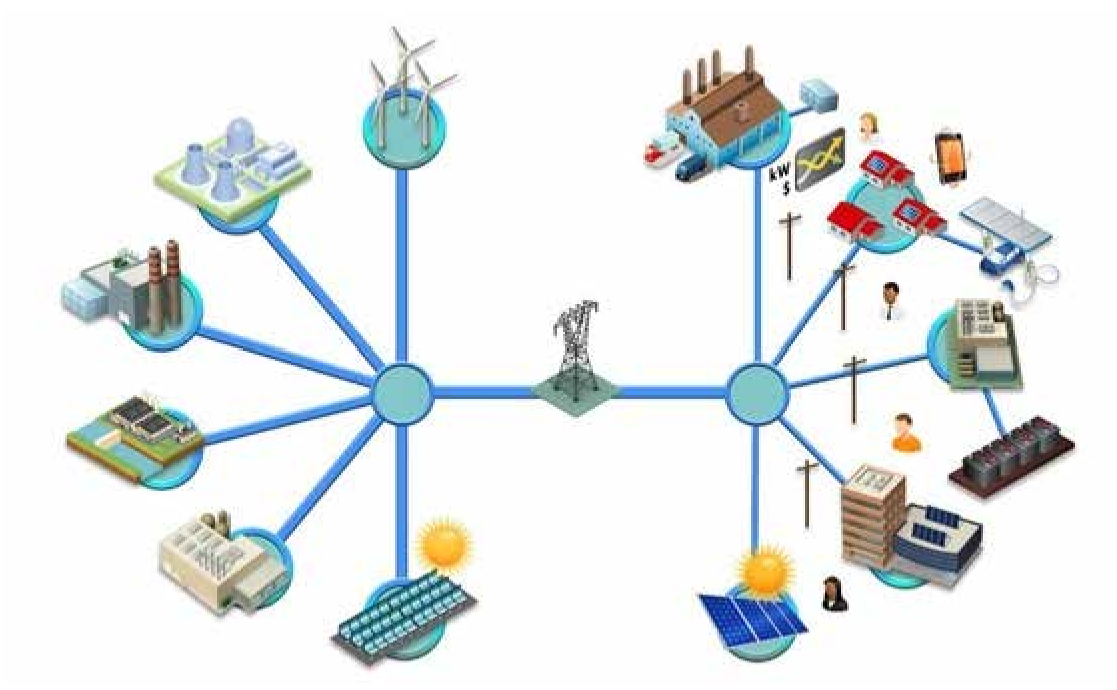


Figure 2: Picture of the emerging Integrated Grid

Source - EPRI

- **Prosumers**: The existing grid is designed for one way flow of electrons from generating stations to loads at the customer premises. And it was operated in that fashion for over a century. All equipment, systems, processes and operating procedures are designed to facilitate this one-way flow of electricity. However, now with rooftop PV or Micro Wind Turbines on customer premises being connected to the grid, a customer can inject electricity in to the grid that the utility can sell to any customer on the network. So the traditional customer who was only a buyer of electricity has become a producer and a consumer – "prosumer" now. This again brings out both engineering challenges as well as business process challenges. In engineering terms it need to be assessed how much "reverse power flow" from a customer premises can be accommodated in the low voltage grid; and in terms of business challenges, the utility need to put in place new/smart metering and control systems as well as policies for accounting and payment mechanisms. Utility need to constantly evaluate the capacity of the last mile network before approving connectivity for rooftop PV systems which require network models and load flow studies. Yet another challenge for utilities!

- **Transmission v/s Energy Storage**: A host of energy storage technologies are fast approaching commercialization and already MW-scale lithium ion and Sodium Sulphur (NaS) batteries are commercially deployed for certain grid applications. In many geographies, building transmission lines has been a herculean task as people dislike high voltage transmission lines passing through their habitations. In USA and several other countries, it takes well over a decade to establish the right of way for a high voltage transmission line and the cost of right of way is often higher than the actual line construction cost. In the emerging paradigm of distributed generation coupled with energy storage, utilities could avoid bringing high voltage transmission lines to congested urban areas or expensive neighbour hoods. In this scenario, large capacity battery storages (other storage technologies may also be relevant according locational considerations) and distributed generation can be designed to service the local load.

  This model of "distributed generation + energy storage + distribution/consumption" is a challenge to the traditional model of "generation + transmission + distribution". In the distributed generation model, network losses are also lower compared to the traditional model. This is highly relevant in regions with high transmission and distribution losses. So we can expect to see in the coming years, many regions and pockets opting for distributed generation and storage instead of bringing electricity through high voltage transmission lines and building substations and distributing it.

- **Changing nature of Loads**: Incandescent lamps and induction motors comprised of majority of the loads in the traditional grid. Both of them could accommodate frequency and voltage excursions to certain extent. If the voltage drops even by 50% still an incandescent bulb could burn with lower luminosity. But in the present day digital word, majority of the new loads require quality power at constant frequency and voltage. In the traditional grid, majority of the generation resources (large hydro and thermal stations) could accommodate load fluctuations to certain extent and could keep the voltage and frequency constant; but in the emerging grid with larger share of renewable generation resources which are intermittent, sudden drop in generation can take place any time and balancing the grid is becoming a nightmare for power system operators. When the share of renewables exceed the limit of spinning reserve maintained in a power system, it can cause serious fluctuations anytime. Hence we are now exploring demand-side controls. When sudden loss of generation happens, utility should be able to switch off certain loads (water pumping, air conditioning etc) at customer premises so that supply-demand equilibrium is achieved to ensure grid stability. The changes in the nature of loads have further complicated this grid balancing.

- **Electric Vehicles**: Electric Vehicles (EVs) are becoming an integral part of the electric grid. The globally accepted model for low carbon development is "electrification of all human activities including transportation and agriculture to the extent possible". In India, Government has launched a National Mission on Electric Mobility in 2013 with the target of 2 million four wheelers and 4-5 million two wheelers by 2020. Although this mission was moving slowly owing to a variety of teething issues including availability of charging stations, now, GoI has accorded priority for faster roll out of EVs to address the pollution in cities reaching dangerous levels.

  EVs are big loads on the grids as car batteries are 10kWh to 100kWh whereas bus batteries can be from 100kWh to 300kWh. These will have unprecedented impacts on the distribution grid as it is not a stationary load for which the grid up-gradation can be made at any particular location. EVs may be charged from different locations with in a city based on where the EV owner is driving on a particular day. Huge investments are required to setup charging stations city wide as well as to upgrade the capacity of transformers and cables to accommodate the new loads from EVs. Even if a separate commercial tariff is applied on EV charging stations, cost recovery from necessary grid upgrades will not be viable. EV batteries can act as an energy storage device which can pump electricity back to the grid. Large fleets of EVs connected to the grid can be aggregated as virtual power plants which could support short term supply-demand balancing. This could help the distribution grid to tackle the intermittency of rooftop PV generation at street level.

  All the above factors are going to affect the grid operations in a profound manner in the coming days leading to a paradigm shift. So the evolving 21st Century Grids are going to be drastically different than the one that we are used to for over a century.

- **Microgrids and DC Grids**: Microgrid is top on the list of smart grid technologies in the developed countries - reason: critical infrastructure (airports, military bases, hospitals etc) have no stand-by power supply systems. At the heart of a microgrid is an intelligent control centre that can island the local grid (microgrid) from the utility grid and can control and curtail (if required) the load within that microgrid to match the emergency demand with the available generation and storage facilities. Smart microgrids that can island from the grid is considered as a fall back safety net against cyber attacks. While it is easy for an attacker to target the control centre of a large utility, it will be impossible to attack thousands of microgrids with each of it having its own control centres. In case of an attack and breakdown of the utility control centre, the microgrids can island from the main grid and can serve critical loads till main grid is back in operation.

  Today the electricity generated from solar PV is converted from DC to AC and distributed which is again converted to DC for the digital appliances such as computers, LED lights, LCD/LED TVs, flat screen monitors, security cameras, cell phones etc. Almost half the energy generated is lost in these two conversions (DC to AC and again AC to DC). As the share of DC generation and DC consumption both are increasing steadily, it makes business sense to have DC distribution system in parallel to AC distribution in offices and homes. Already in certain hotels and office buildings there is 5V DC distribution system on which USB connections are provided.

  Several teams around the world are working on standards for DC Grids. In India, ISGF facilitated the creation of a Low Voltage Direct Current (LVDC) Forum in 2013 which has been adopted by IEEE. This LVDC Forum has selected 48V DC for indoor applications in India and standards for the same has been issued by Bureau of Indian Standards (BIS) in November 2017 (IS 16711:2017 - 48 V ELVDC Distribution Systems –Guidelines). DC Grids could also facilitate reliable rural electrification with solar PV, batteries and DC appliances – LED lights, Brushless DC (BLDC) motors, LED TVs etc.

3.0 OVERVIEW OF SMART GRIDS

The smart grid is the evolving electric grid with advanced automation, control, IT and IOT systems that enables real-time monitoring and control of power flows from sources of generation to sources of consumption. A set of technologies enable these functionalities and help manage electricity demand in a sustainable, reliable and economic manner. Smart grids can provide consumers with real-time information on their energy use, support pricing that reflects changes in supply and demand, and enable smart appliances and devices to help consumers exercise choices in terms of usage of energy.

"Smart grid is an electricity grid with communication, automation and IT systems that enable real time monitoring and control of bi-directional power flows and information flows from points of generation to points of consumption at the appliances level."

3.1 WHAT IS SMART GRID

As summarized in the previous pages, a shift from centralized generation to decentralize generation is happening. The traditional boundaries between generation, transmission and distribution are fast disappearing and the grid is evolving into an integrated smart grid, a unique solution which integrates all type of power generation and helps the consumer becomes a producer and consumer (prosumer). Each household will be able to generate and store electricity for its own use or sell it to the grid. Smart grid technologies can empower customers with real time control and the choice to generate, store and consume electricity at lowest cost available or sell it to the grid during the surplus generation while ensuring high quality and availability of power. With the help of programs like demand response (DR), customers can change their consumption patterns by shifting their consumption from expensive peak hours to cheaper off peak hours making the power flow more interactive, efficient, more environment and customer friendly.

Smart Grid - Analogy with Human Body

The picture below depicts the analogy of a smart grid with human body.

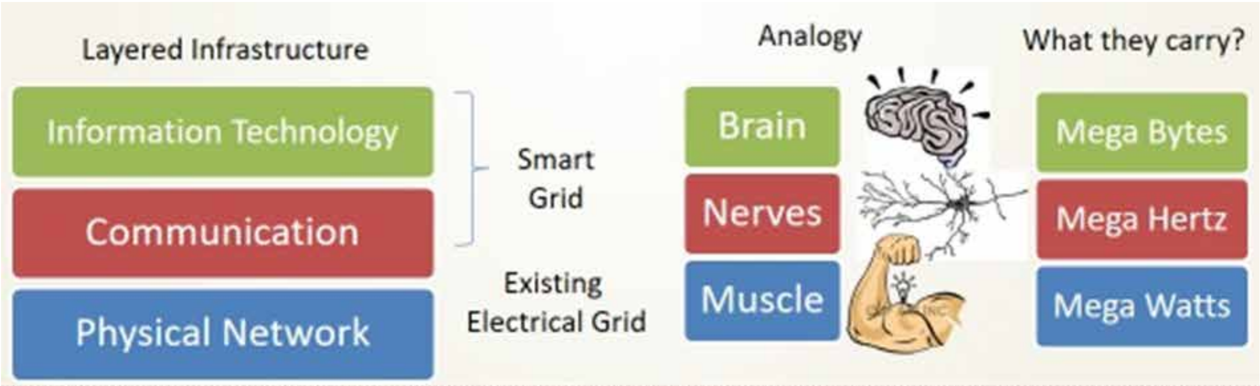


Figure 3: Analogy of a Smart Grid with Human Body

Key components to make an existing grid smarter is to have two way communicable sensors to monitor and control power flows in real time and IT systems to process the data captured and issue commands and alerts.

3.2 DRIVERS FOR SMART GRID

Since the early 21st century, advancement in electronic communication technology is being used to resolve the limitations and costs of the electrical grid. Technological limitations on metering no longer force peak power prices to be averaged out and passed on to all consumers equally.

Key drivers for smart grids for different stakeholders in the Indian context are:

I. UTILITIES:

- Reduction in Aggregate Technical and Commercial (AT&C) losses
- Peak load management – multiple options from direct load control to price incentives to customers
- Reduction in power purchase cost
- Better asset management
- Increased grid visibility
- Self-healing grid- faster restoration of electricity after fault or disturbances
- Renewable energy integration

II. CUSTOMERS:

- 24x7 Power for All
- Improved reliability of supply to all customers – no power cuts, no more DG sets and inverters for back up
- Improved quality of supply – no more voltage stabilizers
- User friendly and transparent interface with utilities
- Increased choice for customers – including green power
- “Prosumer” enablement – can produce own electricity and consume or sell
- Options to save money by shifting loads from peak hours to off-peak periods

III. GOVERNMENTS AND REGULATORS:

- Satisfied customers
- Financially sound utilities
- Tariff neutral system upgrade and modernization
- Reduction in emission intensity

3.3 FUNCTIONALITIES AND KEY COMPONENTS OF SMART GRIDS

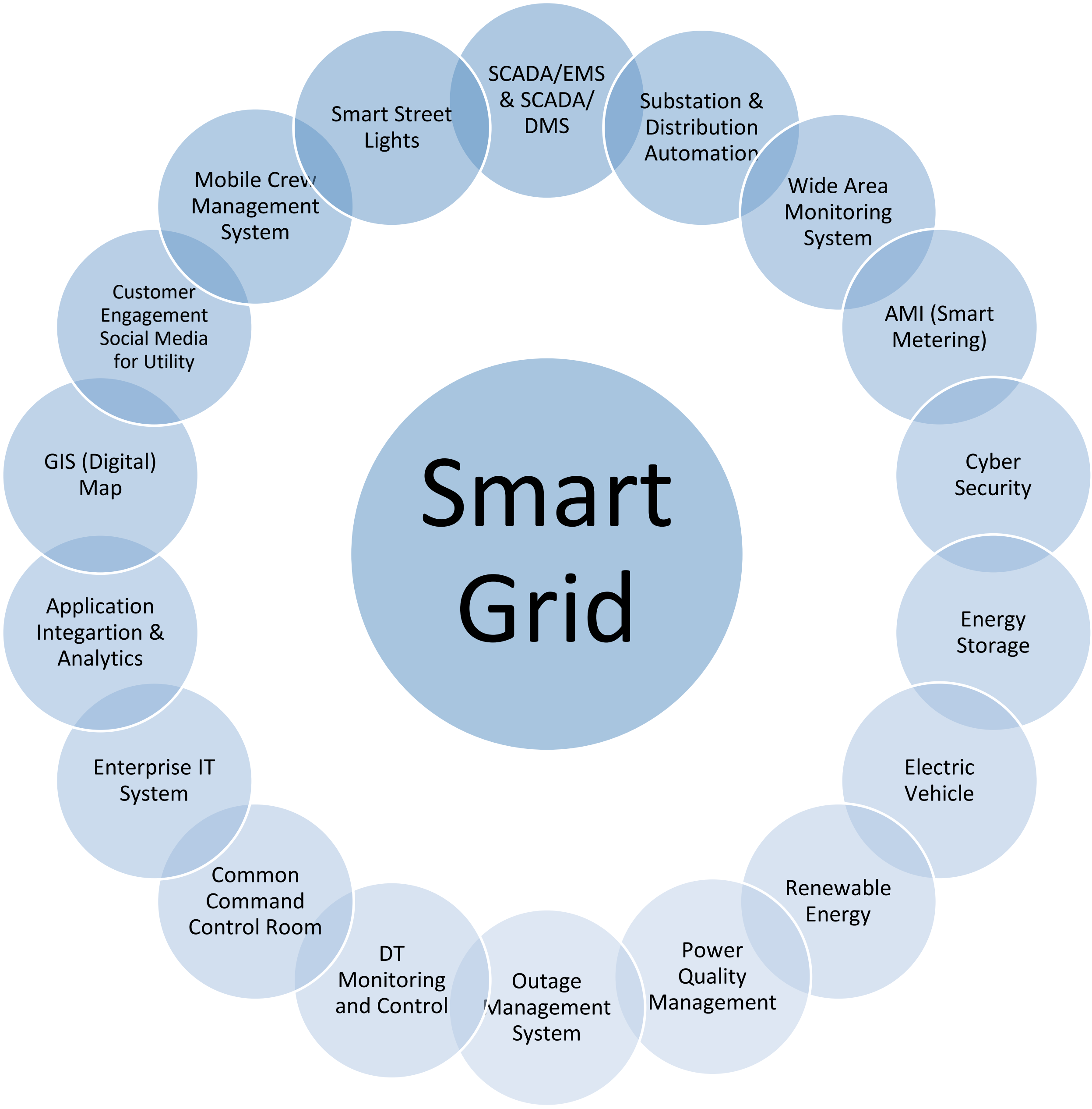


Figure 4: Smart Grid Functionalities

3.3.1 SMART GRID COMPONENTS FOR TRANSMISSION SYSTEM

I. SCADA SYSTEM

Extra high voltage (EHV) transmission network (110kV and above) was traditionally smart or intelligent with automation and real-time communication systems integrated for system operations. The load dispatch centres or control centres of EHV systems have Supervisory Control and Data Acquisition (SCADA) and Energy Management System (EMS) which help monitor and control the power flows in real-time. In order to facilitate the functioning of SCADA/EMS, the EHV network have dedicated communication systems between the control centre and all generating stations and EHV Substations. From the control centre the operators can control generation as well as loads at the substations.

SCADA Overview

SCADA refers to a system that collects data from various sensors at a factory, power plant, transmission system or in other remote locations and then sends this data to a central computer which then manages and controls the system. SCADA has the ability to monitor an entire system in real time and can run with relatively little human intervention. This is facilitated by data acquisitions from various sensors and meters.

Components of SCADA

SCADA has a Master Station and several remote stations that are equipped with:

In the Master Station:

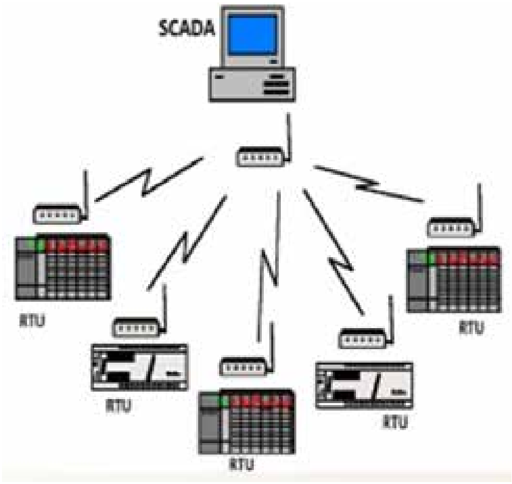
- Local Area Network (LAN)
- Servers
- LCD Screens

In a Remote Stations:

- Transducers (analog inputs)
- Interposing Relays
- Remote Terminal Unit (RTU)
- Local Display
- Logger/Archiver

Functioning of SCADA

- Data Acquisition
- Supervisory Control
- Tagging
- Time Synchronization of RTUs
- Alarms
- Logging (Recording)
- Load Monitoring with Display and Logging
- Trending



RTUs are installed at field devices - substations and other field equipment. SCADA communicate with a large range of external devices like programmable logic controllers (PLC) and industry specific meters through the RTUs. In order to link up and access with these devices, various open communication standards are used. And these devices need to have a mechanism to open up its parameters (or data) for SCADA to access - either for read, write or both. SCADA assigns a variable or memory location for each individual parameter or data from each device. This variable is called "Tag". "Tagging" means the process of managing tags. "Trending" displays provide a powerful means of displaying, evaluating and selecting data for further processing and analysis.

Communication System for SCADA

SCADA require dedicated and reliable communication systems between various field devices (RTU) and the Master Station. Traditionally electric utilities used Power Line Carrier (PLC) communications in the past. The analog PLC could support limited bandwidth. PLC based SCADA are still in operation in many places.

Other communication options for SCADA are:

- Fiber Optic Cables (optic fiber ground wire or OPGW can be used as earth wire on EHV lines)
- Microwave Communication
- Satellite Communication
- PSTN or public telecom network can also be leveraged by leasing dedicated communication links from telecom operators (MPLS networks)

II. ENERGY MANAGEMENT SYSTEM (EMS)

Energy Management System (EMS) is a set of computer-aided tools used by electric grid operators to monitor, control, and optimize the performance of the generation and/or transmission systems.

Functions of EMS

- Real time network analysis and contingency analysis
- Study functions like power flow, power factor, security enhancement etc
- Real time generation functions – allows the operator to monitor, analyze and control real time generation and automatic generation control (AGC)
- Economic dispatch - helps the dispatcher to determine economic base points for a selected set of units
- Reserve monitoring for calculating spinning reserve, operating reserve and regulating reserve
- Production costing – calculates the current cost of generating power of online units
- Load forecasting
- Transaction scheduling

Advanced functionalities:

- Enhanced grid reliability
- Increased grid capacity
- Advanced contingency awareness
- Decreased system support cost

- Secure system that meets regulatory requirements

EMS works along with a SCADA system and EMS helps the control room operator to manage the transmission system operation efficiently and economically.

III. WIDE AREA MONITORING SYSTEM (WAMS)

With the deployment of phasor measurement units (PMU), fast and accurate measurements from grid equipment is possible. Real-time wide area monitoring applications have strict latency requirements in the range of 100 milli-seconds to 5 seconds. A fast communication infrastructure is needed for handling the huge amounts of data from PMUs. Smart grid applications are designed to exploit these high throughput real-time measurements.

While SCADA data is collected in 1-5 seconds, PMU data is captured in milliseconds. SCDA data has no time stamps but PMU data is accurately time stamped. While SCADA is like an X-Ray, PMU Data is like an MRI scan of the grid.

3.3.2 SMART GRID FUNCTIONALITIES AT DISTRIBUTION LEVEL

The distribution grid comprises of medium voltage (33 & 11kV) and low voltage (415/230V) network which traditionally had limited automation systems. Main reason for this was the cost of communication system for automation. Distribution grid in large utilities run in to hundreds of thousands of kilometres and establishing reliable communication system between all end points and the control centre was way too expensive. So there is no visibility of power flows in the low voltage network. Faults are also not automatically detected. Only when customers complain about an outage the crew is dispatched to locate the fault and repair it. Hence the key focus of smart grid initiatives are focused on modernizing the distribution grid with advanced automation and control features. The main technologies in this domain are:

- Supervisory Control and Data Acquisition (SCADA) and Distribution Management Systems
- Distribution Automation
- Substation Automation
- Advanced Metering Infrastructure (AMI) or Smart Metering
- Geographical Information System (GIS)
- Peak Load Management
- Power Quality Management
- Outage Management System
- Distribution Transformer Monitoring System
- Mobile Crew Management System
- Enterprise IT Systems
- Application Integration
- Smart Street Lights (with noise and pollution sensors)
- Energy Storage
- Electric Vehicles

- Distributed Energy Resources and Renewable Energy Integration
- Customer Care Centre
- Customer Engagement
- Social Media
- Cyber Security
- Analytics
- Smart Homes, Buildings Energy Management Systems /Home Energy Management Systems (BEMS/ HEMS)

I. SCADA AND DISTRIBUTION MANAGEMENT SYSTEMS (DMS)

Features of SCADA system explained under previous section are similar for distribution SCADA as well. While all RTUs for transmission SCADA are placed in high voltage substations, in case of distribution SCADA besides RTUs in substations, there may be Field RTUs (FRTUs) in distribution network at power transformer and distribution transformer locations. Communication options for transmission SCADA and distribution SCADA are also same – utilities select what is appropriate depending upon local considerations.

Distribution Management System (DMS)

DMS is a collection of software applications designed to monitor and control the entire distribution network efficiently and reliably.

DMS Functions

- Network Visualization and Support Tools
- Applications for Analytical and Remedial Actions
- Utility Planning Tools
- System Protection Schemes

II. DISTRIBUTION AUTOMATION (DA)

Distribution Automation (DA) refers to various automated control techniques that optimize the performance of power distribution networks by allowing individual devices to sense the operating conditions of the grid around them and make adjustments to improve the overall power flow and optimize performance. In present scenario, grid operators in centralized control centres identify and analyse their power system manually and intervene by either remotely activating devices or dispatching a service technician.

DA can be a critical component in outage prevention. The sensors and communications associated with DA can provide early detection of the devices that might not be working properly, thus allowing the utility to replace those devices before an outright failure occurs. DA is considered the core part of a smart grid, interacting with almost all other smart grid applications and making the grid more efficient and reliable. DA helps enable renewable energy (RE) by dynamically adjusting distribution controls to accommodate variability, power ramping and bi-directional power flows.

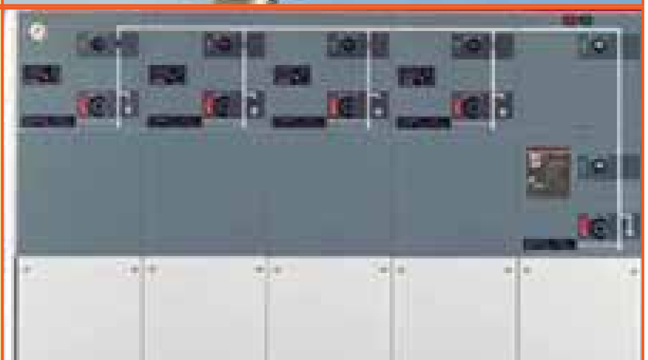
At the heart of the Distribution Automation is SCADA/DMS. Other key components of DA are Remote Monitoring Unit (RMU), Sectionalizer, Reclouser, Fault Locator and Capacitor Banks which are described in the next page.

SECTIONALIZER is a protective device, used in conjunction with a reclouser, or breaker and reclosing relay, which isolates faulted sections of the distribution lines. The sectionalizer cannot interrupt fault current.

RECLOUSERS are designed to operate like a station breaker and can interrupt fault current and reclose a pre-set number of times before going to lockout the faulted sectiont. Sectionalizer counts the breaker and reclouser operations during a fault sequence and open when they reach their pre-set count limit while the breaker or reclouser is still open.

FAULT LOCATOR: the DA system and its automated distribution devices enable faulted load blocks to be quickly identified, isolated and power is re-routed to downstream load blocks. However, the actual fault still has to be found and repaired by field crews before all customers can be restored.

RING MAIN UNITS (RMU) are installed in strategic locations on every feeder to monitor and control the Sectionalizers, Reclousers and other equipment in the network



CAPACITOR BANKS: DA system helps in controlling the capacitor banks for controlling the voltage and power factor.

Figure 5: Components of Distribution Automation Systems

III. SUBSTATION AUTOMATION

Substation Automation (SA) system enables an electric utility to remotely monitor, control and coordinate the distribution components installed in the substation. SA has been focused on automation functions such as monitoring, controlling, and collecting data inside the substations. SA overcomes the challenges of long service interruptions due to several reasons such as equipment failures, lightning strikes, accidents and natural catastrophes, power disturbances and outages in substations.

Main component of SA is digital (or numeric) relays and associated communication systems which can be operated remotely.

IV. ADVANCED METERING INFRASTRUCTURE (AMI)

Advanced Metering Infrastructure (AMI) or Smart Metering comprises of Smart Meters, Data Concentrator Units (DCUs)/gateways/routers/access points, Head End System (HES), Meter Data Management System (MDMS) communicating over bi-directional Wide Area Network (WAN), Neighborhood Area Network (NAN)/Field Area Network (FAN) and Home Area Network (HAN). Multiple smart meters can connect to a DCU/gateway/router/access point which in turn send aggregated data to the HES. The smart meter can also directly communicate with the HES using appropriate WAN technologies (for example GPRS sim cards in the smart meters can directly send data to the HES on servers in the control room). The Meter Data Management System (MDMS) collects data from the HES and processes it before sharing with billing system and other IT applications. Appliances such TV, fridge, air conditioners, washing machines, water heaters etc can be part of the Home Area Network (HAN).

At the heart of AMI, is the Smart Meter. The key features that make a meter 'smart' are the addition of a communication module capable of two-way Machine to Machine (M2M) communications and a remote connect/disconnect switch. A smart meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the computers in the utility control centre. Smart Meters usually have real-time or near real-time sensors, power outage notification, and power quality monitoring features.

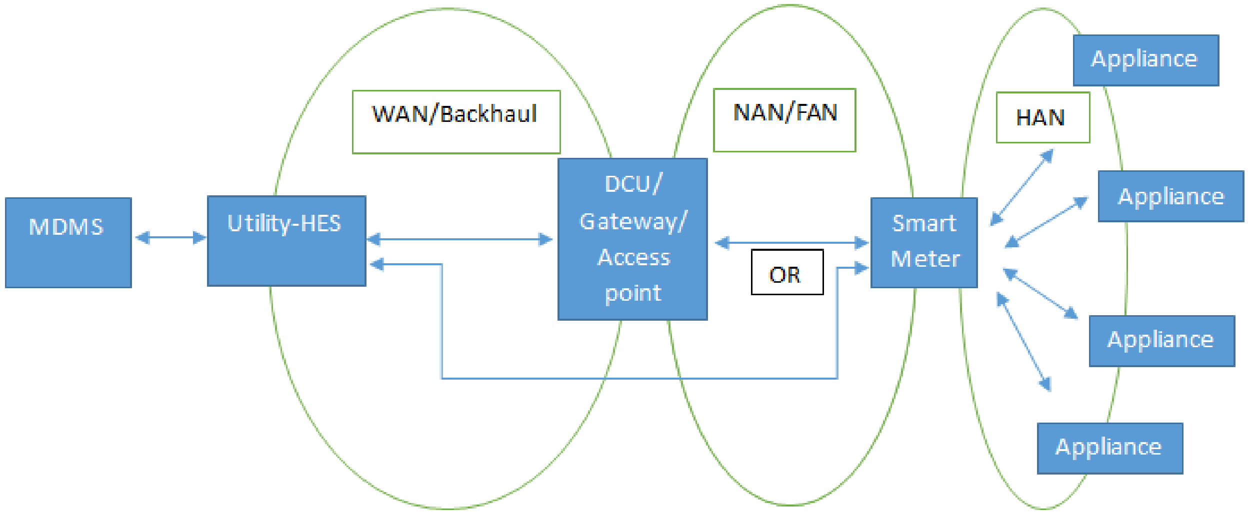


Figure 6: Typical Architecture of AMI

In-Home display (IHD) is a device kept in the customer's premises that could display meter data and get confirmation from the consumer regarding his/her participation in a demand response program. Hence consumers will become informed and conscious. However, with the rise of the smart phone applications or 'apps', customers would not require IHDs at their homes. A smart phone can work as an IHD and hence the utility or customers need not invest in IHDs.

V. GEOGRAPHICAL INFORMATION SYSTEM (GIS)

All electrical assets mapped on a GIS map (digital map) and all consumers indexed to that map is a very important tool for a utility to plan and manage their assets and operations. GIS map can be integrated with other automation and IT applications in the utility as depicted in the figure below which will help asset optimization and outage detection and faster restoration.

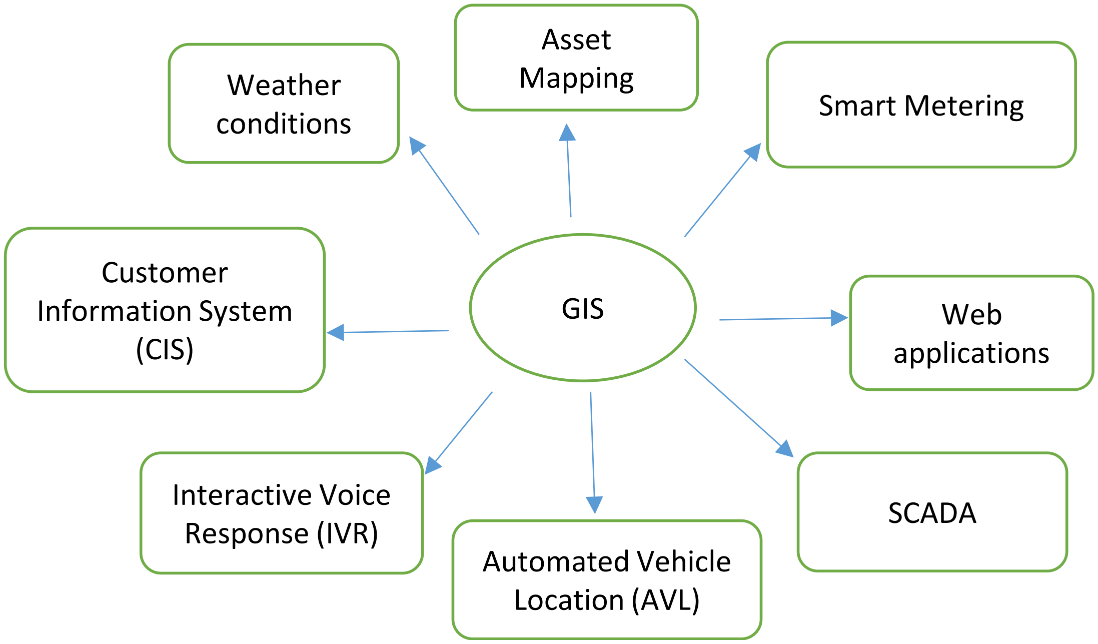


Figure 7: GIS Functionalities

GIS maps need to be updated on a regular basis. Whenever a new asset is added or removed or a new customer is given connection or an existing customer is removed, that information must be captured in the GIS map so that it remains up to date.

The GIS maps of electric utilities would ideally include all the roads and buildings in a town/locality. It can be a valuable asset for other infrastructural service providers in the town for planning and management of services like water distribution, gas distribution, transport planning and management etc.

VI. PEAK LOAD MANAGEMENT

Peak load management is achieved through a combination of policies and techniques such as Time of Use Tariffs, Critical Peak Pricing and Demand Response programs.

Demand Response (DR)

Demand response is a mechanism in which the utility can curtail the load at customer premises or disconnect certain equipment of the customer remotely from the utility's control centre. Customer participation for DR program is sought through incentives and penalties. The customer engagement is the major success factor for the demand response programs. Here the utility plays the role of shifting the load from peak hours/higher market price hours to off-peak hours/lower market price hours of certain equipment of the customer that is mutually agreed – large pumps, air-conditioners, heaters, machineries etc. The benefits of DR include avoiding the use of the most expensive generation plants during peak hours, avoiding construction of additional generation, transmission and distribution capacity, and avoiding brownouts and blackouts. Auto Demand Response (ADR) is shown in the figure below using OpenADR Standard.

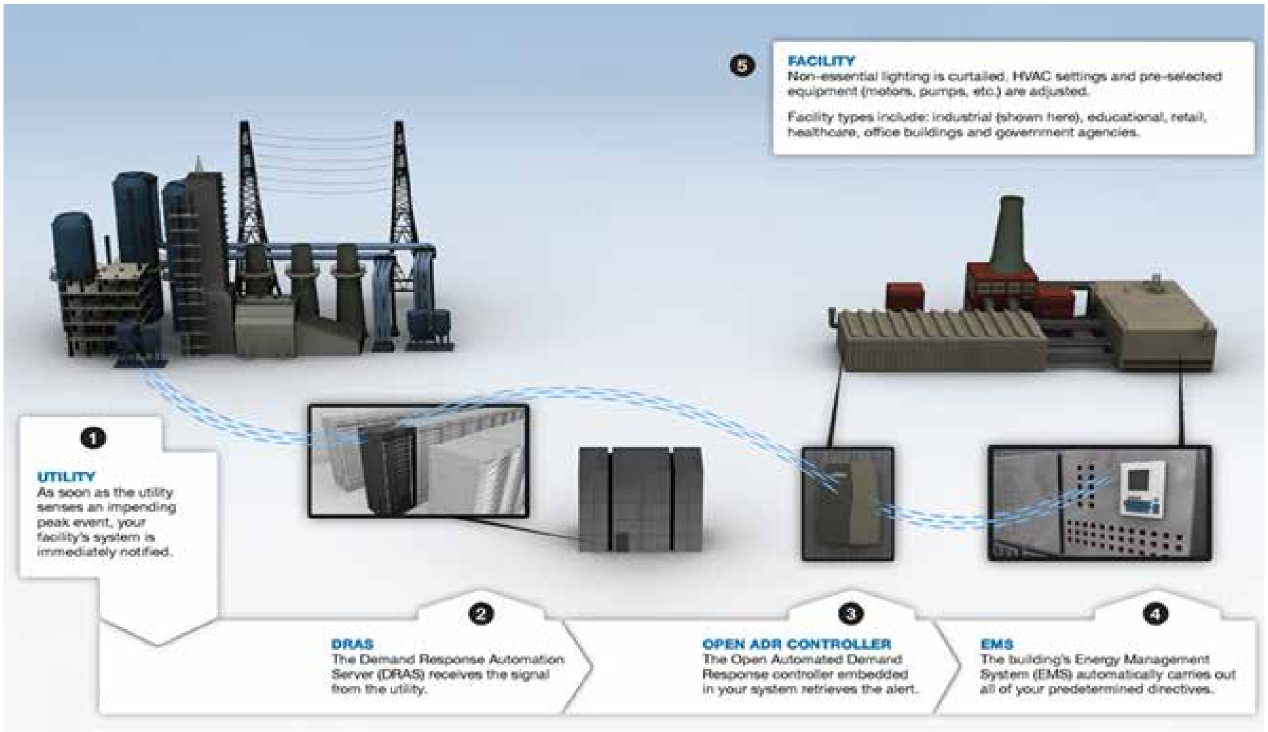


Figure 8: Demand Response Process Flow

Image Source – https://www.smartgrid.gov/files/C6-Honeywell-final-draft-091814.pdf

VII. POWER QUALITY MANAGEMENT

Voltage variation beyond stipulated limits and interruptions are major power quality issues faced by customers. With proliferation of distributed and variable generation resources such as solar PV and wind turbines which operates intermittently, it is increasingly difficult to maintain quality of supply. On the other hand, modern loads with switch-mode power supply (SMPS) such as computers, television, washing machines, air-conditioners, refrigerators, LED lights, furnaces, inverter, UPS etc inject harmonic distortion on the power system. Voltage and current are in sinusoidal wave form whereas the above category loads with power electronics in them are in square wave form which lead to generation of harmonics.

With smart meters in the network, the utility will be capable of measuring specific aspects such as power factors and voltages in near real-time. This will enable the utility to take appropriate actions to enhance the power quality. Corrective measures to be undertaken to mitigate the power quality issues are described in detail in Module -7.

VIII. OUTAGE MANAGEMENT SYSTEM (OMS)

Outage Management System (OMS) provides the capability to efficiently identify and resolve outages and to generate and report valuable historical information. Geographic information System (GIS) based OMS will help to resolve customer complaints faster during power outages. OMS will enable quick identification of probable faulty locations and reduce the response time of customer complaints. OMS will work in conjunction with GIS, Customer Information System (CIS), Enterprise Resource Planning (ERP), Mobile Crew Management System and Automated Call Handling Systems, such as an Interactive Voice Response (IVR) system. OMS of an electric utility can be leveraged by other infrastructure and services providers in a city at marginal cost.

IX. DISTRIBUTION TRANSFORMER (DT) MONITORING SYSTEM

In most distribution utilities in India hundreds of distribution transformers (DTs) get burned during every summer owing to over loading or phase imbalances of the DTs. Remote monitoring of DTs will prevent overloading, phase imbalance and burn outs of DTs. This will transform into huge financial savings taking into account the high technical losses that occur in the system owing to phase-imbalances - one phase gets overloaded while other two phases are low on load. With monitoring systems in place the loads can be re-distributed to remove such imbalances on transformers. With DT monitoring systems, overloaded DTs can be identified and replaced with higher capacity DTs as load in the locality increases.

X. MOBILE CREW MANAGEMENT SYSTEM

Mobile crew management system enables a utility to allot maintenance jobs to the crews in the field on real-time basis. In the traditional model, crew attending any work in the field will always return to their base station and then they will be dispatched to the next work. This way their productivity is reduced. With mobile crew management systems, the work will get allotted to the crew with required skills, tools and spare parts and nearest to the work location. In that scenario, from one work location to another work location they can quickly move, increasing their productivity multiple times. Also information on the type of fault is made available on their Mobile to support trouble shooting. Good mobile crew management applications will have real time scheduling engine.

XI. ENTERPRISE IT SYSTEMS

Enterprise IT systems include:

- IT Network – LAN/WAN
- Mail-Messaging Systems
- Management Information Systems with Dashboards
- Enterprise Resource Planning (ERP)
- Portal/Website – Intranet and Customer Portal

With ERP, information that is fragmented in different systems can seamlessly flow throughout the organization so that it can be shared by business processes in grid operations, engineering, procurement, finance, accounting, human resources, and other areas of the utility.

Typical ERP modules for a Distribution Utility include:

- CRM – system to track new connections and disconnections, track customer consumption, payment records, defaulters etc
- Enterprise Asset Management (EAM)
- Contracts Management
- Materials Management
- Projects Management
- Human Resources Management
- Finance Management

XII. ENTERPRISE APPLICATION INTEGRATION (EAI)

Some of the data captured from field equipment and customer operations are used by multiple applications in a utility and each applications calling data from different databases creates serious issues in data integrity. The best way to handle this problem is through Application Integration using a middleware platform. All data bases will be connected to this middleware and all applications will also be linked to the middleware which will facilitate different applications to call data from same database. Service Oriented Architecture (SOA) is commonly used for application integration using a middleware tool.

XIII. SMART STREET LIGHTS (WITH NOISE AND POLLUTION SENSORS)

Latest entrant in the smart grid and smart city solutions is smart street lighting. Typical street lights using sodium vapour lamps consume huge amount of power. These are being replaced with LED lamps in many cities and small towns. The saving from energy consumption will pay for the replacement cost in less than two years in most cases. The new LED lights can be remotely controlled – features like increase/decrease luminosity, switch off alternate lights during lean hours etc are possible. The lights can be connected on GPRS, RF Mesh or WiFi in the city for its remote operation. The newest trend is to install noise sensors and pollution sensors on the street light poles (cobra heads) which will leverage the same communication band-width to transmit the data to the control centres for monitoring noise and air pollution.

XIV. ENERGY STORAGE

Energy Storage Systems (ESS) will play a significant role in meeting energy needs by improving the operating capabilities of the grid as well as mitigating infrastructure investments. ESS can address issues with the transmission and dispatch of electricity, while also regulating the quality and reliability of the power generated by traditional and variable sources of power. ESS can also contribute to emergency preparedness. Modernizing the grid will require a substantial deployment of energy storage. Energy storage technologies—such as pumped hydro, compressed air energy storage, various types of batteries, flywheels, electrochemical capacitors, etc. - provide for multiple applications: energy management, backup power, peak shaving/shifting, frequency regulation, voltage support, renewable energy integration and grid stabilization.

XV. ELECTRIC VEHICLES

Electric Vehicles (EV) are propelled by an electric motor which is powered by batteries which can be recharged using an external power source often called as Electric Vehicle Supply Equipment (EVSE). The most serious concern electric utilities have is controlling when EV load is connected to their grid. A high percentage of consumers will instinctively charge their EVs when they get home from work; the absence of load management would likely have a destabilizing effect on the grid. Utilities must be prepared for multiple customers on the same transformer wishing to charge their EVs at the same time.

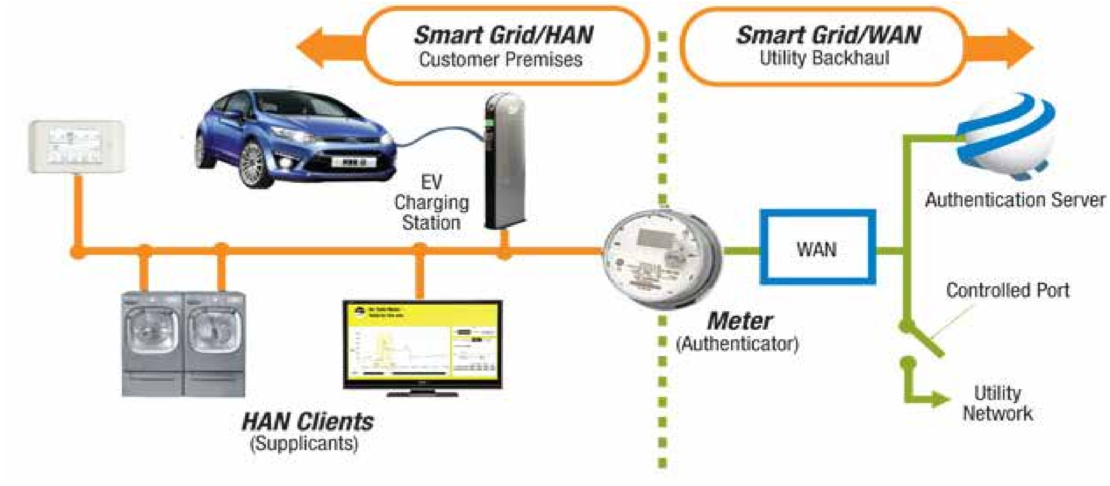


Figure 9: EV Technologies & Integration (Image Source- RTC magazine report)

Smart Grid technologies will enable EV charging to be scheduled intelligently. In addition, it enable the storage capacity of the batteries in EVs to be used as a supplementary source of power at times of peak load; portion of the power available in those batteries could be fed back into the network during the peak time and the battery recharged during off peak time. Vehicle –Grid Integration (VGI) is an important component of the emerging smart grid technologies.

XVI. DISTRIBUTED ENERGY RESOURCES AND RENEWABLE ENERGY INTEGRATION

Distributed energy resources (DER) are small, modular, energy generation and storage devices such as rooftop PV systems, micro wind turbines, energy storage batteries such as batteries in UPS, Inverters and EVs etc. DER systems may be either connected to the local electric power grid or isolated from the grid in stand-alone applications.

Renewable Energy Integration focuses on incorporating renewable energy, distributed generation, energy storage and demand response into the electricity transmission and distribution systems. A systems approach is being used to conduct integration development and demonstrations to address technical, economic, regulatory, and institutional barriers for using renewable and distributed systems. In addition to fully addressing operational issues, the integration also establishes viable business models for incorporating these technologies into capacity planning, grid operations, and demand-side management.

The goal of renewable energy integration is to advance system design, planning, and operation of the electric grid to:

- Mitigate the intermittency of the renewable energy resources through better forecasting, scheduling and dispatch of the power system as well as flexibility in demand and generation
- Reduce emissions through increased use of renewable energy and other clean distributed generation resources

- Increase asset use through integration of distributed systems and customer loads to reduce peak load and thus lower the costs of electricity
- Support achievement of renewable portfolio standards for renewable energy and energy efficiency
- Ensure reliability, security, and resiliency of the grid despite intermittency and variability of generation from renewable resources

XVII. CUSTOMER CARE CENTRE

Most distribution utilities today have state of the art 24x7 Customer Care Centre (CCC) with sophisticated systems to address multiple calls. In India there is a four digit common number (1912) allotted for electricity complaints. All operational and customer related systems are integrated with CCC so that the call agent can address all types of queries from the customers. CCC is becoming an important part of the smart grid domain.

Latest addition to this is Chatbots for interaction with customers. Chatbots are algorithms that can engage with real people in chat sessions. Many questions can be answered by chatbots instead of call agents. Entire interaction between the customer and the chatbots are recorded and analysed by advanced analytical tools which will help rectify several issues in the system which are otherwise difficult to detect.

XVIII. CUSTOMER ENGAGEMENT

Experiences from around the globe indicate that engagement of customers and their active participation is key to successful implementation and operation of smart grid projects. Customers need to be taken in to confidence right from the beginning by making them aware of the benefits of the new systems as well as educating them how to enjoy the benefits of the new time of use tariff regime, demand response schemes etc. so that they can effectively manage their energy consumption and monitor their bills. Specialized agencies may be engaged by utilities to undertake a holistic communication campaign to engage the customers from the project design stage itself.

XIX. SOCIAL MEDIA FOR UTILITIES

For a power utility, a call centre has traditionally been the single touch-point with its customers. For utilities to be able to cope up with the changing times and start excelling in their energy delivery, the customer service models are undergoing a paradigm shift. A large number of electric utilities in the US are already using social media platforms like Facebook, Twitter etc., to connect with their customers, issue outbound communications, track customer complaints and queries etc. They are also being used as effective mediums for promoting energy efficiency measures, imparting safety tips and proper usage of domestic appliances, influencing customer behaviour and forging positive customer relationships particularly during power outages and recovery efforts from weather related incidents. However, reports indicate that 48 percent of U.S. customers believe companies need to do a better job of integrating their online and offline experiences, and over 50 percent of people surveyed in 2014 believed that local utilities should harness the real-time communications of various social media channels to share information. Utilities can provide much better services by integrating social media in their outage management, crisis/disaster handling, billing and collection and other customer related issues. In addition, social media can be a platform for promotion of clean energy, DSM/DR activities, tariff plans, electric vehicle usage etc. It can also prove as an effective tool for branding and promotion of good will.

XX. CYBER SECURITY

The power sector is the critical infrastructure of a nation and other sectors depend directly and indirectly on the power sector. Cyber-physical security is protection of the assets (both hardware and software) from natural and manmade disasters and intended and unintended activities. Since physical assets are associated with the cyber space of a utility, cyber-physical security completely defines the security paradigm of a utility. This dependency of the physical assets on the cyber assets (and vice versa), has prompted the utilities to inject resiliency and robustness into their grids.

ISGF in association with National Critical Information Infrastructure Protection Centre (NCIIPC) and VJTI, a renowned engineering institute in Mumbai, India has prepared a comprehensive framework for assessment of cyber security readiness of power sector utilities and assessed a select set of utilities in 2014-15. The top ten findings from those assessments were circulated to all utilities in India to comply with. In 2016, ISGF in association with NCIIPC has prepared the Indian Manual on Cyber Security for Power Systems which is presently being reviewed by Central Electricity Authority (CEA) on behalf of Ministry of Power. Most of the recommendations have already been incorporated in the BIS Standard IS 16335: “Power Control systems - Security Requirements”.

XXI. ANALYTICS

In today’s competitive utilities market, the need to carefully and efficiently manage the power grid is of paramount importance. Utilities must stay on top of shifting energy policies and changes in technology while balancing concerns about energy security, environmental sustainability and economic competitiveness. At the same time, customers demand reliability. The analytics solutions has the capabilities to analyse raw data captured from within the energy grid, and produce trends and odd events and other key operational parameters a utility needs to optimize capital expenditures, reduce operating costs, quickly locate faults and make the grid more efficient as well as address the customer needs.

XXII. SMART HOMES, BUILDING ENERGY MANAGEMENT SYSTEM/HOME ENERGY MANAGEMENT SYSTEM (BEMS/HEMS)

BEMS/HEMS is a computer based control system installed in buildings that controls and monitors the building’s mechanical and electrical equipment such as air-conditioning and ventilation, lighting, water heaters, pumps, other power consuming equipment, fire protection and security systems

Smart homes/buildings would offer monitoring and control of the electricity usage within the building premises. Energy management systems is the core of home/building automation by providing a means to efficiently consume electricity. In addition to a smart meter that would remotely connect and disconnect the supply, smart appliances would provide the energy consumption data to the customer and the utility. The customer could view the consumption data via an In-Home Display (IHD) device or via SMS, e-mail, mobile app or by logging on to a customer portal. Loads could also be remotely controlled via the aggregators or energy management systems.

3.4 SMART GRID MATURITY MODEL

The Smart Grid Maturity Model (SGMM) is a management tool that utilities can leverage to plan their smart grid journey, prioritize their options, and measure their progress as they move towards the realization of a smart grid. The SGMM was founded by utilities for utilities when the Global Intelligent Utility Network Coalition, a smart grid collaboration of 11 utilities, saw the need in the industry for such a tool. The model describes eight domains, which contain logical groupings of incremental smart grid characteristics and capabilities that represent key elements of smart grid strategy, organization, implementation, and operations. Utilities use the SGMM framework to assess their current state of smart grid implementation, define their goals for a future state, and generate inputs into their road mapping, planning, and implementation processes.

SGMM is maintained by the Software Engineering Institute (SEI) at Carnegie Mellon University (CMU) with the support of the U.S. Department of Energy.

3.4.1 OVERVIEW OF THE MODEL:

The SGMM describes 8 domains containing logical groupings of incremental smart grid characteristics, which represent key elements of smart grid strategy, organization, operation, and capability

SMR	Strategy, Management, and Regulatory *Vision, planning, governance, stakeholder collaboration*	TECH	Technology *IT architecture, standards, infrastructure, integration, tools*
OS	Organization and Structure *Culture, structure, training, communications, knowledge management*	CUST	Customer Pricing, customer participation & experience, advanced services
GO	Grid Operations *Reliability, efficiency, security, safety, observability, control*	VCI	Value Chain Integration *Demand & supply management, leveraging market opportunities*
WAM	Work and Asset Management *Asset monitoring, tracking & maintenance, mobile workforce*	SE	Societal and Environmental *Responsibility, sustainability, critical infrastructure, efficiency*

Figure 10: Domains of SGMM

3.4.2 SGMM LEVELS

PIONEERING 5	Breaking new ground; industry-leading innovation
OPTIMIZING 4	Optimizing smart grid to benefit entire organization; may reach beyond organization; increased automation
INTEGRATING 3	Integrating smart grid deployments across the organization, realizing measurably improved performance
ENABLING 2	Investing based on clear strategy, implementing first projects to enable smart grid (may be compartmentalized)
INITIATING 1	Taking the first steps, exploring options, conducting experiments, developing smart grid vision
DEFAULT 0	Default level (status quo)

Figure 11: Smart Grid Maturity Model – levels

SGMM study is carried out in two stages

- Compass Survey (AS-IS)
- Aspiration Survey (TO-BE)

In the compass survey is conducted by a certified SGMM Navigator in which the senior leadership teams from various functions (8 domains) of the utility answers questions related to the present state of the utility in each of the 8 domains so that "AS-IS" state is determined. The compass survey results are shared with the utility which they may discussed amongst their teams.

Once the utility senior management in principle agree with the "AS-IS" state determined from the compass survey, another visioning workshop will be conducted by the SGMM Navigator. In the visioning workshop the utility discuss various pros and cons and define the TO-BE states in each domain different time horizons. No utility wants to be in Level-5 in all domains. Depending on their business priorities and present state, the utility set their target state in each domain.

Once the "TO-BE" state is defined, the utility can prepare how to ascend from the present state to the "TO-BE state and what technologies and systems to be implemented and conduct its cost-benefit analysis.

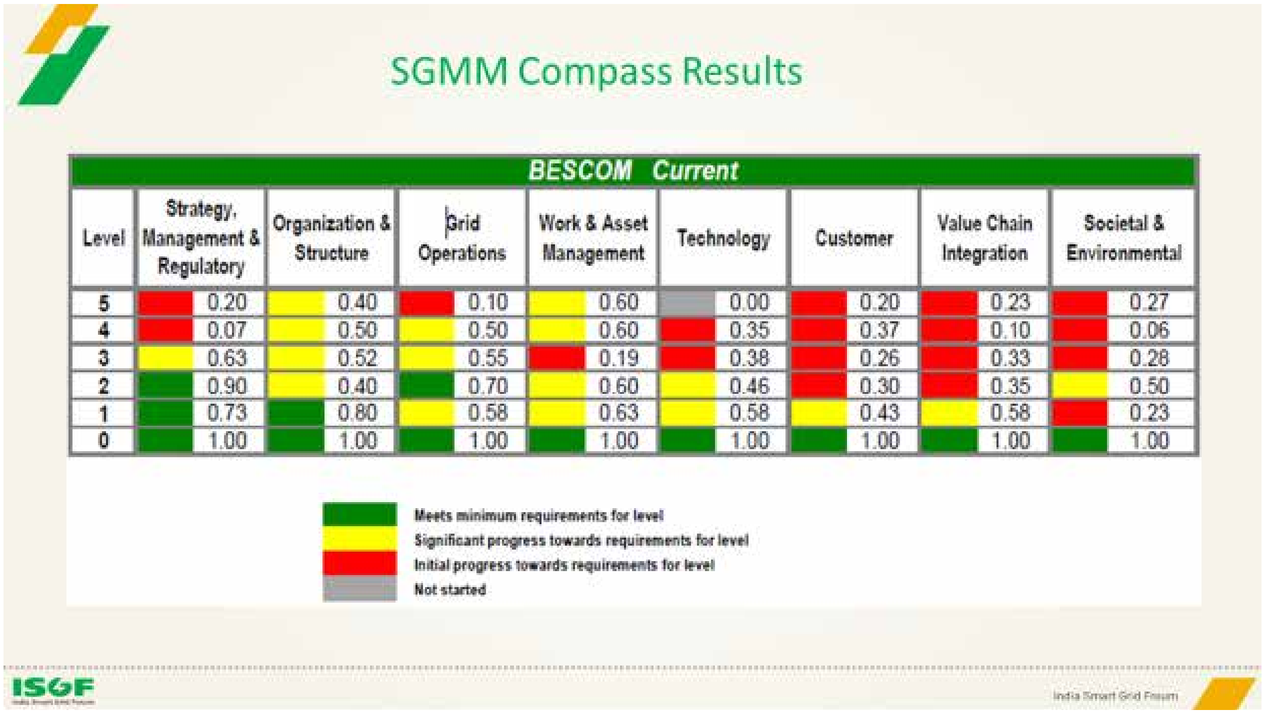
I. BENEFITS TO THE UTILITY:

Many utilities have reported that the SGMM comparison yields additional insights about their smart grid progress and plans. Major investor-owned utilities and small public power utilities alike, in the US and around the world, have reported finding the model a valuable tool to help them:

- Identify where they are on the smart grid journey
- Develop a shared smart grid vision and roadmap
- Plan for technological, regulatory and organizational readiness
- Assess resource needs to move from one level to another
- Create alignment and improved execution
- Communicate with internal and external stakeholders using a common language
- Prioritize options and support decision making
- Compare against themselves over time and to the rest of the community
- Measure their progress

II. TYPICAL SGMM ASSESSMENT OF AN INDIAN UTILITY:

ISGF conducted SGMM assessment of Bangalore Electricity Supply Company Ltd (BESCOM) in India in 2016/17. The AS-IS result from the compass survey is given below:



SGMM Compass Results

BESCOM Current								
Level	Strategy, Management & Regulatory	Organization & Structure	Grid Operations	Work & Asset Management	Technology	Customer	Value Chain Integration	Societal & Environmental
5	0.20	0.40	0.10	0.60	0.00	0.20	0.23	0.27
4	0.07	0.50	0.50	0.60	0.35	0.37	0.10	0.06
3	0.63	0.52	0.55	0.19	0.38	0.26	0.33	0.28
2	0.90	0.40	0.70	0.60	0.46	0.30	0.35	0.50
1	0.73	0.80	0.58	0.63	0.58	0.43	0.58	0.23
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Meets minimum requirements for level
Significant progress towards requirements for level
Initial progress towards requirements for level
Not started

ISGF
India Smart Grid Forum

Figure 12: SGMM Results of AS-IS Survey of BESCOM

Figure 13: BESCOM Smart Grid Roadmap suggested by ISGF

MODULE 1

21ST CENTURY GRIDS – EVOLVING TRENDS IN GRID MODERNIZATION

Abstract

Module 1 sets the tone of this Smart Grid Handbook by discussing 21st Century Electric Grids and the Evolving Trends in Grid Modernization. The Module discusses the changing picture of the electric grid from a traditional grid where central generation dominates the power supply to an integrated grid where Distributed Energy Resources (DERs), mostly Renewable Energy Resources (RESs), play an important role. Various new technologies are overviewed in this Module including Electrical Energy Storage (ESS), New Generation Technologies related to RES, Solid State Transformer (SST), Electric Vehicle (EV) and Microgrid as a foundation to present the plurality of Smart Grid visions as embraced by many developed and developing countries around the world. The Module concludes with the Smart Grid Vision and Roadmap for India.

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1 21ST CENTURY GRIDS – EVOLVING TRENDS INGRID MODERNIZATION

1.0 INTRODUCTION

Electric grid is considered to be the biggest engineering achievement of the 20th century. We built large power plants that generate electricity which is transported over high voltage transmission networks to long distances and distribute the electricity at low voltage to millions of customers. The power system consisting of limited number of power stations injecting electricity in to the grid and millions of customers drawing electricity from the grid remained as the basic model of electrification for over a century. However in the past few years we see the emergence of a distinct trend with proliferation of distributed generation resources which has put the electric grids on the threshold of a paradigm shift. After 100 years of focus on centralized power generation, the shift is now towards de-centralized generation. In the recent past (from 2010), the picture of the grid has changed dramatically in many geographies. Some of the visible characteristics of this shift are:

- With the increasing share of generation resources being added at the distribution end, the traditional boundaries between generation, transmission and distribution are fast disappearing
- With consumers becoming "prosumers", the grid that is built for one-way flow of electricity is now experiencing bi-directional flow of electrons
- With decreasing cost of energy storage solutions, there is already a debate on whether to invest in transmission or in storage – the choice between "Generation + Transmission + Distribution" AND "Distributed Generation + Storage + Distribution" is becoming real. This is even more relevant in regions where T&D losses are very high as with distributed generation there are fewer network losses
- The nature of loads have changed – Incandescent lamps and induction motors that could accommodate frequency and voltage excursions comprised majority of the load on the grid in the past. The present day digital loads require quality power at constant frequency and voltage
- Power purchase is moving from Volumetric Tariffs to Transactive Tariffs as Inflexible Demand has become Price Responsive Demand

- The "Merit Order Dispatch" has graduated towards an " Energy Efficient and Environmentally Responsible Dispatch" regime
- Solar PV has already achieved grid parity in many parts of the globe which is about to unleash a rooftop PV revolution and with increasing quantum of wind power being added the power mix on the grid is changing more towards intermittent generation resources
- Large fleets of Electric Vehicles that can be aggregated as virtual power plants which could support short term supply-demand balancing will make the grid even more dynamic and complex

In the traditional electric grid, the ability to monitor power flows and control it in real-time is limited to high voltage networks which are equipped with automation systems. In the low voltage network, the power system operator has no visibility on who is consuming how much electricity when and where. In a smart grid equipped with sensors and smart meters which are connected to computers in the control room, it is possible to remotely monitor and control the flow of electricity in real time to every customer or even to every smart appliance inside a customer's premise. So the evolving smart grid of the 21st century will be drastically different – the grid will soon emerge as the ***"grid of things"*** like how the internet is evolving as ***"internet of everything"***.

1.1 CHANGING PICTURE OF THE ELECTRIC GRID

Some of the disruptive changes taking place in the power systems are described in detail below:

1.1.1 INTEGRATED GRID

Traditionally the power system was vertically divided in to three segments as Generation, Transmission and Distribution. In the recent years, increasingly larger share of new generation resources such as rooftop PV, micro-wind turbines, energy storage devices (batteries and electric cars etc) are being connected to the low voltage grid. This is leading to the fast dis-appearance of the traditional boundaries between generation, transmission and distribution. It is a very disruptive trend for electric utilities as their organizational structures and functions are also segregated in to Generation, Transmission and Distribution silos. Traditionally all generation from the power plants flowed in to the transmission department which accounted for total receipts from generation. With rooftop PVs connected at customer premises to the distribution grid on a net-metering scheme which department of the utility will account for the total monthly generation and energy inputs, energy balance etc? Similarly, the System Operations group forecast the demand and generation department will schedule the available plant capacity for next day. With distributed generation assuming larger share in the energy mix, there is a need for forecasting potential generation from the distributed resources connected to the grid at customer premises in order to accurately schedule and dispatch. But neither the customers who own these resources have any capability nor the distribution department of the utility which deal with this segment of the grid has any expertise. Last but not the least the generation department has no visibility of distributed generation. In order to manage a grid with distributed generation resources connected at all voltage levels in the grid, utilities need to invent new organizational structures, new skills and operating rules which will require new investments. Management and operation of the evolving integrated grids are going to be major challenge in the transitional term.

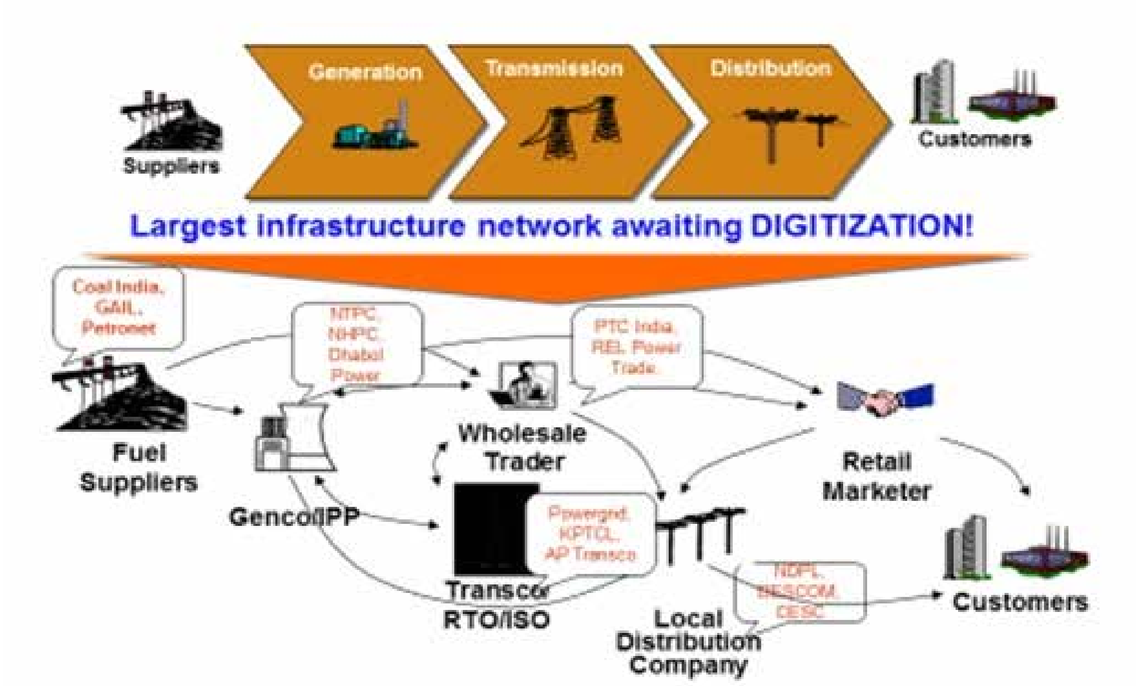


Figure 1-1: Structure of Traditional Grid

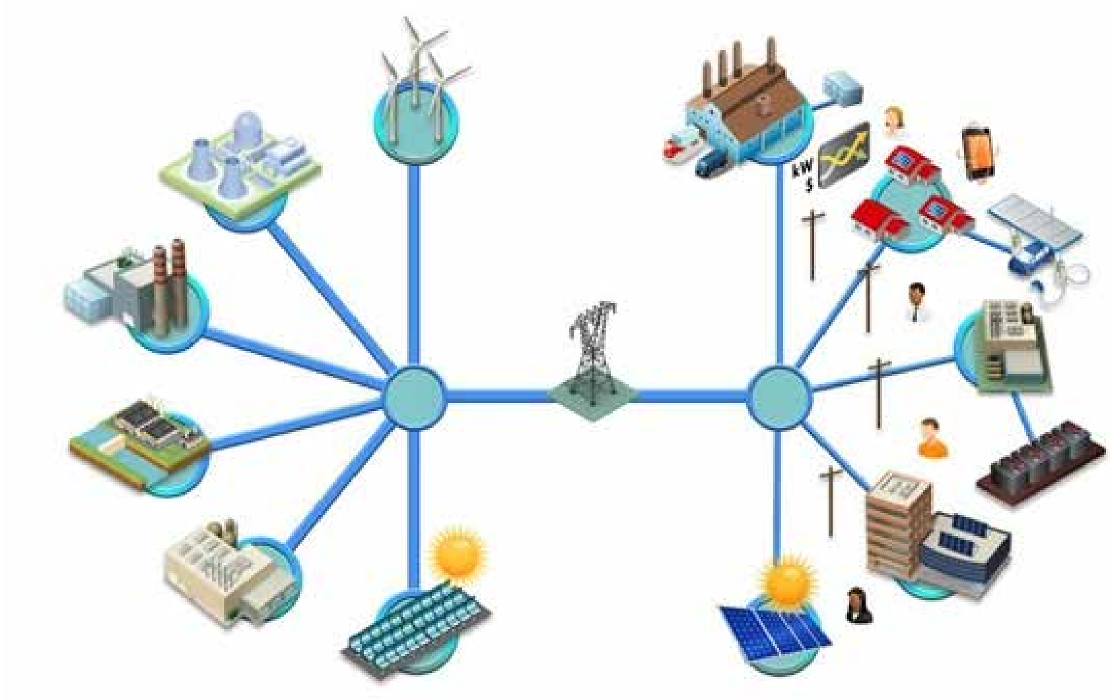


Figure 1-2: Picture of the emerging Integrated Grid

Source - EPRI

1.1.2 PROSUMERS

The existing grid is designed for one way flow of electrons from generating stations to loads at the customer premises and it was operated in that fashion for over a century. All equipment, systems, processes and operating procedures are designed to facilitate this one-way flow of electricity. However, now with rooftop PV or micro wind turbines on customer premises being connected to the grid, a customer can inject electricity in to the grid that the utility can sell to any customer on the network. So the traditional customer who was only a buyer of electricity has become a producer and a consumer – "prosumer" now. This again brings out both engineering challenges as well as business process challenges. In engineering terms it need to be assessed how much "reverse power flow" from a customer premises can be accommodated in the low voltage grid; and in terms of business challenges, the utility need to put in place new/smart metering and control systems as well as policies for accounting and payment mechanisms. Utility need to constantly evaluate the capacity of the last mile network before approving connectivity for rooftop PV systems which require network models and load flow studies. Yet another challenge for utilities!

1.1.3 TRANSMISSION V/S ENERGY STORAGE

A host of energy storage technologies are fast approaching commercialization and already MW-scale lithium ion and Sodium Sulphur (NaS) batteries are commercially deployed for certain grid applications. In many geographies, building transmission lines has been a herculean task as people dislike high voltage transmission lines passing through their habitations. In USA and several other countries, it takes well over a decade to establish the right of way for a high voltage transmission line and the cost of right of way is often higher than the actual line construction cost. In the emerging paradigm of distributed generation coupled with energy storage, utilities could avoid bringing high voltage transmission lines to congested urban areas or expensive neighbourhoods. In this scenario, large capacity battery storages (other storage technologies may also be relevant according locational considerations) and distributed generation can be designed to service the local load.

This model of "distributed generation + energy storage + distribution/consumption" is a challenge to the traditional model of "generation + transmission + distribution". In the distributed generation model, network losses are also lower compared to the traditional model. This is highly relevant in regions with high transmission and distribution losses. So we can expect to see in the coming years, many regions and pockets opting for distributed generation and storage instead of bringing electricity through high voltage transmission lines and building substations and distributing it.

1.1.4 CHANGING NATURE OF LOADS

Incandescent lamps and induction motors comprised of majority of the loads in the traditional grid. Both of them could accommodate frequency and voltage excursions to certain extent. If the voltage drops even by 50% still an incandescent bulb could burn with lower luminosity. But in the present day digital world, majority of the new loads require quality power at constant frequency and voltage. In the traditional grid, majority of the generation resources (large hydro and thermal stations) could accommodate load fluctuations to certain extent and could keep the voltage and frequency constant; but in the emerging grid with larger share of renewable generation resources which are intermittent, sudden drop in generation can take place any time and balancing the grid is becoming a nightmare for power system operators. When the share of renewables exceed the limit of spinning reserve maintained in a power system, it can cause serious fluctuations anytime. Hence we are now exploring demand-side controls. When sudden loss of generation happens, utility should be able to switch off certain loads (water pumping, air conditioning etc) at customer premises so that supply-demand equilibrium is achieved to ensure grid stability. The changes in the nature of loads have further complicated this grid balancing.

1.1.5 ELECTRIC VEHICLES

Electric Vehicles (EVs) are becoming an integral part of the electric grid. The globally accepted model for low carbon development is "electrification of all human activities including transportation and agriculture to the extent possible". In India, Government has launched a National Mission on Electric Mobility in 2013 with the target of 2 million four wheelers and 4-5 million two wheelers by 2020. Although this mission was moving slowly owing to a variety of teething issues including availability of charging stations, now, GoI has accorded priority for faster roll out of EVs to address the pollution in cities reaching dangerous levels.

EVs are big loads on the grids as car batteries are 10kWh to 100kWh whereas bus batteries can be from 100kWh to 300kWh. These will have unprecedented impacts on the distribution grid as it is not a stationary load for which the grid upgradation can be made at any particular location. EVs may be charged from different locations within a city based on where the EV owner is driving on a particular day. Huge investments are required to setup charging stations city wide as well as to upgrade the capacity of transformers and cables to accommodate the new loads from EVs. Even if a separate commercial tariff is applied on EV charging stations, cost recovery from necessary grid upgrades will not be viable. EV batteries can act as an energy storage device which can pump electricity back to the grid. Large fleets of EVs connected to the grid can be aggregated as virtual power plants which could support short term supply-demand balancing. This could help the distribution grid to tackle the intermittency of rooftop PV generation at street level.

All the above factors are going to affect the grid operations in a profound manner in the coming days leading to a paradigm shift. So the evolving 21st Century Grids are going to be drastically different than the one that we are used to for over a century.

1.2 NEW TECHNOLOGIES

Several emerging technologies are expected to be commercially viable before the end of this decade which include:

- Energy storage systems
- New generation technologies:
    - Next Generation Solar
    - Wave Energy
    - Next Generation Wind Turbine
    - Waste to Energy
    - Next Generation Nuclear Plants
- Solid State Transformer (SST)
- DC Grids
- V2G (and B2G) Technologies
- Hybrid Concepts (Solar & Wind)

1.2.1 ENERGY STORAGE SYSTEMS (ESS)

During the past two decades billions of dollars have been invested in research, development and deployment (RD&D) of energy storage systems. Several types of energy storage systems are under development. Some of the technologies shown promise are:

- Batteries: Different battery chemistries are being tried and tested for different applications – Sodium Sulphur (NaS) batteries, Lithium-Ion batteries, Flow batteries, Advanced Lead Acid batteries etc
- Compressed Air Energy Storage
- Flywheels
- Super Capacitors

Details on various ESS technologies are given in Module-9

Figure 1-3 depicts the price trend of batteries in the recent past and figure 1-4 gives price prediction for Lithium Ion Batteries up to 2030.

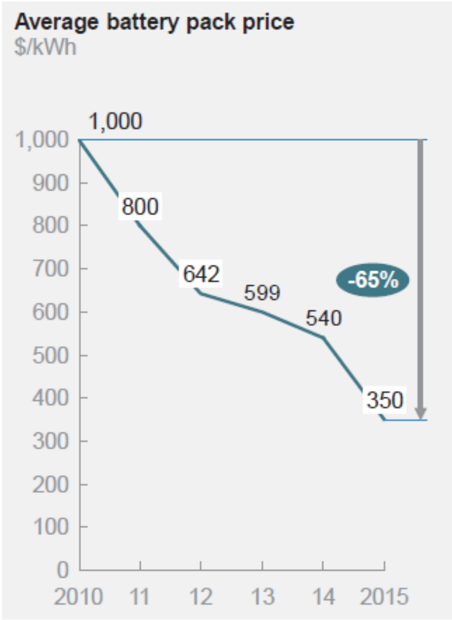


Figure 1-3: Average Battery Pack Price

Source: BNEF report on "an integrated perspective on the future of mobility"

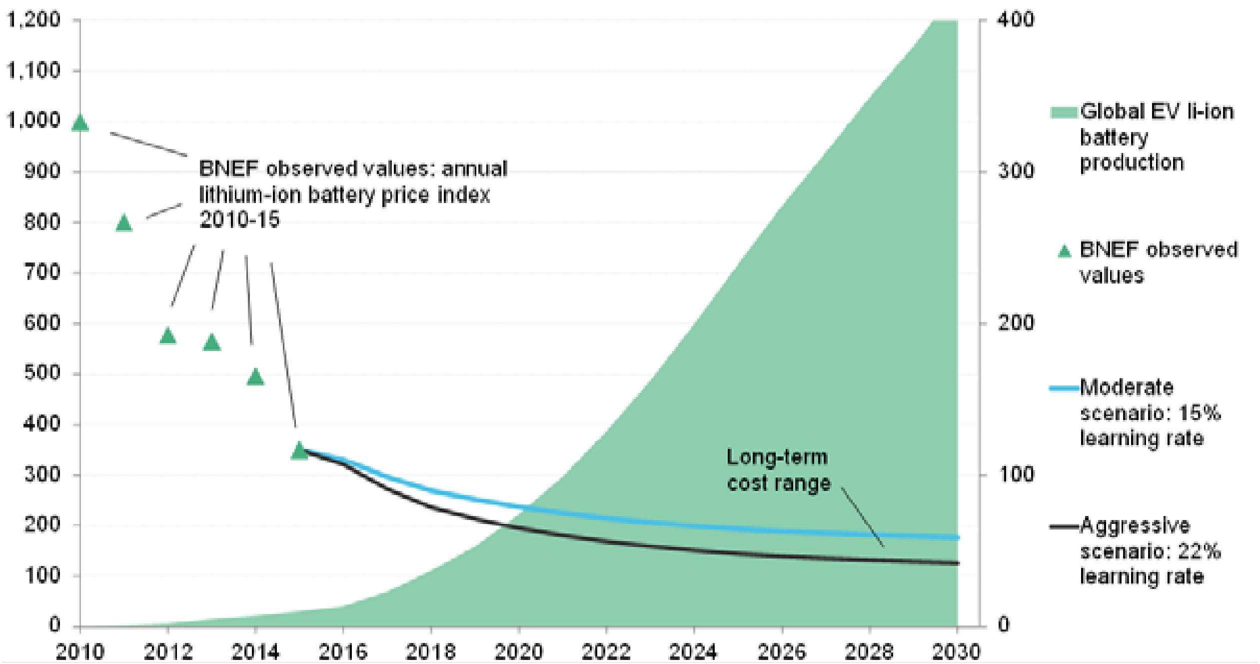


Figure 1-4: Lithium-ion battery cost outlook, 2011-2030

Source: BNEF

The current (2017) prices of Lithium Ion batteries (LFP and NMC type battery chemistries) is in the range of US$ 250 per kWh.

1.2.2 NEW GENERATION TECHNOLOGIES

Some of the promising new generation technologies are briefly mentioned here:

I. NEXT GENERATION SOLAR

The solar cells made of crystalline silicone had cell efficiencies below 15% in the 1970s has now improved to 24% by 2014. Yet most commercially available cells are below 20% efficiency with panels/module efficiency of 16-18%. The next generation cells in laboratories have efficiencies above 30% and expected to be commercially available by turn of this decade. Similarly the efficiency gains in solar inverters has also been very marginal in the past decades. Yet the prices of PV modules have been falling constantly at much greater pace as can be seen from Figure 1.5. During 2009-14 period the PV module prices fell by 75%. The deployment of solar PV has grown in geometrical proportions from 2.6 GW in 2004 to 177 GW by 2014.

According to Prof. Ray Kurzweil, solar PV has been doubling its share every two years for the past 25 years. In 2012 solar PV was producing 0.5% of world's total energy supply which has now doubled twice in 4 years to reach 2% - another 6 doublings or 12 years only to make it 100% theoretically – yet we will be using only 1/10,000 of the sun light we get on earth!!!

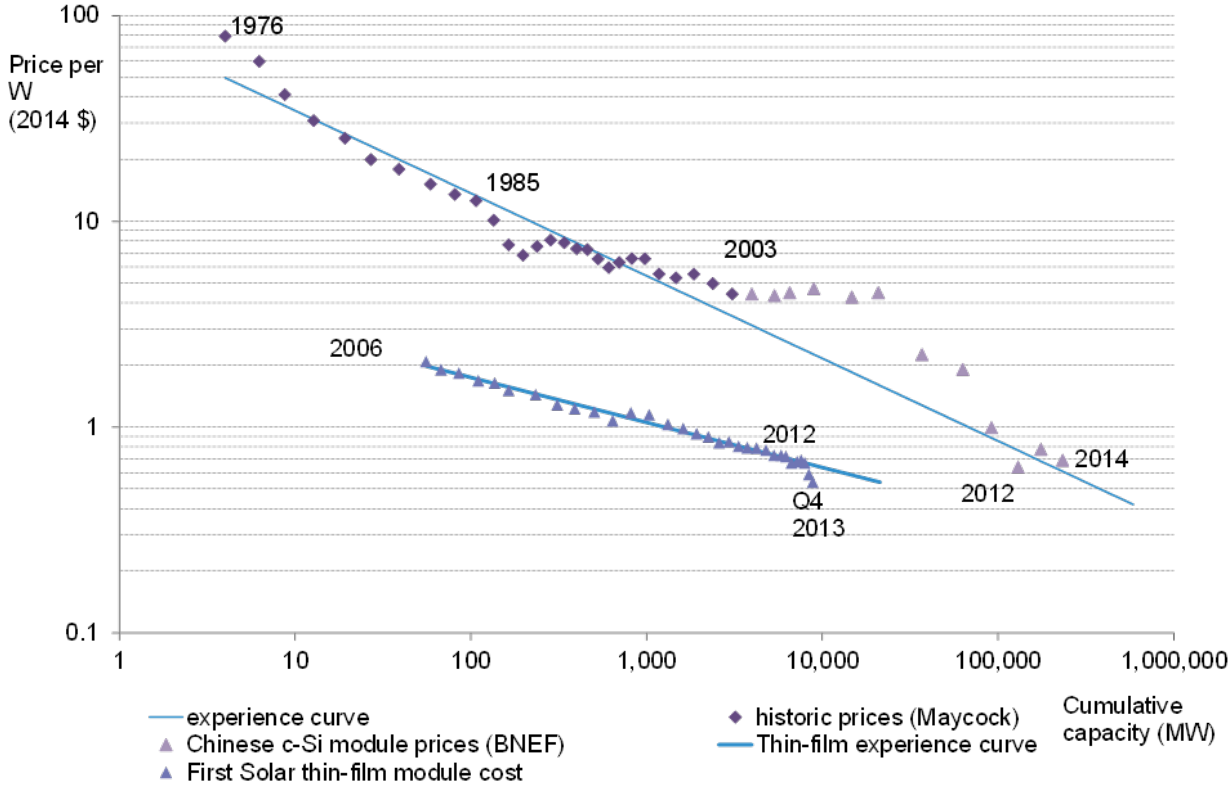


Figure 1-5: Solar photovoltaic experience curve, 1976-2014

Source: BNEF

Unlike wind or other forms of renewable energy the solar PV can be deployed in all sizes by all kind of users – few watt systems on calculators and other electronic devices to kW scale modules on building roofs to MW or GW scale systems connected to the grid. Since the technology offers this wide choice of sizes and prices, the next phase of solar PV growth is going to be viral – in the hands of actual consumers of electricity. It has already achieved price parity with grid power as explained in the previous section.

Table 1 1: Trend of Solar Tariff in Indian Solar Bids (Dec 2010 to Feb 2017)

Name	Year	Lowest (Rs/Kwh)	Weighted Average Price (Rs/Kwh)
NSM P1 B1 (Mah)	Dec'10	10.95	12.16
NSM Batch P1 B2 (Raj)	Dec'11	7.49	8.79
Orissa Phase B1	Mar'12	7	8.36
Orissa Phase B2	Dec'12	7.28	8.73
Karnataka P1	Apr'12	7.94	8.34
Madhya Pradesh P1	Jun'12	7.9	8.05
Tamil Nadu	Mar'13	5.97	6.48*
Rajasthan	Mar'13	6.45	6.45 (L1)
Andhra Pradesh	Apr'13	6.49	6.49 (L1)
Punjab Phase 1	Jun'13	7.2	8.41
Uttar Pradesh Phase 1	Aug'13	8.01	8.9
Karnataka Phase 2	Aug'13	5.5	6.87
Madhya Pradesh Phase 2	Jan'14	6.47	6.86
Andhra Pradesh Phase 2	Oct'14	5.25	5.75
Karnataka	Nov'14	6.71	6.94
Telangana	Nov'14	6.46	6.72
Punjab (Capacity 5-24 MW)	Feb'15	6.88	7.17
Punjab (Capacity 25-100 MW)	Feb'15	6.88	7.16
NTPC Anantapur	May'15	6.16	6.16*** (L1)
Uttar Pradesh Phase 2	June'15	7.02	8.04
Madhya Pradesh	June'15	5.051	5.36
Telangana Group 1	Aug'15	5.4991	5.73
Telangana Group 2	Aug'15	5.1729	5.62
Punjab	Sep'15	5.09	5.65
Uttarakhand	Oct'15	5.57	5.766
AP-500 MW Bundling Scheme	Nov'15	4.63	4.63
AP-350 MW Bundling Scheme	Dec'15	4.63	4.63
AP-150 MW Bundling Scheme (DCR)	Dec'15	5.12	5.123
Haryana (State Scheme)	Dec'15	5.00	5.00
Rajasthan-420 MW Bundling	Jan'16	4.34	4.351
UP-100 MW Bundling	Jan'16	4.78	4.78
Rajasthan-100 MW Bundling (DCR)	Mar'16	5.06	5.068

Name	Year	Lowest (Rs/Kwh)	Weighted Average Price (Rs/Kwh)
Telangana-50 MW Bundling (DCR)	Mar'16	5.19	5.19
MH-450 MW VGF	Jan'16	4.41	NA
UP-165 MW VGF	Feb'16	4.43	NA
Jharkhand-200	March'16	5.20	5.464
Jharkhand-1000	March'16	5.08	5.356
Telangana-350 MW Bundling	May'16	4.66	4.667
Karnataka-500 MW Bundling	May'16	4.78	4.79
MH-50 MW (VGF-DCR)	June'16	4.43	4.43
AP-400 MW (VGF)	June'16	4.43	4.43
Karnataka-920 MW (VGF)	June'16	4.43	4.43
Karnataka-50 MW (VGF-DCR)	June'16	4.43	4.43
CG-100 (VGF)	June'16	4.43	4.43
NSM PII B2 (Raj)	July'16	4.35	4.35
REWA Solar Project(MP)	Feb'17	2.97	3.30

Another important factor to be noted is that a GW scale solar farm can be installed in a year (that is provided land and money are available), but a thermal project can take 3-5 years in the best scenario. What above statistics and trends are indicating is that solar PV (Renewables) is poised to be the main source of energy by 2030. We need to work around on enabling technologies like grid integration of solar PV, energy storage and other sophisticated systems to forecast, schedule and dispatch solar generation efficiently.

II. WAVE ENERGY

Wave energy from the ocean waves has been a slow starter for several decades. The traditional approaches to tapping the energy from wave revolved around water turbines on floating buoys. The main challenge was to create regular output of energy from ocean swells which are 5-10 seconds apart. Other challenges included materials that can survive the high corrosion of sea water and weather shocks from high waves and storms. In the last 5-6 years we have witnessed few ground breaking developments. Particularly the designs and pilot projects of Wavestar Energy (Denmark), Eco Wave Power (Israel) and Carnegie Wave Energy (Australia) are worth mentioning.

Wavestar commissioned the test section of a 600kW wave energy unit at Roshage Pier near Hansthlom in Denmark in 2009 and is connected to the Danish grid since February 2010. This test section with a capacity of 100kW has two floats of 5 meter diameter which are installed in sea depths of 5-8 meters and wave heights of 6 meters. The 600kW commercial model will have 20 floats of 6 meter diameter which will be installed in sea depths of 10-20 meters and wave heights of 8 meters. The design involves kinetic energy harvesters called floats which move up and down with the kinetic

Figure 1-6: Typical Wave Energy Plant

motion of the waves and this up-down movement is converted to rotatory motion that drives the turbo-generators through a hydraulic mechanism with an efficiency >65%. The ultrasonic sensors on the floats and the predictive analytics can forecast waves and the system is equipped with a mechanism to lift the floats above the sea level when storms and high waves are predicted. Next generation design of Wavestar envisage incorporating wind turbines on the same structures that supports the floats. European Commission has approved funding of a 1MW plant in Belgium under the Horizon 2020 program.

Eco Wave Power (EWP), an Israeli company that demonstrated a novel ways to convert the wave energy in to electricity through a test bed in Ukraine and a pilot project at Jaffa port in Israel in 2011. Later a demonstration project was undertaken in the Black Sea in 2012. Ocean University of China forged a joint venture with EWP in 2012 and granted permission to construct a 100kW plant in Zoushan Island in eastern Zhejiang province. EWP entered in to an agreement with Gibraltar to build a 5 MW plant which is connected to the grid and will supply power to the grid on commercial basis through a power purchase agreement. A 100kW unit as first phase of this project is now operational. This will be expanded to 5 MW in phases by 2020.

EWP design consist of two devices – wave clapper and power wing – which can continuously derive energy from the waves. These devices are equipped with sensors that can predict the intensity of upcoming waves and lift or lower the floats accordingly. This technology was demonstrated in Black Sea in 2012. The key feature of the EWP design is that it converts ocean wave motions (kinetic energy) to a generator on the ground through high pressure hydraulic fluid through sub sub-sea cables. Only the floats, its supporting structure and the cables are inside the sea. Rest all equipment are on the shore.

Other notable development in the wave energy are US Navy's StingRAY project and Carnegie Wave Energy Project (supported by Australian Renewable Energy Agency). The Carnegie's plant consist of 3 units of 240kW and are in operation for over a year and supplying electricity and desalinated water to Australia's largest Naval Base in Garden Island. Carnegie's next designs will have 1 MW capacity for each unit.

According to IEA, the world electricity demand was 17500 TWh and the sea has a potential to generate over 100,000 TWh! Sea can be a source of very cheap energy once initial capital cost comes down. India with thousands of kilometers of ocean front should seriously look at these emerging technologies. As in the case of every other new technology, with volumes the prices will fall. Cheap power from the waves can be used for desalination of sea water to produce affordable drinking water which is going to be a major area of concern in the coming days.

Besides wave energy, many R&D projects are going on to tap energy from ocean currents, tides and also the ocean thermal energy conversion (OTEC).

III. NEXT GENERATION WIND TURBINES

Next generation wind turbines with Multiple Rotors and Floating Wind Turbines are already in trial operations and expected to revolutionise the wind energy domain.

Figure 1-7: Wind Turbine with Multiple Rotors

Image Source: WikiMedia

Figure 1-8: Floating Wind Turbine in Portugal

Image Source: Cleantechnica

These inventions are expected to be commercially viable by end of this decade.

Globally, while there has been much written about the precipitous drop in the price of solar PV, less has been written about the drop in wind prices. While the recent record low prices for wind in auctions in Peru, Morocco and Mexico will not be replicable everywhere in the short term, we can expect prices to continue to come down, and unlike solar, they were already low to begin with. Although it may seem like wind and solar are in a 'race' to get the lowest cost, as will be seen below, at a certain point, that is no longer the question. There is plenty of room for both technologies in most systems for the foreseeable future, and the local resource, demand curve and system characteristics will determine the relative amounts of each technology that are optimal in each system.

IV. WASTE TO ENERGY

Power generation from waste, particularly municipal solid waste (MSW) is attracting acceptance around the world. With ever increasing urbanization, average daily generation of MSW is about 1kg per person and it keep increasing with GDP growth and at a much higher level of GDP (>US$5000 per capita) that growth of waste generation gets decoupled from GDP growth – otherwise the trend has been more prosperity, more waste! Developed world addressed the problem of MSW with segregation of waste in to different categories such as recyclable, bio-degradable, non-degradable etc. In most developing countries the practice been to dump all kinds of waste together and rag pickers sort out what is valuable for them and the rest is used as landfill. Instilling a culture of segregation of waste in to different categories at user end look highly impractical in India (and most other developing countries) owing to a variety of factors. With latest incineration technologies, the MSW can be efficiently burnt to produce electricity and industrial heat.

India did several experiments with waste-to-energy plants in the last 3-4 decades, starting with a pilot plant in Delhi in the 1980s which never functioned. A modern design plant constructed at Okhla in the 2000s again has technical issues. A more recent plant was built in Ghazipur (on the outskirts of Delhi) recently by IL&FS. Even this plant has technical issues.

China has mastered the art of waste to energy plants that can burn MSW efficiently without any segregation. There are over two dozen plants in operation and now 700 cities in China are building similar plants. A typical plant is in the Haikou City in Southern China with a capacity of 48 MW running efficiently on MSW supplied by the city government on a long term contract. The city government gives approx. US$10/MT of MSW and also buy the electricity from the plant at 1.5 times the price of power from a coal plant. Still the city government save huge amount having no other expenses towards handling the MSW. Indian cities generate huge amounts of waste that municipalities are struggling to handle. In most cities the waste is creating severe environmental and health problems. All municipal towns (1300+) should seriously consider building waste to energy plants.

V. NEXT GENERATION NUCLEAR PLANTS

Nuclear renaissance was on the threshold when Fukushima accident happened in 2011. The Fukushima accident has inflicted serious damage to the future of nuclear power. Worldwide there are 436 nuclear reactors in operation for power production while 48 have been shut down; and 149 are under construction or planning stages. USA leads with 99 operating reactors contributing about 20% of the electricity produced while 48 reactors have been shut down and 18 are under construction. In France 58 operating reactors contribute to 76% of the electricity there and 12 have been shut down. Table –1-2 shows the status of reactors in operation, already shutdown and under planning and construction stage. It is interesting to note that none of the Western European countries except UK are planning for new reactors while most Eastern

European countries have kept nuclear option very much alive with Russia alone planning 25 reactors followed by Romania, Czech Republic, Hungary and Armenia. India has 21 rectors in operation contributing to 3.5% of the county's electricity. Another 24 rectors are in various stages of planning.

Table 1-2: Global Nuclear Energy Fact Sheet

S. No.	Country	Reactors Operable	Reactors Shutdown	Reactors Planned	Share of Nuclear Energy (%)
1	Argentina	3	0	2	4.8
2	Armenia	1	1	1	34.5
3	Belgium	7	1	0	37.5
4	Brazil	2	0	0	2.8
5	Bulgaria	2	4	1	31.3
6	Canada	19	6	2	16.6
7	China	32	0	42	3
8	Czech Republic	6	0	2	32.5
9	Finland	4	0	1	33.7
10	France	58	12	0	76.3
11	Germany	8	28	0	14.1
12	Hungary	4	0	2	52.7
13	India	21	0	24	3.5
14	Iran	1	0	2	1.3
15	Japan	43	17	9	0.5
16	Korea RO (South)	25	0	8	31.7
17	Mexico	2	0	0	6.8
18	Netherlands	1	1	0	3.7
19	Pakistan	3	0	2	4.4
20	Romania	2	0	2	17.3
21	Russia	35	5	25	18.6
22	Slovakia	4	3	0	55.9
23	Slovenia	1	0	0	38
24	South Africa	2	0	0	4.7
25	Spain	7	2	0	20.3
26	Sweden	9	3	0	34.3
27	Switzerland	5	1	0	33.5
28	Ukraine	15	4	2	56.5
29	United Kingdom	15	30	4	18.9
30	USA	99	0	18	19.5
	Total	436	118	149	

Source: World Nuclear Association; compiled by S.Ramani, Times of India, 2016

Radioactive waste and accidents—including the United States' Three Mile Island in 1979, Ukraine's Chernobyl in 1986 and Japan's Fukushima Daiichi in 2011—have prompted many to argue nuclear is just too dangerous. Yet many climate scientists say nuclear has to be part of the solution. Citing the dangers of global warming, they say there's no realistic path forward without a "substantial role" for nuclear. Their public appeal calls for a fresh approach to nuclear power in the 21st century. Total causalities from the three major nuclear accidents in the whole history of nuclear power in the last 70+ years less than 400 people where as in India alone more than 400 people die every day from road accidents.

The nuclear power industry has been developing and improving reactor technology for more than five decades and is starting to build the next generation of nuclear power reactors to fill new orders. Several generations of reactors are commonly distinguished. Generation I reactors were developed in 1950-60s, and outside the UK none are still running today. Generation II reactors are typified by the present US and French fleets and most in operation elsewhere. So-called Generation III (and III+) are the advanced reactors. The first are in operation in Japan and others are under construction or ready to be ordered. Generation IV designs are still on the drawing board and will not be operational before 2020 at the earliest. About 85% of the world's nuclear electricity is generated by reactors derived from designs originally developed for naval use. These and other nuclear power units now operating have been found to be safe and reliable, but they are being superseded by better designs.

The next-gen designs promise to be safer, cheaper, and more efficient. They're drawing venture capital from tech titans, including Microsoft co-founder Bill Gates, Amazon CEO Jeff Bezos, and former SpaceX partners. Nearly 50 start-ups working in the U.S. and Canada alone have raised more than $1.3 billion in private investment, according one report in December 2015. Some startups are working on small modular reactors (SMR) that could be portable and prefabricated. Some are working on nuclear fusion, long considered the holy-grail for pollution-free energy. Others try innovative fuels and alternative coolants. Bill Gates-backed nuclear startup TerraPower has built the Waste-Annihilating Molten Salt Reactor. TerraPower design is a traveling wave reactor that runs on depleted uranium and produces very little nuclear waste. They estimate that if all 270,000 metric tons of existing high-level nuclear waste went into their reactors, they could produce enough electricity to power the world for 72 years, even assuming projected increases in global energy demand. Conventional reactors, fuelled by pellets of solid uranium oxide, use only 3-4 percent of uranium's energy so the waste remains radioactive for hundreds of thousands of years. But because TerraPower's reactor uses uranium in a liquid rather than solid form, it extracts 96 percent of the energy. Another startup, Transatomic Power, has built a new molten salt nuclear reactor that reuses nuclear waste and automatically shuts down if there's a power outage. In this design, if a molten salt reactor loses electric power (as happened at the Fukushima plant following the tsunami), the fuel automatically drains into an auxiliary tank and freezes solid in a few hours. Hence, no meltdown. But critics say, molten salt is corrosive and messy to work with. Reactor suppliers in North America, Japan, Europe, Russia and elsewhere have a dozen new nuclear reactor designs at advanced stages of planning or under construction (seven designs), while others are at a research and development stage. Fourth-generation reactors are at R&D or concept stage. Since many of these new designs are yet to be prototyped, it could take another 20 years for their commercialization.

1.2.3 SOLID STATE TRANSFORMER (SST)

This is another interesting technology under development. First patent for Solid State Transformer (SST) was filed in 1980s but owing to availability of suitable materials the technology remained in the labs only. Now with breakthroughs in material sciences, SST is fast approaching commercialization. An SST can take both AC and DC inputs as well as give AC and DC outputs; and enable bi-directional power-flows. It can also improve power quality – reactive compensation and harmonic filtering. SST will be only 1% in size and weight of a comparable distribution transformer. SSTs of 11-15kV ratings are expected to be commercialized in next 5-7 years. This will radically change the electric grid where AC and DC will merge!

1.2.4 MICROGRIDS AND DC GRIDS

Microgrid is top on the list of smart grid technologies in the developed countries - reason: critical infrastructure (airports, military bases, hospitals etc) have no stand-by power supply systems. At the heart of a microgrid is an intelligent control centre that can island the local grid (microgrid) from the utility grid and can control and curtail (if required) the load within that microgrid to match the emergency demand with the available generation and storage facilities. Smart microgrids that can island from the grid is considered as a fall back safety net against cyber attacks. While it is easy for an attacker to target the control centre of a large utility, it will be impossible to attack thousands of microgrids with each of it having its own control centres. In case of an attack and breakdown of the utility control centre, the microgrids can island from the main grid and can serve critical loads till main grid is back in operation.

Today the electricity generated from solar PV is converted from DC to AC and distributed which is again converted to DC for the digital appliances such as computers, LED lights, LCD/LED TVs, flat screen monitors, security cameras, cell phones etc. Almost half the energy generated is lost in these two conversions (DC to AC and again AC to DC). As the share of DC generation and DC consumption both are increasing steadily, it makes business sense to have DC distribution system in parallel to AC distribution in offices and homes. Already in certain hotels and office buildings there is 5V DC distribution system on which USB connections are provided.

Several teams around the world are working on standards for DC Grids. In India, ISGF facilitated the creation of a Low Voltage Direct Current (LVDC) Forum in 2013 which has been adopted by IEEE. This LVDC Forum has selected 48V DC for indoor applications in India and standards for the same has been issued by Bureau of Indian Standards (BIS) in November 2017 (IS 16711:2017 - 48 V ELVDC Distribution Systems –Guidelines). DC Grids could also facilitate reliable rural electrification with solar PV, batteries and DC appliances – LED lights, Brushless DC (BLDC) motors, LED TVs etc.

1.2.4 V2G TECHNOLOGIES

The Electric Vehicle (EV) batteries could act both as load as well as generation resources. Millions of EVs connected to the grid can be aggregated as virtual power plants (VPP) and support the grid during supply-demand imbalances. This is again becoming increasingly relevant with proliferation of rooftop PV which is intermittent. Vehicle to Grid (V2G) technologies are ready for commercialization. However EV manufacturers are reluctant to facilitate V2G functionality in EVs owing to warranty on the batteries. The V2G trials in past few years in several research centres indicate that if the depth of discharge of the EV battery is limited with in specified limits during V2G operations, there will be little or no impacts on the battery life. We expect V2G to play a major role in the 21st century grids with major share of renewable generation resources.

1.2.5 HYBRID CONCEPTS

An ideal wind-solar hybrid system is one that generates electrical energy by using an optimal combination of wind turbines and solar photovoltaic (PV) panels, along with shared infrastructure that allows for greater economic and social utilisation of both the resources.

Primarily, there are three types of wind-solar hybrids – smalls cale hybride, co-located hybrids and true hybrids.

Small-scale hybrids include various small-scale watt-class and kilowatt class projects, which are deployed for off-grid renewable energy-based generation.

A co-located hybrid comprises two independent generating systems located in close proximity to each other. This allows them to share large transmission equipment such as a common substation and grid infrastructure.

Meanwhile, in a true hybrid system, the two technologies, wind and solar, work in tandem and use common components to produce a single electricity output more efficiently. In such systems, the output of the entire network is capped at rated output of the bigger system.

1.3 OVERVIEW OF SMART GRIDS

The smart grid is the evolving grid with advanced automation, control, IT and IOT systems that enables real-time monitoring and control of power flows from sources of generation to sources of consumption. A set of technologies enable these functionalities and help manage electricity demand in a sustainable, reliable and economic manner. Smart grids can provide consumers with real-time information on their energy use, support pricing that reflects changes in supply and demand, and enable smart appliances and devices to help consumers exercise choices in terms of usage of energy.

"Smart grid is an electricity grid with communication, automation and IT systems that enable real time monitoring and control of bi-directional power flows and information flows from points of generation to points of consumption at the appliances level."

1.3.1 DRIVERS FOR SMART GRID

Since the early 21st century, advancement in electronic communication technology is being used to resolve the limitations and costs of the electrical grid. Technological limitations on metering no longer force peak power prices to be averaged out and passed on to all consumers equally. In parallel, growing concerns over environmental damage from fossil-fired power stations has led to a desire to use large amounts of renewable energy. Dominant forms such as wind power and solar power are highly variable and hence the need for more sophisticated control systems to manage supply-demand balance.

Key drivers for smart grids in the Indian context are:

- Reduction in AT&C losses
- Demand side management (TOU Tariff—Dynamic pricing based for peak demand and peak supply)
- 24x7 Power for All
- Outage reduction
- Renewable energy integration
- Improved energy efficiency
- Reliable grid stability
- Faster restoration of electricity after fault or disturbances
- Grid flexibility (backup power)
- Reduction in peak demand
- Reduction in power purchase cost

1.3.2 KEY FUNCTIONALITIES AND COMPONENTS OF SMART GRIDS

Following are the key functionalities and components of smart grids:

- Supervisory Control and Data Acquisition (SCADA) and Energy Management Systems (EMS) at Transmission level and SCADA and Distribution Management Systems (DMS) at distribution level
- Distribution Automation
- Substation Automation
- Advanced Metering Infrastructure (AMI)
- Geographical Information System (GIS) Map
- Peak Load and Power Quality Management
- Outage Management System
- Distribution Transformer Monitoring System
- Mobile Crew Management System
- Enterprise IT Systems
- Application Integration
- Wide Area Monitoring Systems (WAMS)
- Smart Street Lights (with noise and pollution sensors)
- Energy Storage
- Electric Vehicles
- Distributed Energy Resources and Renewable Energy Integration
- Common Command Control Room
- Customer Engagement
- Social Media for Utility
- Cyber Security

1.4 SMART GRID VISION AND ROADMAP FOR INDIA

Ministry of Power with the inputs from India Smart Grid Forum (ISGF) and India Smart Grid Task Force (ISGTF) have issued Smart Grid Vision and Roadmap for India in August 2013. Smart Grid Vision for India in this document is to "Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders"

In order to achieve this vision, stakeholders are advised to formulate state/utility specific policies and programs in alignment with following broad policies and targets which are in line with MoP's overarching policy objective of "Access, Availability and Affordability of Power for All"

1.4.1 DISTRIBUTION

- Appropriate policies and programs to provide access to electricity for all with uninterrupted life line supply (8 hours/day minimum, including the evening peak) and electrification of 100% households by 2017. Also, continuous improvement in quality and quantum of supply.
- Completion of on-going programs which will lay the building blocks of smart grids such as system strengthening, consumer indexing, asset mapping as part of RAPDRP, and planning for integration of such systems into future smart grid deployments.
- Enabling programs and projects in distribution utilities to reduce AT&C losses to below 15% by 2017, below 12% by 2022, and below 10% by 2027.
- Integrated technology trials through a set of smart grid pilot projects by 2015. Based on outcome of the pilots, full rollout of smart grids in pilot project areas by 2017; in major urban areas by 2022 and nationwide by 2027.
- Availability of an indigenous low cost smart meter by 2014. After successful completion of pilots, AMI roll out for all customers in a phased manner based on size of connection (and geography and utility business case), starting with consumers with load >20 KW by 2017, 3- phase consumers by 2022 and all consumers by 2027 by deploying smart meters and necessary IT and communication infrastructure for the same. Innovative and sustainable financing/business models for smart meter roll outs may be developed.
- Working with other stakeholders, building the National Optical Fiber Network (NOFN) by connecting 2,50,000 village Panchayats in the country by Optical Fiber Cable and extending the fiber link to all the 33/11 kV and above substations to build a backbone communications network for the power sector by 2017.
- Modernisation of distribution sub-stations and conversion of sub-stations in all urban areas (starting with metro cities) to Gas Insulated Substations based on techno-commercial feasibility in a phased manner through innovative financing models.
- Development of Microgrids, storage options, virtual power plants (VPP), solar photovoltaic to grid (PV2G), and building to grid (B2G) technologies in order to manage peak demand, optimally use installed capacity and eliminate load shedding and black-outs.
- Policies for mandatory roof top solar power generation for large establishments, i.e., with connected load more than 20kW or otherwise defined threshold.
- EV charging facilities may be created in all parking lots, institutional buildings, apartment blocks etc; and quick/fast charging facilities to be built in fuel stations and at strategic locations on highways.
- Microgrids in 1000 villages/industrial parks/commercial hubs by 2017 and 10,000 villages/industrial parks/commercial hubs by 2022, which can island from the main grid during peak hours or grid disturbances.
- Optimally balancing different sources of generation through efficient scheduling and dispatch of distributed energy resources (including captive plants in the near term) with the goal of long term energy sustainability

1.4.2 TRANSMISSION

- Development of a reliable, secure and resilient grid supported by a strong communication infrastructure that enables greater visibility and control of efficient power flow between all sources of production and consumption by 2027.

- Implementation of Wide Area Monitoring Systems (WAMS, using Phasor Measurement Units, or PMUs) for the entire transmission system. Installation of a larger number of PMUs on the transmission network by 2017 or sooner, as guided by the results of initial deployments. Indigenization of WAMS technology and PMU development and development of custom made analytics for synchro phasor data by 2017.
- Setting up of Renewable Energy Monitoring Centre's (REMCs) and Energy Storage Systems to facilitate grid integration of renewable generation.
- 50,000 Kms of optical fiber cables to be installed over transmission lines by the year 2017 to support implementation of smart grid technologies.
- Enabling programs and projects in transmission utilities to reduce transmission losses to below 4% by 2017 and below 3.5% by 2022.
- Implement power system enhancements to facilitate evacuation and integration of 30 GW renewable capacity by 2017, 80 GW by 2022, and 130 GW by 2027 – or targets mutually agreed between Ministry of New and Renewable Energy (MNRE) and MoP.

1.4.3 POLICIES, STANDARDS AND REGULATIONS

- Formulation of effective customer outreach and communication programs for active involvement of consumers in the smart grid implementation.
- Development of state/utility specific strategic roadmap(s) for implementation of smart grid technologies across the state/utility by 2014. Required business process reengineering, change management and capacity building programs to be initiated by 2014. State Regulators and utilities may take the lead here.
- Finalization of frameworks for cyber security assessment, audit and certification of power utilities by end of 2013.
- Policies for grid-interconnection of captive/consumer generation facilities (including renewables) where ever technically feasible; policies for roof-top solar, net-metering/feed-in tariff; and policies for peaking power stations by2014.
- Policies supporting improved tariffs such as dynamic tariffs, variable tariffs, etc., including mandatory demand response (DR) programs, starting with bulk consumers by 2014, and extending to all 3-phase (or otherwise defined consumers) by 2017.
- Policies for energy efficiency in public infrastructure including EV charging facilities by 2015 and for demand response ready appliances by 2017. Relevant policies in this regard to be finalized by 2014.
- Development/adoption of appropriate standards for smart grid development in India–first set of standards by 2014; continuous engagement in evolution of applicable standards relevant to the Indian context. Active involvement of Indian experts in international bodies engaged in smart grid standards development.
- Study the results of the first set of smart grid pilot projects and recommend appropriate changes conducive to smart grid development in the Indian Electricity Act / National Power Policy by end of 2015.
- Development of business models to create alternate revenue streams by leveraging the smart grid infrastructure to offer other services (security solutions, water metering, traffic solutions etc.) to municipalities, state governments and other agencies.

- Development of Skill Development Centers for smart grid development in line with the National Skill Development Policy 2009 for Power Sector by 2015.

1.4.4 OTHER INITIATIVES

- Tariff mechanisms, new energy products, energy options and programs to encourage participation of customers in the energy markets that make them "prosumers" – producers and consumers – by 2017.
- Create an effective information exchange platform that can be shared by all market participants, including prosumers, in real time which will lead to the development of energy markets.
- Investment in research and development, training and capacity building programs for creation of adequate resource pools for developing and implementing smart grid technologies in India as well as export of smart grid know-how, products and services.

While many of the targets envisaged by 2017 are yet to be achieved, some of the targets have been steeply raised by Government of India (as in the case of renewable energy, smart metering etc). However the approach of this road map is still relevant and it is time for an updated version of the roadmap

1.4.5 NATIONAL SMART GRID MISSION (NSGM)

During stakeholder consultations in 2013 to finalize the Smart Grid Roadmap, there was unanimous demand for launching a National Smart Grid Mission (NSGM) which will plan and undertake smart grid developments in the country. Accordingly Ministry of Power with inputs from ISGF and ISGTF prepared the framework for NSGM which was approved by GoI in March 2015. The basic structure of NSGM is given below:

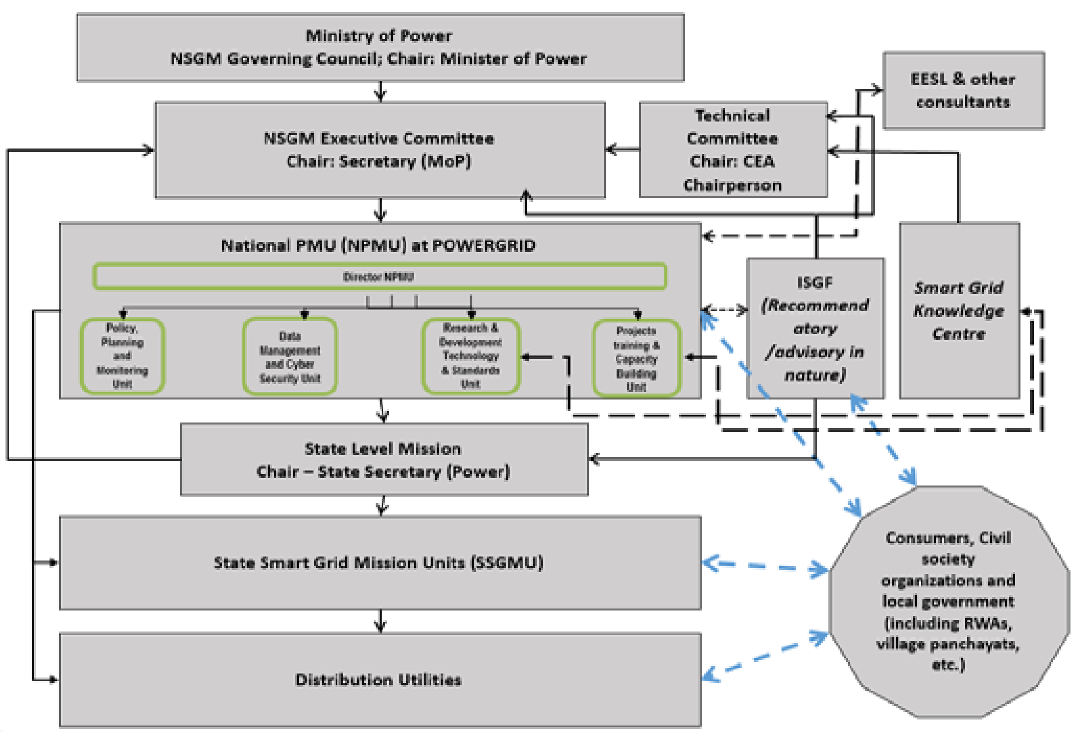


Figure 1-9: National Smart Grid Mission Framework

For day-to-day operations, NSGM has a NSGM Project Management Unit (NPMU) headed by the Director NPMU. He will be a Member of the Governing Council and Empowered Committee, and Member Secretary of Technical Committee. NPMU will be the implementing agency for operationalising the Smart Grid activities in the country under the guidance of Governing Council and Empowered Committee. NSGM is now operational and the NPMU is housed in Power Grid Corporation Ltd (POWERGRID).

Corresponding to the NSGM, each of the States will also have a State Level Mission which would be chaired by the Power Secretary of the State. The administrative / operation and maintenance expenses in this regard would be borne by respective States. NSGM will provide support for training and capacity building to State Level Project Monitoring Units (SLPMUs) for smart grid activities.

The Smart Grid Knowledge Center (SGKC) being developed by POWERGRID with funding from MoP will act as a Resource Centre for providing technical support to the Mission in all technical matters. This include development of technical manpower, capacity building, outreach, suggesting curriculum changes in technical education etc. Ministry of Power has already sanctioned Rs 9.8 crore in this regard. The SGKC shall undertake programs and activities envisaged for it as per the guidance from NPMU. The Head of SGKC will report to Director NPMU.

The support from NSGM for implementation of Smart Grid projects would primarily consist of the following indicative (not exhaustive) list of activities:

- Assistance in formulation of projects including pre-feasibility studies, technology selection, cost-benefit analysis, financing models etc.
- Funding of these projects, together with State Discoms and other financing agencies
- Training and Capacity Building for SLPMUs & Project Implementation teams
- Technology selection guidelines and best practices
- Facilitate Consumer Awareness initiatives
- Project Appraisal post implementation

To start the above activities, 30% of the project cost of smart grid for most of the components will be provided as grant from the NSGM budget. For certain selected components such as training and capacity building, consumer engagement etc., there will be a 100% grant. The extent of funding from NSGM budget will be finalized by the Empowered Committee of the NSGM. The balance project cost (hardware, software applications, erection testing commissioning, integration etc.) is to be funded through innovative financing models which may include PPP model.

ISGF
India Smart Grid Forum

MODULE 2

INTRODUCTION TO SMART GRIDS

Abstract

This module starts with the elaboration of smart grid concept described in Module 1. Smart Grid components and technologies at transmission and distribution systems are described in detail. The module ends with an introduction to Smart Grid Maturity Model (SGMM)

Module 2: Table of Content

List of Figures

2 INTRODUCTION TO SMART GRIDS

2.0 INTRODUCTION

The smart grid is the evolving grid with advanced automation, control, IT and IoT systems that enables real-time monitoring and control of power flows from sources of generation to sources of consumption. A set of technologies enable these functionalities and help manage electricity demand in a sustainable, reliable and economic manner. Smart grids can provide consumers with real-time information on their energy use, support pricing that reflects changes in supply and demand, and enable smart appliances and devices to help consumers exercise choices in terms of usage of energy.

"Smart grid is an electricity grid with communication, automation and IT systems that enable real time monitoring and control of bi-directional power flows and information flows from points of generation to points of consumption at the appliances level."

2.1 WHAT IS SMART GRID?

As summarized in the above section, a shift from centralized generation to decentralize generation is happening. The traditional boundaries between generation, transmission and distribution are fast disappearing and the grid is evolving into an integrated smart grid, a unique solution which integrates all type of power generation and helps the consumer becomes a producer and consumer (prosumer). Each household will be able to generate and store electricity for its own use or sell it to the grid. Smart grid technologies can empower customers with real time control and the choice to generate, store and consume electricity at lowest cost available or sell it to the grid during the surplus generation while ensuring high quality and availability of power. With the help of programs like Demand Response (DR), customers can change their consumption patterns by shifting their consumption from expensive peak hours to cheaper off peak hours making the power flow more interactive, efficient, more environment and customer friendly.

Smart Grid – Analogy with Human Body

The picture below depicts the analogy of a smart grid with human body.

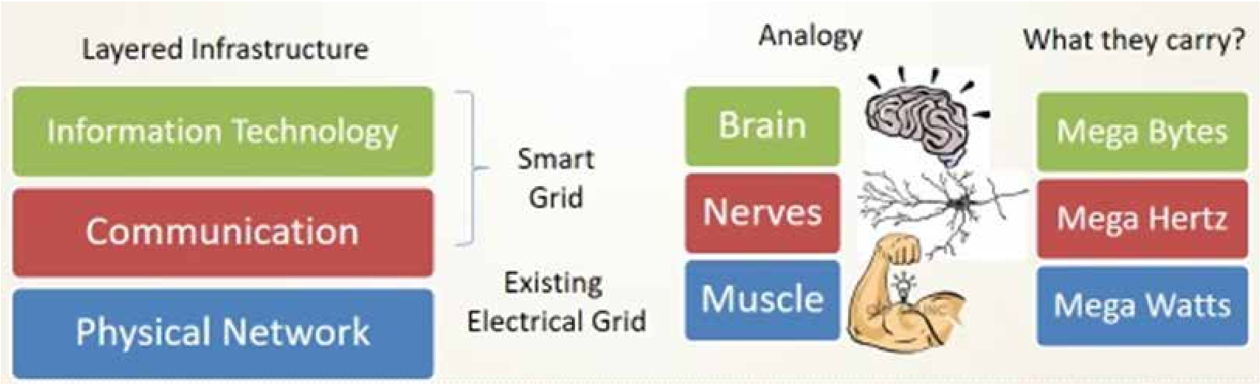


Figure 2-1: Analogy of a Smart Grid with Human Body

Key components to make an existing grid smarter is to have two way communicable sensors to monitor and control power flows in real time and IT systems to process the data captured and issue commands and alerts.

2.2 DRIVERS FOR SMART GRID

Since the early 21st century, advancement in electronic communication technology is being used to resolve the limitations and costs of the electrical grid. Technological limitations on metering no longer force peak power prices to be averaged out and passed on to all consumers equally.

Key drivers for smart grids for different stakeholders in the Indian context are:

I. UTILITIES

- Reduction in Aggregate Technical and Commercial (AT&C) losses
- Peak load management – multiple options from direct load control to price incentives to customers
- Reduction in power purchase cost
- Better asset management
- Increased grid visibility
- Self-healing grid- faster restoration of electricity after fault or disturbances
- Renewable energy integration

II. CUSTOMERS

- 24x7 Power for All
- Improved reliability of supply to all customers – no power cuts, no more DG sets and inverters for back up
- Improved quality of supply – no more voltage stabilizers
- User friendly and transparent interface with utilities
- Increased choice for customers – including green power

- "Prosumer" enablement – can produce own electricity and consume or sell
- Options to save money by shifting loads from peak hours to off-peak periods

III. GOVERNMENTS AND REGULATORS

- Satisfied customers
- Financially sound utilities
- Tariff neutral system upgrade and modernization
- Reduction in emission intensity

2.3 FUNCTIONALITIES AND KEY COMPONENTS OF SMART GRIDS

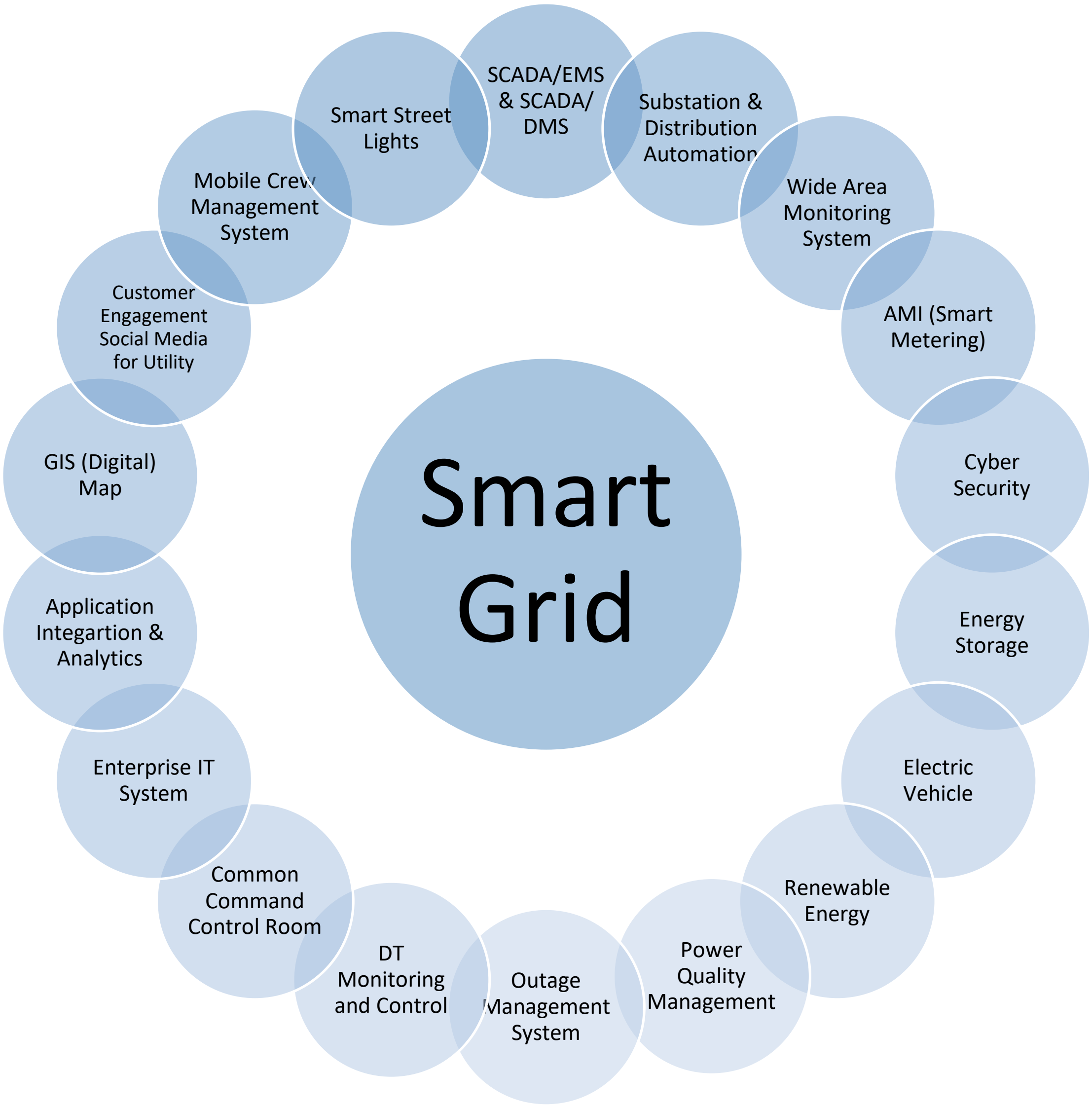


Figure 2-2: Smart Grid Functionalities

2.3.1 SMART GRID COMPONENTS FOR TRANSMISSION SYSTEM

I. SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM (SCADA)

Extra High Voltage (EHV) transmission network (110kV and above) was traditionally smart or intelligent with automation and real-time communication systems integrated for system operations. The load dispatch centres or control centres of EHV systems have Supervisory Control and Data Acquisition (SCADA) and Energy Management System (EMS) which help monitor and control the power flows in real-time. In order to facilitate the functioning of SCADA/EMS, the EHV network have dedicated communication systems between the control centre and all generating stations and EHV Substations. From the control centre the operators can control generation as well as loads at the substations.

SCADA OVERVIEW

SCADA refers to a system that collects data from various sensors at a factory, power plant, transmission system or in other remote locations and then sends this data to a central computer which then manages and controls the system. SCADA has the ability to monitor an entire system in real time and can run with relatively little human intervention. This is facilitated by data acquisitions from various sensors and meters.

COMPONENTS OF SCADA

SCADA has a Master Station and several Remote Stations that are equipped with:
In the Master Station:

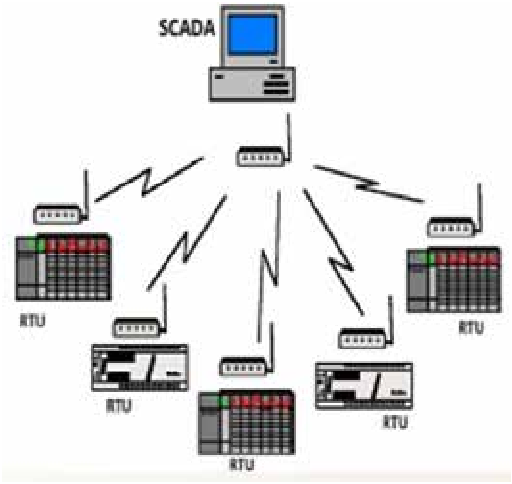
- Local Area Network (LAN)
- Servers
- LCD Screens

In a Remote Station:

- Transducers (analog inputs)
- Interposing Relays
- Remote Terminal Unit (RTU)
- Local Display
- Logger/Archiver

FUNCTIONING OF SCADA

- Data Acquisition
- Supervisory Control
- Tagging
- Time Synchronization of RTUs
- Alarms
- Logging (Recording)
- Load Monitoring with Display and Logging
- Trending



RTUs are installed at field devices - substations and other field equipment. SCADA communicates with a large range of external devices like Programmable Logic Controllers and industry specific meters through the RTUs. In order to link up and access with these devices, various open communication standards are used, and these devices need to have a mechanism to open up its parameters (or data) for SCADA to access - either for read, write or both. SCADA assigns a variable or memory location for each individual parameter or data from each device. This variable is called "Tag". "Tagging" means the process of managing tags. "Trending" displays provide a powerful means of displaying, evaluating and selecting data for further processing and analysis.

COMMUNICATION SYSTEM FOR SCADA

SCADA require dedicated and reliable communication systems between various field devices (RTU) and the Master Station. Traditionally electric utilities used Power Line Carrier (PLC) communications in the past. The analog PLC could support limited bandwidth. PLC based SCADA are still in operation in many places.

Other communication options for SCADA are:

- Fiber Optic Cables- Optic Fiber Ground Wire (OPGW) can be used as earth wire on EHV lines
- Microwave Communication
- Satellite Communication
- Public Telecom Network can also be leveraged by leasing dedicated communication links from telecom operators (MPLS networks)

MAJOR FUNCTIONS OF SCADA

- acquisition from RTUs and storage of data in online database
- Processing of data for converting the raw values to engineering values and checking quality
- Historical data storage and retrieval
- Sequence of events recording, reconstruction and replay of events
- Protective and informative tagging of power system devices
- State estimation and load management
- Generalized calculations – for adding and removing operator's defined calculations
- Providing user interface to operators
- Inter control center communication
- Real time and historical trends
- SCADA works in combination with Energy Management System.

ADVANTAGES AND DISADVANTAGES OF SCADA

Advantages

- Flexible, simple, reliable
- Increased efficiency - less manpower
- Self-checking and reliable

Disadvantages

- High initial capital investment
- Lack of trained persons in utilities
- False alarms at times
- Cyber Security threat

II. ENERGY MANAGEMENT SYSTEM (EMS)

Energy Management System (EMS) is a set of computer-aided tools used by electric grid operators to monitor, control, and optimize the performance of the generation and/or transmission systems.

Functions of EMS

- Real time network analysis and contingency analysis
- Study functions like power flow, power factor, security enhancement etc
- Real time generation functions – allows the operator to monitor, analyze and control real time generation and automatic generation control (AGC)
- Economic dispatch - helps the dispatcher to determine economic base points for a selected set of units
- Reserve monitoring for calculating spinning reserve, operating reserve and regulating reserve
- Production costing – calculates the current cost of generating power of online units
- Load forecasting
- Transaction scheduling

Advanced functionalities:

- Enhanced grid reliability
- Increased grid capacity
- Advanced contingency awareness
- Decreased system support cost
- Secure system that meets regulatory requirements

EMS works along with a SCADA system and EMS helps the control room operator to manage the transmission system operation efficiently and economically.

III. WIDE AREA MONITORING SYSTEM (WAMS)

With the deployment of Phasor Measurement Units (PMU), fast and accurate measurements from grid equipment is possible. Real-time wide area monitoring applications have strict latency requirements in the range of 100 milli-seconds to 5 seconds. A fast communication infrastructure is needed for handling the huge amounts of data from PMUs. Smart grid applications are designed to exploit these high throughput real-time measurements.

While SCADA data is collected in 1-5 seconds, PMU data is captured in milliseconds. SCADA data has no time stamps but PMU data is accurately time stamped. While SCADA is like an X-Ray, PMU Data is like an MRI scan of the grid.

2.3.2 SMART GRID FUNCTIONALITIES AT DISTRIBUTION LEVEL

The distribution grid comprises of medium voltage (33 & 11kV) and low voltage (415/230V) network which traditionally had limited automation systems. Main reason for this was the cost of communication system for automation. Distribution grid in large utilities run in to hundreds of thousands of kilometres and establishing reliable communication system between all end points and the control centre was way too expensive. So there is no visibility of power flows in the low voltage network. Faults are also not automatically detected. Only when customers complain about an outage the crew is dispatched to locate the fault and repair it. Hence, the key objective of smart grid initiatives are focused on modernizing the distribution grid with advanced automation and control features. The main technologies in this domain are:

- Supervisory Control and Data Acquisition (SCADA) and Distribution Management Systems (DMS)
- Distribution Automation
- Substation Automation
- Advanced Metering Infrastructure (AMI) or Smart Metering
- Geographical Information System (GIS)
- Peak Load Management (PLM)
- Power Quality Management (PQM)
- Outage Management System (OMS)
- Distribution Transformer Monitoring System
- Mobile Crew Management System
- Enterprise IT Systems
- Application Integration
- Smart Street Lights (with noise and pollution sensors)
- Energy Storage
- Electric Vehicles
- Distributed Energy Resources and Renewable Energy Integration
- Customer Care Centre
- Customer Engagement
- Social Media
- Cyber Security
- Analytics
- Smart Homes, Buildings Energy Management Systems /Home Energy Management Systems (BEMS/HEMS)

I. SCADA AND DISTRIBUTION MANAGEMENT SYSTEMS (DMS)

Features of SCADA system explained under previous section are similar for distribution SCADA as well. While all RTUs for transmission SCADA are placed in high voltage substations, in case of distribution SCADA besides RTUs in substations, there may be Field RTUs (FRTUs) in distribution network at power transformer and distribution transformer locations. Communication options for transmission SCADA and distribution SCADA are also same – utilities select what is appropriate depending upon local considerations.

DISTRIBUTION MANAGEMENT SYSTEM (DMS)

DMS is a collection of software applications designed to monitor and control the entire distribution network efficiently and reliably.

DMS FUNCTIONS

- Network Visualization and Support Tools
- Applications for Analytical and Remedial Actions
- Utility Planning Tools
- System Protection Schemes

II. DISTRIBUTION AUTOMATION (DA)

Distribution Automation (DA) refers to various automated control techniques that optimize the performance of power distribution networks by allowing individual devices to sense the operating conditions of the grid around them and make adjustments to improve the overall power flow and optimize performance. In present scenario, grid operators in centralized control centres identify and analyse their power system manually and intervene by either remotely activating devices or dispatching a service technician.

DA can be a critical component in outage prevention. The sensors and communications associated with DA can provide early detection of the devices that might not be working properly, thus allowing the utility to replace those devices before an outright failure occurs. DA is considered the core part of a smart grid, interacting with almost all other smart grid applications and making the grid more efficient and reliable. DA helps enable Renewable Energy (RE) by dynamically adjusting distribution controls to accommodate variability, power ramping and bi-directional power flows.

At the heart of the Distribution Automation is SCADA/DMS. Other key components of DA are:

Ring Main Unit (RMU), Sectionalizer, Reclouser, Fault Locator and Capacitor Banks which are described below:

SECTIONALIZER is a protective device, used in conjunction with a reclouser, or breaker and reclosing relay, which isolates faulted sections of the distribution lines. The sectionalizer cannot interrupt fault current.

RECLOUSERS are designed to operate like a station breaker and can interrupt fault current and reclose a pre-set number of times before going to lockout the faulted sectiont. Sectionalizer counts the breaker and reclouser operations during a fault sequence and open when they reach their pre-set count limit while the breaker or reclouser is still open.

FAULT LOCATOR: the DA system and its automated distribution devices enable faulted load blocks to be quickly identified, isolated and power is re-routed to downstream load blocks. However, the actual fault still has to be found and repaired by field crews before all customers can be restored.

RING MAIN UNITS (RMU) are installed in strategic locations on every feeder to monitor and control the Sectionalizers, Reclousers and other equipment in the network

CAPACITOR BANKS: DA system helps in controlling the capacitor banks for controlling the voltage and power factor.

Figure 2-3: Components of Distribution Automation Systems

III. SUBSTATION AUTOMATION

Substation Automation (SA) system enables an electric utility to remotely monitor, control and coordinate the distribution components installed in the substation. SA has been focused on automation functions such as monitoring, controlling, and collecting data inside the substations. SA overcomes the challenges of long service interruptions due to several reasons such as equipment failures, lightning strikes, accidents and natural catastrophes, power disturbances and outages in substations.

Main component of SA is digital (or numeric) relays and associated communication systems which can be operated remotely.

IV. ADVANCED METERING INFRASTRUCTURE (AMI)

Advanced Metering Infrastructure (AMI) or Smart Metering comprises of Smart Meters, Data Concentrator Units (DCUs)/gateways/routers/access points, Head End System (HES), Meter Data Management System (MDMS) communicating over bi-directional Wide Area Network (WAN), Neighborhood Area Network (NAN)/Field Area Network (FAN) and Home Area Network (HAN). Multiple smart meters can connect to a DCU/gateway/router/access point which in turn send aggregated data to the HES. The smart meter can also directly communicate with the HES using appropriate WAN technologies (for example GPRS sim cards in the smart meters can directly send data to the HES on servers in the control room). The Meter Data Management System (MDMS) collects data from the HES and processes it before sharing with billing system and other IT applications. Appliances such TV, fridge, air conditioners, washing machines, water heaters etc can be part of the Home Area Network (HAN).

At the heart of AMI, is the Smart Meter. The key features that make a meter 'smart' are the addition of a communication module capable of two-way Machine to Machine (M2M) communications and a remote connect/disconnect switch. A smart meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the computers in the utility control centre. Smart Meters usually have real-time or near real-time sensors, power outage notification, and power quality monitoring features.

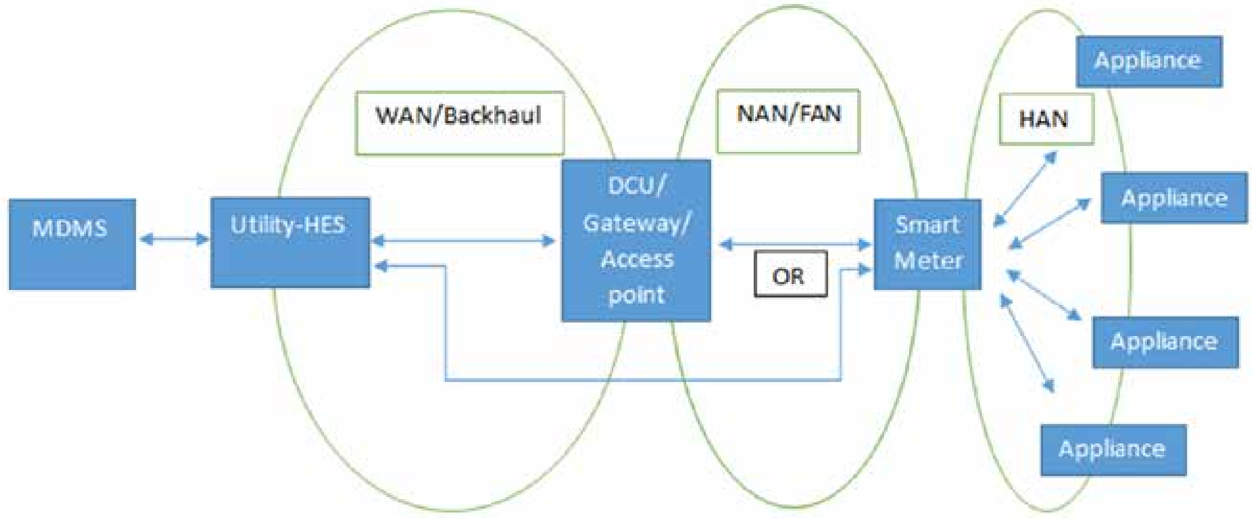


Figure 2-4: Typical Architecture of AMI

In-Home display (IHD) is a device kept in the customer's premises that could display meter data and get confirmation from the consumer regarding his/her participation in a demand response program. Hence consumers will become informed and conscious. However, with the rise of the smart phone applications or 'apps', customers would not require IHDs at their homes. A smart phone can work as an IHD and hence the utility or customers need not invest in IHDs.

V. GEOGRAPHICAL INFORMATION SYSTEM (GIS)

All electrical assets mapped on a GIS map (digital map) and all consumers indexed to that map is a very important tool for a utility to plan and manage their assets and operations. GIS map can be integrated with other automation and IT applications in the utility as depicted in the figure below which will help asset optimization and outage detection and faster restoration.

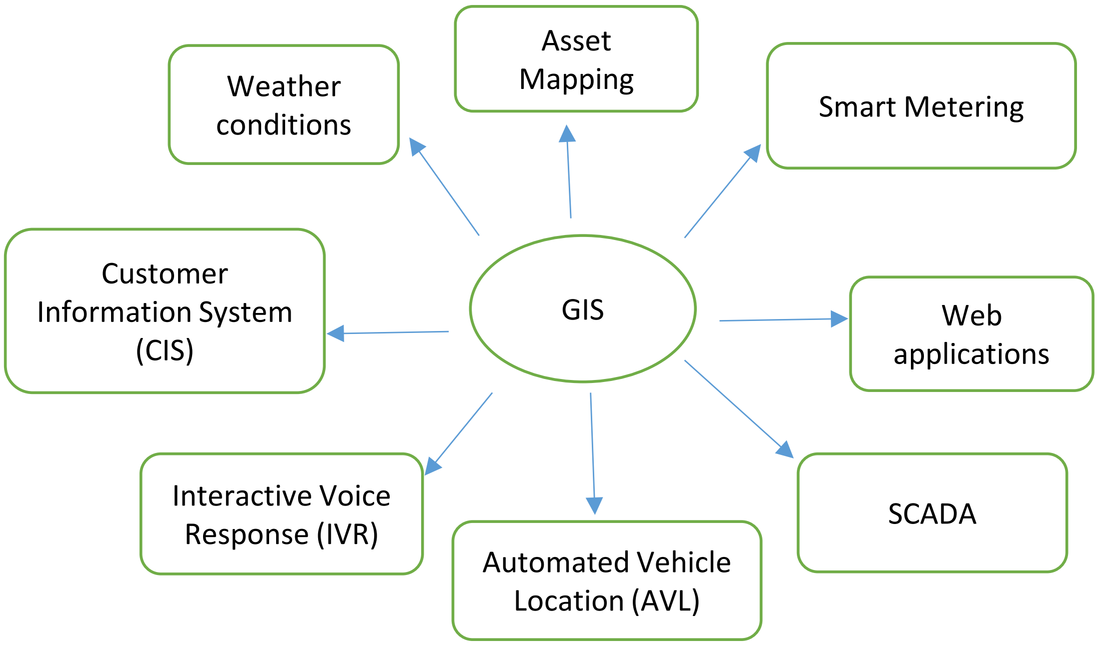


Figure 2-5: GIS Functionalities

GIS maps need to be updated on a regular basis. Whenever a new asset is added or removed or a new customer is given connection or an existing customer is removed, that information must be captured in the GIS map so that it remains up to date.

The GIS maps of electric utilities would ideally include all the roads and buildings in a town/locality. It can be a valuable asset for other infrastructural service providers in the town for planning and management of services like water distribution, gas distribution, transport planning and management etc.

VI. PEAK LOAD MANAGEMENT

Peak load management is achieved through a combination of policies and techniques such as Time of Use Tariffs, Critical Peak Pricing and Demand Response programs.

DEMAND RESPONSE (DR)

Demand response is a mechanism in which the utility can curtail the load at customer premises or disconnect certain equipment of the customer remotely from the utility's control centre. Customer participation for DR program is sought through incentives and penalties. The customer engagement is the major success factor for the demand response programs. Here the utility plays the role of shifting the load from peak hours/higher market price hours to off-peak hours/lower market price hours of certain equipment of the customer that is mutually agreed – large pumps, air-conditioners, heaters, machineries etc. The benefits of DR include avoiding the use of the most expensive generation plants during peak hours, avoiding construction of additional generation, transmission and distribution capacity, and avoiding brownouts and blackouts. Auto Demand Response (ADR) is shown in the figure below using OpenADR Standard.

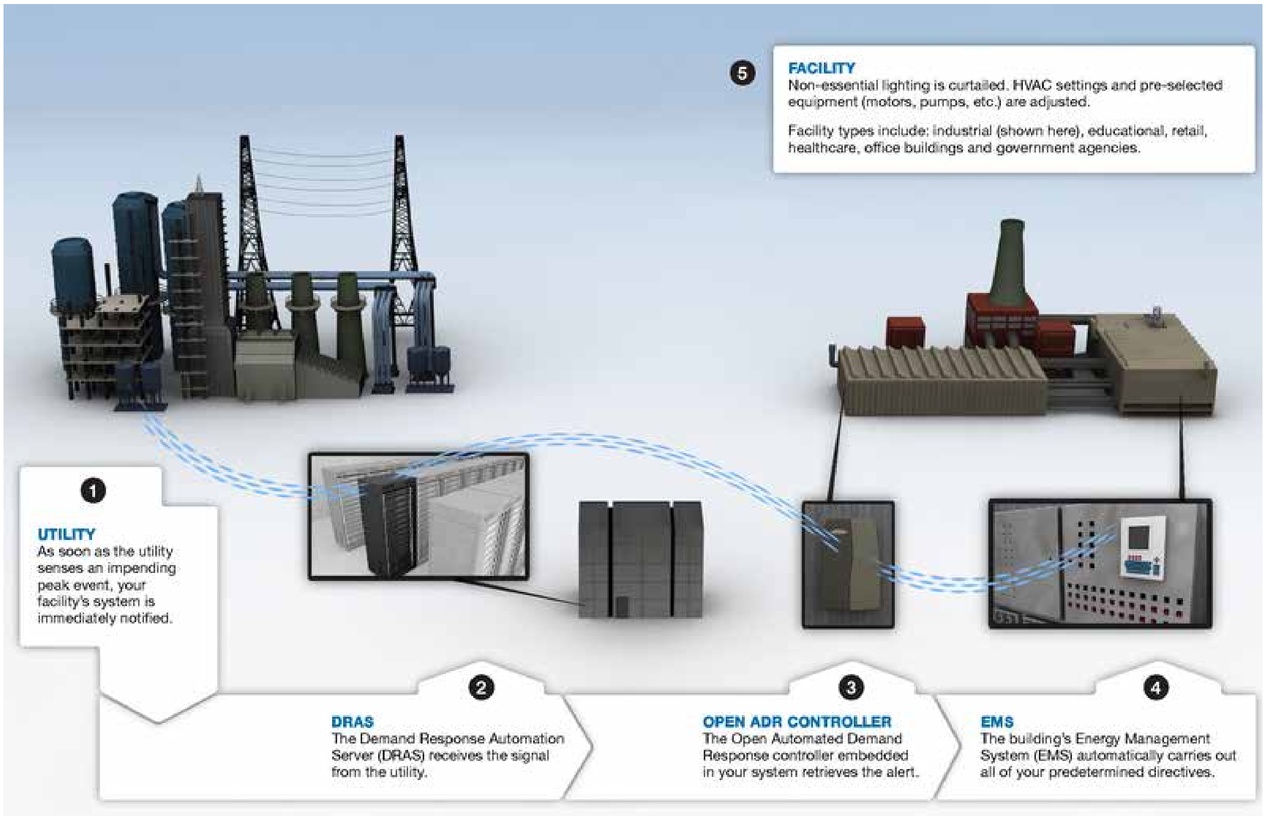


Figure 2-6: Demand Response Process Flow
Image Source – https://www.smartgrid.gov/files/C6-Honeywell-final-draft-091814.pdf

VII. POWER QUALITY MANAGEMENT

Voltage variation beyond stipulated limits and interruptions are major power quality issues faced by customers. With proliferation of distributed and variable generation resources such as solar PV and wind turbines which operates intermittently, it is increasingly difficult to maintain quality of supply. On the other hand, modern loads with switch-mode power supply (SMPS) such as computers, television, washing machines, air-conditioners, refrigerators, LED lights, furnaces, inverter, UPS etc inject harmonic distortion on the power system. Voltage and current are in sinusoidal wave form whereas the above category loads with power electronics in them are in square wave form which lead to generation of harmonics.

With smart meters in the network, the utility will be capable of measuring specific aspects such as power factors and voltages in near real-time. This will enable the utility to take appropriate actions to enhance the power quality. Corrective measures to be undertaken to mitigate the power quality issues are described in detail in Module -7.

VIII. OUTAGE MANAGEMENT SYSTEM (OMS)

Outage Management System (OMS) provides the capability to efficiently identify and resolve outages and to generate and report valuable historical information. Geographic information System (GIS) based OMS will help to resolve customer complaints faster during power outages. OMS will enable quick identification of probable faulty locations and reduce the response time of customer complaints. OMS will work in conjunction with GIS, Customer Information System (CIS), Enterprise Resource Planning (ERP), Mobile Crew Management System and Automated Call Handling Systems, such as an Interactive Voice Response (IVR) system. OMS of an electric utility can be leveraged by other infrastructure and services providers in a city at marginal cost.

IX. DISTRIBUTION TRANSFORMER (DT) MONITORING SYSTEM

In most distribution utilities in India, hundreds of Distribution Transformers (DTs) get burned during every summer owing to over loading or phase imbalances of the DTs. Remote monitoring of DTs will prevent overloading, phase imbalance and burn outs of DTs. This will transform into huge financial savings taking into account the high technical losses that occur in the system owing to phase-imbalances - one phase gets overloaded while other two phases are low on load. With monitoring systems in place the loads can be re-distributed to remove such imbalances on transformers. With DT Monitoring Systems, overloaded DTs can be identified and replaced with higher capacity DTs as load in the locality increases.

X. MOBILE CREW MANAGEMENT

Mobile crew management system enables a utility to allot maintenance jobs to the crews in the field on real-time basis. In the traditional model, crew attending any work in the field will always return to their base station and then they will be dispatched to the next work. This way their productivity is reduced. With mobile crew management systems, the work will get allotted to the crew with required skills, tools and spare parts and nearest to the work location. In that scenario, from one work location to another work location they can quickly move, increasing their productivity multiple times. Also information on the type of fault is made available on their Mobile to support trouble shooting. Good mobile crew management applications will have real time scheduling engine.

XI. ENTERPRISE IT SYSTEMS

Enterprise IT systems include:

- IT Network – LAN/WAN
- Mail-Messaging Systems
- Management Information Systems with Dashboards
- Enterprise Resource Planning (ERP)
- Portal/Website – Intranet and Customer Portal

With ERP, information that is fragmented in different systems can seamlessly flow throughout the organization so that it can be shared by business processes in grid operations, engineering, procurement, finance, accounting, human resources, and other areas of the utility.

Typical ERP modules for a Distribution Utility include:

- CRM – system to track new connections and disconnections, track customer consumption, payment records, defaulters etc
- Enterprise Asset Management (EAM)
- Contracts Management
- Materials Management
- Projects Management
- Human Resources Management
- Finance Management

XII. ENTERPRISE APPLICATION INTEGRATION (EAI)

Some of the data captured from field equipment and customer operations are used by multiple applications in a utility and each application calling data from different databases creates serious issues in data integrity. The best way to handle this problem is through Application Integration using a middleware platform. All data bases will be connected to this middleware and all applications will also be linked to the middleware which will facilitate different applications to call data from same database. Service Oriented Architecture (SOA) is commonly used for application integration using a middleware tool.

XIII. SMART STREET LIGHTS (WITH NOISE AND POLLUTION SENSORS)

Latest entrant in the smart grid and smart city solutions is smart street lighting. Typical street lights using sodium vapor lamps consume huge amount of power. These are being replaced with LED lamps in many cities and small towns. The saving from energy consumption will pay for the replacement cost in less than two years in most cases. The new LED lights can be remotely controlled – features like increase/decrease luminosity, switch off alternate lights during lean hours etc are possible. The lights can be connected on GPRS, RF Mesh or WiFi in the city for its remote operation. The newest trend is to install noise sensors and pollution sensors on the street light poles (cobra heads) which will leverage the same communication bandwidth to transmit the data to the control centres for monitoring noise and air pollution.

XIV. ENERGY STORAGE

Energy Storage Systems (ESS) will play a significant role in meeting energy needs by improving the operating capabilities of the grid as well as mitigating infrastructure investments. ESS can address issues with the transmission and dispatch of electricity, while also regulating the quality and reliability of the power generated by traditional and variable sources of power. ESS can also contribute to emergency preparedness. Modernizing the grid will require a substantial deployment of energy storage. Energy storage technologies—such as pumped hydro, compressed air energy storage, various types of batteries, flywheels, electrochemical capacitors, etc. - provide for multiple applications: energy management, backup power, peak shaving/shifting, frequency regulation, voltage support, renewable energy integration and grid stabilization.

XV. ELECTRIC VEHICLES

Electric Vehicles (EV) are propelled by an electric motor which is powered by batteries which can be recharged using an external power source often called as Electric Vehicle Supply Equipment (EVSE). The most serious concern electric utilities have is controlling when EV load is connected to their grid. A high percentage of consumers will instinctively charge their EVs when they get home from work; the absence of load management would likely have a destabilizing effect on the grid. Utilities must be prepared for multiple customers on the same transformer wishing to charge their EVs at the same time.

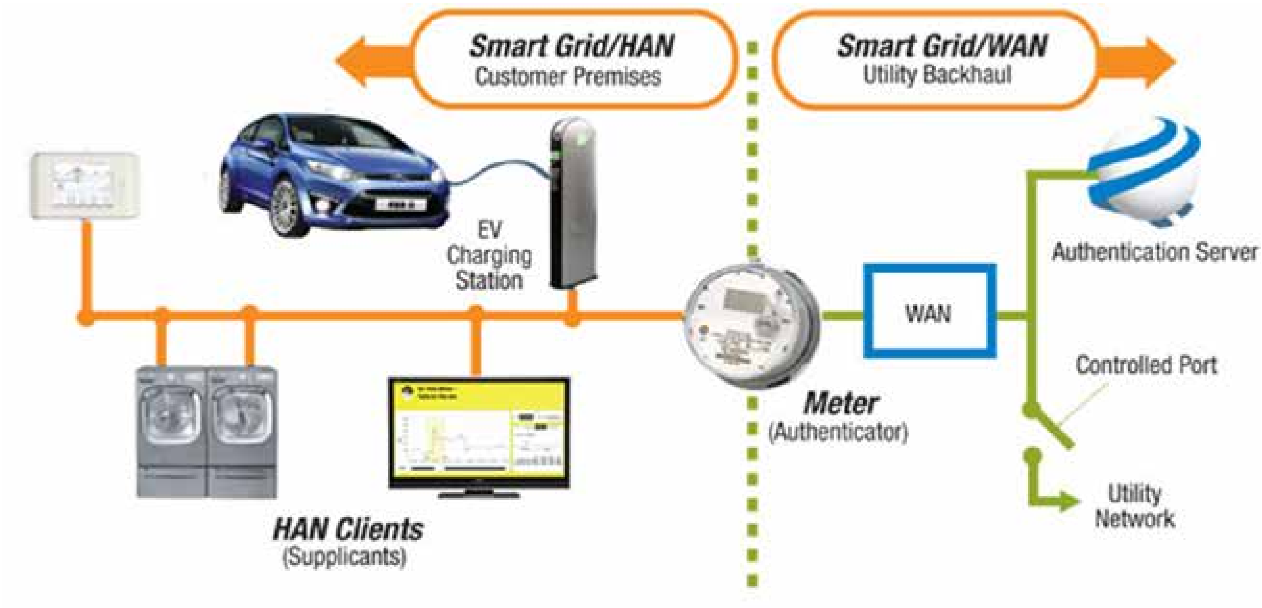


Figure 2-7: EV Technologies & Integration

Source- RTC magazine report)

Smart Grid technologies will enable EV charging to be scheduled intelligently. In addition, it enable the storage capacity of the batteries in EVs to be used as a supplementary source of power at times of peak load; portion of the power available in those batteries could be fed back into the network during the peak time and the battery recharged during off peak time. Vehicle –Grid Integration (VGI) is an important component of the emerging smart grid technologies.

XVI. DISTRIBUTED ENERGY RESOURCES AND RENEWABLE ENERGY INTEGRATION

Distributed Energy Resources (DER) are small, modular, energy generation and storage devices such as rooftop PV systems, micro wind turbines, energy storage batteries such as batteries in UPS, Inverters and EVs etc. DER systems may be either connected to the local electric power grid or isolated from the grid in stand-alone applications.

Renewable Energy Integration focuses on incorporating renewable energy, distributed generation, energy storage and demand response into the electricity transmission and distribution systems. A systems approach is being used to conduct integration development and demonstrations to address technical, economic, regulatory, and institutional barriers for using renewable and distributed systems. In addition to fully addressing operational issues, the integration also establishes viable business models for incorporating these technologies into capacity planning, grid operations, and demand-side management.

The goal of renewable energy integration is to advance system design, planning, and operation of the electric grid to:

- Mitigate the intermittency of the renewable energy resources through better forecasting, scheduling and dispatch of the power system as well as flebility in demand and generation
- Reduce emissions through increased use of renewable energy and other clean distributed generation resources
- Increase asset use through integration of distributed systems and customer loads to reduce peak load and thus lower the costs of electricity
- Support achievement of renewable portfolio standards for renewable energy and energy efficiency
- Ensure reliability, security, and resiliency of the grid despite intermittency and variability of generation from renewable resources

XVII. CUSTOMER CARE CENTER

Most distribution utilities today have state of the art 24x7 Customer Care Centre (CCC) with sophisticated systems to address multiple calls. In India there is a four digit common number (1912) allotted for electricity complaints. All operational and customer related systems are integrated with CCC so that the call agent can address all types of queries from the customers. CCC is becoming an important part of the smart grid domain.

Latest addition to this is Chatbots for interaction with customers. Chatbots are algorithms that can engage with real people in chat sessions. Many questions can be answered by chatbots instead of call agents. Entire interaction between the customer and the chatbots are recorded and analysed by advanced analytical tools which will help rectify several issues in the system which are otherwise difficult to detect.

XVIII. CUSTOMER ENGAGEMENT

Experiences from around the globe indicate that engagement of customers and their active participation is key to successful implementation and operation of smart grid projects. Customers need to be taken in to confidence right from the beginning by making them aware of the benefits of the new systems as well as educating them how to enjoy the benefits of the new time of use tariff regime, demand response schemes etc. so that they can effectively manage their energy consumption and monitor their bills. Specialized agencies may be engaged by utilities to undertake a holistic communication campaign to engage the customers from the project design stage itself.

XIX. SOCIAL MEDIA FOR UTILITY

For a power utility, a call centre has traditionally been the single touch-point with its customers. For utilities to be able to cope up with the changing times and start excelling in their energy delivery, the customer service models are undergoing a paradigm shift. A large number of electric utilities in the US are already using social media platforms like Facebook, Twitter etc., to connect with their customers, issue outbound communications, track customer complaints and queries etc. They are also being used as effective mediums for promoting energy efficiency measures, imparting safety tips and proper usage of domestic appliances, influencing customer behaviour and forging positive customer relationships particularly during power outages and recovery efforts from weather related incidents. However, reports indicate that 48 percent of U.S. customers believe companies need to do a better job of integrating their online and offline experiences, and over 50 percent of people surveyed in 2014 believed that local utilities should harness the real-time communications of various social media channels to share information. Utilities can provide much better services by integrating social media in their outage management, crisis/disaster handling, billing and collection and other customer related issues. In addition, social media can be a platform for promotion of clean energy, DSM/DR activities, tariff plans, electric vehicle usage etc. It can also prove as an effective tool for branding and promotion of good will.

XX. CYBER SECURITY

The critical infrastructure of a nation and other sectors depend directly and indirectly on the power sector. Cyber-physical security is protection of the assets (both hardware and software) from natural and manmade disasters and intended and unintended activities. Since physical assets are associated with the cyber space of a utility, cyber-physical security completely defines the security paradigm of a utility. This dependency of the physical assets on the cyber assets (and vice versa), has prompted the utilities to inject resiliency and robustness into their grids.

ISGF in association with National Critical Information Infrastructure Protection Centre (NCIIPC) and VJTI, a renowned engineering institute in Mumbai, India has prepared a comprehensive framework for assessment of cyber security readiness of power sector utilities and assessed a select set of utilities in 2014-15. The top ten findings from those assessments were circulated to all utilities in India to comply with. In 2016, ISGF in association with NCIIPC has prepared the Indian Manual on Cyber Security for Power Systems which is presently being reviewed by Central Electricity Authority (CEA) on behalf of Ministry of Power. Most of the recommendations have already been incorporated in the BIS Standard IS 16335: “Power Control systems - Security Requirements”.

XXI. ANALYTICS

In today’s competitive utilities market, the need to carefully and efficiently manage the power grid is of paramount importance. Utilities must stay on top of shifting energy policies and changes in technology while balancing concerns about energy security, environmental sustainability and economic competitiveness. At the same time, customers demand reliability. The analytics solutions has the capabilities to analyze raw data captured from within the energy grid, and produce trends and odd events and other key operational parameters a utility needs to optimize capital expenditures, reduce operating costs, quickly locate faults and make the grid more efficient as well as address the customer needs.

XXII. SMART HOMES, BUILDING ENERGY MANAGEMENT SYSTEM/HOME ENERGY MANAGEMENT SYSTEM (BEMS/HEMS)

BEMS/HEMS is a computer based control system installed in buildings that controls and monitors the building’s mechanical and electrical equipment such as air-conditioning and ventilation, lighting, water heaters, pumps, other power consuming equipment, fire protection and security systems

Smart homes/buildings would offer monitoring and control of the electricity usage within the building premises. Energy management systems is the core of home/building automation by providing a means to efficiently consume electricity. In addition to a smart meter that would remotely connect and disconnect the supply, smart appliances would provide the energy consumption data to the customer and the utility. The customer could view the consumption data via an In-Home Display (IHD) device or via SMS, e-mail, mobile app or by logging on to a customer portal. Loads could also be remotely controlled via the aggregators or energy management systems.

Functions of BEMS and Typical Architecture of Smart Homes are depicted in the diagrams below:

Figure 2-8: Functions of BEMS

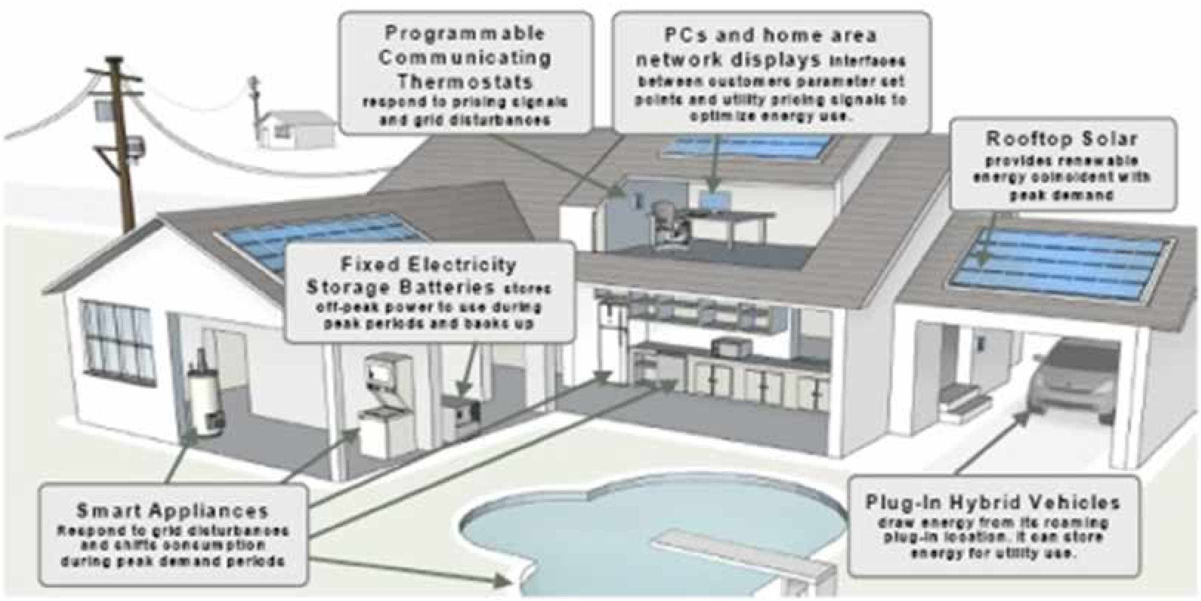


Figure 2-9: Typical Architecture of Smart Home

Source: EIA Energy Outlook, 2009 Reference Case Presentation

2.4 SMART GRID MATURITY MODEL

The Smart Grid Maturity Model (SGMM) is a management tool that utilities can leverage to plan their smart grid journey, prioritize their options, and measure their progress as they move towards the realization of a smart grid. The SGMM was founded by utilities for utilities when the Global Intelligent Utility Network Coalition, a smart grid collaboration of 11 utilities, saw the need in the industry for such a tool. The model describes eight domains, which contain logical groupings of incremental smart grid characteristics and capabilities that represent key elements of smart grid strategy, organization, implementation, and operations. Utilities use the SGMM framework to assess their current state of smart grid implementation, define their goals for a future state, and generate inputs into their road mapping, planning, and implementation processes.

SGMM is maintained by the Software Engineering Institute (SEI) at Carnegie Mellon University (CMU) with the support of the U.S. Department of Energy.

2.4.1 OVERVIEW OF THE MODEL

The SGMM describes 8 domains containing logical groupings of incremental smart grid characteristics, which represent key elements of smart grid strategy, organization, operation, and capability.

SMR	Strategy, Management, and Regulatory *Vision, planning, governance, stakeholder collaboration*	TECH	Technology *IT architecture, standards, infrastructure, integration, tools*
OS	Organization and Structure *Culture, structure, training, communications, knowledge management*	CUST	Customer Pricing, customer participation & experience, advanced services
GO	Grid Operations *Reliability, efficiency, security, safety, observability, control*	VCI	Value Chain Integration *Demand & supply management, leveraging market opportunities*
WAM	Work and Asset Management *Asset monitoring, tracking & maintenance, mobile workforce*	SE	Societal and Environmental *Responsibility, sustainability, critical infrastructure, efficiency*

Figure 2-10: Domains of SGMM

2.4.2 SGMM LEVELS

PIONEERING 5	Breaking new ground; industry-leading innovation
OPTIMIZING 4	Optimizing smart grid to benefit entire organization; may reach beyond organization; increased automation
INTEGRATING 3	Integrating smart grid deployments across the organization, realizing measurably improved performance
ENABLING 2	Investing based on clear strategy, implementing first projects to enable smart grid (may be compartmentalized)
INITIATING 1	Taking the first steps, exploring options, conducting experiments, developing smart grid vision
DEFAULT 0	Default level (status quo)

Figure 2-11: Smart Grid Maturity Model – levels

SGMM study is carried out in two stages

- Compass Survey (AS-IS)
- Aspiration Survey (TO-BE)

In the compass survey is conducted by a certified SGMM Navigator in which the senior leadership teams from various functions (8 domains) of the utility answers questions related to the present state of the utility in each of the 8 domains so that "AS-IS" state is determined. The compass survey results are shared with the utility which they may discussed amongst their teams.

Once the utility senior management in principle agree with the "AS-IS" state determined from the compass survey, another visioning workshop will be conducted by the SGMM Navigator. In the visioning workshop the utility discuss various pros and cons and define the TO-BE states in each domain different time horizons. No utility wants to be in Level-5 in all domains. Depending on their business priorities and present state, the utility set their target state in each domain.

Once the "TO-BE" state is defined, the utility can prepare how to ascend from the present state to the "TO-BE state and what technologies and systems to be implemented and conduct its cost-benefit analysis.

I. BENEFITS TO THE UTILITY

Many utilities have reported that the SGMM comparison yields additional insights about their smart grid progress and plans. Major investor-owned utilities and small public power utilities alike, in the US and around the world, have reported finding the model a valuable tool to help them:

- Identify where they are on the smart grid journey
- Develop a shared smart grid vision and roadmap
- Plan for technological, regulatory and organizational readiness
- Assess resource needs to move from one level to another
- Create alignment and improved execution
- Communicate with internal and external stakeholders using a common language
- Prioritize options and support decision making
- Compare against themselves over time and to the rest of the community
- Measure their progress

II. TYPICAL SGMM ASSESSMENT OF AN INDIAN UTILITY

ISGF conducted SGMM assessment of Bangalore Electricity Supply Company Ltd (BESCOM) in India in 2016/17. The AS-IS result from the compass survey is given below:

SGMM Compass Results

BESCOM Current								
Level	Strategy, Management & Regulatory	Organization & Structure	Grid Operations	Work & Asset Management	Technology	Customer	Value Chain Integration	Societal & Environmental
5	0.20	0.40	0.10	0.60	0.00	0.20	0.23	0.27
4	0.07	0.50	0.50	0.60	0.35	0.37	0.10	0.06
3	0.63	0.52	0.55	0.19	0.38	0.26	0.33	0.28
2	0.90	0.40	0.70	0.60	0.46	0.30	0.35	0.50
1	0.73	0.80	0.58	0.63	0.58	0.43	0.58	0.23
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Meets minimum requirements for level
Significant progress towards requirements for level
Initial progress towards requirements for level
Not started

ISGF India Smart Grid Forum

Figure 2-12: SGMM Results of AS-IS Survey of BESCOM

During the Aspiration Workshop in consultation with the senior management of BESCOM, ISGF suggested the following smart grid roadmap for BESCOM for 2020, 2025, 2030 and 2035:

Figure 2-13: BESCOM Smart Grid Roadmap suggested by ISGF

India Smart Grid Forum

MODULE 3

ADVANCED METERING INFRASTRUCTURE

Abstract

This Module covers the evolution of the metering Industry. It also covers the benefits of Advanced Metering Infrastructure (AMI), key challenges in implementing AMI, popular communication standards and innovative business models for rolling out AMI in India. Fundamentally last mile connect has been one of the challenges in the country and reasons of high AT&C loose. " What cannot be measured cannot be controlled" – Metering is the need of the hour to implement Measurement of power distributed and payment received while leveraging technologies like AMI to automate, enhance efficiency and traceability.

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3 ADVANCED METERING INFRASTRUCTURE

3.0 INTRODUCTION

Electric utility metering has been making gradual progress since 1970s when South Africa introduced prepaid metering system in certain localities where it was difficult to collect money. Later in the 1980s some utilities in USA tried with automatic meter reading (AMR) to read meters installed in hazardous or in-accessible locations. While prepaid meters progressed from key-pad operated meters to two-way smart card operated pre-payment system in the 1990s, the AMR technology progressed rapidly from walk-by AMR (standing near a meter and down loading the readings with a hand held unit) to drive-by AMR to fixed line AMR. Both these systems (prepaid meters and AMR) are still in use in different geographies to address specific business needs of utilities.

Smart metering or Advanced Metering Infrastructure (AMI) is a new metering technology started development in early 21st century. The key difference between AMR and AMI is that AMR require only one way communication (meter to utility's computer), AMI require two-way communication between the meter and the utility's computer. With AMI, a meter can be programmed as prepaid or post-paid, the firmware inside the meter can be upgraded; and the meter can be disconnected and connected back remotely. AMI also deploy advanced software solutions such as meter data management system (MDMS) that can facilitate a whole new set of new services for the utility.

3.0.1 DESCRIPTION OF AMI

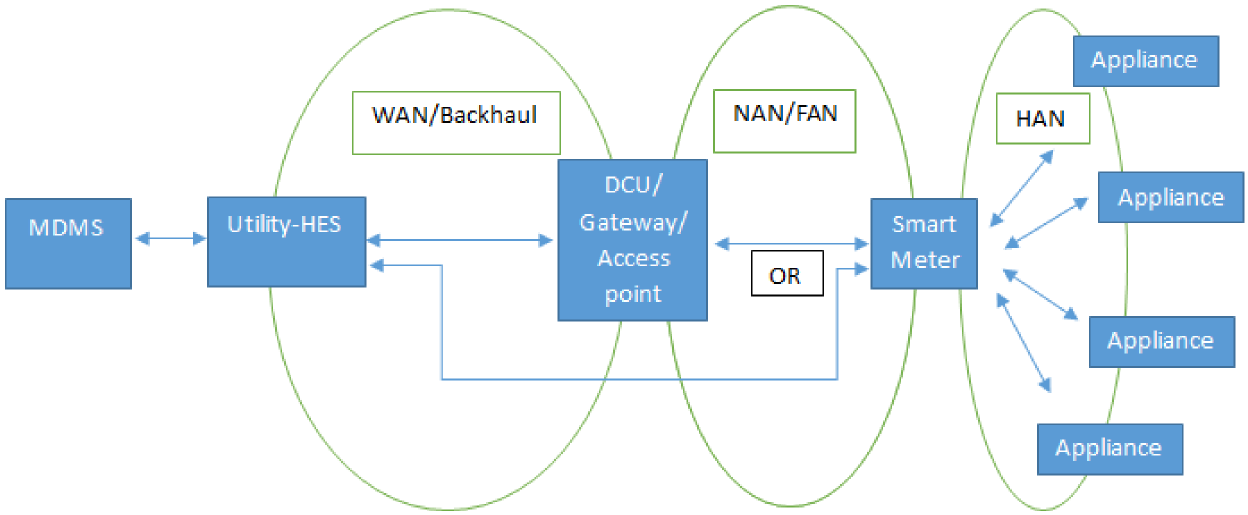

Figure 3-1: Typical Architecture of AMI

Typically, AMI comprises of Smart Meters, Data Concentrator Units (DCUs)/gateways/routers/access points, Head End System (HES), Meter Data Management System (MDMS) communicating over bi-directional Wide Area Network (WAN), Neighborhood Area Network (NAN)/Field Area Network (FAN) and Home Area Network (HAN). Multiple smart meters in a locality can connect to a DCU/gateway/router/access point which in turn send aggregated data to the HES. HES is the software that pulls the meter data to the computer and also sends out utility's commands to the meters. In a typical AMI architecture, a group of meters in a locality will be connected to a data concentrator unit (DCU) over power line communication or wireless communication. The DCU can be connected on a choice of communication technologies ranging from GPRS to Ethernet depending on the available technology options in the location for wide area network (WAN). In certain cases some smart meter can also directly communicate with the HES using appropriate WAN connectivity options. The Meter Data Management System (MDMS) collects data from the HES and processes it before sharing with other utility applications like billing, customer care etc. Appliances such as TV, fridge, air conditioners can be part of the Home Area Network (HAN) which can be controlled through the smart meter.

What makes a meter 'smart' is the communication module capable of two-way Machine to Machine (M2M) communications and a remote connect/disconnect switch. In-Home display (IHD) is a device kept in the consumer's premises that could display meter data and get confirmation from the consumer regarding his/her participation in a demand response program. Hence consumers will become informed and conscious of their power usage. However, with the rise of the smart phone applications or 'apps', consumers need not install IHDs in their homes. A smart phone can work as an IHD and hence the utility will not have to invest in purchasing IHDs.

Figure 3-2: In-Home Devices

3.0.2 BENEFITS OF AMI

The benefits of AMI are explained below:

I. REDUCED METERING READING AND DATA ENTRY COST

In a scenario without smart meters, utility has to authorize its personnel to visit the meter at customer premises and record the reading either manually or via a Hand Held Unit (HHU) which entails a recurring expense every month. With the implementation of Advanced Metering Infrastructure (AMI) that employs two-way communications, meter and meter data can be managed remotely. Meter data will be sent to the utility servers automatically using the communication infrastructure. So the meter reading cost will be substantially reduced. In addition, the data entry cost will be reduced to nil.

II. REDUCED HUMAN ERRORS AND TIME CONSUMPTION

There are always chances of human errors when a meter is read manually or even via an HHU. With meter data reaching the servers of the utility automatically, either scheduled or on-demand, the number and potency of human errors will reduce drastically.

III. REDUCTION OF AT&C LOSSES

AMI will enable real time energy accounting and hence will reduce the theft and increase the billing efficiency. Hence the AT&C losses will substantially reduce.

IV. REDUCTION IN PEAK POWER PURCHASE COST

AMI will enable better estimation of loads and hence the utility can implement Time of Use tariffs which will lead to shifting a portion of the peak load to off-peak hours. Hence the utility will not have to purchase expensive power during the peak hours.

V. ENABLING FASTER RESTORATION OF ELECTRICITY SERVICE AFTER FAULT

In today's scenario, a utility get to know about an outage from its call centers when they receive the calls from the affected customers. Subsequently, the maintenance crew visit the field, identify the location of the outage and rectify the fault. It is pertinent to mention that this process of getting to know the outage via calls from customers and visiting the field leads to huge financial losses because of the increased outage duration. As per the new standard published by the Bureau of Indian Standards (BIS), IS 16444 (A.C. Static Direct Connected Watthour Smart Meter Class 1 and 2 — Specification) all smart meters will be capable of sending last gasp and first breathe messages to utility server. The last gasp message is an intimation to the utility in case of power-off condition and the first breathe message informs the utility about the power-on condition. This will empower the utility to exactly identify the affected area and number of customers in case of faults; and the utility's call center would already have received information about the fault before the customer calls. This will help to reduce the restoration time and in turn lead to financial savings and increased customer satisfaction.

VI. REDUCTION IN OTHER METER SERVICES

Apart from remote meter reading and last gasp/first breathe signalling, smart metering enables a number of other services such as remote connect/disconnect, remote firmware upgrade, remote programming/ configuration requests from the Head End System. Utilities may disconnect electricity to the customer if the sanctioned load is exceeded, under pre-programmed event conditions, under pre-paid agreements, for customers moving out of the premises, for non-paying customers etc. Also, the meter's firmware needs to be upgraded (albeit less frequently), it needs to be programmed/configured frequently and dead meters need to be identified automatically. AMI enable these services to be executed remotely which will reduce the number of truck rolls that will not only save time and efforts of the utility personnel, but will also lead to financial savings.

VII. POWER QUALITY ENHANCEMENT

The smart meter will be capable of measuring specific aspects such as power factor, over/under voltage, over current etc. which will be sent to the utility server in near real-time. This will enable the utility to enhance the power quality as it will be acquiring power quality data from other sources as well. With the improvement in power quality, there will be less I2R losses as well.

VIII. ASSET OPTIMISATION

AMI data will help fine-grain the power flows on the distribution network that will help the utility to identify segments of overloading and segments of under-loading which is a very valuable information for system planning and upgrades in the most optimum manner. AMI data can also help in load balancing which can reduce I2R losses. Furthermore, AMI will help in reducing the failure rate of distribution transformers.

IX. OTHER BENEFITS

In addition to the above mentioned benefits, the carbon footprint of the utility will improve as the number of truck rolls will reduce. Customers will experience the following benefits due to AMI:

- Faster restoration of electricity in case of outages
- Error-free bills and no need for visiting billing centers
- Time of Use tariff and savings on electricity bills
- Ability to monitor and manage electricity consumption and options to save money via Time of Use tariffs
- Ability to remotely manage and control appliances at home/office (with additional home/building automation tools)

Furthermore, the carbon footprint will reduce due to reduced patrolling for outage detection, meter reading, connection/reconnection etc.).

The main features of the smart meters are:

- Metrology section
- Load break switch (or latching relay) for remote connection/disconnection
- Data exchange protocol
- Communication module for bi-directional communications

The smart meter can function in pre-paid or post-paid modes, and as net-meters as well where it would calculate the bidirectional flow of electricity.

The smart meter shall measure voltages and currents in each phase, power factor, current demand, maximum demand and number of tamper events. It shall also log data for power quality-related events such as power on/off, under/over voltage, over current etc.

As per IS:16444, the maximum power consumption of a smart meter at reference voltage, reference temperature and reference frequency is 5W and 15 VA during idle mode of communication. The additional power requirement of the communication module during data communication shall be 7W (maximum).

There shall be a separate battery back-up for real time clock and display. In addition, provision has to be made for sending last gasp and first breathe notifications to the HES.

The data exchange protocol shall be as per IS:15959 (Part 2) which is based on IEC 62056 (DLMS). There shall be two load break switches (one each in phase and neutral) for single phase smart meters; and one load switch in each of the three phases for three-phase smart meters.

The smart meter would perform the following functionalities:

- Remote meter reading (scheduled and on-demand)of electrical energy parameters
- Remote connection and disconnection
- Detecting, recording and reporting tampers
- Remote firmware upgrade
- Facilitate faster detection of outages using last gasp and first breathe notifications
- Multi-tariff calculation (Time of Use and Time of Day tariffs)
- Net metering

If full potential of smart meters is extracted, this would provide an accentuated level of 'smartness' that would be much higher than smart phones. This is because smart meters can act as home automation gateways where data related to electricity, water, gas, internet, telephone and TV usage could be sent on the same communication network before being shared with the respective servers. However which way the industry would progress is difficult to predict.

Utilities who have implemented full AMI have realized that the biggest benefit of AMI is the facility to communicate with the customers in real-time on matters beyond metering. AMI infrastructure is being leveraged for effective customer interactions and engagements which is invaluable.

3.1 COMMUNICATION TECHNOLOGIES FOR AMI

The following table depicts some of the available choices for communication technologies for AMI deployment.

Table 3-1: Communication technologies for AMI

Technology/ Protocol	Last Mile/NAN/FAN	Home Area Network (HAN)	Backhaul/WAN and Backbone
Wireless	6LoWPAN-based RF mesh, ZigBee, Wi-Fi, Millimeter Wave Technology	6LoWPAN-based RF mesh, ZigBee, Wi-Fi, Bluetooth, Z-Wave, NFC	Cellular, Satellite, LPWA, Long Wave Radio, TVWS, Private Microwave Radio links (P2P and P2MP)
Wired	PLC, Ethernet, Serial interfaces (RS-232, RS-422, RS-485), DSL	PLC, Ethernet, Serial interfaces (RS-232, RS-422, RS-485)	Optical Fiber, Ethernet, PLC, DSL

Note: This list is indicative only.

3.2 ARCHITECTURES IN SMART METERING

In the present scenario of smart metering, Data Concentrator Units (DCU), aggregators and gateways are key elements. These devices not only increase the total cost of ownership, but also fail to offer reliable, scalable and interoperable last mile connectivity. Experiences from around the world shows that none of the solutions offer 100% reliable connectivity all the time. The best range often heard is between 95-98%; and in many cases it is well below 90%!

Some of the popular communication architectures deployed for AMI worldwide are discussed here.

Architecture deployed by Enel (Italy) - an early mover

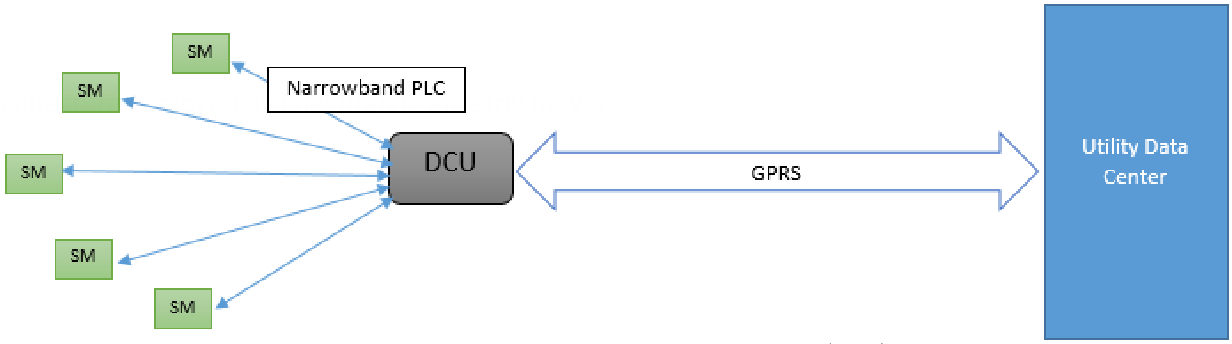

Figure 3-3: AMI Architecture Deployed by Enel (Italy)

Architecture deployed by CenterPoint Energy (Houston, USA) - another early mover

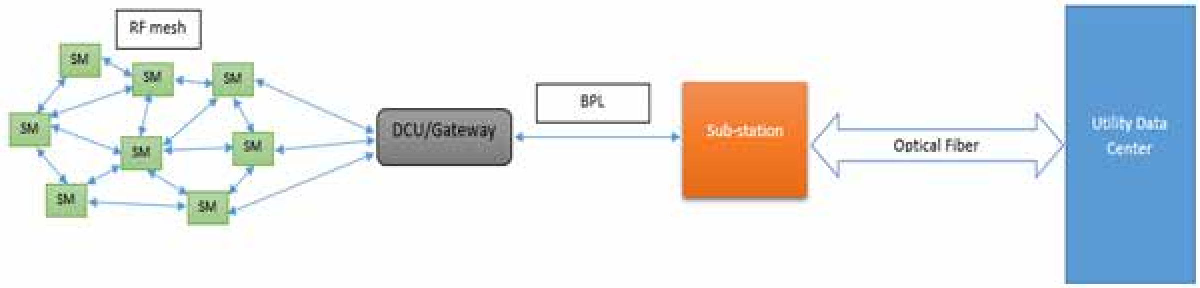

Figure 3-4: AMI Architecture Deployed by CenterPoint Energy (USA)

Typical AMI architecture with RF mesh as last mile – this has emerged as a popular solution amongst utilities in many geographies

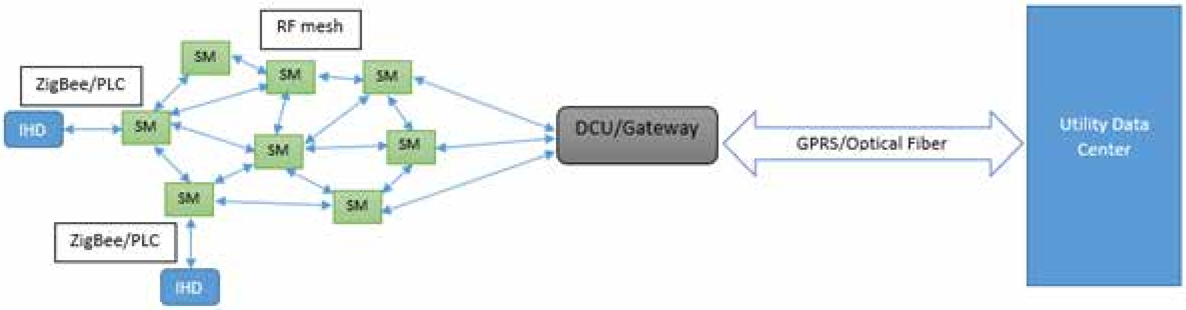

Figure 3-5: AMI Architecture with RF Mesh as Last Mile

Emerging Architecture for Smart Grid and Smart City Applications - RF mesh canopy networks is the latest trend

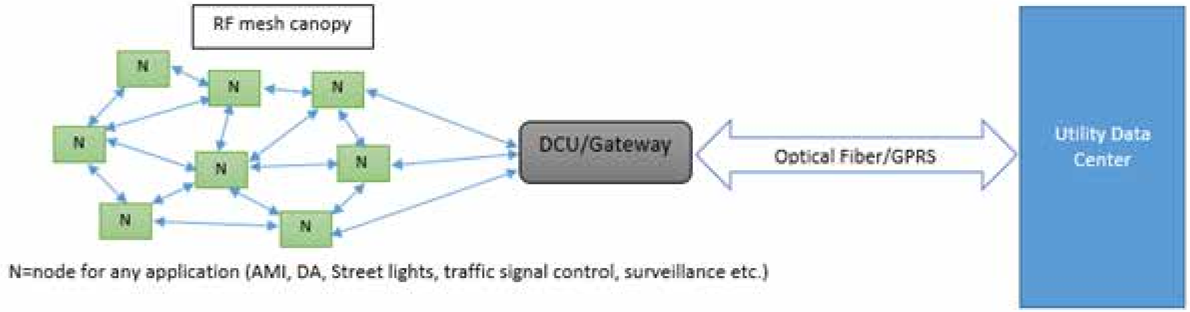

Figure 3-6: Emerging Architecture for Smart Grid and Smart City

We at ISGF believe that by 2020, almost every building (residential/commercial/industrial/public institutions etc.) in urban and semi-urban areas on earth will have broadband internet connectivity (perhaps except in some conflict regions). The smart meter, smart appliances, utility's Head End System (HES) and other applications can connect to the Internet and eliminate the need of intermediate entities such as DCUs/ gateways. As shown in Figure 3-7, smart meters and smart appliances can be connected to the Wi-Fi network in the home/building/campus. Meter data is sent over the broadband internet which can be accessed by the utility's HES and received in the MDMS which integrates the meter data with all utility applications; and applications with consumers on their smart phones eliminating the need for in-home displays (IHDs).

Communication Architecture for next generation Smart Metering – IP Metering

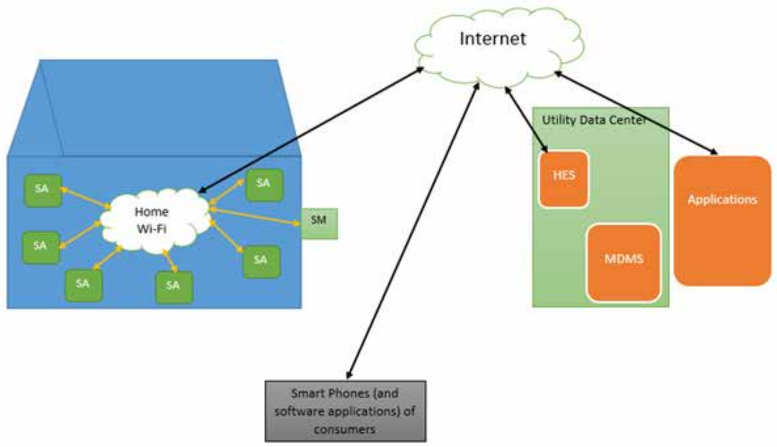

Figure 3-7: Communication Architecture for next generation Smart Metering – IP Metering

Table 3-2: Communication technologies for AMI

SA	Smart Appliances
SM	Smart meter
HES	Head End System
MDMS	Meter Data Management System

I. RATIONALE FOR IP METERING IN INDIA

The Government of India was pursuing a program, National Optical Fiber Network (NOFN), to provide broadband connectivity to 250,000 villages, which is now being expanded to 600,000 villages under the “Digital India” program for providing universal broadband access to all citizens. Ministry of Power has proposed to fund the extension of NOFN to all 33kV and above substations as part of Integrated Power Development Scheme (IPDS) and Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) programs. These schemes are going to provide broadband access to most part of the country as well as create a dedicated fiber backbone network for the power system.

The advantage of the proposed architecture is that it leverages the existing communication infrastructure, that is, broadband connection in buildings and homes, and hence reduces the total cost of ownership as additional network elements such as data concentrator units, gateways etc. are not required. Wi-Fi connectivity is maintained by Broadband Service Providers (BSP) who have the expertise and resources to maintain such networks with very high reliability. IP networks are scalable and reliable and can be monitored and controlled in real time. Questions regarding the security of Wi-Fi networks cannot pose a major threat as people are widely using their laptops and other mobile devices for all kinds of online transactions when connected to Wi-Fi networks. As far as inter-operability is concerned, if all the meters follow common data models/routing tables, the MDMS can accept data from different makes of meters – similar to smart phones of different makes with different operating systems connected on Wi-Fi are able to communicate with each other so long as the users understand the same language.

II. SUMMARY OF BENEFITS OF USING HOME BROADBAND-BASED ARCHITECTURE FOR SMART METERING

The communication architectures presently deployed for smart metering include intermediate entities such as data concentrator units/gateways and creation of a dedicated parallel communication network for the electric utility which they have no expertise in maintaining and upgrading as new communication technologies are evolving at faster pace. This also involves use of wireless spectrum which is a limited and expensive resource in every country today. Experiences from around the world indicate that none of the communication solutions presently deployed for smart metering have 100% reliability despite having a dedicated network. These architectures not only increase the total cost of ownership but also fail to offer reliable, scalable and interoperable last mile connectivity.

In today's world, where internet is everywhere, smart meters and smart appliances could be connected directly on internet; and utility's HES can leverage internet to collect the meter data on the server and the MDMS can integrate that with other applications. In other words, the broadband internet that is present in almost all homes, buildings and campuses, can be used for providing last mile connectivity for smart metering. By doing do, devices such as data concentrator units, gateways and in-home displays will not be needed and highly reliable, scalable and interoperable last mile connectivity can be provided. Wherever there is no Wi-Fi, the electric utility may provide Wi-Fi which will be cheaper than other last mile connectivity options.

In the IPv6 regime where every meter can have an IP address, the proposed IP Metering solution can offer multiple benefits to utilities and governments:

- No need for a parallel telecom infrastructure – huge savings in cost of deployment and maintenance for the utility
- No need for separate spectrum for utility applications – instead government can allocate that spectrum to telcos and/or other users for additional revenue
- More reliability, scalability, security and capability to monitor and control – IP networks can be monitored in real time which itself is a good measure against cyber attacks

3.3 INTEROPERABILITY

Interoperability can be achieved at Devices-Level or at the System-Level. Device-Level interoperability will enable smart meters manufactured by different meter manufacturers to communicate with each other. On the other hand, System-Level interoperability will enable different Head End Systems (HES) to communicate to the same Meter Data Management System (MDMS). In order to solve the issue of interoperability in smart meters, ISGF suggests the following options:

- **Long-term rate contract**: While procuring smart meters (and associated hardware and software for AMI), a rate contract of 7-10 years with select meter vendor (s) whose meters are interoperable may be considered. Hence when new customers are to be added to the AMI network, the same meter manufacturers can provide the existing/already deployed solution to the Utility at previously agreed rates. This will enable seamless integration of new smart meters.
- **Choose communications technology first**: Another approach is to first choose the communication technology and then select the meter manufacturer/s. In such a case, all potential meter manufacturers will have to integrate this communication technology into their meters. Hence Device-Level interoperability will be easily achieved. The communication solutions provider will certify that their network interface card (NIC) is integrated with the meters that will connect with the Head End System (HES).
- **Third-party certification**: A Utility can also opt for a third-party certification for ensuring Device-Level interoperability. In such a case, a Utility will ask the meter manufacturers to present an Interoperability Certificate acquired from the certification agency.
- **Wi-Fi for last mile connectivity**: Smart meter and smart appliances can connect to the Utility servers using Wi-Fi in the building. Moreover, choosing Wi-Fi for providing last mile connectivity can solve issues of interoperability, scalability, maturity, reliability and cost effectiveness.

- **Multiple HES with one MDMS**: In case multiple communication technologies for smart metering are selected by a Utility (over successive tenders) each having its own Head End System (HES), a common MDMS may be chosen that can interface with multiple HES. In such a case, all communication interfaces will have to be standardised as per IEC 61968: Application integration at electric utilities - System interfaces for distribution management. This is a series of standards that define interfaces for the major elements of an interface architecture for Distribution Management Systems in utilities. This option is often the last resort if all the above options are not possible.

Table 3-3: Comparison of options for achieving interoperability in smart metering

Option Parameter	Long-term rate contract	Choose communications technology first	Third-party certification	Wi-Fi for last mile connectivity	Multiple HES with one MDMS
Feasibility	High	High	Moderate	High	Moderate
Cost effectiveness	High	High	High	High	Low
Integration Time*	Minimum	Minimum	Moderate	Minimum	Maximum
Expertise required by Utility	Least	Moderate	Least	Least	High

* Integration time is the time required to integrate new smart meters into the Utility's AMI network.

The utility may choose the appropriate option to achieve interoperability in smart metering. Selecting Wi-Fi for providing last mile connectivity option proves to be the best solution as it is mature, scalable, reliable and cost effective

3.4 AMI INITIATIVES IN INDIA

The Ministry of Power (MoP) mandated Central Electricity Authority (CEA) to prepare the functional requirements and technical specifications for indigenous smart meters. CEA released the first edition of the Smart Meter Specifications in June 2013. However, the distribution companies implementing 14 smart grid pilot projects issued different specifications in different states. This issue was brought to the attention of MoP by India Smart Grid Forum (ISGF). MoP requested the Bureau of Indian Standards (BIS) for formulating a national standard for smart meters. Subsequently, BIS assigned this task to the Technical Committee under Electro Technical Division (ETD- 13) to prepare the standards for smart meters.

In August 2015, BIS published the new Smart Meter Standard, IS 16444: AC Static Direct Connected Watthour Smart Meter – Class 1 and 2 Specification covering single phase energy meters; three phase energy meters; single phase energy meters with Net Metering facility and; three phase energy meters with Net Metering facility.

Another standard IS 15959: Data Exchange for Electricity Meter Reading, Tariff and Load Control — Companion Specification has been revised and published as IS 15959: Part 2-Smart Meter in March 2016.

Ministry of Power in 2016, announced the Government's vision to rollout smart metering on fast track for customers with a monthly consumption of 200kWh and above by December 2019. This goal is reiterated in the UDAY program and in the Tariff Policy announced by MoP.

3.4.1 METER STANDARDS AND SPECIFICATIONS

In June 2016, the Central Electricity Authority (CEA) issued the specifications of single phase and three phase smart meters, and functional requirements of AMI in India. All utilities have been advised to abide by these specifications and minimum functional requirements and mandated all meters to be conforming to latest Indian Standards as listed below:

a. Standards for smart meters and associated data protocol

- BIS Standard for Smart Meters (IS 16444) published in August 2015
- BIS Standard on Data Protocol (IS 15959 Part 2) published in March 2016
- No standard required for Communications – each utility to decide the suitable/appropriate communication technology (It is not prudent to specify any single communication technology for the entire country)

b. BIS Standard on Smart Meters (IS 16444) applies to:

- Single phase electricity meters
- Three phase electricity meters
- Single phase electricity meters with Net Metering facility
- Three phase electricity meters with Net Metering facility

These meters can be operated as both pre-paid and post-paid electricity meters. There is no need for another standard for pre-paid electricity meters.

3.4.2 TEST INFRASTRUCTURE FOR TESTING METERS CONFORMING TO IS 16444

New tests mentioned in the smart meter standard are:

- Test for power consumption: test infrastructure needs to change its THRESHOLD values
- Test for Communicability of smart meters and check connect-disconnect functionality
  - o This is optional in IS 15959 (Part 2)
  - o A Utility can test connect-disconnect function using any available communication technology in the test lab; and it will still work if a connect/disconnect signal is sent to the same meter using any other communication technology when deployed in the field

3.4.3 RETROFITTING OF OLD METERS

As per IS 16444, the communication module has to be a part of the smart meter (either in-built or pluggable units). Hence retrofitting will not be possible. This was a decision taken by the technical committee at BIS as the stakeholders cited the following concerns if the communication module is retrofitted on existing meters:

- Theft of communication module
- Increased points of failure
- The unsuccessful use case of AMR in R-APDRP (where meter manufacturers were blaming the MODEM makers who in turn blamed the telecom network operators for poor bandwidth and vice versa)

Sending engineers and technicians to customer premises again and again to check and rectify the meter-modem-bandwidth issues is several times more expensive than the cost of new meter and communication device. Hence retrofitting communication modules on already-installed meters should not be considered.

3.4.4 MANUFACTURING CAPACITY AND CAPABILITY

As we understand, all the large meter manufacturers in the country are working on smart meters complying with IS 16444 requirements. If they speed up they can complete testing in 4-6 months. Several small players claim they have meters complying with IS 16444. The UDAY program has set a target of 35 million smart meters by December 2019 which is possible considering the AMI work undertaken in other countries. The table below depicts a snapshot of the AMI rollout plans in other countries.

Table 3-4: Snapshot of AMI rollout plans in other countries

Country	No. of meters in the country by 2020 (in million)	Expected penetration rate by 2020 (%)	Total no. of smart meters expected to be installed by 2020 (in million)	Rollout timelines
Austria	5.7	95	5.4	2012-2019
Denmark	3.2	100	3.2	2014-2020
Estonia	0.7	100	0.7	2013-2017
Finland	3.3	100	3.3	2009-2013
France	35	95	33.2	2014-2020
Greece	7	80	5.6	2014-2020
Ireland	2.2	100	2.2	2014-2019
Italy	36.7	99	36.3	2001-2011
Luxemburg	0.26	95	0.24	2015-2018
Malta	0.2	100	0.2	2009-2014
Netherlands	7.6	100	7.6	2012-2020
Poland	16.5	80	13.2	2012-2022
Romania	9	80	7.2	2013-2022
Spain	27.7	100	27.7	2011-2018
Sweden	5.2	100	5.2	2003-2009
UK – Great Britain	31.9	99.5	31.8	2012-2020

Source: EU document on 'Country fiches for electricity smart metering'

Some more data on roll out plans and penetration rates:

- North America is expected to achieve a penetration of about 80% for deployment of smart meters by 2020.
- Combined, Europe has a target of 75% penetration by 2020.
- Asia Pacific has a target of 60% penetration by 2020.
- Latin America has a target of 30% penetration by 2020.
- Middle East and Africa have a target of 5% penetration by 2020.
- Combined, the world targets 50-55% penetration by 2020.
- Presently, USA has a smart meter penetration rate of about 35-40%.
- China has a target of 435 million smart meters by 2020. SGCC (China) will account for 380 million out of the 435 million.
- UK has a target of 53 million smart meters by 2022 and 80% penetration by 2020.
- Korea has a target of 100% (20 million meters) smart metering by 2020. By 2016, it plans to do 10 million smart meters.
- France has a target of 95% smart meters by 2020.
- Japan has a target of 47 million smart meters by 2019.
- India has a target of 35 million smart meters by 2019.
- Mexico has a target of 21 million smart meters by 2020.

3.4.5 PROCUREMENT STRATEGY

Having explored various options, the following procurement framework is recommended:

- International Competitive Bids (ICB) for lots of 5-10 million meters may be issued by a Nodal agency (central or state) so that price discovery is achieved faster. PFC, REC or a state Nodal agency may issue such RFPs according to the functional requirements of AMI and smart meter specification finalized by CEA
- From the above tender, manufacturers/suppliers of meters and different communication devices based on the best evaluated prices may be empanelled. The rates may be made firm for a given timeline and the annual capacities of each supplier may be declared
- A Utility may appoint an AMI Implementation Agency (ideally a System Integrator or a large engineering company) through a transparent procurement process. The Utility in consultation with the appointed AMI Implementation Agency will select the meters, suitable communications technology for AMI only OR also capable of providing connectivity for multiple applications such as smart metering, distribution automation, street light management, distribution transformer monitoring, electric vehicles etc. based on their smart grid roadmap. This may be achieved through undertaking pilot implementations or trial with select communication technologies shortlisted by the Nodal agency as described above
- Once the communications technology is selected, the Utility can choose any of the meter suppliers empanelled (step-2) whose meters can be integrated with the chosen communications technology selected. This process ensures device-level interoperability; and if a meter fails to operate, the utility can purchase another meter from any manufacturer from the empanelled list at empanelled rates and hence will not be locked to a specific manufacturer

3.4.6 ROLLOUT METHODOLOGY

The utility may prioritize the customers and locations for deployment of AMI according to

- Feeders having majority of customers with high monthly consumption (>1000 units, >500 units, >200 units in that order of priority)
- Feeders/pockets with high AT&C loss areas (>15% pockets/feeders)
- Feeders/towns with high annual energy sales (above a certain million units/year)

AMI rollout may be undertaken for full feeders so that online energy auditing can be undertaken. All feasible communication technologies may be allowed to operate in order to encourage innovation in view of the fact that the communication technologies advance much faster compared to other electrical technologies.

IPv6 shall be made mandatory as this is in line with the IPv6 roadmap of the Ministry of Communications & IT in India.

3.4.7 BUSINESS MODELS

Innovative business models may be explored to eliminate the technology risk for the utilities. Also business models that reduce the capex and requirement of technical manpower to maintain the AMI system at the utility may be considered favourable. One such business model is where in AMI is provided as a service for a monthly fee per customer. In this model, a financial intermediary such as a bank or any other financial institution will procure the smart meters and lease them to the utility against a monthly rent for a period of ten years. Since AMI involves expertise in three distinct domains, namely, metering, telecommunication and information technology (including both software and hardware), and experience from around the world shows that no one agency could master these distinct components of AMI, it is proposed to appoint a Metering Services Agency (MSA) who will be responsible (along with their sub-contractors and associates) for a variety of functions related to implementation of AMI and its maintenance. An MSA can bring in a competent team of metering experts, communications solution provider and system integrator; and if any one of these agencies fail in their role, MSA can replace them. As far as the utility is concerned MSA has the single point responsibility for providing smart metering services. The monthly payment per meter to the MSA may be based on mutually agreed service level agreements.

India Smart Grid Forum

MODULE 4

COMMUNICATIONS AND CYBER SECURITY

Abstract

Smart grid is a promising power delivery infrastructure integrated with information and communication technologies (ICT). Its bi-directional communication and electricity flow enable both utilities and customers to monitor, predict, and manage energy usage efficiently and reliably. It also advances energy and environmental sustainability through the integration of vast distributed energy resources. This modile covers various communication technologies available along with the frequencies at which they operate. It also covers Machine to Machine (M2M) applications in power sector. Increased digitization of the power system, interconnection and integration of ICT with legacy devices and protocols introduce cyber vulnerabilities and hackable points into the grid. Failure to address these problems will hinder the modernization of the existing power system. Further, power grid is a critical infrastructure and protecting it from cyber attacks is a critical national security issue. In order to build a reliable and resilient smart grid, an overview of relevant cyber security and privacy issues is covered along with a case study of STUXNET and Ukraininan power grid cyber attack. Key findings of ISGF-NCIIPC pilot survey are listed for creating awareness about cyber hygiene and security preparedness.

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4 COMMUNICATIONS AND CYBER SECURITY

4.0 INTRODUCTION

As explained in the previous modules, smart grid is an electric network with automation, communication and IT systems that can monitor power flows from points of generation to points of consumption and control the power flow or curtail the load to match generation in real time or near-real time. In order to monitor and control the power flows, there is a need to deploy thousands of sensors/connected devices on the grid. These connected devices would require a robust, scalable, reliable, interoperable and cost effective communications networks for the wide area, local/field/neighbourhood area, and homes/buildings.

Smart grid uses Machine to Machine (M2M) communication technologies that allows wired/ wireless systems to communicate with the devices of same ability without human intervention. M2M communication uses a device (sensor, meter etc.) to capture an 'event' (motion, video, meter reading, temperature etc.), which is relayed through a network (wireless, wired or hybrid) to an application (software program) that translates the captured event into meaningful information. M2M is a subset of Internet of Things (IoT) in which every 'thing' such as electricity, gas and water meters, appliances such as television, refrigerator, air conditioner etc., street lights, security cameras, vehicles, dustbins, etc. are connected to a telecommunications network. Besides M2M, IoT includes Human-to-Machine communication (H2M) and Machine-to-Human communications (M2H) also.

It is pertinent to mention that the Internet Protocol (IP) addressing system based on IP version 4 (IPv4) addresses have already exhausted and hence standardization and adoption of IPv6 in the telecom sector will provide an opportunity of having trillions of devices which can be IP enabled and seamlessly addressable through wireless or wired broadband connections.

A number of sectors ranging from Power, Banking and Financial Services, Automotive/Transport, Health, Safety and Surveillance to Agriculture will be transformed and revolutionized by using M2M/IoT.

4.1 RELEVANCE OF M2M COMMUNICATIONS IN THE POWER SECTOR

Every year, India loses over 250 billion units of electricity as AT&C losses which translates to a loss of over USD 17 billion[1] (Rs 100,000 crores) per year. Transition to smart grids will achieve the objectives of reducing AT&C losses and providing 24x7 power for all households.

Traditional electricity networks have been designed for 'unidirectional' flow of electricity, revenue and information. Electricity is generated centrally at a power plant and is transmitted over high voltage transmission lines before being distributed over medium voltage and low voltage distribution lines. Communications is used only to monitor and control the power flow up to the high voltage and medium voltage substations using Supervisory Control and Data Acquisition (SCADA) systems.

In a smart grid, two-way Machine to Machine (M2M) communications would be used to monitor and control the power flow in the low voltage grid till the end consumers. This would be done by deploying SCADA/DMS (Distribution Management Systems). Also, there would be distributed generation with millions of rooftop PVs and connected electric vehicles wherein electricity would be generated much closer to the end consumer. M2M communications would help in monitoring and controlling these intermittent, unpredictable and dispersed sources of generation. This bidirectional flow of electricity, revenue and information in a smart grid is a major transformation from the traditional grid.

Smart metering would benefit both, consumers and utilities by enabling remote reading, remote connection disconnection, remote load control via time of day or time of use prices, detecting outages early etc. Wide Area Monitoring System (WAMS) would offer a high degree of visibility in the electricity grid which would synchronously measure the phase of the current and voltage vectors.

Electric vehicles would not only provide a clean and efficient means of transport, but would act as virtual power plants which could supply power to the grid in case of an outage. By commissioning an outage management system, power outages would not only be identified in near-real time, but also help in early restoration of power.

Through smart micrograds in important load centres, the connected loads and the electricity generation and storage can be intelligently controlled. In case of an outage in the main grid or a cyber attack, these microgrids can be islanded from the main grid.

The initial attempts to implement M2M communications in the power sector was SCADA/EMS by transmission utilities (TRANSCOS) and later AMR (Automated Meter Reading) by distribution utilities (DISCOMS). Now, many DISCOMS are also in the process of implementing SCADA/DMS and Distribution Automation.

It is believed that the grid will emerge as the 'Grid of Things' just like the Internet is evolving as the 'Internet of Things'. The 'Grid of Things', coupled with IoT and M2M communications can also be referred to as the 'Internet of Energy'. The following figure sheds more light into this concept:

[1] Taking Rs 4/unit as the tariff

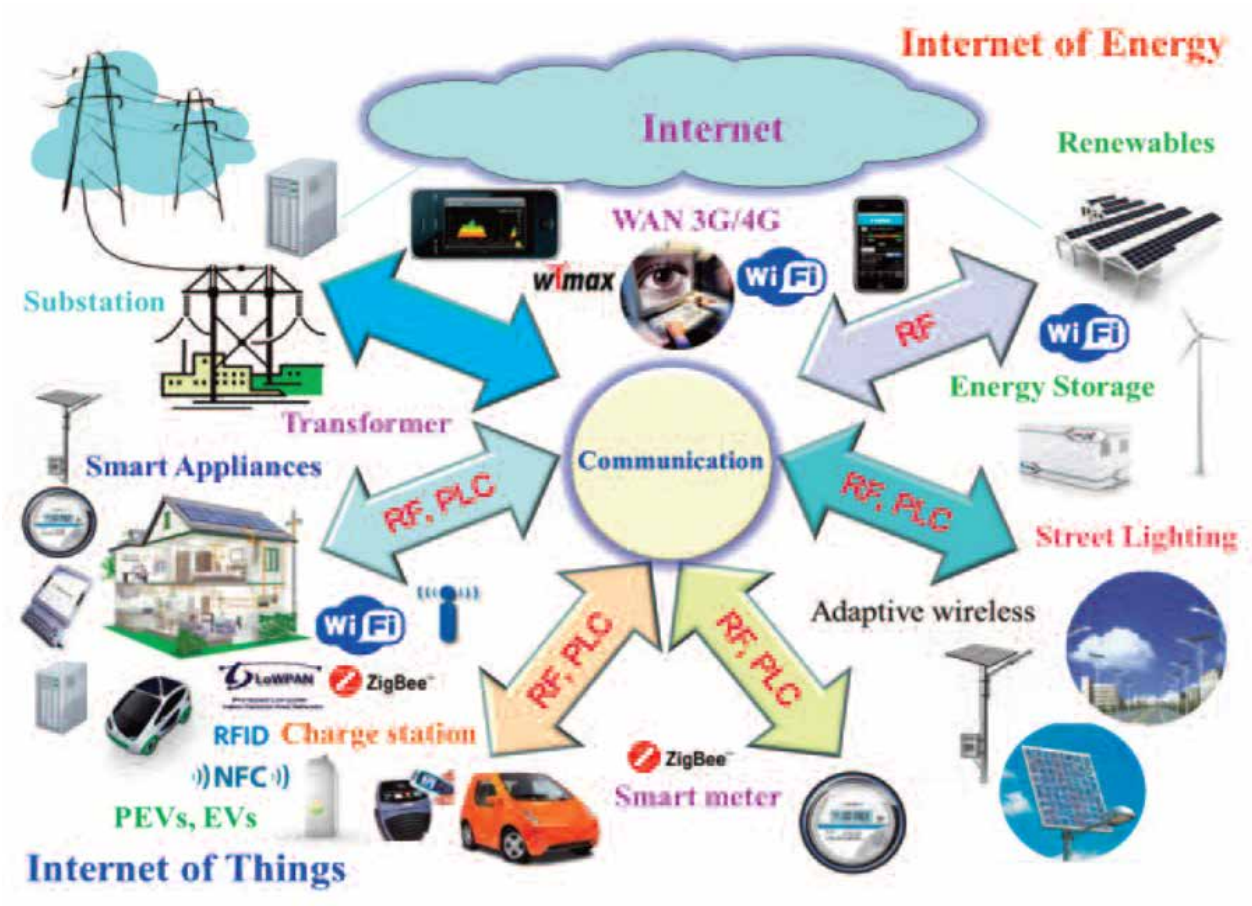

Figure 4-1: Internet of Energy: Internet of Things in The Power Sector

Source: IERC Cluster Book (2012) on Internet of Things

4.2 COMMUNICATION TECHNOLOGIES & STANDARDS AVAILABLE FOR USE IN THE POWER SECTOR

The following table depicts a snapshot of the above mentioned technologies with respect to the applications:

Table 4-1: Types of Communication Technologis

Technology/ Protocol	Last Mile/NAN/FAN	Home Area Network (HAN)	Backhaul/WAN and Backbone
Wireless	6LoWPAN-based RF mesh, ZigBee, Wi-Fi, Millimeter Wave Technology	6LoWPAN-based RF mesh, ZigBee, Wi-Fi, Bluetooth, Z-Wave, NFC	Cellular, Satellite, LPWA, Long Wave Radio, TVWS, Private Microwave Radio links (P2P and P2MP)
Wired	PLC, Ethernet, Serial interfaces (RS-232, RS-422, RS-485), DSL	PLC, Ethernet, Serial interfaces (RS-232, RS-422, RS-485)	Optical Fiber, Ethernet, PLC, DSL

The following table compares some of the popular communication protocols and technologies:

Table 4-2: Communication protocols

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireless				
Low Power RF				
6LoWPAN – based RF Mesh	Various frequency bands in the 800 MHz, 900 MHz and 2400 MHz bands	• Lightweight • Versatile (can be used with any physical and data link layer) • Ubiquitous • Scalable • Manageable and secure connectivity (IPSec is inbuilt) • Can be used in the sub-GHz range	• All low power wireless personal area networks are unreliable due to uncertain radio connectivity, battery drain, device lock ups, physical tampering etc. 6LoWPAN being a low power wireless PAN would also encounter this limitation[3].	• AMR - NAN • AMI - NAN • SCADA/DMS - NAN • SCADA/EMS - NAN • DCS for Generation • WAMS - NAN • Substation Automation • Distributed Generation • Electric Vehicles • Energy Storage • Microgrids • Home/Building Automation
Bluetooth	2.4 GHz	• Mature technology • Easy to implement	• Low data security • Extremely short range • Only connects 2 devices at a time • Not very reliable • Not interoperable with all devices	• Reading data from smart meters using a HHU • Home/Building Automation • Enabling prepayment functionalities
InfraRed	2.4 GHz	• Low power consumption • Inexpensive • Less interference	• Communication is line of sight • Extremely short range • Easily blocked by objects such a people, walls, plants etc.	• Reading data from smart meters using a HHU • Home/Building Automation • Enabling prepayment functionalities

[3]http://tools.ietf.org/html/rfc4919

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireless				
Low Power RF				
NFC	13.56 MHz	• Consumes less power • Almost instantaneous connectivity between devices	• Extremely short range • Expensive • Low information security • Low market penetration	• Reading data from smart meters using a HHU • Enabling prepayment functionalities
RFID	Various frequency bands from 100 KHz to 2.4 GHz	• Mature technology • Can penetrate through objects (plastic, human body, wood etc.)	• Extremely short range • Low data security • Expensive modules • Connectivity can be hampered easily	• Reading data from smart meters using a HHU • Enabling prepayment functionalities
Wi-Fi	2.4 GHz	• Mature technology • High home/ office penetration • High data rates achievable • Easy to implement	• Limited range • Poor building penetration • High interference from other sources • Power consumption higher than those technologies that operate in the sub- GHz band	• AMR - NAN • AMI - NAN • Home/Building Automation
ZigBee	Various frequency bands in the 800 MHz, 900 MHz and 2400 MHz bands	• High market penetration in the home-automation domain • Low cost communication modules	• Low reliability • Larger stack size • Not interoperable with non-ZigBee devices • Range is less (In India can only be used in the 2.4 GHz band)	• AMR - NAN • AMI - NAN • SCADA/DMS - NAN • SCADA/EMS - NAN • DCS for Generation • WAMS - NAN • Substation Automation • Distributed

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireless				
Low Power RF				
ZigBee			• Higher power consumption as compared to those protocols that operate in the sub-GHz range • Need a middleware for communication between nodes and server • ZigBee IP is designed to operate only in 868 MHz, 915 MHz and 920 MHz • All low power wireless personal area networks are unreliable due to uncertain radio connectivity, battery drain, device lock ups, physical tampering etc.	• Electric Vehicles • Energy Storage • Microgrids • Home/Building Automation
Z-Wave	Various frequency bands from 865 MHz to 956 MHz	• Low power consumption • Can be used in the sub-GHz range	• Poor market penetration in India • Expensive modules • Not very scalable • Only 1 manufacturer (Sigma Designs) produces Z-Wave modules	• AMR – NAN • AMI - NAN • SCADA/DMS - NAN • SCADA/EMS - NAN • DCS for Generation • WAMS - NAN • Substation Automation • Electric Vehicles • Distributed Generation

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireless				
Low Power RF				
Z-Wave				• Energy Storage • Microgrids • Home/Building Automation
Cellular	For India, 900 MHz, 1800 MHz, 2100 MHz and 2300 MHz is allocated	• Mature technology • Rapid deployment • Communication modules are low cost and standardised	• Unsuitable for online substation control due to reliability and coverage issues • Coverage not 100% • Reliability not the best • Short technology life-cycle (2G, EDGE, 3G, LTE etc.)	• AMR - WAN • AMI - WAN • SCADA/DMS – (WAN and Backbone) • SCADA/EMS – (WAN and Backbone) • DCS for Generation • WAMS - WAN • Substation Automation • Distributed Generation • Electric Vehicles • Energy Storage • Microgrids • Home/Building Automation
Low Power Wide Area (LPWA)	TV spectrum, 900 MHz, 2.4 GHz, 5 GHz	• Long range • Low power consumption • Require low bandwidth	• Not available in India (as on today) • Require cheap modules with a long battery life to outweigh cellular technology • Additional spectrum may need to be allocated	• AMR - WAN • AMI - WAN • SCADA/DMS – (WAN and Backbone) • SCADA/EMS – (WAN and Backbone) • DCS for Generation • WAMS - WAN • Substation Automation • Distributed Generation • Electric Vehicles • Energy Storage • Microgrids • Home/Building Automation

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireless				
Low Power RF				
Satellite	Various frequency bands from 1-40 GHz	• Broad coverage • Quick implementation • Useful for hilly remote areas	• Affected by severe weather • High cost	• AMR - WAN • AMI - WAN • SCADA/DMS – (WAN and Backbone) • SCADA/EMS – (WAN and Backbone) • DCS for Generation • WAMS - WAN • Substation Automation • Distributed Generation • Electric Vehicles • Energy Storage • Microgrids • Home/Building Automation
Long Wave Radio	Typically 100-200 KHz	• Extremely high range • Reliable • Energy efficient as lower frequency is used • Reception is possible at basements as these waves travel very close to the Earth's surface	• Propagation of waves is affected by obstacles such as forests, mountains and high-rise buildings • Need regulatory approval to use the spectrum (typically in the 100 KHz -200 KHz range). In the sub-GHz region, only 865-867 MHz is license free • Very high radiated power	• AMR - WAN • AMI - WAN • SCADA/DMS – (WAN and Backbone) • SCADA/EMS – (WAN and Backbone) • DCS for Generation • WAMS - WAN • Substation Automation • Distributed Generation • Electric Vehicles • Energy Storage • Microgrids • Home/Building Automation

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireless				
Low Power RF				
TVWS (TV White Space)	TV frequency bands specific to different countries	• Unused TV channels are used • Antenna height is nominal - Typically 30-40 meters • Low radiated power (<5W typically)	• Require regulatory approval for spectrum usage, effective radiated power and other necessary parameters • Dynamic allocation of TV frequency bands is complex	• AMR –(WAN and NAN) • AMI –(WAN and NAN) • SCADA/DMS – (NAN and WAN) • SCADA/EMS – (NAN and WAN) • DCS for Generation • WAMS - WAN • Substation Automation • Distributed Generation • Electric Vehicles • Energy Storage • Microgrids • Home/Building Automation
Private Microwave Radio Networks(P2P and P2MP)	Various frequency bands in the 400 MHz range, 900 MHz range, and 2.4 GHz to 70 GHz range.	• Inexpensive installation as compared to optical fiber • Increased reliability (as a result of using licensed spectrum – less interference)	• Typically use licensed radio spectrum • Expensive as compared other RF technologies	• AMR (NAN and WAN) • AMI (NAN and WAN) • SCADA/DMS (NAN, WAN and Backbone) • SCADA/EMS (NAN, WAN and Backbone) • DCS for Generation • WAMS (NAN and WAN) • Substation Automation • Distributed Generation • Energy Storage • Microgrids • Home/Building Automation

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireline				
PLC	Narrowband PLC: 200 Hz–500 KHz Broadband PLC: 2–30 MHz	• Ready infrastructure • Communication possible in challenging environments such as underground installations, metal-shielded cases etc. • Long technology life-cycle • Many standards and protocols available	• Point-to-point communication • Can cause disturbances on the lines • Not suitable where power cables are not in a good condition; initial and ongoing line conditioning and maintenance can add significant O&M costs • Bespoke engineering and trained manpower required for O&M • Communication not possible in case of an outage • Absence of regulations on use of frequency bands	• AMR (NAN and WAN) • AMI (NAN and WAN) • SCADA/DMS (NAN, WAN and Backbone) • SCADA/EMS (NAN, WAN and Backbone) • DCS for Generation • WAMS (NAN and WAN) • Substation Automation • Distributed Generation • Energy Storage • Microgrids • Home/Building Automation
FTTx	Depending on application	• Extremely fast • Very high bandwidth • Very low attenuation	• Limited availability • High installation cost	• AMR - NAN • AMI - NAN • Distributed Generation • Energy Storage • Microgrids • Home/Building Automation

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireline				
Serial interfaces (RS-232, RS-422 and RS-485)	Depending on the signal frequency.	• Mature protocols • Easy to implement • Inexpensive installation	• Wires add to the network complexity • Less range • Network architecture limited to point-to-point or daisy chain • Extremely less throughput	• AMR (between meter and modem) • SCADA/DMS - NAN • SCADA/EMS – NAN • DCS for Generation • WAMS - NAN • Substation Automation • Distributed Generation • Energy Storage • Microgrids • Home/Building Automation
DSL	0-2.208 MHz	• Inexpensive (installation and use) • High SLA • Less installation time • Bonded DSL provides inherent redundancy	• Low data security • Lower throughput • Higher latency	• AMR (NAN and WAN) • AMI (NAN and WAN) • SCADA/DMS (NAN, WAN and Backbone) • SCADA/EMS (NAN, WAN and Backbone) • DCS for Generation • WAMS (NAN and WAN) • Substation Automation • Distributed Generation • Energy Storage • Microgrids • Home/Building Automation
Ethernet	16 MHz, 100 MHz, 250 MHz, 500 MHz, 600 MHz, 1 GHz, 1.6-2.0 GHz	• Inexpensive (installation and use) • Excellent throughput • Low installation time • Easily scalable	• Lowest data security • Lowest SLA • Highest latency • Bursts of additional bandwidth not possible	• AMR (NAN and WAN) • AMI (NAN and WAN) • SCADA/DMS (NAN, WAN and Backbone) • SCADA/EMS (NAN, WAN and Backbone) • DCS for Generation • WAMS (NAN and WAN)

Technology/ Protocol	Typically used Frequency Band/Bands	Advantages	Limitations	Relevance for Smart Grids in India
Wireline				
Ethernet				• Substation Automation • Distributed Generation • Energy Storage • Microgrids • Home/Building Automation

4.2.1 COMMUNICATION NETWORK REQUIREMENTS IN A SMART GRID

Table 4-3: Communication Network Requirements in a Smart Grid

Application	Network Requirement				
	Bandwidth	Latency	Min Reliability	Security	Power Backup
AMI	10-100 kbps/ node, 500 kbps backhaul	2-15 sec	99%	High	Not Necessary
Demand Response	14-100kbps/ node	500 ms to several minutes	99%	High	Not Necessary
Wide Area Situational Awareness	600-1500 kbps	20-200 ms	100.00%	High	24 Hours or more
Electric Vehicles (Transportation)	9.6-56 kbps	2 sec - 5 min	99.99%	Relatively High	Not Necessary
Distribution Grid Management	9.6 - 100 kbps	100 ms - 2 sec	99%	High	24- 72 Hrs

Source: http://energy.gov/sites/prod/files/gcprod/documents/Smart_Grid_Communications_Requirements_Report_10-05-2010.pdf

Different smart grid applications have different bandwidth and latency requirements. For example, smart metering requires less bandwidth with no severe latency conditions whereas substation automation poses requirements of higher bandwidth and improved latency. Apart from availability, reliability of communication networks is a key characteristic for critical applications such as SCADA and substation automation. Using standards-based technologies will ensure a high degree of scalability and interoperability. The choice of operating frequency is vital for deciding the power consumption of the devices and range of the communications network. Having a long technology life-cycle, compliance to regulations and total cost of ownership are other key characteristics. Moreover, all communication technologies must possess the necessary measures to be resilient to cyber attacks.

The selection of a technology will depend on the envisaged application:

- For mission critical applications (such as SCADA/DMS, Wide Area Monitoring System, Distribution Automation etc), security, reliability and latency will be the key criteria for deciding a communication technology. Cost will be of least priority
- For non-critical applications (such as AMI, connectivity for Distributed Generation, etc) cost will be decisive

4.3 GLOBAL FREQUENCY SPECTRUM ALLOCATION SCENARIO

Globally, various countries have allocated un-licensed frequency bands in excess of 7 MHz. North America and South America have allocated the most (26 MHz) in the sub-GHz band. Australia also believes that de-licensing a substantial amount of spectrum is the way forward and has allocated 13 MHz. Europe, Africa and most middle-eastern countries have access to 7 MHz of un-licensed spectrum. In the recent past Japan has de-licensed 8 MHz for M2M/IoT/IoE/Smart Cities initiatives.

The Table below shows wireless frequency spectrum allocation in some countries/regions.

Table 4-4: Wireless Frequency Spectrum Allocation in Some Countries/Regions

Country	Frequency Band
North America and South America	433.075-434.775 MHz and 902-928 MHz
Africa and Middle-Eastern countries	433.05-434.79 MHz and 863-870 MHz
Europe	433.05-434.79 MHz, 863-870 MHz, 870 – 876 MHz
Japan	426-430 MHz and 920-928 MHz
Australia	915-928 MHz
India	865-867z and 433-434 MHz

4.4 INDIAN SCENARIO

4.4.1 THE 433 TO 434 MHZ BAND

As per the notification G.S.R. 680 (E), 433-434 MHz frequency band was de-licensed in September 2012. The specifications require that the maximum effective radiated power and maximum channel bandwidth be 10mW and 10 KHz respectively. In addition to using an in-built antenna, the devices (that operate on this frequency band) are meant for indoor applications only. Currently, there are very few devices deployed in this band.

4.4.2 THE 865 TO 867 MHZ BAND

As per the notification G.S.R. 168 (E), 865-867 MHz frequency band was de-licensed in March 2005. The specifications require that the maximum transmitted power, maximum effective radiated power and maximum channel bandwidth be 1 W, 4 W and 200 KHz respectively. This band can be used for Radio Frequency Identification (RFID) or any other low power wireless devices or equipment.

Currently this band is not congested as M2M/IoT/Smart City initiatives are still gathering pace. However, with introduction of more and more devices, this frequency band may not remain adequate to meet the expected demand.

4.4.3 THE 2.4 TO 2.4835 GHZ BAND

As per the notification G.S.R. 45 (E), this frequency band was de-licensed in January 2005. The specifications require that the maximum transmitted power, maximum effective radiated power and maximum antenna height be 1 W (in a spread of 10 MHz or higher), 4 W and within 5 meters above the roof-top of an existing authorized building respectively. This band can be used for any wireless equipment or device.

At present, too many devices use this frequency band. These include (but are not limited to) Wi-Fi and Bluetooth devices, microwave ovens, cordless phones etc. High interference, limited range and high power consumption (of the devices) limit the use of this band for M2M/IoT/Smart Cities.

4.4.4 THE 5.150 TO 5.350 GHZ BAND AND 5.725 TO 5.875 GHZ BAND

As per G.S.R. 46 (E), these frequency bands were de-licensed in January 2005. The specifications require that the maximum mean effective isotropic radiated power and maximum mean effective isotropic radiated power density be 200 mW and 10 mW/MHz respectively in any 1 MHz band. In addition, the antenna must be in-built or indoor. This band can be used for indoor applications only. These include usage within the single contiguous campus of an individual, duly recognized organization or institution.

Although this frequency band offers low interference, it is not widely used in today’s scenario.

4.4.5 THE 5.825 TO 5.875 GHZ BAND

As per the notification G.S.R. 38 (E), this frequency band was de-licensed in January 2007. The specifications require that the maximum transmitted power and the maximum effective isotropic radiated power be 1 W (in a spread of 10 MHz or higher) and 4 W respectively. This band can be used for any wireless equipment or device.

This frequency band also offers low interference, but will not be ideal for low power applications due to relatively high power consumption and limited range. However this band could be used for point to point and point to multipoint links.

SELECTION OF A FREQUENCY BAND

The sub-GHz frequency bands offer compelling advantages as compared to other (higher) frequency bands. Below 1 GHz, the further down we go, the better the performance will be in terms of range, interference, signal to noise ratio, penetration and power consumption.

At present, the 865-867 MHz band is the most suitable frequency band for outdoor applications by virtue of the reasons mentioned above. For indoor applications, the 2.4-2.4835 GHz band is preferred.

WAY FORWARD FOR INDIA

Low power RF is expected to be the most effective communications technology that would offer connectivity to a large number of devices. The main reasons for this include, but are not limited to low operating cost, less power consumption, less interference, high signal to noise ratio and more penetration.

The 865-867 MHz band (de-licensed in 2005) may not be sufficient to cater to the needs of the IoT/M2M/ Smart City applications in which billions of devices would be connected. Another de-licensed band in the sub-GHz range, the 433-434 MHz, which was de-licensed in 2012, may only be suitable for indoor applications because of the current regulations on maximum power of 10mW. The sub-GHz frequency bands are best utilized when they are used for outdoor applications in NAN/ FAN/ LAN.

The table below lists the applications that could use low power RF technology:

Table 4 5: Potential Applications on Low Power RF Technology

Potential applications on low power RF technology	Potential applications on low power RF technology (contd.)
Electricity (Grid)	Buildings (Automation and Management) • Residential Buildings • Commercial Buildings • Industrial Buildings • Shopping Malls
Renewable Energy	EV Charging Stations
Gas	Parking Lots
Water Distribution: • Portable Water • Non-portable Water • Industrial Water • Agricultural Water • Other Water Bodies (Ponds, Lakes, Tanks etc.)	Hospitals and E-Healthcare • Primary Healthcare Centers • Super Specialty Hospitals • E-Healthcare
Rivers and Canals – Monitoring and Management	Theater and Auditoriums
Waste Collection, Monitoring and Management • Hazardous Waste (Toxic/Reactive/ Corrosive/Explosive) • E-Waste • Medical/Bio-Medical Waste • Sanitation and Sewage • Rain Water/Storm Water/Drainage • Radio Active Waste • Municipal Solid Waste (incl. Religious Waste)	Places of worship
Sports Academies	Training Centers
Smart Agriculture	Industrial Automation
Home Automation	Street Lighting

4.5 PLC COMMUNICATION TECHNOLOGIES

Power-line communication (PLC) is a communication method that uses electrical wiring to simultaneously carry both data, and alternating current (AC) electric power transmission or electric power distribution. It is also known as power-line carrier, power-line digital subscriber line (PDSL), mains communication, power-line telecommunications, or power-line networking (PLN). Power-line carrier communication (PLCC) is mainly used for telecommunication, tele-protection and tele-monitoring between electrical substations through power lines at high voltages, such as 110 kV, 220 kV, 400 kV. This can be used by utilities for advanced energy management techniques fraud detection and network management, automatic meter reading (AMR), advanced metering infrastructure, demand side management, load control, and demand response.

PLC technology is presently limited in India to high voltage transmission lines. In the distribution grid, it can be used for providing last mile connectivity as well as for creating a Field Area and Wide Area Networks. A key requirement of this technology is the existence of a power cables with good quality joints suitable for carrying data. Issues such as noise generated by different loads on the power line, dynamic changes in the line impedance and absence of trained man-power capable of bespoke engineering are some of the issues that will need to be addressed in order to make this technology ready to use.

PLC technology can be divided in to Narrow Band PLC and Broad Band PLC (BPL). There needs to be a frequency band allocated for PLC communications.

Globally, IEEE 1901.2[4], PRIME, G3-PLC, ITU-T G.hnem[5], IEC 61334, TWACS, Meters and More, and HomePlug C&C are some of the popular standards/protocols available for implementing Narrowband PLC systems.

The following table throws more light into the technical details of Global Standards/Protocols on Narrowband PLC Systems

Table 4-6: Global Standards/Protocols on Narrowband PLC

Standard/Protocol	Frequency band	Maximum data rate
IEEE 1901.2 - 2013	<500 KHz	500 Kbps
PRIME	42-89 KHz	128.6 Kbps
G3-PLC	35-91 KHz	33.4 Kbps
ITU-T G.hnem	10-490 KHz	1 Mbps
IEC 61334	60-76 KHz	Upto 2.4 Kbps
TWACS	200-600 Hz	100 bps
Meters and More	3-148.5 KHz	28.8 Kbps (nominal) and 4.8 Kbps (effective)
HomePlug C&C	10-450 KHz	7.5 Kbps

Source: ISGF White Paper on 'Need for Allocating a Frequency Band for Power Line Carrier Communications' published on December 18, 2014

[4] http://standards.ieee.org/findstds/standard/1901.2-2013.html

[5] Developed by ITU-T: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6094004&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6094004

Globally, IEEE 1901-2010, HomePlug Green PHY and ITU-T G.hn (G.9960/G.9961) are some of the popular standards/protocols for implementing **Broadband PLC** systems.

The following table throws more light into the technical details of Global Standards/Protocols on Broadband PLC Systems

Table 4-7: Global Standards/Protocols on Broadband PLC

Standard/Protocol	Frequency band	Maximum data rate
IEEE 1901-2010	< 100 MHz	> 100 Mbps
HomePlug Green PHY	2-30 MHz	10 Mbps
ITU-T G.hn (G.9960/G.9961)	25-200 MHz	2 Gbps

Source: ISGF White Paper on 'Need for Allocating a Frequency Band for Power Line Carrier Communications' published on December 18, 2014

Europe, USA, Japan and China are regions where frequency bands have been allocated for PLC communications. The following table mentions the regions and frequency bands allocated for PLC:

Table 4-8: Global Frequency Allocation for PLC Communications

Region	Frequency band for PLC
Europe	CENELEC A: 3-95 KHz for power utilities CENELEC B: 95-125 KHz for any application CENELEC C: 125-140 KHz for in-home networking with mandatory CSMA/CA protocol CENELEC D: 140-148.5 KHz Alarm and Security systems
USA	10-490 KHz, and 2-30 MHz
Japan	10-450 KHz
China	3-500 KHz

4.6 CONCEPTUAL DESCRIPTION OF M2M COMMUNICATIONS IN THE POWER SECTOR

The various elements in M2M communications include a Wide Area Network (WAN)/Backhaul Network, Neighbourhood Area Network (NAN)/Field Area Network (FAN), Home Area Network (HAN), sensors, home gateway, Data Concentrator Unit (DCU)/Gateway and an application/data center. Presence of a home gateway would be decided by the nature of the application that is being catered to. In addition, a Backbone/Core network would also be present. The figure below depicts a typical conceptual description of M2M communications.

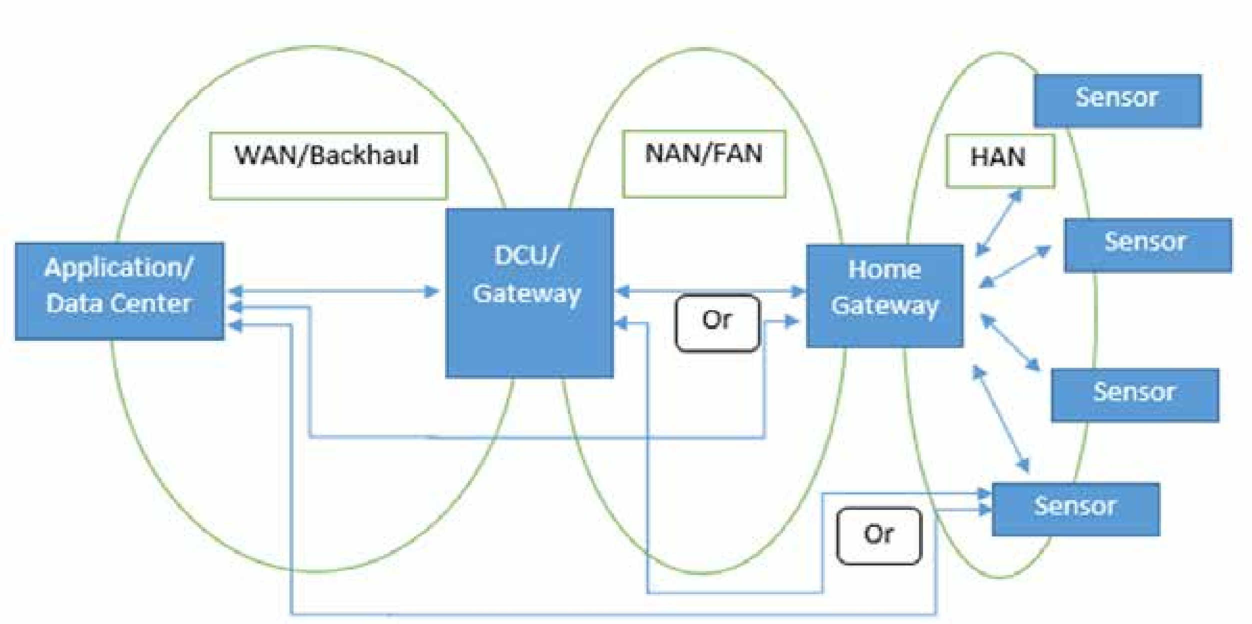

Figure 4-2: Typical Conceptual Description of M2M Communications

Multiple sensors in a Home Area Network (HAN), Field Area Network (FAN) or Wide Area Network (WAN) would communicate with the home gateway, DCU/gateway or application/data center respectively. The home gateway, if present, would relay data from the sensors to the application/data center via the DCU/gateway. Considering Advanced Metering Infrastructure (AMI), the smart meter could act either as a sensor or a home gateway.

4.7 APPLICATIONS OF M2M/IOT IN THE POWER SECTOR

The power sector has a number of use cases where M2M communications plays a vital part. These include (but are not limited to):

- Automatic Meter Reading (AMR)
- Advanced Metering Infrastructure (AMI)
- SCADA/EMS (Supervisory Control and Data Acquisition/Energy Management System) for TRANSCOS
- SCADA/DMS (Supervisory Control and Data Acquisition/Distribution Management System) for DISCOMS
- Distributed Control System (DCS) for GENCOS and Operations
- Wide Area Monitoring System (WAMS) using Phasor Measurement Units (PMUs)
- Substation Automation and Distribution Automation
- Distributed Energy Resources Management Systems (DERMS)
- Centralized Generation Resources
- Grid-connected and Off-grid Microgrids
- Demand Response (DR)

- Electric Vehicles and Charging Station Infrastructure
- Energy Storage Systems
- Home Energy Management/Building Energy Management, Gateways and Routers
- Public and Enterprise Networks
- Smart appliances and devices such as washers, dryers, refrigerators, thermostats, etc.
- Connected devices such as phones and computers.

Exploring Key Applications of M2M/IoT in Power Sector

Some of the M2M communications used in the power sector are explained below:

4.7.1 AUTOMATED METER READING (AMR)

AMR is used extensively for HT consumers, distribution transformers and feeders. Both GSM and CDMA were used in India for AMR. It is reported that reliability is poor owing to a variety of reasons. The following architecture was used for AMR in RAPDRP: (Note: Communications is only ONE-WAY)

Figure 4-3: Automated Meter Reading Architecture

4.7.2 ADVANCED METERING INFRASTRUCTURE (AMI)

Advanced Metering Infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customer premises equipment. The diagram below represents a typical architecture of AMI:

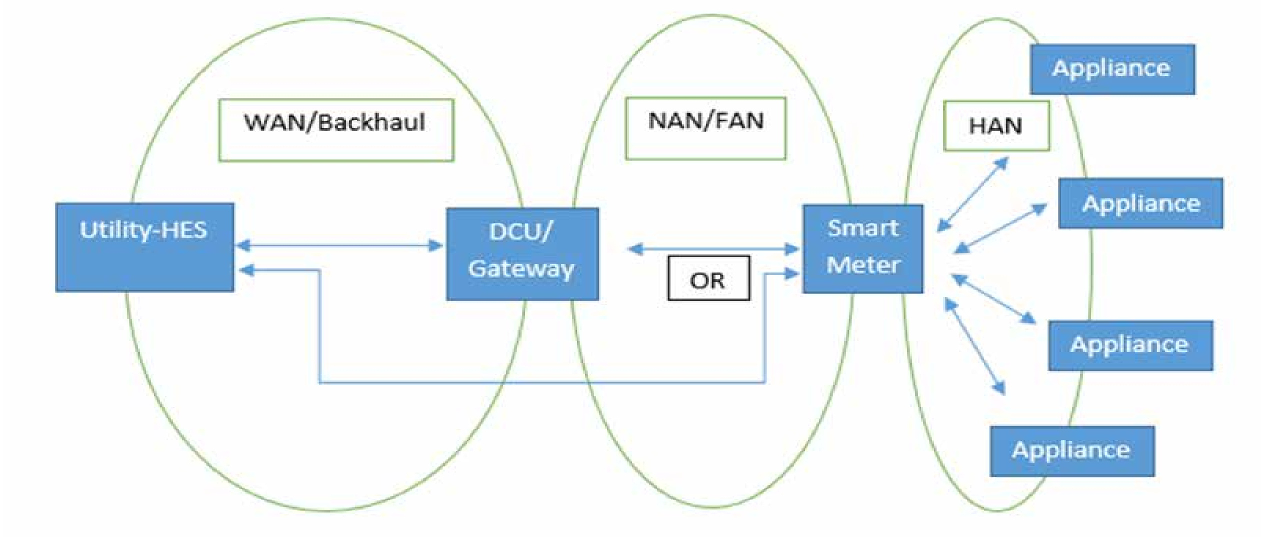

Figure 4-4: Typical Architecture of Advanced Metering Infrastructure

It is pertinent to mention the following:

- AMI can also be implemented without using a DCU. That is, the meters may directly communicate with the Utility-HES using any of the technologies that offer wide area connectivity
- DCU could also be replaced by any other gateways/routers

Utilities have millions of consumers and hence millions of meters to record the electricity usage. IPv6, with its ' virtually limitless' address space, can provide IP addresses to each and every energy meter and thus assists in making every meter reachable, accessible and controllable from a remote central location. The second aspect is security. Since security is an integral part of IPv6, enhanced protection can be implemented in an end-to-end network.

4.7.3 SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA)

Supervisory Control and Data Acquisition (SCADA) is a system for acquiring and analyzing information obtained from numerous devices placed on the electrical grid. In addition, various grid elements can be controlled using SCADA. Apart from measuring voltage, current, active power, reactive power, power factor, etc., SCADA enables acquiring the status of switches, protection relays and faults of Feeder Terminal Unit (FTU) as well. Flow detection and momentary voltage drop measurement can also be achieved. On the other hand, switches and relays can be controlled from the control center.

Typically, a Remote Terminal Unit (RTU) serves as an intermediate entity between the control center and Intelligent Electronic Devices (IEDs) on the grid. The communication requirements for SCADA are very stringent. These include (but are not limited to) extremely high availability, reliability and information security, along with very low latency. The SCADA system is used both, at the distribution level (SCADA/DMS) and at the transmission level (SCADA/EMS). SCADA/DMS is operated by the distribution companies (DISCOMS) for low voltage distribution lines. SCADA/EMS is operated by the transmission companies (TRANSCOS) for high voltage transmission lines. A typical architecture of SCADA/DMS and SCADA/EMS is depicted below:

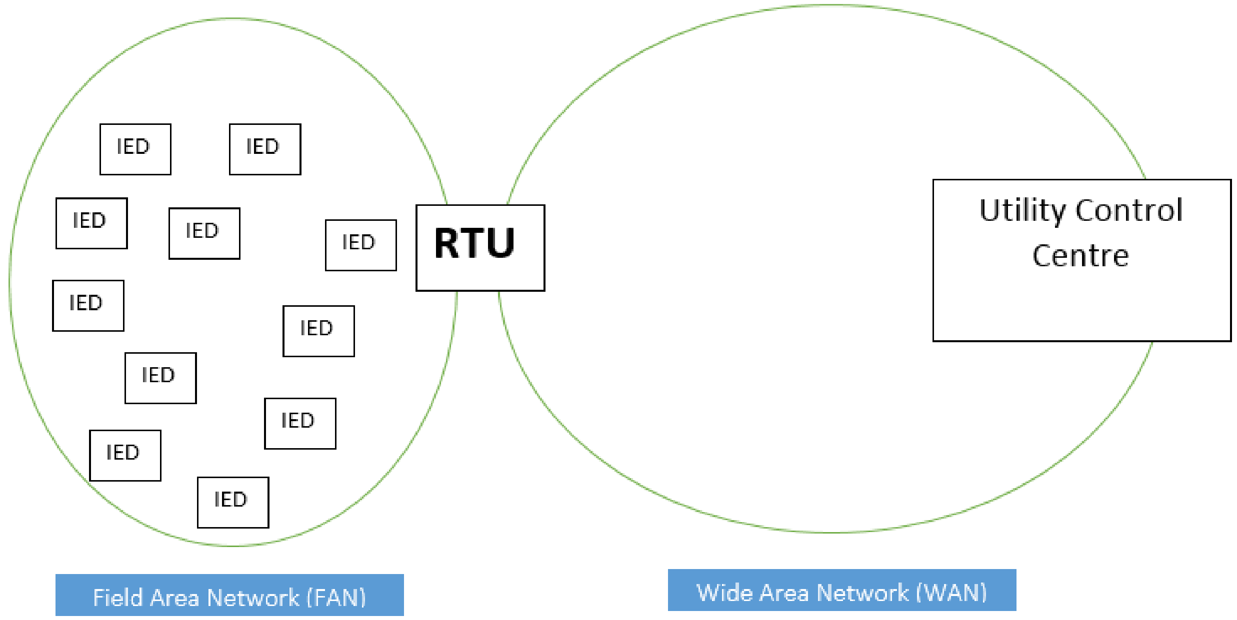

Figure 4-5: Typical Architecture of SCADA/DMS and SCADA/EMS

In India, SCADA/EMS has been implemented for all the state transmission grids and the 5 regional grids (now a single unified grid) for reliable and integrated operation. As a result, the number of grid failures have also reduced. As part of RAPDRP (Part A), all the state owned DISCOMS are implementing SCADA/DMS systems in large towns.

4.7.4 WIDE AREA MONITORING SYSTEM (WAMS)

Wide Area Monitoring System (WAMS) is used to obtain both, magnitude and phase of the voltages and currents using Phasor Measurement Units (PMUs). The reading is time synchronized using Global Positioning System (GPS). Real time situational awareness is achieved by using WAMS via voltage stability assessment, state estimation, oscillation detection and post-fault analysis.

A typical architecture of a Wide Area Monitoring System consists of Phasor Measurement Units (PMUs) that send the data to a Phasor Data Concentrator (PDC) in a substation which in turn, send the data to the utility control center.

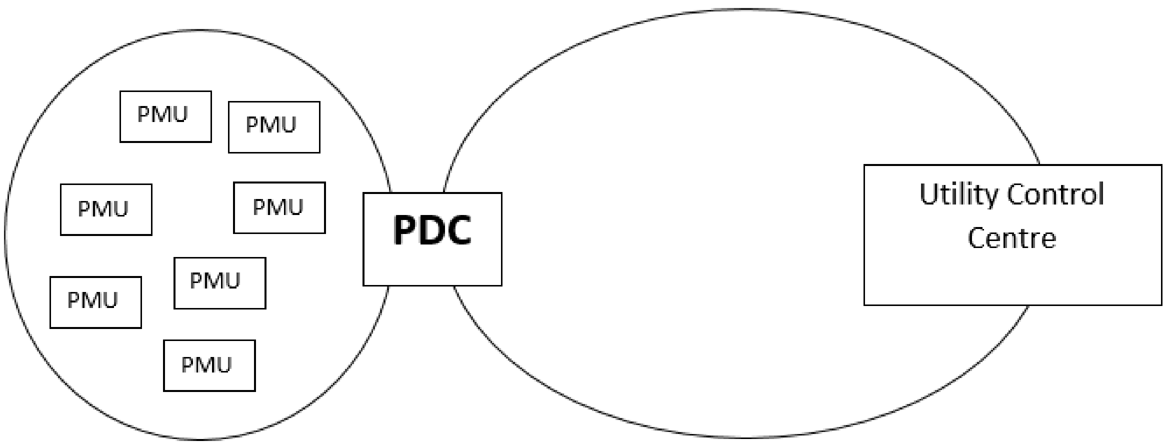

Figure 4-6: Typical Architecture of Wide Area Monitoring System

Power Grid Corporation of India Limited (POWERGRID) has already installed 34 PMUs and associated PDCs in NLDC, WRLDC, NRLDC and SLDC; and is in the process of commissioning 1700 Phasor Measurement Unites (PMUs) at various sub-stations, power plants and other strategic locations across the Indian power sector.

Recent studies have revealed possibilities of GPS spoofing attacks on the WAMS data. PMU use GPS time stamping for synchro-phasor data. One can use RF receiver-transmitter pair to spoof the PMU with false time stamping. Various schemes are being proposed to mitigate cyber attacks on WAMS system.

4.7.5 SUBSTATION AUTOMATION AND DISTRIBUTION AUTOMATION

Apart from transforming the voltage levels, modern substations include 'smart' devices for monitoring and controlling the operation of transformers, circuit breakers, protective relays, capacitor banks, switches, voltage regulators, static VAR compensators, etc. Substation automation and distribution automation, being critical for the functioning of a utility, impose stringent communications requirements of availability, reliability, latency and security.

Distribution automation involves employing automation elements at various places on the electricity grid such as Ring Main Units (RMUs), distribution transformers, reclosers etc. This centralized monitoring and control of the distribution networks improves the reliability and efficiency of the electrical network.

Currently in India, IEC 60870-5-104 communication protocol is widely used for substation automation. Very few utilities are using IEC 61850 because of the limited expertise in implementing this protocol.

4.7.6 DISTRIBUTED GENERATION

Distributed generation refers to the generation of electricity by using small scale technologies very close to the end user. Examples of distributed generation using renewables include solar, small hydro, wind, biogas and hydrogen energy. Non-renewable fuels such as diesel, natural gas and kerosene are also used for distributed generation of electricity. Distributed generation of electricity would not only reduce the demand supply gap, but would also enable consumers in becoming 'prosumers' wherein they would feed electricity into the grid and generate revenue.

Apart from communicating the amount of electricity generated in near real-time to a control center, M2M communications would be used for remote asset monitoring and controlling the amount of energy generation as per the needs of the utility.

The Government of India has set a target of generating 40 GW of power by deploying solar PV systems on 20 million rooftops by 2022.

4.7.7 ELECTRIC VEHICLES

India has launched the National Mission for Electric Mobility (NMEM) for expediting the adoption and manufacturing of electric and hybrid vehicles in India. To achieve this objective, a National Electric Mobility Mission Plan 2020 was released in 2012 which lays the vision and provides a roadmap for achieving significant penetration of these efficient and eco-friendly vehicles in India by 2020. It aims to transform India as a leader in the two-wheeler and four-wheeler market (encompassing electric and hybrid vehicles) with anticipated sales of around 6-7 million units by 2020.

M2M communications are vital for the functioning of the electric vehicle charging infrastructure because information regarding charging of the electric vehicle needs to be sent to the utility for billing purposes. Hence choosing a reliable and secure communications technology is a necessary requirement for the electric vehicle charging infrastructure.

4.7.8 ENERGY STORAGE

Renewable energy generation being intermittent and variable, requires energy storage technologies for viable operation. Storage facilities would not only store electricity during non-peak hours and provide power during outages, but also provide low cost ancillary services such as load following and spinning reserves.

M2M communications, both at the supply side and the demand side, would provide the necessary visibility in the grid by being able to monitor and control the amount of electricity storage in near real-time.

With India aiming to aggressively increase renewable generation capacity, lost cost and efficient energy storage technologies along with reliable M2M communications would provide another stimulus to achieve the envisaged targets.

4.7.9 MICROGRIDS

A microgrid is a local grid with an integrated energy system that intelligently manages the interconnected loads and distributed energy resources. The generation and distribution of power can be operated in island mode or grid connected mode.

Microgrids can customize the local energy demand curve for a particular area by integrating conventional power supply with locally installed distributed generation viz. solar, wind, biomass, waste to energy etc and the energy storage inside the microgrid.

For efficient operation of microgrids, reliable M2M communications is required. India envisages to promote thousands of off-grid microgrids to electrify remote villages and islands as well as implement grid-connected smart microgrids that can island from main grid when needed.

4.7.10 HOME ENERGY MANAGEMENT/BUILDING ENERGY MANAGEMENT

Smart homes would offer monitoring and control of the electricity usage within the consumer premises. Aggregators or energy management systems would form the core of home automation by providing a means to efficiently consume electricity. In addition to a smart meter that would remotely connect and disconnect the supply, smart appliances would provide the energy consumption data to the consumer and the utility. The consumer could view the consumption data via an In-Home Display (IHD) device or via SMS, e-mail or by logging on to a consumer portal. Loads could also be remotely controlled via the aggregators or energy management systems.

4.7.11 ENTERPRISE NETWORKS

In addition to the above mentioned use cases, communications will be used by a utility for establishing enterprise networks as well.

4.8 CYBER SECURITY

4.8.1 INTRODUCTION

Protection of the critical infrastructure (encompassing energy, transportation, banking and finance, communication and IT, defence, space, law enforcement, sensitive government organisations, critical manufacturing and e-governance) is the primary objective of any nation and the power sector assumes top priority. With this convergence of the electrical technologies, information technologies and operational technologies in a smart grid, security of industrial control systems has become extremely important. The security of the information infrastructure directly decides the reliability of the power system infrastructure. The key objectives of security in a smart grid include ensuring availability, confidentiality, integrity and accountability. These objectives are achieved by preventing denial of service (DoS), false data injection, spoofing and privilege escalation .

Before the advent of smart grids, security of industrial control systems was limited to prevention of online attacks. However, today's scenario mandates protection of critical cyber assets that include (but are not limited to) substations and control centres of the electricity Utilities (Generation, Transmission and Distribution), and load dispatch centres. Hence 'cyber- physical security' completely signifies the need of the hour.

Electric power grid are comprised of cyber assets, physical assets and human resources. In such a cyber-physical-human environment, failures may originate from cyber attacks, physical attacks or through disgruntled human resource. Attacks such as Aurora Vulnerability (2007), Stuxnet (2010) and Shamoon (2012) have shown vulnerability of the industrial control systems to cyber attacks and proving that they are neither resilient nor robust. It is the increased connectivity in a smart grid that has resulted in increased vulnerability. Also, the use of standard IT components and IP-based communications make the power system more prone to attacks. Recent cyber attacks on Ukrainian power grid (December 2015 & 2016) has demonstrated weakness of protocols used in substation automation against highly coordinated cyber attacks and involvement of nation-states. .

As compared to enterprise IT systems, industrial control systems result in a more severe impact affecting the safety, health, environment and the financial strength of a nation. Hence these systems must remain available for 99.9 to 99.999 % of the time. On the other hand, the enterprise IT systems remain reliable even if they are available for 95 to 99% of the time. This makes typical security options like patching vulnerability more difficult as one need to shut down the system during the process of patching. Sophisticated cryptography algorithms and encryption techniques are not available for power grid communication due to low processing power of remote terminal units (RTUs) and time critical nature of the operation. Furthermore, most industrial control systems last for a minimum of 15-20 years whereas enterprise IT systems need to be replaced every 3-5 years.

4.8.2 INITIATIVES BY GOVERNMENT OF INDIA

All Utilities in India have been mandated to appoint a Chief Information Security Officer (CISO) which would oversee the hardware and software inventory not just as book keeping exercise, but identify the ownership and operation after ensuring accountability within the organisation. While some Utilities have already appointed CISOs, other Utilities are following suit.

Identification of the cyber security posture of the organisation is something that Utilities need to do on a priority basis in order to plug the loopholes. In addition to a regular cyber security audit, performing a vulnerability, threat and risk analysis is extremely important. This is only possible if the Utility has a sound cyber security policy, which would act as yard-stick against which the audit will take place. Having a 'sectoral' regulator and 'sectoral' incident sharing would be highly beneficial for enforcing regulations and raising awareness amongst the 'sector'. For this, it is imperative to define and identify 'sectors' – as per region, Utility (Generation, Transmission or Distribution), energy domains (power, gas, water) or so. Insuring the Utility against cyber-physical attacks might just be the long term solution that is required for the protection of the industrial control systems.

In January 2014, the Government of India established the National Critical Information Infrastructure Protection Centre (NCIIPC) which is the nodal agency responsible for the facilitation, identification, prioritisation, assessment, remediation and protection of the critical information infrastructure. With a vision to facilitate a safe, secure and resilient information infrastructure for the critical sectors of the nation, NCIIPC faces the challenges of identifying critical information infrastructure and incoming/outgoing dependencies on other infrastructure, developing parameters and metrics, and performing retro-modification and gap analysis of these dependencies. In the power sector, NCIIPC is playing a key role in acting on the responsibilities it has envisaged. Setting up an incident reporting and sharing centre is of high priority as the organisation plans to provide tailored advisories to the Utilities. It has online help desks available for consultation in case of a threat or an attack. NCIIPC is participating in workshops and projects aimed towards providing training and spreading awareness in this field.

In India, the Bureau of Indian Standards (BIS) is the national standards body for promoting and nurturing standards movement. The BIS Standard, IS 16335 - Security Standard for Power Systems, has been published. It provides information for identification and protection of critical assets used in the generation, transmission, distribution and trading of electricity. Security management for personnel and assets, electronic and physical security of assets, incident reporting and response, recovery planning, and auditing and conformance procedures form integral aspects of this draft standard.

As part of the capacity building initiatives by India Smart Grid Forum (ISGF) and its associates, two workshops on cyber security for power systems have been conducted in 2014 for power system professionals. In the recently conducted workshop in Delhi, the faculty included experts from the Government, ISGF Member Organisations and leading R&D organisations in India. Over 40 delegates from Utilities (Generation, Transmission and Distribution), Industry, Academia and R&D organisations from India and overseas attended the workshop. The topics included Smart Grid Pilot Projects in India, Cyber Security for Critical Infrastructure, Threats and Attacks on Smart Grids, Cyber Security Framework for Smart Grids (Design and Implementation), Smart Grid Communications, Network and Information Security, Building Cyber Attack Resilience, Cyber Security Audit and Assessment, and ISGF-NCIIPC Cyber Security Assessment Project for the Indian Power sector. ISGF has conducted 6 workshops so far.

ISGF, in collaboration with NCIIPC, has completed a survey-based project, 'ISGF-NCIIPC Cyber Security Assessment Project' wherein Utilities (Generation, Transmission and Distribution) were surveyed. This was a unique research project to assess the cyber security readiness amongst the Indian Utilities. Obtaining realistic understanding of the cyber security challenges and raising awareness amongst the stakeholders were the key objectives of this project. The assessment was informal in nature as the intention was not to formally audit and certify for compliance but to benchmark for assessing cyber security preparedness. After the completion of the survey, the top 10 findings and recommendations was sent to the Ministry of Power for the benefit of all power utilities in India (which did not include individual findings). In addition, each organization taking part in the survey, was provided with their own copy of cyber security gap analysis report.

As an offshoot from this project, ISGF has recently prepared a manual on cyber security for power systems. This Manual on cyber security for power systems in India will provide actionable inputs to the stakeholders in the power sector. This Manual is applicable to the following stakeholders:

- Generation Companies
- Transmission Companies
- Distribution Companies
- Load Dispatch Centers
- Equipment Manufacturers
- IT Hardware and Software OEMs
- System Integrators
- Service Providers (including communication system providers and agencies implementing microgrids)

Mandatory Requirements have been defined in this Manual and grouped into the following controls: Organisation, System Protection, Information Protection, Audits, Assessments, Certification and Testing, Personnel and Training, Physical Security and Operations.

Besides this, ISGF has formulated a 2-semester program on Cyber Security for Power Systems for M. Tech. students which will be offered by many universities.

4.8.3 BUILDING RESILIENCE IN A UTILITY'S CYBER SPACE

Let us learn some of the key steps to build cyber resilience in a utility. The first step is to appoint a Chief Information Security Officer (CISO). Utilities should appoint a CISO from the Senior Management. The officer may not be an expert, but should understand the importance of cyber security and implications of not having comprehensive cyber security controls. The second step is to formulate an Information Security Policy. Sub-policies and procedures specific to key operational areas should also be prepared. The organisations need to establish a formal mechanism in which all stakeholders (Employees, contractors, sub-contractors and so on) are required to read and acknowledge the relevant portions of the policies. The third step is to audit and asses cyber security readiness of the utility. This includes identifying and notifying Critical Information Infrastructure and subsequently identifying incoming and outgoing dependencies. Identification of Critical Information Infrastructure should not be done as a book keeping exercise but for identifying ownership and streamlining operations. The process for obtaining approval for notifying Critical Information Infrastructure needs to be initiated. Regular internal and external audit for the cyber security must be conducted.

The auditors must be changed on a regular basis... In addition, penetration testing and red team testing may be undertaken regularly. The fourth step is to undertake VTR assessment atleast for Critical Information Infrastructure. After conducting VTR analysis, utilities must apply and/or update the security controls and assess the security posture again. The fifth step is to assess the risk. This includes residual risk calculation and mapping to financial risk. Risk assessment and mitigation processes should be established and/or reviewed regularly. In order to understand the magnitude of the problem by the Senior Management, it is essential to formulate a mechanism for evaluating and approving residual Information Security risk in a manner similar to the existing Financial or Operational risk. It is important to mention that the Information Security risk should be owned by the utility. If the utility is outsourcing the operations, the responsibility of securing the cyber space lies with the utility itself. In addition, the business continuity plan needs to be appropriately regulated. People are usually the weakest link in the security chain. Manipulating people's behaviour is the easiest and the least-expensive vector for attackers to exploit. Thus, it is important to conduct background checks of employees and have a well defined HR policy. The next step is to have an incident reporting procedure or plan. This includes definition of an incident and incident management drills.

Inspite of all the preventive measures, the attacker will always have the upper hand because the attacker needs to be lucky only once, whereas the utility has to make sure that it prevents all cyber incidents. Hence, it is extremely important to have an incident reporting plan that will not only define a cyber incident, but also specify responsibilities and steps to be taken in case of an incident. The next step is to undertake automated monitoring of inbound and outbound communications. It is required to observe unusual or unauthorised activities. Automated mechanism should be implemented for monitoring inbound and outbound traffic because it provides effective monitoring. Also, deployment of automatic intrusion prevention systems and intrusion detection systems is a must. It is also recommended to maintain documentation of the monitoring process. Lastly, it would be beneficial to deploy data diodes to ensure unidirectional flow of information.

The next step is to dispose Critical Digital Assets (CDA) in the right way. Policies for disposal of Critical Digital Assets must be formulated to ensure no data is inadvertently being leaked outside the organisation. Physical destruction of CDA may be considered as a part of organisation's disposal process. It is extremely important to define procedures and guidelines for use of smartphones and portable media such as USB drives, internet dongles, etc. because they are among the foremost source of malware infection and system compromise. They may also adopt the procedure for blocking unauthorised removable media such as USB drives on systems by using Vendor Identification or Product Identification methods. The next step is to have a Service Level Agreement (SLA) for Information security while dealing with outside agencies. This will force the other organisations to consider security with the service they are providing. It is very important to consider system hardening while procurement of hardware and software. It will help in making the utility's system secure by design. Before procuring any software, firmware or hardware, the utility must investigate about the product's cyber security-related aspects.

The selected products must then be tested, both individually and within the utility's overall environment, to assess the product's effectiveness. The next step is to ensure physical security of critical utility sites. For a utility, ensuring physical security is as important as cyber security. High-delay-time fencing products, vehicle barriers, retractable bollards, crash-rated gates and sally ports, video surveillance, intrusion detection systems and advanced motion analytics around the entire perimeter should be common elements at critical utility sites. Utilities must also use biometric readers and access control badges for more stringent control of unauthorised physical access prevention and detection. The next step is to have a robust IT architecture for the utility. The enterprise IT systems and industrial control systems should be physically or logically isolated. The PLCs and RTUs should not be connected to public networks such as the internet. This eliminates majority of the threats. Even responsibilities should be segregated and Role Based Access Control (RBAC) should to be implemented. RBAC is an approach that restricts access to systems to only authorised users irrespective of age, seniority, department, etc. It is advisable to segregate the utility's cyber space into zones such as external zone, corporate zone, manufacturing zone, cell zone, safety zone and so on. In this way, a defence in depth architecture is created and the attacker has to break through all the perimeters in order to attack the industrial control systems. Subsequently, it is very important to apply perimeter protection for each zone. Hence, dual corporate firewalls, dual control system firewalls, dual control system LAN firewall, field level firewalls, etc., should be common elements in the utility's network. This will make it difficult for an attacker to breach the system.

Dual firewalls are 2 firewalls used instead of one. So for data packets to pass, conditions in both firewalls must be favourable. This adds robustness to the system. It is extremely important to create a De-Militarised Zone (DMZ) which is a network that separates the internal LAN from other untrusted networks. Typically, external-facing servers, resources and services are located in the DMZ so they are accessible from the Internet but the rest of the internal LAN remains unreachable. This provides an additional level of security to the LAN as it prevents the attackers from directly accessing internal servers and data via the internet. Any service that is being provided to the users is typically placed in the DMZ. Examples include mail, web, FTP, VoIP and so on. The next step is to have separate budgetary allocation for cyber security. It should not be the case that the IT department allocates money for cyber security. Budgetary allocation for cyber security should be done in addition to what is allocated to the IT department.

It is very important to assess the cyber security readiness and the security posture regularly. Apart from cyber security audits, it is very important to conduct cyber security readiness assessments at least once a year. This will not only tell you where you stand, but it will also help you set the milestones for future deployments. The next step is to undertake security awareness trainings and capacity building exercises regularly. Effectiveness of security awareness training needs to be reviewed regularly. Practical exercises may be included in the security awareness training that simulates actual cyber attacks.

4.8.4 CASE STUDY OF STUXNET

Stuxnet is a sophisticated, complex piece of malware with many different components and functionalities. It is considered the first true cyber weapon used to infect any industrial control system. The effects that it caused cannot be compared to any other attack till date. Reports suggest that this malware was targeted towards the Uranium enrichment nuclear program of Iran. The code was 1Mb long and was twenty times larger than most other malware. Industrial control systems (ICS) are operated by a specialized code on programmable logic controllers (PLCs). The PLCs are often programmed from Windows computers not connected to the Internet or even the internal network. In addition, the industrial control systems themselves are also unlikely to be connected to the Internet. ICS usually consider availability and ease of maintenance first and security last. ICS usually consider the “airgap” as sufficient security because they are not connected to the Internet. In case of Stuxnet, first, the attackers needed to conduct reconnaissance. As each PLC is configured in a unique manner, the attackers needed schematics of the ICS. These design documents may have been stolen by an insider or even retrieved by an early version of Stuxnet or other malicious binary. It is believed that Stuxnet 0.5 was out much earlier before it was first detected. Once attackers had the design documents and potential knowledge of the computing environment, they would develop a more advanced version of Stuxnet. Each feature of Stuxnet was implemented for a specific reason and for the final goal of potentially sabotaging the ICS.

We shall now discuss the attack in a snap shot. Stuxnet entered a system via a USB drive and infected all machines running Microsoft windows. By stealing two digital certificates, the worm was able to evade automated-detection systems. Stuxnet then checked whether a given machine was part of the target industrial control system made by Siemens. Such systems are deployed in Iran to run high-speed centrifuges for enriching nuclear fuel. If the system wasn’t a target, Stuxnet did nothing; if it was the target, the worm attempted to access the internet to download a more recent version of itself. The worm then compromised the target system’s programmable logic controllers, and exploited “zero day” vulnerabilities that are weaknesses that are not identified by security experts at that time. In the beginning, Stuxnet spied on the operations of the targeted system. Then it used the information it gathered to take control of the centrifuges, making them spin to failure. Meanwhile, it provided false feedback to outside controllers, ensuring that they won’t know what was going wrong until it was too late to do anything about it.

4.8.5 CASE STUDY OF UKRAINIAN POWER GRID CYBER ATTACK

The cyber-attack on three power companies in Ukraine on 23 December, 2015 was an eye opener for power grid industry. STUXNET was mainly confined to industrial control system (ICS) infection. It has not touched traditional silos of generation, transmission and distribution aspects of power grid. However, Ukrainian power grid attack was the first known instance where a cyber attack had actually infected distribution substation automation protocols and devices rendering large demography without electricity. The coordinated cyber attack disconnected substations from the grid leaving more than 225,000 customers without access to electricity for more than 6 hours.

The CRASHOVERRIDE malware used in the cyber attack was a modular framework consisting of an initial backdoor, a loader module and several supporting and payload modules including modules for IEC 104, IEC 61850 and OPC. The severity of the attack was increased by data wiper modules of the malware. It cleared all registry keys associated with system services and overwrites all ICS configuration files across hard drives specifically targeting ABB PCM600 configuration files used in substation automation. Once executed, the data wiper module clears registry keys, erase files and kill processes running on the system thereby rendering the system unsuable and making restoration of normalcy difficult.

Both, STUXNET and Ukrainian power grid, cyber attacks have changed perspective of security experts and grid operators towards vulnerability of power grid. Grid operators and utilities have started taking security of power grid more seriously by preparing incident response plans for such attacks. Resilient grid has become key word with efforts to systematic and robust backups of engineering files such as PLC logic, project files, IED/RTU configuration files and installers for ICS devices and protocol gateways. It has busted myth of airgap between operational technology (OT) and enterprise IT network zones. It is also clear that the energy sector is not isolated from generic cyber attacks like ransomware that locks computing machines with vital information and unlocks it only after hefty amount is paid in return.

In conclusion, greater degree of digitization, bi-directional information flow and interconnectedness in the power system results in better situational awareness, grid monitoring and reliable and quality delivery of electricity. However, it also results in grid vulnerability against any cyber attacks. Utilities, grid operators and regulators needs to take proactive measures to address current and potential cybersecurity issues.

India Smart Grid Forum

MODULE 5

ARCHITECTURE, INTEROPERABILITY AND STANDARDS

Abstract

This module describes Architecture, Interoperability and Standards for smart grids. The module starts with the National Institute of Standards and Technology (NIST), USA smart grid conceptual model which is followed by a detailed discussion on the Smart Grid Architecture Model (SGAM). The Smart Grid Architecture Model (SGAM) is an outcome of the EU Mandate M/490's Reference Architecture working group. Interoperability, a key requirement of smart grid, is then discussed. The module concludes with a discussion on standards including the Indian scenario of standards for smart grids.

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5 ARCHITECTURE, INTEROPERABILITY AND STANDARDS

5.0 INTRODUCTION

The envisioning, planning, designing and deployment of Smart Grids can be a very complex exercise. The quickly evolving standards landscape, existing legacy systems at utilities, the plethora of architecture options, challenges in integration etc., are few of the main challenges faced by the utilities in the Smart Grid era. Hence, a means to communicate a common view and language about a system context to utilities, regulators, industry and customers is vital to ensure a better understanding throughout the life cycle of modernization. Also, there can be several approaches towards integration and hence alternate implementations of architectures is also possible. Well defined methods to help the utility transition from current state to future state leveraging standards based interoperability are key to a successful Smart Grid. All of this is even more critical in the era of increasing penetration of distributed energy resources (DER's) in the grid. The current grid in many parts of the world are still a classic traditional grid where power flows from the generation sink to the consumption sink. However, the introduction of the distributed energy resources (DER's) is changing that paradigm to multiple generation sinks located across the entire grid and closer to the consumption sinks.

A Smart Grid vision is achieved by bringing together enabling technologies, changes to business processes, and a holistic view of the end-to-end requirements of grid operation. This can be called a Smart Grid Enabling stack. This morphed over time into a SGAM (Smart Grid Architecture Model) framework. This is further explained in this module.

However, a SGAM alone is not sufficient. The evolution of Smart Grids from pilot projects and limited scope deployments with minimal impact to existing operations and systems to large scale initiative, implies impact to multiple utility systems and processes spanning over customer services, system operations, planning, engineering and field operations, and adjacencies. This co-ordination between all the systems in the context of people, process and technologies cannot be accomplished without seamless integration leveraging standards based interoperability. Systems interoperability, information and data management are therefore among the key elements of a successful Smart Grid implementation. Any intelligent automated operation will require data-driven actions which will not only require timely and accurate data but more effective coordination, orchestration and synchronization across the layers of the SGAM model in all dimensions. Standards therefore are vital guidepost that enables the glue (integration) to maintain interoperability between the systems, processes and across the enterprise.

The daunting need to represent the Smart Grid domain in a coherent yet abstract manner with all the major stakeholders. The NIST conceptual model [NIST 2009] was considered as the first essential input though some regions modified it to adapt to other regional contexts. The NIST model is described in this module.

It is not enough to just represent the Smart Grid domain in a coherent and abstract manner. It has to be used to define an architectural framework that would support a variety of different approaches corresponding to different stakeholders requirements and make it in a timeframe or shapshot. This would require several architecture viewpoints to be developed and put together into a reference architecture over the entire system lifecycle. This means that, on a complex system like the Smart Grid, it is not always possible to cover all viewpoints and choices had to be made. Hence, the essential and the most relevant ones have to be chosen and documented using the rationales, limitations and implications.

Lastly, the model has to be accompanied with a methodology that will allow the users of the architectural model to apply it to a large variety of use-cases that would form the bedrock of the implementations, which will be unique at every utility.

This module includes a description of the NIST conceptual model, the SGAM, the Interoperability framework and covers mapping tools developed by IEC.

Deploying a smart grid can be a daunting task considering the existing legacy infrastructure at most utilities. In this module, the important role being played by standards is highlighted. However standards themselves are not enough, as where and how they are used is a matter of choice which the utility has to make. In such a scenario, the architecture and interoperability aspects of the smart grids becomes important. These terms have several interpretations and often confusing. Architecture refers to the modular structure of the components that build the smart grids. Modularity is the degree to which a system's components may be separated and recombined [1]. Thus having a highly modular structure will bring in flexibility in the smart grid design. Different components can be independently developed by multiple competing vendors there by decreasing cost and increasing efficiency. The flip side, to having a high degree of modularity is that one has to define the overall architecture as to what the modules are and how they are interacting. For example, an advanced distribution management system would have modules, such as (i) network operations, (ii) asset management, (iii) geographical information system, and (iv) outage management system etc. In the following section several smart grid architectural frameworks will be discussed. Ensuring interoperability bewteen these modules is the next challenge. The interfaces for these modules can be physical (hardware) or logical (software). In the following sections a framework for defining interoperability will be presented. The next challenge is to actually implement these interfaces and modules down to the technical specifications level. This is where standards will play a role. The interdependency between architecture, interoperability and standards is depicted in the figure 1 below.

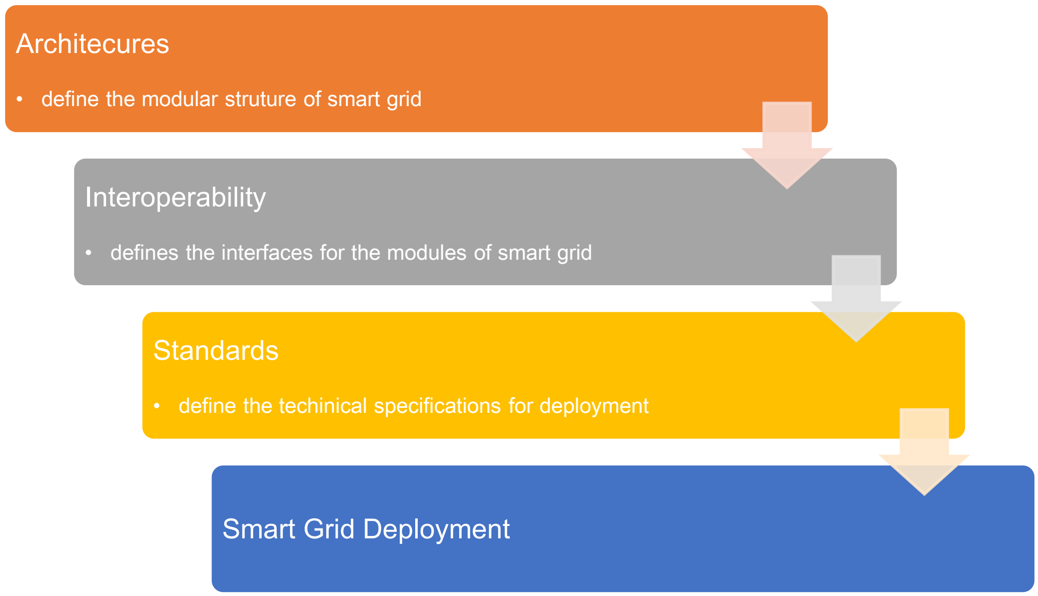

Figure 5-1: Interdependency between Architectures, Interoperability and Standards

5.1 ARCHITECTURES FOR SMART GRIDS

Architecture comprises of fundamental concepts in its environment embodied in its elements, relationships, and based on the principles of its design and evolution.

Smart grid is not a specific technology or a product, rather it is an ecosystem of various products, systems connected across the physical, communication and information technologies. Under such a scenario, developing an architecture for the smart grid will be a crucial step. Several model architectures have been proposed, and in this module, some of the key smart grid architectures will be discussed.

5.1.1 NIST SMART GRID CONCEPTUAL MODEL

The Smart Grid is a complex system of systems for which a common understanding of its major building blocks and how they interrelate must be broadly shared. NIST has developed a conceptual architectural reference model to facilitate this shared view. This model provides a means to analyze use cases, identify interfaces for which interoperability standards are needed, and to facilitate development of a cyber security strategy. [NIST2009].

NIST also came out with a Smart Grid Reference architecture. A Reference Architecture describes the structure of a system with its element types and their structures, as well as their interaction types, among each other and with their environment. Describing this, a Reference Architecture defines restrictions for an instantiation (concrete architecture). Through abstraction from individual details, a Reference Architecture is universally valid within a specific domain. Further architectures with the same functional requirements can be constructed based on the reference architecture. Along with reference architectures comes a recommendation, based on experiences from existing developments as well as from a wide acceptance and recognition by its users or per definition. [ISO/IEC42010].

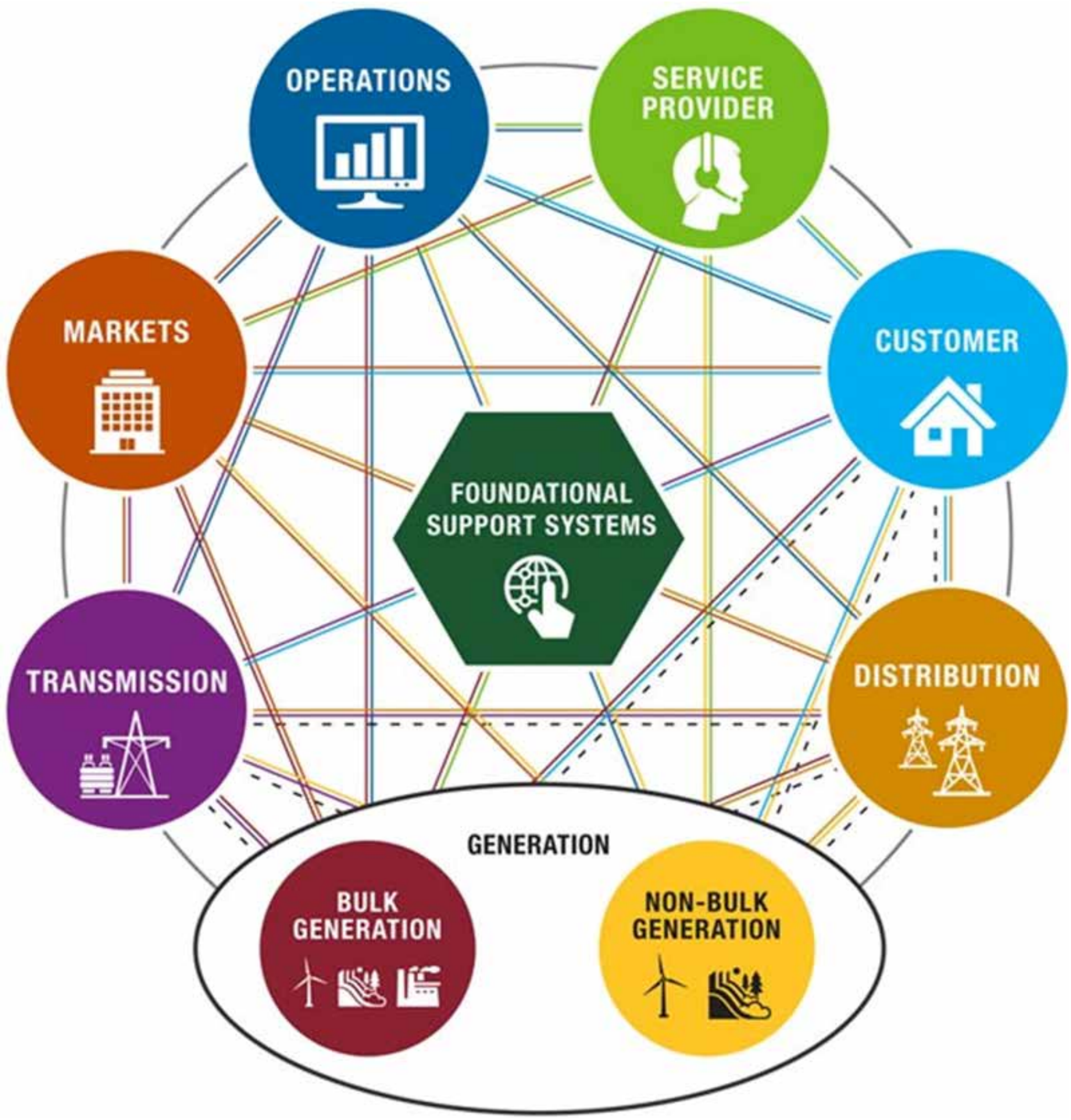

Figure 5-2: NIST and IEEE Smart Grid Domains.

Source: IEEE Smart Grid Domains and Sub-Domains, http://smartgrid.ieee.org/resources/73-domains

To integrate the —Distributed Energy Resources (DER) into the NIST Model, it has been extended by a new —Distributed Energy Resources Domain, which is (in terms of electricity and communications) connected with the other NIST Domains shown in Figure 5-2.

The extension of the NIST Model with a new DER Domain is necessary for the following reasons: Distributed Energy Resources require a new class of use cases In order to comply to future anticipated regulation and legislation explicit distinction of Distributed Energy Resources will be required Distributed Energy Resources represent the current situation A consistent model requires clear criteria to separate the new DER Domain from the existing Domains, especially from Bulk Generation and the Customer Domain. Initial criteria are used. Separation criteria for the DER-Domain.

- Control - The generation units in the Customer Domain can not be remote controlled by an operator. The generation units in the DER and Bulk Generation Domain are under control of an operator, (approximately comparably with the controllability of bulk generation units today).

- Connection point - The generation units in the bulk generation domain are predominantly connected to the high voltage level. The generation units in the DER Domain are predominantly connected to the medium voltage level (in some cases also to the low voltage level) and the generation units in the customer domain to the low voltage level.

5.1.2 STRUCTURE OF SGAM FRAMEWORK

An architectural framework is defined as comprising of conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders [ISO/IEC42010].

The SGAM framework is established by merging the concept of the interoperability layers with the smart grid planes. This merge results in a model (depicted in below figure) which spans three dimensions:

Domain

One dimension of the Smart Grid Plane covers the complete electrical energy conversion chain, partitioned into 5 domains: Bulk Generation, Transmission, Distribution, DER and Customers Premises.

Interoperability (Layer)

Interoperability is seen as the key enabler of smart grid. Consequently the proposed SGAM framework needs to inherently address interoperability. For the understanding on interoperability in the context of smart grid and architectural models, a definition and requirements for achieving interoperability are given.

In order to allow a clear presentation and simple handling of the architecture model, the interoperability categories described in the GridWise Architecture model are aggregated in SGAM into five abstract interoperability layers: Business, Function, Information, Communication and Component

Zone

One dimension of the Smart Grid Plane represents the hierarchical levels of power system management, partitioned into 6 zones: Process, Field, Station, Operation, Enterprise and Market [IEC62357-2011].

Smart Grid Planes

The Smart Grid Plane is defined from the application to the Smart Grid Conceptual Model of the principle of separating the Electrical Process viewpoint (partitioning into the physical domains of the electrical energy conversion chain) and the Information Management viewpoint (partitioning into the hierarchical zones (or levels) for the management of the electrical process. [IEC623572011, IEC 62264-2003]

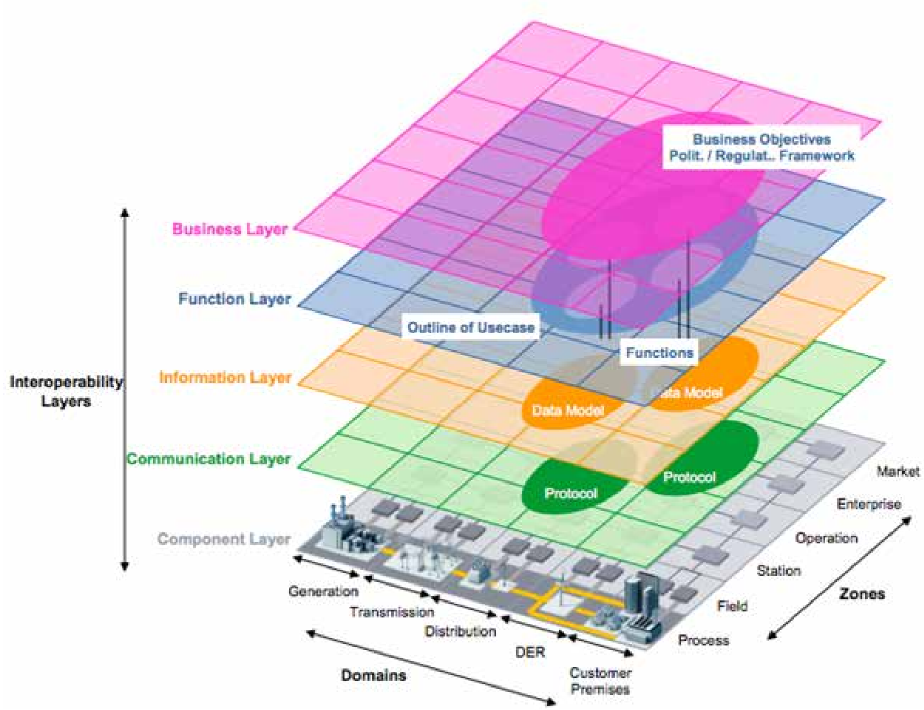

Figure 5-3: SGAM Framework

The SGAM framework and its methodology are intended to present the design of smart grid use cases in an architectural viewpoint allowing it both- specific but also neutral regarding solution and technology. In accordance to the present scope of the M/490 program, the SGAM framework allows the validation of smart grid use cases and their support by standards.

The SGAM framework consists of five layers representing business objectives and processes, functions, information exchange and models, communication protocols and components. These five layers represent an abstract and condensed version of the interoperability categories. Each layer covers the smart grid plane, which is spanned by electrical domains and information management zones. The intention of this model is to represent on which zones of information management interactions between domains take place. It allows the presentation of the current state of implementations in the electrical grid, but furthermore to depict the evolution to future smart grid scenarios by supporting the principles universality, localization, consistency, flexibility and interoperability.

The SGAM framework uses the five interoperability layers and represents the entities and their relationships in context of smart grid domains, information management hierarchies and interoperability aspects.

I. WHAT CAN SGAM BE USED FOR ?

SGAM can be used for the following key purposes:

- Compare different architectures
- Coordinate work between different TCs and stakeholders
- Identify gaps in SG standardization
- Map use cases

- Design architectures
- Develop interface specifications
- Map portfolio
- Map customers and competitors
- Identify new applications, services
- Analyze installed architectures and migration scenarios
- Map own R&D effort; Investigate core competencies
- Investigate business models, overlap of own offerings

SGAM also supports detailed views and is primarily leverages a use-case driven approach which can be very purposeful for the organization. No two organizations or utilities are alike the use cases will drive the overall model.

II. SMART GRID ARCHITECTURE MODEL (SGAM) INTEROPERABILITY LAYERS

In order to allow a clear presentation and simple handling of the architecture model, the interoperability categories described in the GWAC stack are aggregated into five abstract interoperability layers.

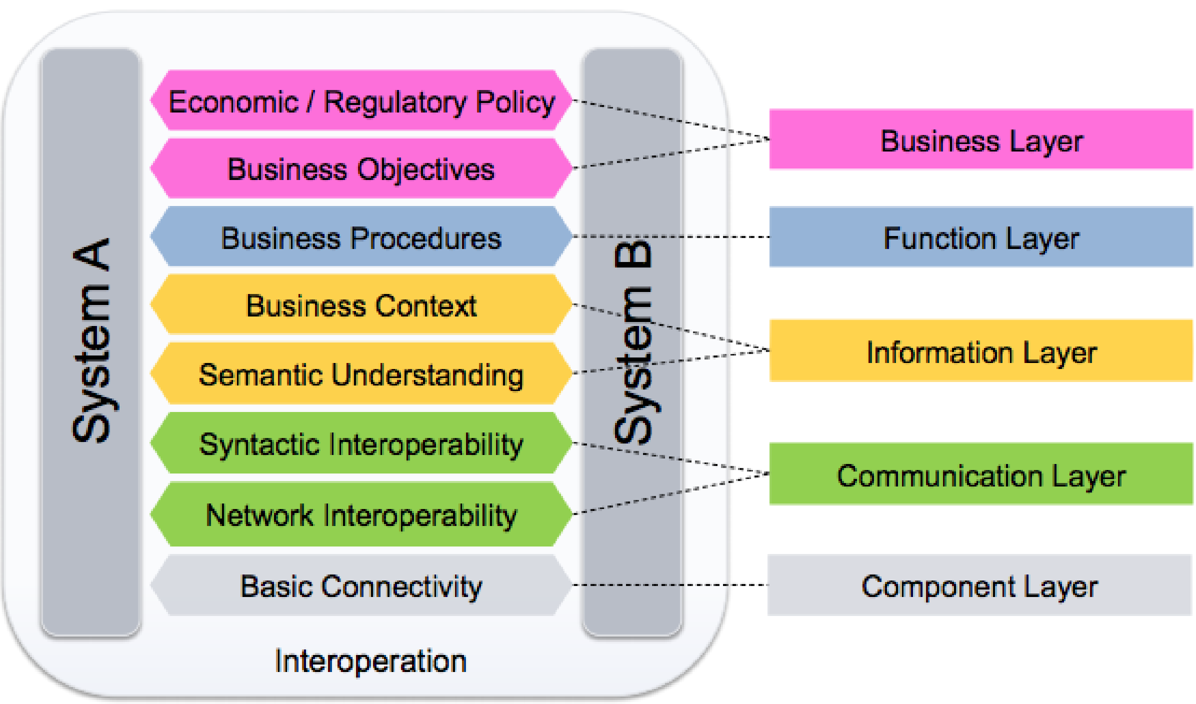

Figure 5-4: Grouping of GWAC stack into interoperability layers

III. BUSINESS LAYER

The business layer represents the business view on the information exchange related to smart grids. SGAM can be used to map regulatory and economic (market) structures and policies, business models, business portfolios (products & services) of market parties involved. Also business capabilities and business processes can be represented in this layer. In this way it supports business executives in decision making related to (new) business models and specific business projects (business case) as well as regulators in defining new market models.

IV. FUNCTION LAYER

The function layer describes functions and services including their relationships from an architectural viewpoint. The functions are represented independent from actors and physical implementations in applications, systems and components. The functions are derived by extracting the use case functionality which is independent from actors.

V. INFORMATION LAYER

The information layer describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models. These information objects and canonical data models represent the common semantics for functions and services in order to allow an interoperable information exchange via communication means.

VI. COMMUNICATION LAYER

The emphasis of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function or service and related information objects or data models.

VII. COMPONENT LAYER

The emphasis of the component layer is the physical distribution of all participating components in the smart grid context. This includes system actors, applications, power system equipment (typically located at process and field level), protection and tele-control devices, network infrastructure (wired / wireless communication connections, routers, switches, servers) and any kind of computers.

VIII. SGAM DOMAINS

The smart grid plane covers the complete electrical energy conversion chain. This includes the domains listed in the below table.

Table 5-1: SGAM Domains

Domain	Description
Bulk Generation	Representing generation of electrical energy in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plant (i.e. PV, CSP)– typically connected to the transmission system
Transmission	Representing the infrastructure and organization which transports electricity over long distances
Distribution	Representing the infrastructure and organization which distributes electricity to customers
DER	Representing distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3 kW to 10.000 kW). These distributed electrical resources may be directly controlled by DSO
Customer Premises	Hosting both - end users of electricity, also producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plants, airports, harbors, shopping centers, homes). Also generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines… are hosted

IX. SGAM ZONES

The SGAM zones represent the hierarchical levels of power system management [IEC 62357]. These zones reflect a hierarchical model which considers the concept of aggregation and functional separation in power system management.

The concept of aggregation considers multiple aspects in power system management:

- Data aggregation – data from the field zone is usually aggregated or concentrated in the station zone in order to reduce the amount of data to be communicated and processed in the operation zone
- Spatial aggregation – from distinct location to wider area (e.g. HV/MV power system equipment is usually arranged in bays, several bays form a substation; multiple DER form a plant station, DER meters in customer premises are aggregated by concentrators for a neighborhood) In addition to aggregation, the partitioning in zones follows the concept of functional separation. Different functions are assigned to specific zones. The reason for this assignment is typically the specific nature of functions, but also considering user philosophies. Real-time functions are typically in the field and station zone (metering, protection, phasor-measurement, automation etc.). Functions which cover an area, multiple substations or plants, city districts are usually located in operation zone (e.g. wide area monitoring, generation scheduling, load management, balancing, area power system supervision and control, meter data management etc.). The SGAM zones are described in the below table.

Table 5-2: SGAM Zones

Zone	Description
Process	Including the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind …) and the physical equipment directly involved. (e.g. generators, transformers, circuit breakers, overhead lines, cables, electrical loads any kind of sensors and actuators which are part or directly connected to the process,…).
Field	Including equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controller, any kind of intelligent electronic devices which acquire and use process data from the power system.
Station	Representing the areal aggregation level for field level, e.g. for data concentration, functional aggregation, substation automation, local SCADA systems, plant supervision…
Operation	Hosting power system control operation in the respective domain, e.g. distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems.
Enterprise	Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders …), e.g. asset management, logistics, work force management, staff training, customer relation management, billing and procurement…
Market	Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market..

Organizations can have actors in several domains and zones. In the smart grid plane, the areas of the activity of these actors can be shown. E.g. according to the business area of a transmission utility it is likely that the utility covers all segments of the transmission domain, from process to market. A service provider offering weather forecast information for distribution system operators and DER operators could be located to the market zone interacting with the operation zone in the distribution and DER domain.

5.2 INTEROPERABILITY FOR SMART GRIDS

In order to allow a clear presentation and simple handling of the architecture model, the interoperability categories described in the GridWise Architecture model are aggregated in SGAM into five abstract interoperability layers: Business, Function, Information, Communication and Component.

It is very important to understand that it is advisable to implement system-level interoperability and not device-level interoperability which allows changing of end-devices while ensuring they (end-devices) interoperate immediately. In case of smart metering or AMI, India has opted for system-level interoperability wherein, it has defined a data exchange protocol and data can be transported from and to the smart meter using any communication protocol. In case a utility wants to implement device-level interoperability in AMI, it has to choose a particular communications technology that will be integrated by all meter manufacturers.

5.2.1 SMART GRID INTEROPERABILITY FRAMEWORK BY GRIDWISE

The interoperability categories introduced by the GridWise Architecture Council [GWAC2008] represent a widely accepted methodology to describe requirements to achieve interoperability between systems or components

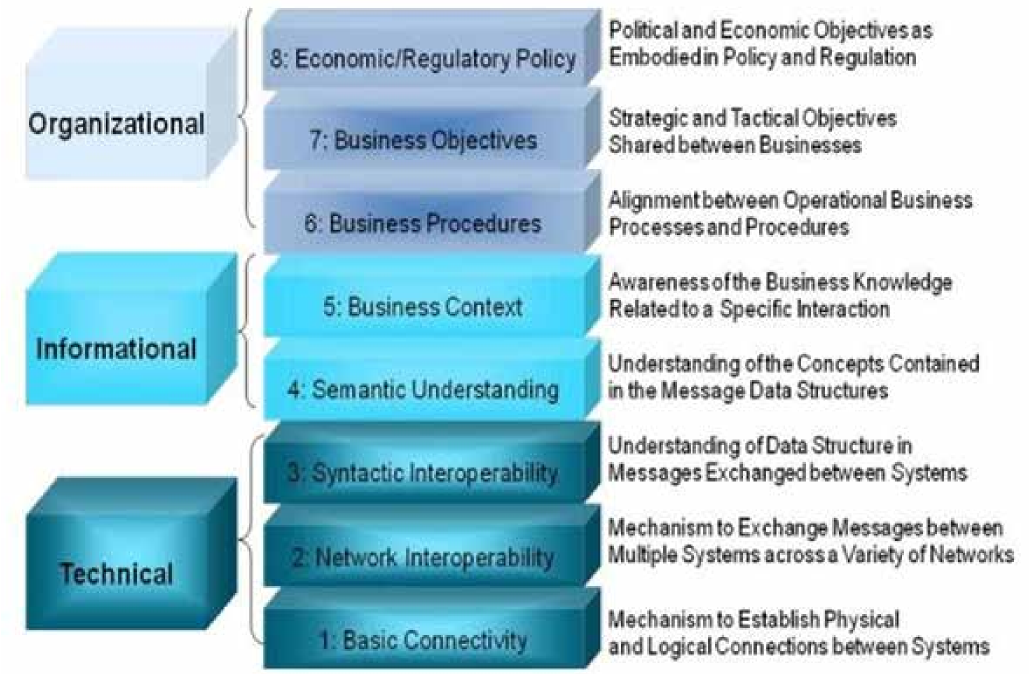

Figure 5-5 A: Interoperability Categories defined by GWAC [GWAC2008]

The individual categories are divided among the three drivers —Technical, Informational and Organizational. These interoperability categories underline the definition of interoperability. Hence for the realization of an interoperable function, all categories have to be covered, by means of standards or specifications.

To encourage communication and the development of a smart grid interoperability community, the GridWise Architecture Council (GWAC) has created an Interoperability Context-Setting Framework. This conceptual model has been helpful to explain the importance of organizational alignment in a utility in addition to technical and informational interface specifications for smart grid devices and systems.

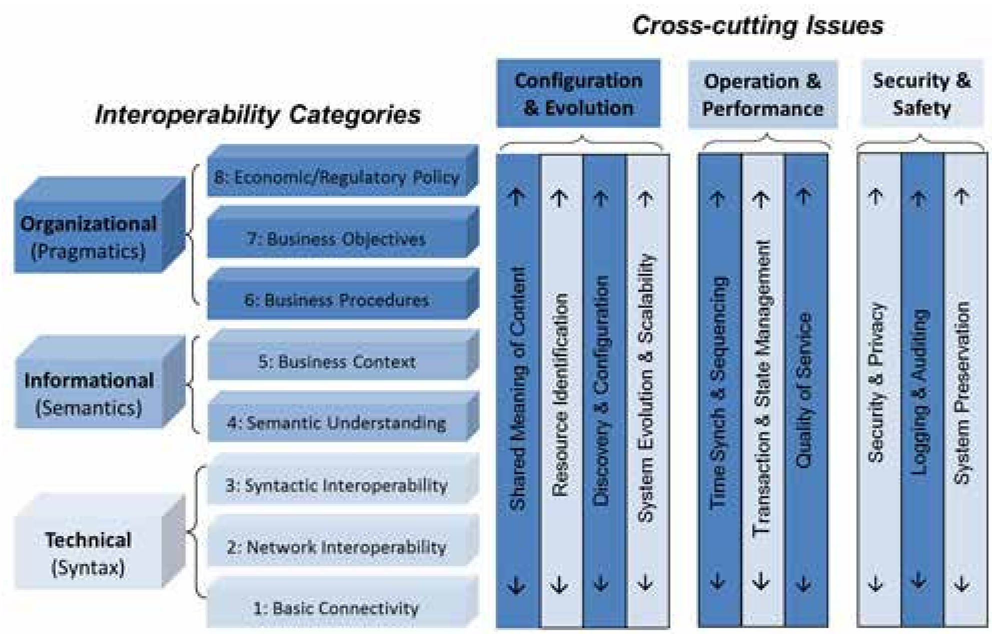

Figure 5-5 B: Interoperability context setting framework

Cross-cutting issues are topics which need to be considered and agreed on when achieving interoperability [GWAC 2008]. These topics may affect several or all categories to some extent. Typical cross-cutting issues are cyber security, engineering, configuration, energy efficiency, performance and others.

5.3 STANDARDS FOR SMART GRIDS

Smart grid represents the end-to-end integration of bulk generation, T&D, distributed generation, and customer systems overlaid with sensors and connected with multiple information and communication systems. Smart grid is expected to use digital information, automation, communication, and a high level of system integration to modernize the electric grid.

All these pieces need to be able to communicate with one another. If all hardware and information systems were supplied by a single vendor, there would be a very high probability that all of the pieces would connect and exchange whatever information they need to work properly. In a scenario that includes multiple suppliers that want to provide equipment or information systems, there has to be some sort of standard or interface that enables the systems to work together. Generally, standards are developed through the iterations that lead to a dominant vendor or technology that defines a de facto standard (e.g. DVD and BlueRay). If there was a single provider or a de facto standard that had emerged, then a separate standards setting process would be unnecessary.

The electric grid, however, is supported by multiple suppliers reduce the risks associated with dependence on a single supplier. Competition among provides a more reliable supply chain, lowers costs, and increases potential innovation benefits. Systems with multiple suppliers require standards to better define how all the hardware and information pieces connect.

Standards are developed and maintained by standards development organizations or standards bodies, also referred to as SDOs. Well-known standards organizations include the ISO, W3C, IEEE, NEMA, NAESB, and OASIS.

For smart grid in the US, NIST is the organization designated under EISA to lead and manage standards development activities. Specifically, NIST has primary responsibility" to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems…". To carry out this charge, NIST is collaborating with the GWAC, numerous expert working groups and SGIP Cyber Security Working Group to identify and recommend standards to address each of the various components of smart grid. NIST formed the Smart Grid Interoperability Panel (SGIP) in order to establish a governing board of industry representatives to help guide the identification and development of standards. The SGIP is a public-private partnership structured to provide the broad industry representation necessary to review recommendations from each of the working groups and assure they reflect the consensus required to support standards adoption. Recommendations from the NIST working group and PAPs will be passed to different SDOs for development of the actual standards. EISA specifically names and refers to the following standards organizations that will play a role in smart standards development:

- Institute of Electrical and Electronics Engineers (IEEE)
- National Electrical Manufacturers Association (NEMA)
- International Electrotechnical Commission (IEC)
- American National Standards Institute (ANSI)
- German Standards Institute (Deutsches Institut für Normung)

- International Organization for Standardization
- International Telecommunication Union
- Society of Automotive Engineers (SAE) to address electric vehicles

Standards relevant to smart grid are also likely to involve many other organizations representing the utility, consumer electronics, and other related industries.

Smart grid is a journey and not a product; and standards play an important role in moving forward towards the short term and long term goals. A short term goal might be to implement advanced metering infrastructure (AMI) which involves the use of multiple standards for the data exchange protocol, metrology, neighbourhood area network/field area network, wide area network etc. As a long term goal, a DISCOM may choose to integrate AMI with outage management system (OMS), supervisory control and data acquisition (SCADA), geographical information system (GIS) etc. If this level of integration needs to be performed seamlessly, all interfaces need to be defined/specified. One such example is the IEC 61968 (Application integration at electric utilities - System interfaces for distribution management). This set of standards is limited to the definition of interfaces and is implementation independent; it provides for interoperability among different computer systems, platforms, and languages, thereby implementing system-level interoperability. Another example of system-level interoperability is defining the data exchange protocol only and not defining the communication protocols.

5.3.1 NEED OF DEFINING STANDARDS

Standardisation brings all players/companies on a level-playing field which apart from increasing global trade, accelerates new technologies, brings in economies of scale and hence trust via compliance to standards. In addition, industry organisations get to know the views/mindset of peer companies with respect to both current and future offerings. Furthermore, if global standards are followed, manufacturers will have to manufacturer only one product that serves all markets.

Standards eliminate incompatibilities between vendor products and simplify testing, implementation, system security, maintenance, and development of monitoring and operational practices necessary to manage grid resources. Standards also:

- Establish technical specifications to achieve the required level of compatibility, interchangeability, or commonality to obtain interoperability between system components and systems;
- Establish a common perception and understanding of system operations;
- Provide data compatibility and eliminate data incompatibilities; and
- Facilitate collaboration between units within an organization and between organizations, which facilitates system interoperability.

5.3.2 SMART GRIDS STANDARDS MAPPING TOOL

One of the best resources for exploring the myriad of standards on smart grids, the Smart grid standards mapping tool developed and maintained by IEC. With this tool, one can easily and instantly identify the standards that are needed for any part of the Smart Grid – no need to be a standards expert. With this tool you are also able to identify any given standard in relation to its role within the Smart Grid. New standards are added regularly. The maping tool is available at [3]. The figure below presents a view of the map.

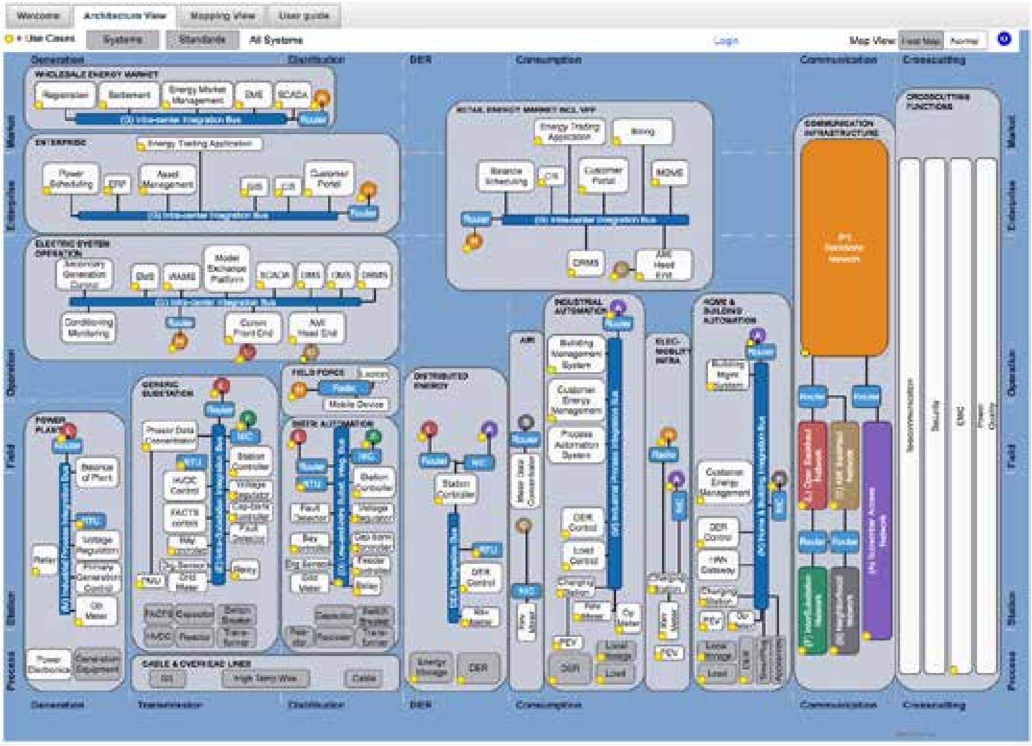

Figure 5-6: IEC Smart Grids Standards Mapping Tool

Source- IEEE Smart Grid Standards Mapping Tool, http://smartgridstandardsmap.com/

5.4 INDIAN SCENARIO OF STANDARDS FOR SMART GRIDS

In India, the Electronics and IT Department (LITD) under BIS is the primary department that formulates standards on smart grids. The scope of this department is:

“Standardization in the field of electronics and Information Technology”

The sectional committee LITD 10 is the committee that formulates standards on smart grids. The scope of LITD-10 (POWER SYSTEM CONTROL AND ASSOCIATED COMMUNICATIONS), is: “To prepare Indian Standards relating to: Power system control equipment and systems including EMS (Energy Management System), DMS (Distribution Management System), SCADA (Supervisory Control and Data Acquisition), Distribution Automation, Smart Grid, Teleprotection and associated Communications used in planning, operation and maintenance of power systems”.

LITD 10 has 7 Panels (P1, P2, P3, P4, P5, P6, P7) under it:

- P1 – Interoperability

  This Panel has formulated a standard on ‘Power system communications – Interoperability – Guidelines’ which will be released as IS 16334:2015.

- P2 – Security

  This Panel has formulated a standard on ‘Power control systems – Security Requirements’ which will be published as IS 16335:2015.

- P3 – Common Information Model

This Panel has formulated standards on ‘Common Information Model (CIM) for information exchange in the context of electrical utilities’ which will be published as IS 16336 Part 1, Part 2 and Part 3.

- P4 – Phasor Measurement Unit (PMU)

  This Panel is formulating a standard on PMUs.

- P5 – Distribution Management System (DMS)

  This Panel is formulating a standard on DMS.

- P6 – Digital Architecture Framework

  This Panel is formulating a standard on the digital architecture of electric utilities.

- P7 – Advanced Metering Infrastructure (AMI)

This Panel is formulating a draft on AMI. However, this may now not be required as all aspects of AMI have been covered in IS 16444 and the 'CEA Functional Requirements of AMI in India'.

Also, the Electro Technical Department (ETD) under BIS also formulates standards related to smart grids. The scope of this department is:

"Standardization in the field of electrical power generation, transmission, distribution and utilization equipment, and insulating materials, winding wires, measuring and process control instruments and primary and secondary batteries".

The sectional committee ET 13 formulates standards related to smart meters. The scope of ETD-13 (Equipment For Electrical Energy Measurement Tariff And Load Control) is: "To prepare international standards for equipment for electrical energy measurement, tariff - and load control, customer information, payment, local and/or remote data exchange, using electromechanical and/or electronic, technologies for applications ranging from electrical energy generation to residential. The standards may include requirements and test methods to cover mechanical, environmental, electrical, safety, metrology dependability aspects as well as functional requirements and data models".

In August 2015, this committee published a smart meter standard, IS 16444. In addition, the committee published IS 15959 Part 2 which is the data exchange protocol for smart meters.

ETD has constituted ET 46 to formulate a standard on Large Scale Renewable Energy Integration. Work in being carried out in this Panel.

ETD has constituted ET 50 to formulate a standard on LVDC and Microgrids. Work in being carried out in this Panel.

ETD has constituted ET 51 to formulate a standard on Electrotechnology in Mobility. Work in being carried out in this Panel.

REFERENCES

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[3] IEEE Smart Grid Standards Mapping Tool, http://smartgridstandardsmap.com/

India Smart Grid Forum

MODULE 6
LARGE SCALE RENEWABLE ENERGY INTEGRATION

Abstract

This module describes Renewable Energy Generation Resources and the state of renewable energy deployments in India. Different characteristics of renewable energy resources and the challenges faced in large scale RE integration are discussed in detail. To conclude, possible solutions and successful international case studies and the learnings from such projects are analysed.

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6 LARGE SCALE RENEWABLE ENERGY INTEGRATION

6.0 INTRODUCTION

During the last few centuries fossil fuels have been used as the primary source of energy. They have had a huge growth as they were considered cheaper than other sources of energy and their environmental impact was neglected. Now that environmental problems of global magnitude have emerged, the world has started to look towards cleaner sources of energy.

Renewable energy is defined as energy sources that are replenished by natural processes on a sufficiently rapid time-scale so that they can be used by human beings indefinitely, provided the quantity taken per unit of time is not too great. Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth.

Generating electricity from renewables have the following benefits:

- **Environmental Impact**: Generation of electricity from renewables instead of fossil fuels offer significant environmental benefits such as reduction in global warming and improved air quality by little or no greenhouse and carbon emissions
- **Sustainable and low cost of operation**: Renewables are economically more sustainable than other sources of energy. The cost of energy from renewables is dependent on the investment and not on the increasing or decreasing prices of resources and fuels. On the other hand, the average cost of energy from renewables is expected to decrease over time as the technology matures. In addition, renewable energy resources require less maintenance as compared to conventional generation resources
- **Reduction in fuel imports**: High penetration of renewables enhances the energy security of a nation by reducing the dependency on imported fuel and thereby reducing the risks from political instability of the exporting country, high fuel prices, trade disputes, etc

6.1 RENEWABLE ENERGY TECHNOLOGIES

There are many types of renewable energy sources such as solar, wind, hydro, biomass, geothermal and tidal. Each of these technologies has its own share of advantages and disadvantages.

6.1.1 SOLAR ENERGY

Sun's energy can be harnessed using two different technologies, solar thermal technology and solar photovoltaics. Solar thermal technology uses sun's heat whereas solar photovoltaics directly convert sunlight into electricity.

In solar thermal technology, thermal power is used to generate electricity using steam turbine or gas turbine or heat engine. Thermal energy can also be stored for any usage during non-sunshine periods. They also can be combined with conventional systems for higher output and stability. These abilities make solar thermal technology easier to integrate into the grid. The barriers for solar thermal technology are high cost, direct sunlight requirement and its high water usage requirement.

Solar photovoltaic are semiconductor materials that convert sun's light into electricity. Output electricity from photovoltaic is Direct Current (DC). Inverters are used to convert this DC output to alternating current (AC). Photovoltaic system's inverters have low voltage ride through[1] as well as flexible active and reactive power control capabilities. Photovoltaics don't contribute to the system reserves and the total system inertia.

6.1.2 WIND ENERGY

Wind turbines convert the kinetic energy of wind to electricity using an electric generator. Power output from wind turbines depend on the wind velocity and swept area. Power output from wind turbines increases by the power of wind speed and is directly proportional to the swept area.

Generally, wind turbines start generating electricity at a wind speed of around 3 meters per second (m/s) and reach maximum output at about 11 to 14 m/s. Wind turbines can control power output by rotating horizontally by changing direction and the blade angle to adjust to high wind speeds.

Wind turbines are classified into two different types: horizontal axis and vertical axis. In horizontal axis wind turbines, the axis of rotation is horizontal where as in vertical axis wind turbines the axis of rotation is vertical. Horizontal axis wind turbines are widely used because they are more capable of taking advantage of high wind speeds at higher elevation than vertical axis wind turbines. High initial cost, new transmission infrastructure requirements, large land requirement, disruption to birds and marine ecosystem and noise are some of the barriers for wind energy.

6.1.3 BIOMASS ENERGY

Energy contained in biomass comes from the sun; hence biomass is considered as renewable form of energy. During photosynthesis plants capture sun's energy and this energy is released when they are

[1]Low voltage ride through is capability of a generator to stay connected to the grid in case of voltage dip. This ability assists other generators which require a minimum voltage level to generate power stay operational.

[2]Inertia is the ability of synchronous generators or turbines to determine the immediate frequency in case of power imbalance. During power imbalance such machines will inject or absorb kinetic energy into or from the grid to counteract frequency deviation. Grid systems with low inertia, react more abruptly to changes in generation or load pattern. (Tielens, Pieter; Hertem, Dirk Van, 2012)

burned. Biomass are advantageous as they can be used to generate electricity with the same power plants that use fossil fuels. Seasonal availability, high water content, storage challenges and location dependency are some of the barrier for biomass energy.

Note: Not all forms of renewable energy are clean. Biomass for example on combustion produces sulphur dioxide. However, it still is cleaner than most of the fossil fuels used since any excess carbon dioxide is not released into the environment (carbon neutral). It only releases the amount of carbon previously absorbed during the growth phase.

6.1.4 HYDRO POWER

Hydropower is the utilization of potential energy of falling water or kinetic energy of flowing water. This energy of water is used to rotate mechanical turbines. The mechanical energy of turbines is further converted to electrical energy using generators. Dams are constructed to conserve water and generate electricity during the peak periods. Hydropower resources are of great value as they can be brought on and off line quickly to respond to system load/generation fluctuations. High initial cost and destruction of natural habitat are some of the barriers of hydro power generators.

6.2 RENEWABLE ENERGY SCENARIO IN INDIA

India is the world's fifth largest electricity generator with a total installed capacity of 331 GW (as on 31 October 2017). Renewables account for 60 GW which is about 18% of the total installed capacity. Estimates have shown, India has a huge untapped solar potential of 10,000 GW and wind potential of 2,000 GW. (NITI Aayog, 2015)

Table 6-1: Source wise generation in India as on January 2017

Source	Generation Capacity (GW)
Coal	188.48
Gas	25.32
Diesel	0.83
Nuclear	5.78
Large Hydro	44.18
Small Hydro	4.17
Wind Power	28.70
Bio-Power	4.67
Solar Power	9.01

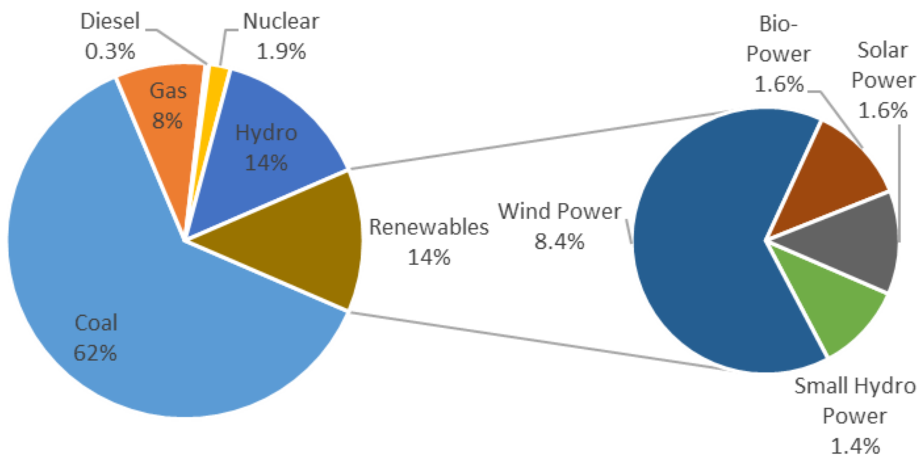

Figure 6-1: Installed capacity of various generation sources in India

6.3 INDIA'S RENEWABLE ENERGY TARGETS

Perceiving the potential advantages of renewable energy, Government of India and different State Governments have undertaken a few measures that have prompted the expansion of renewable energy in the nation. Government of India in 2015, set the target of generating 175 GW from renewable energy sources by 2022, out of which 100GW would be from solar, 60 GW from wind, 10 GW from biomass and 5 GW from small hydro (MNRE, 2015). Power requirement in 2022 is estimated to be 434 GW and 175 GW of RE will contribute to 18.9% of the total power consumption. (Ministry of New and Renewable Energy, 2015)

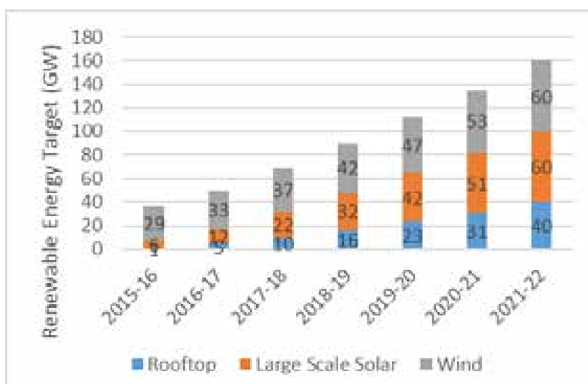

Figure 6-2: (i) India's current RE generation and targets (ii) India's year wise RE targets

6.4 MECHANISMS TO PROMOTE RENEWABLE ENERGY IN INDIA

To achieve the set targets of 175 GW from renewables, India requires a paradigam shift in the planning and Government practices. Currently the government has put into action certain support mechanisms towards the growth of renewable energy such as:

- Feed In Tariff
- Accelerated Depricitation
- Generation Based Incentives for Wind
- Viability Gap Funding for Solar

- Net Metering
- Renewable Energy Certificate Mechanism

6.4.1 FEED-IN-TARIFF (FIT)

Also called fixed price policies, feed-in tariff is a standard tariff rate made available to renewable energy generators to offer a guarantee of payment for the electricity produced. Different tariffs are set for different technologies, depending on the cost of generation. Tariff is set for a number of years to give investors payment security making renewables a low risk investment.

Though FIT is known as the most successful approach to promote renewable energy it does have a few disadvantages. FIT is likely to cause an increase in the price of electricity to customers unless some other funding sources are used. Since FIT is set for long term to provide payment security to the investors, it makes it hard to understand the actual change in the renewable energy cost. (National Renewable Energy Laboratory, 2010)

6.4.2 ACCELERATED DEPRECIATION

Accelerated depreciation is a fiscal incentive which allows investors to claim 80% (40% from April 2017) of depreciation in the first year, allowing them to write off the investment more quickly. The actual benefit will vary from project to project depending upon the capability of the investor to absorb the depreciation benefit. Accelerated Depriciation has been the key instrument for the success of wind energy with almost about 70% wind projects built on Accelerated Depriciation route in India. Accelerated Depriciation is also available for solar energy generators.

6.4.3 GENERATION BASED INCENTIVES (GBI)

Generation based incentives (GBI) provides wind energy producers Rs 0.50 per unit of electricity fed into the grid for a period not less than 4 years and a maximum period of 10 years with a cap of Rs. 100 Lakhs per MW. The total disbursement in a year will not exceed one fourth of the maximum limit of the incentive i.e. Rs. 25.00 Lakhs per MW during first four years. The GBI scheme will be applicable for entire 12th plan period having a target of 15,000 MW (Indian Renewable Energy Development Agency Ltd., 2013)

6.4.4 VIABILITY GAP FUNDING (VGF)

Power generated through solar PV generators shall be purchased by Solar Energy Corporation of India (SECI) at a fixed levelized tariff of Rs. 5.43 per kW for 25 years (Rs. 4.75 per unit if benefit of accelerated depreciation is availed). Payment of VGF to the developers would be made as per their bids, limited to a maximum of Rs. 2.5 crore/MW. Latest actions in 2017 for solar PV farms have brought down the tariffs to Rs 2.42/kWh.

6.4.5 NET-METERING

Net metering allows consumers of electricity with rooftop PV systems to sell excess solar energy to the distribution company. Special meters are installed which run backward in case of energy being tranfered to the grid. Currently all 29 States and UTs have released their respective net metering policies.

Net metering reduces the requirement of batteries which are required to store any excess power generatied after utilization, as consumers can sell the excess electricity to the grid. Net metering provides financial benfits to the PV system owners and reduces their initial system cost (batteries).

6.4.6 RENEWABLE ENERGY CERTIFICATE (REC) MECHANISM

Renewable purchase obligations (RPO) have been the major driving force to promote renewable energy generation in India. The State Electricity Regulators (SERCs) of 25 states and UTs in India have defined their respective RPO regulations to fix a minimum percentage energy purchase from solar and non-solar renewable energy resources. The percentage minimum quantum of purchase from Renewable sources are increased every year and currently ranges from 0.2% to 2% for solar and 5% to 15% for non-solar.

The RPO provide additional financing option for renewable energy generators as they can sell Renewable Energy Certificates (RECs) to the obligated entities (Distribution licensees, open access customers and captive generators) who are not able to fulfill their RPO targets, by purchasing RE power available in their states. This serves as an additional source of income for the RE generators (Who can either sell RE power at preferential tariff or sell RE power to the local DISCOMs/third party at Average Power Purchase Cost (APPC) and get RECs from NLDC to sell them at PowerExchanges) and the mechanism reduces the need to build new transmission lines for high renewable energy generating areas. (Soonee, Garg, & Prakash, 2010)

6.5 GRID PARITY FOR RENEWABLES

With wide usage and the advances in renewable technology and the rising fuel cost for thermal and gas generators, the renewable energy technologies are going to become cheaper than conventional energy generators. Currently, the cost of generation from solar has become cheaper than natural gas based plants and the cost of generation from wind has become cheaper than imported coal based plants. It can be observed from following daigrams that the solar tariffs have decreased by a huge 64% in the last 6 years. (Ministry of New and Renewable Energy, 2016) (Climate Policy Initiative, 2015)

Estimates by NITI Aayog have shown that solar tariff will be equivalent to variable costs of thermal generators by the year 2020-2026 whereas wind tariffs will be equivalent to the variable cot of thermal generatrion by the year 2018-2023. (NITI Aayog, 2015).

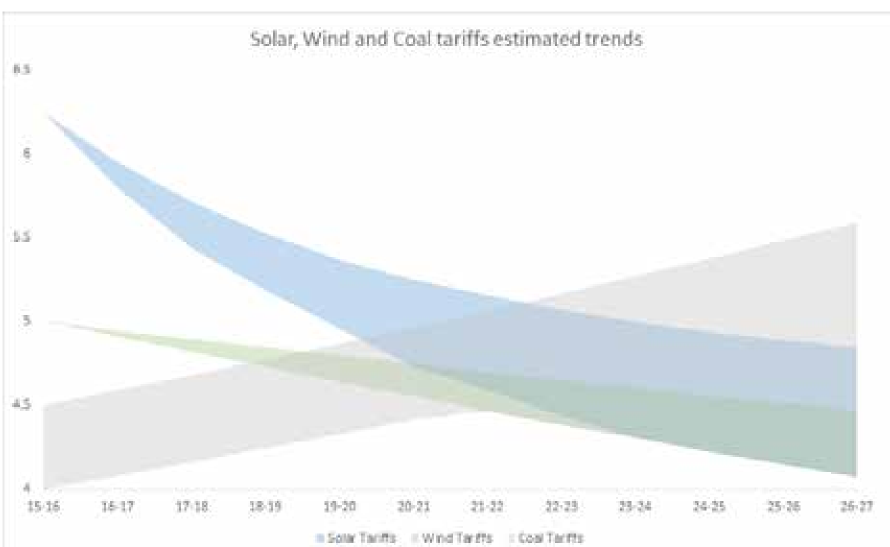

Figure 6-3: Solar, wind and coal tariff estimates (NITI Aayog, 2015)

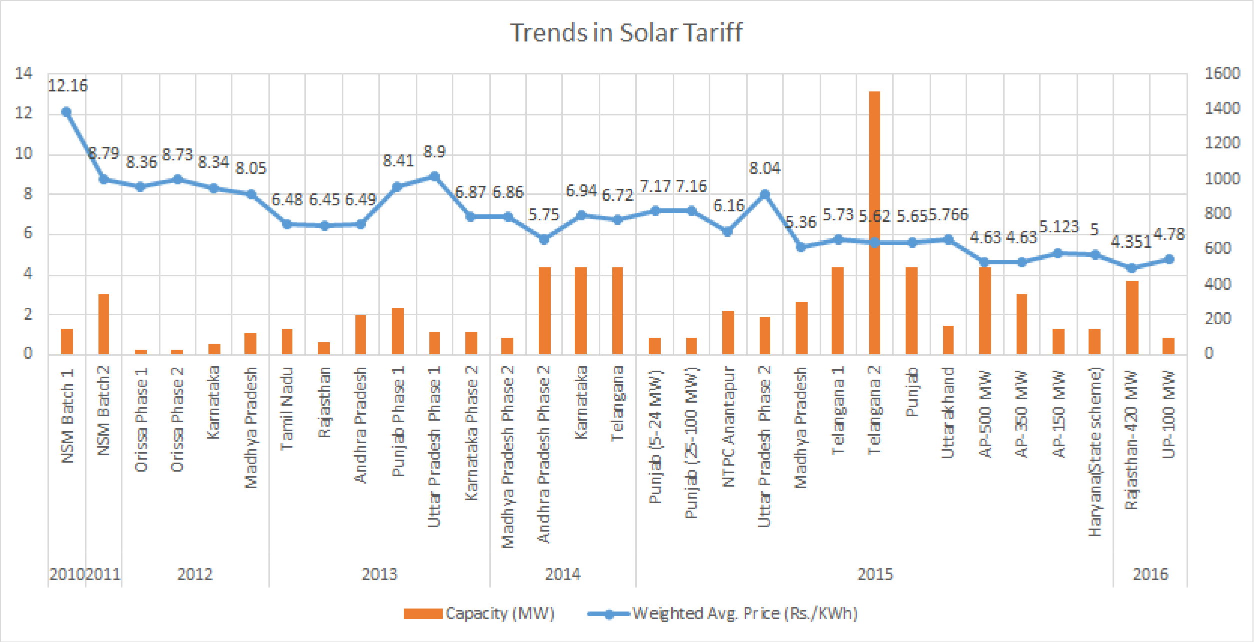

Figure 6-4: Trends in solar Tariff (Ministry of New and Renewable Energy, 2016)

India has harvested only 0.25% of the its total renewable energy potential and thus, renewables present an immense opportunity to be exploited in the future and reduce dependence on fossil fuel. In order to achieve higher share of RE, all non-financial support options should be made available to RE e.g. project development, policy support, legislative enablers, and coordinated implementation ecosystem which would be critical to achieve the 175GW RE targets. The incentive and procurement mechanism should be design while considering the specific characteristics of resource and technology under consideration.

6.6 CHALLENGES TO LARGE SCALE RENEWABLE ENERGY INTEGRATION

All electricity generated needs to be consumed at the same time, electricity generated needs be equal to the electricity demand. Techniques such as forecasting demand and scheduling generators are being used to match the demand and supply. Generation reserves and power outages are used when there is a mismatch. Power outages are being phased out by having larger generation reserves.

The balancing of generation and demand is visible through the grid frequency. When electricity generated is higher than the electricity demand, the frequency increases and when electricity generated is less than the demand, the frequency decreases. The Indian grid is operated at a frequency of 50 Hz with allowable fluctuations in the range of 49.70 to 50.05 Hz.

6.6.1 TYPES OF RENEWABLES

Generally, renewable energy sources can be grouped together into two categories

- Dispatchable
- Non-Dispatchable or Variable renewable energy (VRE)

Dispatchable renewable energy sources can be ramped-up or ramped-down based on demand. Biomass, concentrated solar power with storage, geothermal power and hydro are categorized as dispatchable. The electricity generated from non-dispatchable renewable energy sources also known as Variable Renewable Energy (VRE) depends upon meteorological conditions and/or the time of the day. Integration of VREs in the grid is a more challenging task. This following sections describes the challenges and barriers faced when integrating large scale VREs into the grid.

6.6.2 RENEWABLE ENERGY VS CONVENTIONAL GENERATORS

Conventional generators can control the system frequency by adjusting the power generation output whereas VREs are operated at their maximum power output and do not contribute to the frequency control. Large fluctuations in renewable energy generation could lead to fluctuation of grid frequency. Generators such as coal, nuclear are used as base loads that provide constant generation. Flexible conventional generators such as gas, hydro are used to match the remaining generation requirements.

6.6.3 CHARACTERISTICS OF RENEWABLES

Electricity generated by VRE's has following three distinct characteristics that create challenges for the grid operators in integrating them to the grid: (i) variability, (ii) uncertainty and (iii) location dependency. These characteristics of renewable sources make it difficult for high penetration levels without disrupting the grid stability.

Penetration

Penetration is defined as the percentage of electricity generated by a resource. High penetration of renewable energy into the grid introduces high variability and unpredictability, making it difficult to maintain the grid stability.

Levels	Range
Low Penetration	0% to 10%
Medium Penetration	10% to 30%
High Penetration	More than 30%

I. VARIABILITY

Variability is the difference in generation in two consecutive time periods. Energy from VREs is characterized as variable because the electricity generated varies depending on the availability of sun and wind, cloud cover, wind speed, time of day, seasons, etc. This variability causes fluctuations in the grid voltage and frequency and would require additional support mechanisms described later to balance it. This variability occurs over different time scales, from seconds to hours.

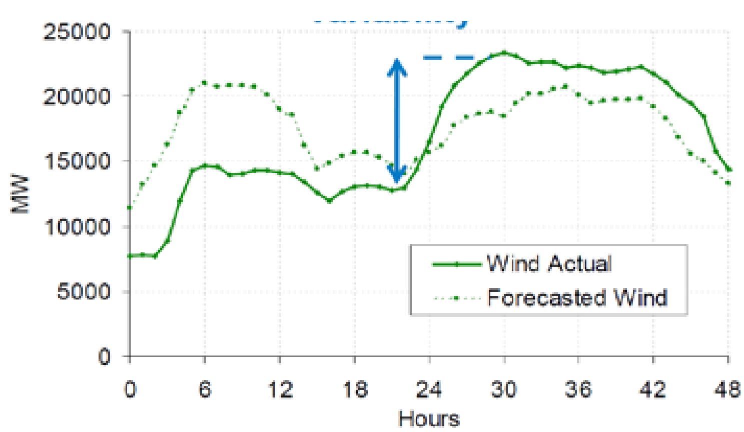

Figure 6-5: Variability in Wind Generation

Source: National Renewable Energy Laboratory, 2013

II. UNCERTAINTY

VREs are also termed as uncertain because of the difficulty to forecast them accurately. This uncertainty occurs over different time scales, from minutes ahead to day ahead.

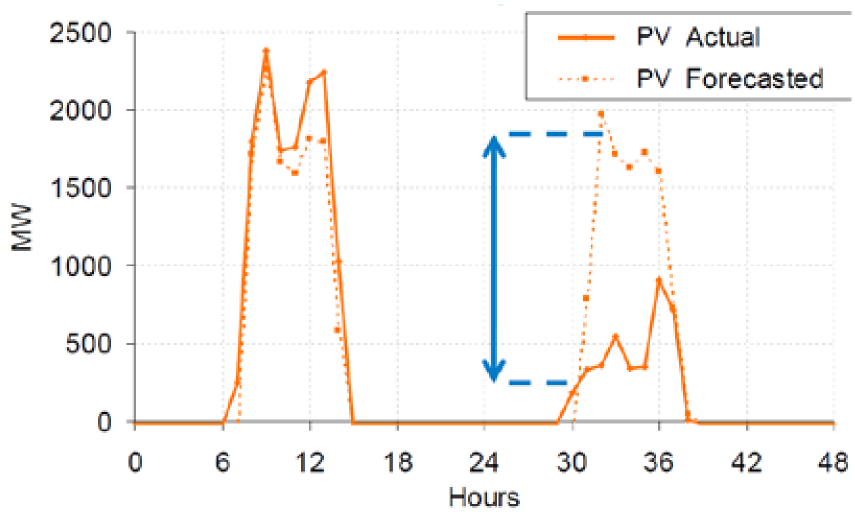

Figure 6-6: Uncertainty In Solar Pv Generation

Source: (National Renewable Energy Laboratory, 2013))

Like renewables, load also varies throughout the day and is unpredictable. Because of this, the grid systems are designed to handle some level of variability and uncertainty.

III. LOCATION DEPENDENCY

Wind and solar resources are distributed based on geographic factors and not generally at the load centres. Hence robust transmission capacity is needed for complete renewable energy integration.

Table 6-3: Characteristics of Different Renewable Energy Technologies (National Renewable Energy Laboratory, 2012)

Technology	Variability (Time Scale)	Dispatachability (+++ Dispatachable ++ Partially Dispatachable + Low partially Dispatachable)	Geographic Diversity Potential (++ High Diversity Potential +Moderate Potential)	Predictability (++ High Predictability + Moderate Predictability)
Solar PV	Minutes to years	+	++	+
Solar Thermal	Hours to years	++	+	++
Small Hydro (Run-of-river)	Hours to years	++	+	++
Large Hydro (Reservior)	Days to years	+++	+	++
Wind	Minutes to years	+	++	+
Bioenergy	Seasonal	+++	+	++

To balance the electricity grid, forecasting demand and scheduling plays an important role which is visible through grid frequency. Renewable Energy Sources are further grouped based on demand and meteorological conditions or time of the day. Characteristic of renewables briefly describe the challenges grid operator face during integration due to variability, uncertainty and location constraints.

6.7 SOLUTIONS FOR RE INTEGRATION

A few important questions to be answered are: How much renewable energy penetration can the grid handle? What is the cost of integrating renewables into the grid? How can increasing penetration be balanced? Following section attempts to answer these questions in depth.

6.7.1 LARGER BALANCING AREAS AND AGGREGATION OF GENERATION SOURCES

Electricity generated from a single wind generator or solar plant is highly variable. But when different wind generators and solar plants are bundled together the aggregated electricity generated becomes more predictable and the variability decreases. When these are aggregated over large geographic area the variability further decreases. Due to this geographic diversity and "law of large numbers" the aggregated generation becomes smooth, decreasing variability. By aggregation of wind generators and solar plants the requirement for flexible reserve capacity decreases significantly. Larger balancing areas also provides excess to more flexible generators.

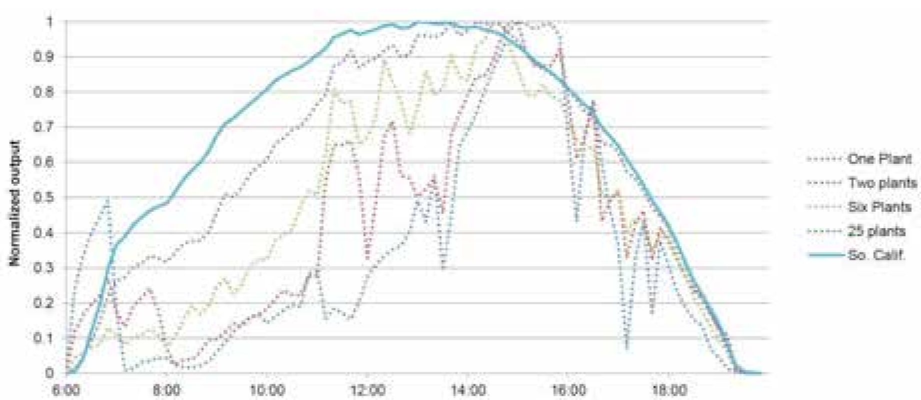

Figure 6-7: Electricity generation from 1, 2, 6, 25 number of solar plants compared to the total Southern California

(Source: NREL)

Electricity generation through solar energy at some level is predictable due to fixed events such as sunrise and sunset. Effect of cloud cover on the other hand is difficult to predict. But when large number of solar plants are aggregated over a large geographic area the variability introduced by cloud cover is significantly reduced.

Larger Balancing Areas in India

In India, State Load Dispatch Centres (SLDC) represent a control area. Currently each state's SLDC handles the power balancing and dispatch individually. Independent studies have proved that dispatching power with joined SLDC balancing and dispatching will have monetary benefits in addition to the capability to balance high renewable penetration levels.

6.7.2 FORECASTING

By aggregation of renewable energy, power system operators smoothen out fluctuations on a shorter time frame. Still it is difficult to predict the generation on a larger time frame. Advancements in forecasting techniques have made it possible to effectively predict the generation from wind and solar to high level of accuracy. Day ahead and hour ahead forecasting is regularly used to schedule power from conventional sources for balancing the uncertainty causes by renewables. Level of confidence and accuracy in forecasting are important. Low level of confidence requires large amount of reserves and vice versa. (APS Physics, 2010)

Indian electricity grid code, 2010 – Section 6.1 (d)

"Wind energy being of variable nature, needs to be predicted with reasonable accuracy for proper scheduling and dispatching of power from these sources in the interconnected system. Hence wind generation forecasting is necessary for increased penetration. Wind generation forecasting can be done on an individual developer basis or joint basis for an aggregated generation capacity of 10 MW and above connected at a connection point of 33 kV and above."

6.7.3 POWER EXCHANGE MARKET

To adapt to unique characteristics of renewables, electricity market needs to: 1) Be adequately flexible to account for high variability and uncertainty of renewables. 2) Develop better management mechanisms required as renewables have low running costs and high initial costs. 3) Design grid codes and regulations to adjust for nonsynchronous generation from most of the renewables which do not support to system inertia. (JENNY RIESZ, 2015)

Flexibility in power market can be improved by making changes to the market designing such as short dispatch interval, larger balancing areas, market for Frequency Control Ancillary Services, reduced time between bidding and dispatch, etc.

6.7.4 UNSCHEDULED INTERCHANGE/DEVIATION SETTLEMENT MECHANISM

Unscheduled Interchange (UI) and Deviation Settlement Mechanism are the mechanism developed to improve grid efficiency, grid discipline, accountability and responsibility by imposing charges on those who over draw or under generate from their schedule.

Deviation Settlement Mechanism in India

From 17th Feb 2014 CERC (Central Electricity Regulatory Commission) replaced the UI (unscheduled interchange) mechanism with the deviation settlement mechanism to further strengthen the grid and improve stability. This move was particularly taken in wake of the two major blackouts in India on 30th and 31st July 2012. Earlier under the UI mechanism the charges were only applicable for grid frequency below 49.2 Hz and was leading to utilities drawing power from the UI instead of adding new capacities since there were no prior financial commitments. Due to such loopholes in the UI mechanism and to promote renewables CERC launched the deviation settlement mechanism which has separate deviation charges for conventional and renewable energy. (Central Electricity Regulatory Commission, 2014)

Convention generators are allowed ±12% or 150 MW (whichever is lower) deviation from schedule when frequency is between 49.7 Hz to 50.05 Hz. Based on the range of deviation additional charges are also levied on the generators as a percentage deviation charges fixed for various grid frequency range. Annexure I shows the applicable deviation charges and additional charges. (Central Electricity Regulatory Commission, 2014)

Wind generators are responsible for forecasting their generation up to an accuracy of 70%. They are to bear UI charges if actual generation is beyond ±30% of the schedule. For generation within ±30% of the schedule the host state will bear UI charges for the variation. However, the UI charges borne by the host State due to the wind generation, shall be shared among all the States of the country in the ratio of their peak demands in the previous month based on the data published by CEA, in the form of a regulatory charge known as the Renewable Regulatory Charge operated through the Renewable Regulatory Fund (RRF). This provision is only applicable for new wind farms with collective capacity of 10 MW and above connected at connection point of 33 KV level and above, and who have not signed any PPA with states or others. (Central Electricity Regulatory Commission, 2010)

Solar Generators will not bear any UI charges for any deviation from schedule, instead the state will bear the UI charges for any deviation. However, the net UI charges borne by the host State due to the solar generation, shall be shared among all the States of the country in the ratio of their peak demands in the previous month based on the data published by CEA, in the form of regulatory charge known as the Renewable Regulatory Charge. This provision is only applicable for new solar generating plants with capacity of 5 MW and above connected at connection point of 33 KV level and above, and who have not signed any PPA with states or others. (Central Electricity Regulatory Commission, 2010)

The hydro generating stations are expected to respond to grid frequency changes and inflow fluctuations. The hydro generating stations shall be free to deviate from the given schedule, without indulging in gaming and causing grid constraint. (Central Electricity Regulatory Commission, 2009) (Forum of Regulators, 2015)

Refer: http://cercind.gov.in/2014/regulation/noti132.pdf

6.7.5 DEMAND RESPONSE

Demand flexibility uses communication and control technology to shift electricity use across hours of the day while delivering end-use services (e.g., air conditioning, domestic hot water, electric vehicle charging) at the same or better quality but lower cost. It does this by applying automatic control to reshape a customer's demand profile continuously in ways that either are invisible to or minimally affect the customer, and by leveraging more-granular rate structures that monetize demand flexibility's capability to reduce costs for both customers and the grid.

Demand response is defined by Federal Energy Regulatory Commission, US (FERC) as,

"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

Demand response provides an additional source power to respond to the variability of the renewables. DR can be used to shift the load to off-peak periods when there is excess renewable energy generation or as a balancing tool available to power system operators for responding to renewable energy generation fluctuations.

Two demand response mechanism are available to power grid operators and utilities (Goldman, Charles; Reid, Michael; Levy, Roger; Silverstein, Alison, 2010),

- Price based: By varying the price of electricity over time to encourage consumers to shift their electricity usage. Time of day tariffs, Critical peak pricing and real time pricing are few of the mechanism.
- Incentive based: By providing financial compensation to participating customers who control their electricity consumption on request. Emergency demand response and direct load control are few of the incentive based demand response mechanism.

6.7.6 STORAGE

Energy can be stored in various forms to be used later. Different storage systems used, can be classified into the following types (SBC Energy Institute, 2013)

Kinetic Energy Based			Potential Energy Based		
Thermal	**Electrical**	**Mechanical**	**Mechanical**	**Electrochemical**	**Chemical**
Sensible Heat Storage	Capacitors	Flywheels	Pumped hydro and compressed air storage	Battery	Chemical reactions based

Storage technologies can be divided into two categories based on the capability of storage.

- **Short timescale**: these technologies can provide operating reserves for a few seconds to minutes. Flywheels and a few batteries based technologies can be categorised as short timescale storage solutions.
- **Long timescale**: these storage solutions can provide flexibility over several hours. High energy batteries, pumped hydro, compressed air storage and Sensible heat storage are categorised as long timescale storage solutions.

Based on the capability of a storage technology to discharge and generate power they can be used to improve power quality or provide grid support mechanisms. Below figure describes the capabilities of pumped hydro, flywheels, various battery and capacitor based storage solutions.

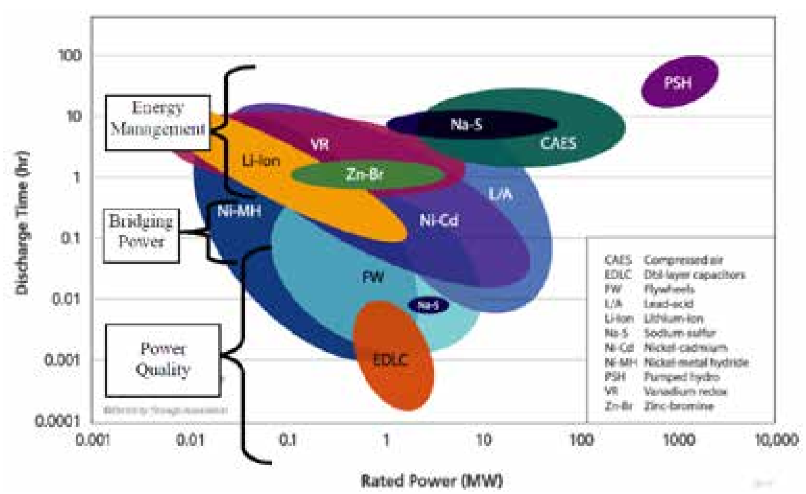

Figure 6-8: Energy Storage technologies and their capabilities (The Role of Energy Storage with Renewable Generation, 2010)

Storage solutions can be used to assist grid operators in three different applications to enable large scale renewable integration (Deloitte Center for Energy Solutions, 2015)

- **Ancillary Services**: To provide for sudden variability in renewable energy generation, storage solutions such as battery can provide short duration power supply to improve power quality and supply.
- **Transmission Support**: Storage solution can be used to reduce transmission constraints by providing localized supply during peak demand periods thus reducing the transmission infrastructure requirements.
- **Pricing**: Storage can be used to provide better prices to wind energy generators by storing energy during the night when wind speeds are high and selling during high cost peaking periods.

Electric vehicles now being promoted for being clean, also have the capability to be used as a storage system which can dispatch power to the grid as an electric vehicle virtual power plant (EVPP). They can be charged during the night when the wind generation is high and can provide all benefits of grid management services similar to other storage solutions. (International Electrotechnical Commission, 2012)

6.7.7 RENEWABLE ENERGY CURTAILMENT

In high penetration scenarios, renewable energy generators are requested to reduce their generation output from what they could have generated to balance for very high generation or any bottlenecks in transmission. This however affect the economics of the renewable energy generators who do not have any fuel cost. Compensation for curtailment may or may not be provided depending on the regulations. Renewable Energy Curtailment provides additional benefit as it enables the curtailed RE sources to be used as additional source of operating reserve thus reducing the requirement of balancing from conventional generators.

6.7.8 TRANSMISSION PLANNING

Since most of the renewable energy generation is not near the load centres, they depend on transmission lines to transmit the electricity produced to the load centres. It is essential that transmission requirements for current and upcoming renewables generating plants are planned.

Green Energy Corridor and Desert Power 2050

Transmission requirement is ever growing due to increasing loads and generation capacities. India has envisaged the increase in renewable energy sources such as wind, solar and hydro in eight RE rich states viz. Tamil Nadu, Karnataka, Andhra Pradesh, Gujarat, Maharashtra, Rajasthan, Himachal Pradesh and Jammu & Kashmir. PGCIL has developed Desert power India 2050 and green corridors to assess the cost and capacity of transmission infrastructure requred to evacuate electricity generated to load centres.

6.7.9 SMART GRID SOLUTIONS

Keeping aside the different techniques, the grid itself needs to be highly reliable, self-regulating and efficient to allow integration of renewables. The grid needs to provide utilities with the required digital intelligence to automate, monitor and control the energy flow. Smart Grid allows better manage various techniques mentioned above such as demand response and storage solutions.

6.7.10 OTHER MEASURES

A few other small but necessary measures are (Ministry of Power, 2016)

- Better real time data transfer between RE generating stations and dispatch centres to improve information flow.
- Enhancement in skills of power systems operators in operation, planning, maintaining and governing of grids with higher renewable energy penetration.

Role of Regulators and Utilities

Power system operators need to weigh the benefits of the various solutions and compare them based on the implementation cost. Storage is costly because of the inefficiency in operation as only 70-85% of the energy is recoverable. Demand response on the other hand have high implementation cost as high incentives are given to the consumers.

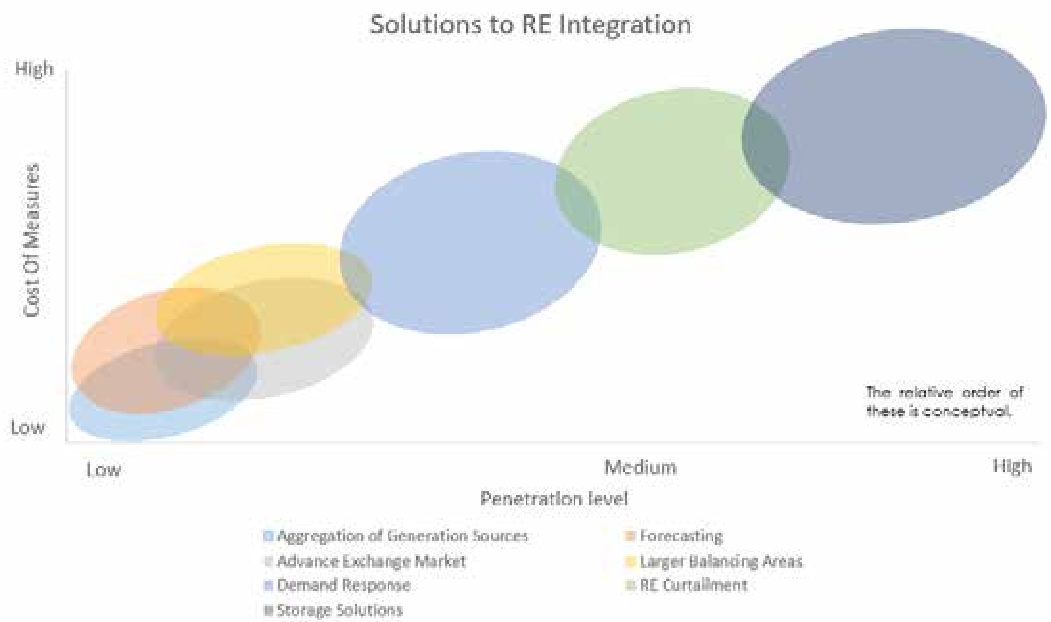

Figure 6-9: Suggested Measures based on their cost of implementation

Source of data - (National Renewable Energy Laboratory, 2010)

Grid Integration Cost

Studies have estimated that the approximate cost of grid integration at around 15% penetration by 2022 would be approximately 10% of the levelized cost of RE in the present context. This cost can be further brought down to 6% by 2022 by innovative planning and operations. (NITI Aayog, 2015)

6.8 INTERNATIONAL CASE STUDIES

No country has similar RE resource potential and every country is developing their RE generation in a unique way. There are many examples to learn from, such as European counties with high renewable penetration and American states with dynamic policy system. This section tries to summarise the method and policy changes adopted by various nations to integrate large renewables into their grid.

6.8.1 GERMANY

Germany currently meets more than 30% of its electricity demand from renewable sources of energy. Wind and solar combine alone account for around 22% of the total energy generation. (Burger, Bruno, 2015)

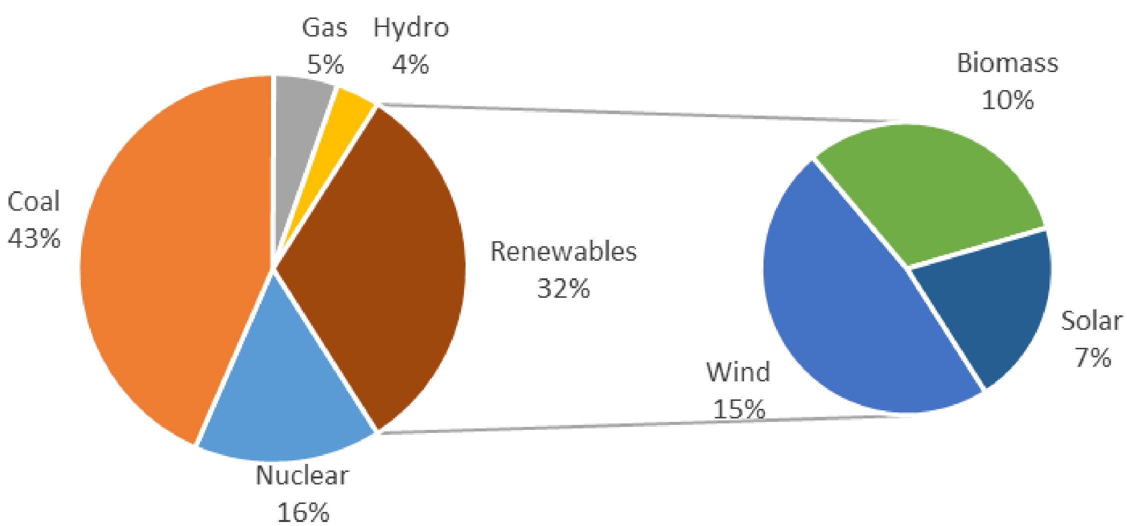

Figure 6-10: Germany source wise energy generation

Renewable Energy Sources Act, 2014 aims to continuously increase the share of renewable energy sources in Germany. The future targets set are (Federal Government Germany, 2014)

- 40% to 45% renewable share by 2020
- 50% to 60% renewable share by 2035
- 80% renewable share by 2050

Germany is sturdily moving away from nuclear energy. Currently Germany gets around 16% electricity from nuclear power plants. Germany plans to shut down all its 17 nuclear reactors by 2022.

Key factors that enable Germany to integrate such high Renewable Energy penetration are:

I. FEED IN TARIFF LAW

Feed in tariff is a policy mechanism introduced to increase the investment in renewable energy technologies by providing a tariff above the retail rate of electricity. Based on the cost of generation of the Technologies, wind, solar and tidal power generators are given a per kWh price. This aims at providing long term security to renewable energy generators.

II. FLEXIBLE OPERATION OF COAL AND NUCLEAR PLANTS

Renewables occupy most of the trading at day ahead power market in Germany due to priority dispatch and hence most of the power from conventional power plant is sold in the balancing market. To balance the variability in generation due to renewables the coal and nuclear power plants in Germany were designed or modified such that they can provide a flexible output.

III. EFFICIENT POWER MARKET

Germany's balancing and day ahead power market have been well tweaked to balance the variability due to renewables.

IV. ADVANCE TECHNOLOGY IN FORECASTING AND POWER OPERATIONS

Advanced power controls, dispatch software and analytical tools have enabled Germany to have such high renewable penetration. These assist the grid to be stable when there is high ramping up or down requirements due to variable renewables. Also day ahead forecasting assist in integrating and balancing the renewables with ease.

V. EXPORTS TO NEIGHBOURING COUNTRIES

Conventional power plants in Germany export their power to neighbouring counties to maintain profitability in such a renewable energy dominant market.

6.8.2 DENMARK

Denmark generated 42% of its total electricity from Wind in 2015 (39% in 2014 and 33% in 2013). In Jan 2014, 61% of the total electricity generation came from wind. Denmark has a target of achieving 100% renewable energy share by 2050. To achieve this target, they aim to increase their wind generation to 50% by 2020 (Danish Energy Agency, 2012). The key factors that currently enabled Denmark to integrate such large percentage of renewables are the three big innovations in the power sector and a few other orthodox techniques.

I. INTEGRATION OF HEAT SUPPLY WITH ELECTRICITY BALANCING

One of the main innovations done in Denmark is the integration of heat supply with electricity balancing. Majority of electricity in Denmark is produced by small combined heat-and-power (CHP) plants. This whole system was designed with flexibility in mind, and which allows CHP plants to vary their electricity output in response to changes in wind output, and thus provide balancing. Many of these CHP plants are fuelled by biomass, rightly balancing non variable RE and VRE itself. This solution is a type of demand response but is specific to controlling of the heating loads.

II. FLEXIBLE COAL PLANTS

Second innovation in generation flexibility is "hourly ramping" and "daily cycling" of coal power plants, adding several modifications in both control software and equipment, have allowed coal plants in Denmark to ramp at rates up to 3-4% of rated output per minute, which is unprecedented among coal plants around the world.

III. DAY AHEAD FORECASTING

Third innovation done was setting up advanced day ahead weather forecasting in power system dispatch. Ability to forecaster weather with high accuracy allows balancing of high shares of renewables, as it makes variable renewables highly predictable and can be dispatched on a day ahead basis. The forecasting system is built to further reduce the errors by constantly comparing the actual output of renewables with the day ahead prediction in real time.

IV. TRANSMISSION PLANNING

Denmark proactively plans new transmission capacity by anticipating future interconnections with upcoming wind farms. This allows transmission network to build up with new generation.

V. STRONG INTEGRATION WITH NEIGHBOURING GRIDS

Lastly, strong integration with the neighbouring grids in Europe including the Nordic Pool market (Finland, Iceland, Sweden, Norway) enable Denmark to balance such high penetration of renewables and keep the grid stable.

VI. MUST RUN PLANTS

Some plants in Denmark are ordered to keep online and available, producing very small amount of energy. These plants allow for any sudden balancing needs.

6.8.3 ERCOT IN TEXAS

In 2014, wind energy in Texas contributed to more than 10% of its total electricity demand and during peak wind generation hours this output reaches the 40% mark. ERCOT is an interesting case because of its isolation from other grids.

Key measures taken by ERCOT to integrate large renewables in the grid are, (Weiss, Jurgen; Tsuchida, Bruce, 2015)

I. NODAL PRICING MARKET AS ENABLER

In 2010, ERCOT launched nodal market which enables generators and loads to sell and purchase electricity at location based pricing. Nodal pricing is a method of determining prices in which market clearing prices are calculated for a number of locations on the transmission grid. This allows the market to better reflect congestion in the transmission system and allow resource specific scheduling.

II. DISPATCH RESOLUTION

ERCOT decreased their dispatch resolution from 15 minute to 5 minute which allows larger renewable energy integration with minimal ancillary services requirement.

III. FORECASTING

Wind in Texas is concentrated only at West Texas and Texas Panhandle. Since its not spread over wide area, the diversity benefits are lost. To account for sudden and rapid changes in the wind generation output ERCOT has implemented ERCOT Large Ramp Alert System using probability based wind forecasting for the next six hours with update resolution of 15 minutes. This allows system operators to schedule and dispatch wind and other balancing resources accordingly.

IV. TECHNOLOGY ADVANCEMENTS

Since Nov 2008, all wind generators had to provide low voltage ride through so that the wind generators do not have to disconnect in case when the system frequency crosses the required 60 Hz range.

V. DEMAND RESPONSE

Demand response majorly used for providing capacity, can also be used for enhancing reliability. ERCOT has launched two demand response programs to improve grid stability. Emergency response service ten minute (ERS-10) and emergency response service thirty minutes (ERS-30). These require load reductions to be available within 10 and 30 minutes respectively.

6.9 ROOFTOP SOLAR PV INSTALLATION- WHAT NEXT FOR THE REVOLUTION

The Government of India has scaled up its electrification drive, to provide electricity to each household by 2019, to electrify all un-electrified households by December 2018 and provide 24*7 electricity access by March 2019 [19], in which rooftop solar has a key role to play. The target of adding 40 GW of renewable power generation through rooftop solar is going to play a key role in achieving power generation of 100 GW through solar energy. As per the market, a good 5kW system for a home costs around 3-4 lakhs to setup (at retail price of approximately INR 40 per Wp), which can provide electricity for 25 years [20]. Additionally, MNRE provides 30% capital subsidy for both commercial and residential roof top solar installations. The Government provides loans at an interest rate of 5% per annum. Rooftop solar also provides solution to the blockage of huge tracts of land for solar power parks.

Albeit for the success of rooftop solar revolution, stricter steps have to be taken up by the Government towards structural change of the distribution system, as the current distribution companies might not like the idea of people producing their own power in the times when the DISCOMS are under hefty debt and liabilities. Thus, there is no denying that sound technical and financial health of DISCOMS is crucial for electricity supply system to function smoothly. On the other hand, rooftop solar systems will play a key role in realizing India's commitment to pursue low-carbon pathway of increasing energy production. Rooftop solar energy generation can be mixed with other renewable and conventional power sources to establish micro-grids that can be utilized to electrify the rural areas, still inaccessible to the utility grid's reach, which can give a significant boost to the rooftop solar generation target.

PROMOTIONAL POLICIES: INDIA

The Ministry of New and Renewable Energy (MNRE) issued a draft for distributed generation, calling for 500 MW of installations by energy service companies (ESCOs). Funding of the projects comes from the Central Government, states and commercial sources. To encourage ESCOs into the market, the ministry plans to set up special category of private developer or operator known as Rural Energy Service Providers, giving the RESPs special incentives and privileges, including upfront capital from the ministry and streamlined approvals. Those that work in the areas with little or no grid access will be preferred for funding. The ministry is encouraging states to offer tax waiving on micro-grids and mini-grids. The ministry encourages the RESPs to develop the system to energize internet access, medical and educational services, potable water, skills and training. Along with the afore-mentioned provisions, the ministry gives the operator of the mini-grids an advantage to sell the power back to the grid, in grid-connected systems, to raise revenue from the installation.

6.10 CONCLUSION

Renewable Energy has now become more cost competitive with fossil fuel in many markets around the world. The current trend has also recorded investments into Renewable Sector. Countries like Germany, Denmark are leading their way to attain complete RE Penetration. The Renewable energy sources Act 2014, in Germany and ERCOT in Texas are taking measures to integrate large renewables into grid.

India Smart Grid Forum

MODULE 7

POWER QUALITY

Abstract

Power quality concerns the interaction between various equipment and the grid. The field of power quality covers a large range of phenomena (referred to as "disturbances"), the most important of which are discussed in this module. If Power Quality Challenges are not addressed properly, it may result in a large increase in the probability of interference (equipment damage or mal-operation). Per-manent Power Quality monitoring is an important part in keeping track of these challenges.

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7 POWER QUALITY

7.0 INTRODUCTION

There are many definitions of power quality, based on the applications. Sometimes power quality is defined from the viewpoint of equipment performance, while in other cases it is defined from the viewpoint of the grid. Although both kinds of definitions are in use, in practice the term power quality is very much used from the viewpoint of the grid. The term “power quality disturbance” is defined as “any deviation from the ideal voltage or current waveform, magnitude or frequency”.

A related term is “power quality interference” or “interference”. It occurs when a device is adversely affected by a disturbance. The aim of all work on power quality is in the end to avoid interference. The approach used to limit the probability of interference is to keep disturbance levels very low. But one should always keep in mind that the ultimate aim is to avoid interference.

The term “power quality” has been around for a long time. One of its first mentioning was in a paper on converters for aerospace used in 1962. Especially since 2000, the term has been used a lot, and the last several years, about one in 40 papers on electric power in the IEEE Xplore database is are about power quality.

Power quality is important for several stakeholders in the electric power system. The ones most im-pacted by poor power quality are the consumers of electric power. But the current quality and even the voltage quality can have an adverse impact on the network operator as well. Other stakeholders are the energy Electricity Regulators, Policy makers and even the general public, as power quality is part of the grid performance which in turn has economic consequences.

7.1 FREQUENCY VARIATIONS

Frequency variations are deviations of the frequency from its ideal value or “nominal value” which is 50 Hz in large parts of the world. An example of frequency variations is shown in Figure 1. The figure shows the values, taken as an average over each 10 seconds, measured first in Turin, Italy and later in Gothenburg, Sweden. As the northern European interconnected system is smaller than the European Continental one, the frequency variations are bigger in the former one.

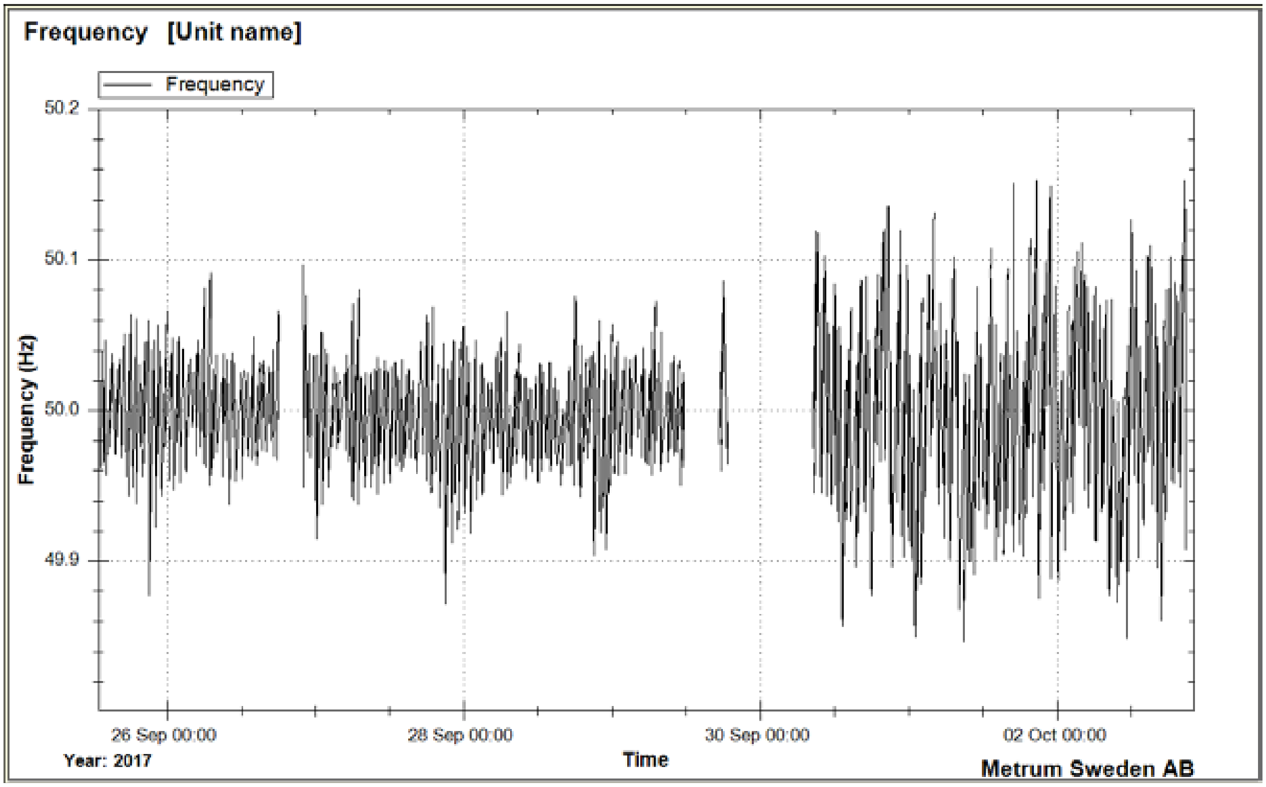


Figure 7-1: Frequency variations on the European continent (left) and in the Northern Europe (right). The gaps in data points occurred when the monitor was moved from one location (country) to anoth-er.

Frequency variations are a concern for the Transmission-System Operator (TSO). Frequency control is an important tool in keeping the balance between Power generation and Demand in an interconnect-ed system. During islanded operation or during large-scale disturbances, the Under Frequency-load-shedding schemes may result in interruptions. Frequency variations are expected to become large in certain types of microgrids. As per CERC Regulations, the Normal frequency range is 49.9 Hz to 50.05 HZ. The Load despatch centre monitors the frequency. As per CERC's Deviation Settlement Mecha-nism (DSM) Regulations, penalties are levied on the errant constituents, responsible for violating the normal range.

7.2 VOLTAGE DIPS

What is a Voltage Dip?

A decrease of the normal voltage level between 10% and 90% of the nominal rms voltage at the power frequency, for durations of 0.5 cycles (20millisecond) to 1 minute (i.e. for short-duration reduction in the rms voltage)

Causes of Voltage Dip

Faults on the transmission or distribution network (most of the times on parallel feeders, (Basically due to short-duration increase in current), Faults in consumer's installation, earth faults, Connection of heavy loads and start-up of large motors.

Consequences of Voltage Dip

Malfunction of Information Technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc) that may lead to a process stoppage, tripping of contactors and electromechani-cal relays, Disconnection and loss of efficiency in electric rotating machines.

An example of a motor-starting dip is shown in Figure 7-2. The figure is the Voltage waveform showing the voltage as a function of time. A more common way of presenting the dip is as an rms voltage as a function of time, as is shown in Figure 3 for the same dip. The rms voltage is calculated, over every cycle of the power-system frequency and the values are shown as a function of time.

Motor starting dips are typically repetitive & are occurring as & when motor starts. An example is shown in Figure 4, measured at the same location as the previous two figures. The highest, lowest and average one-cycle rms voltage are calculated by the monitor every second and shown in the figure as a function of time. The lowest one-cycle rms voltage is significantly below the average value. Also the repetitive character of the dips is clearly visible. In this example, the maximum, minimum and average values were obtained every second. Note also that none of the dips has a residual voltage (lowest one-cycle rms voltage during the event) below 90% of nominal (nominal being 230 V in this case).

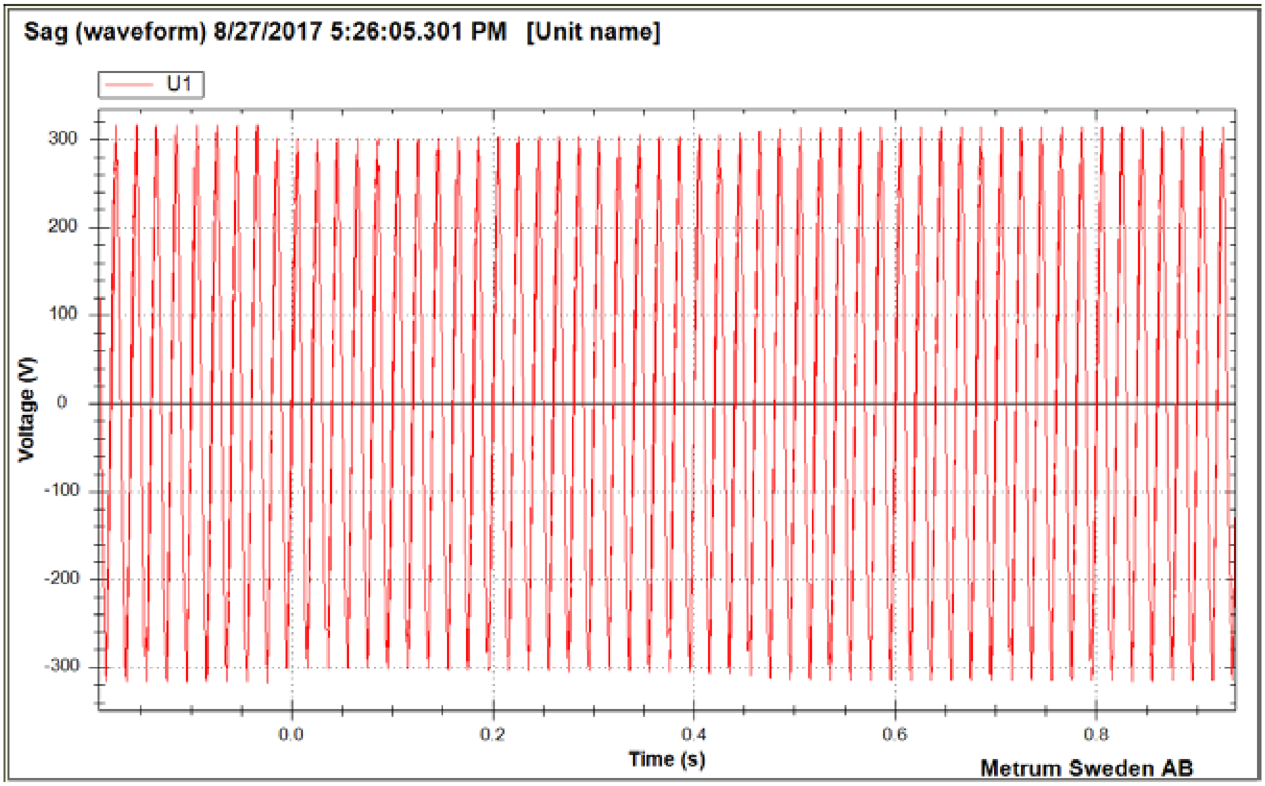


Figure 7-2: Voltage dip due to motor starting – voltage waveform versus time

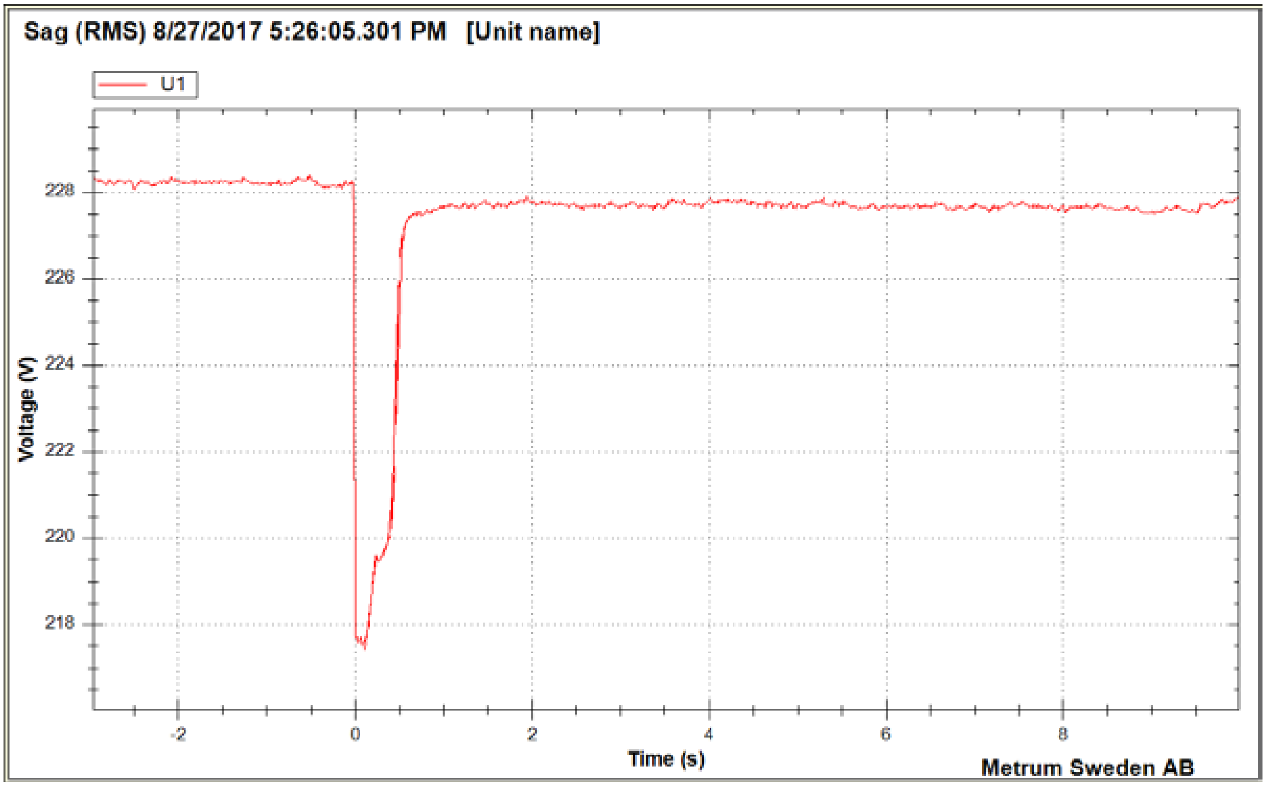


Figure 7-3: Voltage dip due to motor starting – rms voltage versus time

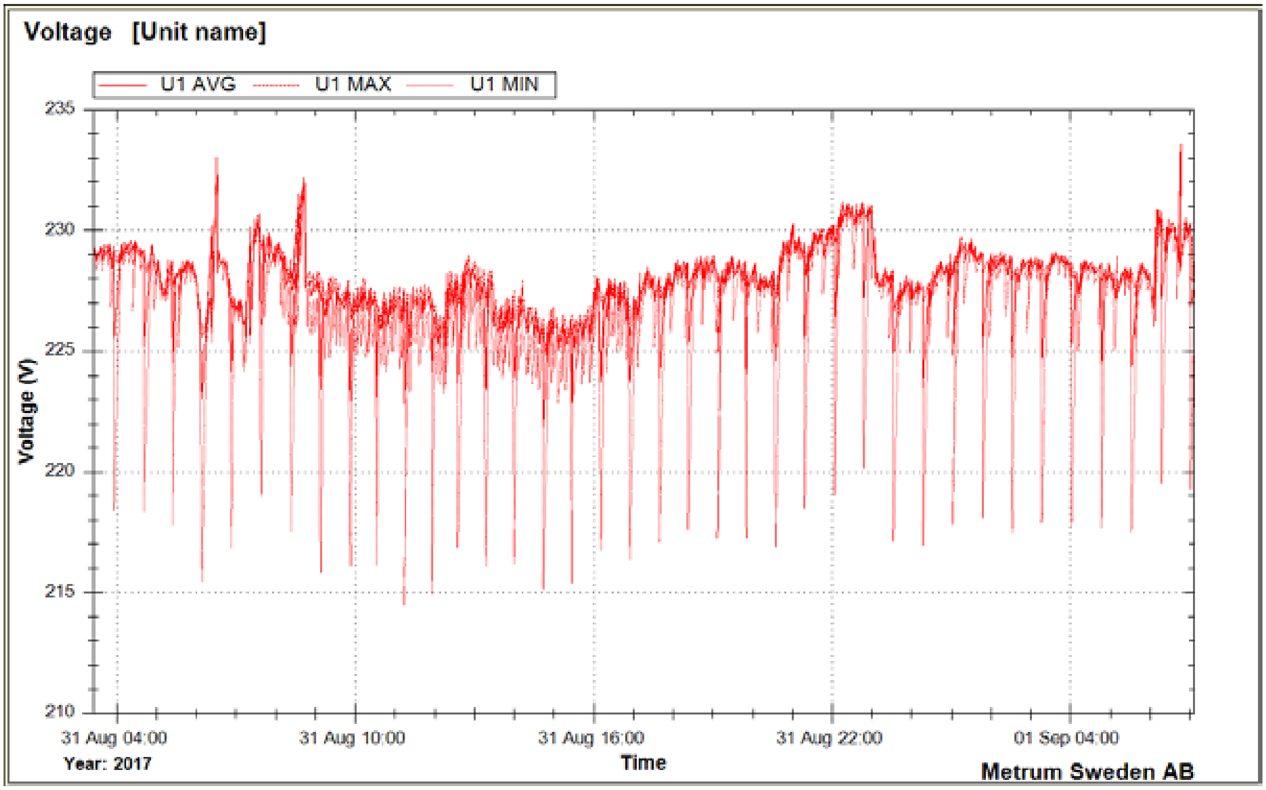


Figure 7-4: Repetitive motor-starting dips in an office building

Motor starting dips are typically shallow, the most severe ones having residual voltages down to 80 or 75% of nominal. Their main impact is often a blinking in the light, but the more severe ones can still result in equipment mal-operation.

The most severe dips are due to short-circuits and earth faults. An example of a voltage dip due to a three-phase fault is shown in Figure 5. Contrary to earlier plots, all three phase-to-neutral voltages are shown here. Three-phase faults are a minority of the faults in the grid; most are single-phase faults. Even though dips due to three-phase faults are still a substantial part of the dips due to faults, the more typical dip is due to a single-phase fault.

An example is shown in Figure 6, measured at three different voltage levels, for one single-phase fault at 400 kV. The same fault typically results in different dips at different locations in the grid, and thus for different customers.

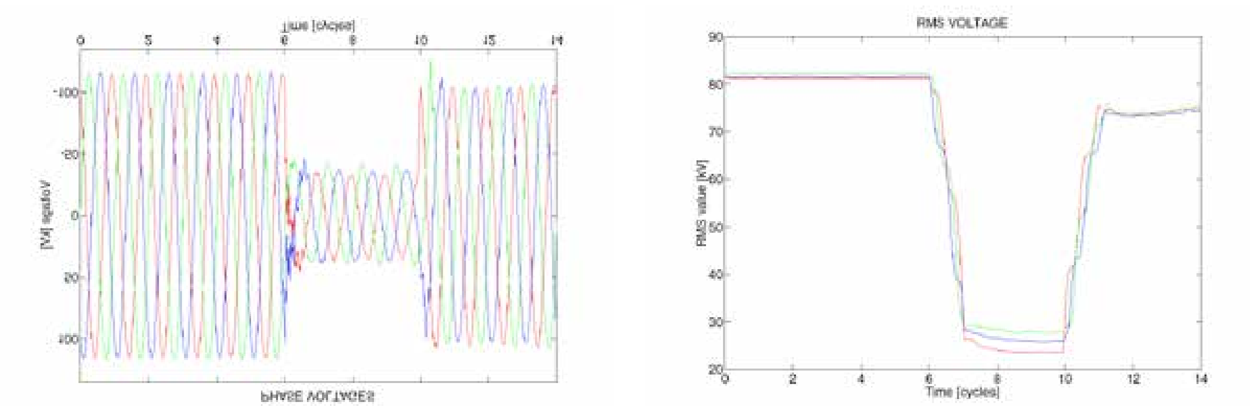


Figure 7-5: Voltage dip due to a three-phase fault: voltage waveform (left) and rms voltage versus time (right). The three colours refer to the three phase-to-neutral voltages.

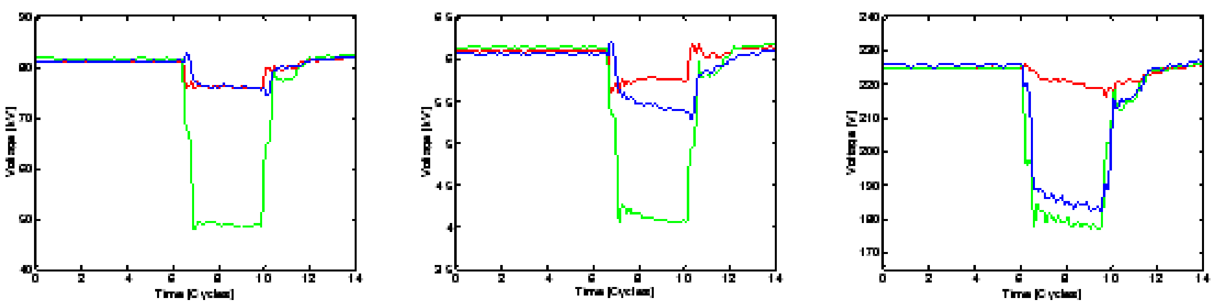


Figure 7-6: Voltage dip due to a single-phase fault at 400 kV; measured at 130 kV (left), 10 kV (middle) and 400 V (right).

Voltage dips are a serious concern for industrial customers. Even shallow dips of just 100-ms duration (5 Cycles) have resulted in the tripping of large industrial installations with many hours of restart time and high economic costs. The tripping of industrial installations due to voltage dips used to be a major point of discussion between network operators and their industrial customers. The introduction of the “responsibility sharing concept” has done a lot to allow for more constructive dialogue. Under this concept, short and shallows dips should be tolerated by the equipment, installation, and/or by the pro-duction process. Long and deep dips should be mitigated by measures in the grid or by “filters” like uninterruptible power supplies or static transfer switches.

Dips are however still a concern and the quest for the perfect solution continues. Especially smaller industries do not have the expertise to understand how to solve dip-related equipment trips. More severe dips can also result in tripping of computers (being nuisance to Office workers or consumer electronics) Repetitive voltage dips can result in a reduction in life time for equipment.

7.3 VOLTAGE SWELLS

What is a Voltage Swell?

Voltage Swell is opposite of Voltage Dip. It is momentary increase of the voltage, at the power fre-quency, outside the normal tolerances, with duration of more than one cycle (20 milliseconds) and typically less than a few seconds.

Causes of Voltage Swells

Start/sudden loss of large loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours)

Consequences of Voltage Swells

Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high

The distributed generation, like solar and wind power, will result in an overall increase of the voltage level with an increasing risk of voltage swells. Voltage swells can also be due to the connection of large single-phase equipment. Such a connection results in the drop in voltage in the phase, to which the equipment is connected. But at the same time, because of the voltage drop over the neutral conduc-tor, it gives a rise in voltage in the other two phases. Due to high production from PV installations, se-vere voltage swells may occur. The combined introduction of PV and Home electric vehicle charging, where one of them or both are connected to single-phase, will increase the risk of voltage swells.

The most severe voltage swells occur due to single-phase faults, as the voltage in the non-faulted phases rises during the fault. In a solidly-earthed system, the highest voltages that can occur are about 130% of nominal. This is the case for a single-phase fault in a long overhead line and a high ground re-sistivity. For cables and for low ground resistivity, the over-voltages will be lower.

Voltage swells are mainly a concern for low-voltage customers, in remote locations. They can result in equipment damage, especially when occurring regularly. PV installations are typically equipped with anti-islanding protection; voltage swells result in their tripping. Due to lack of measurements in low-voltage networks, the customer is often not aware of the occurrence of swells and its impact on his equipment. In impedance-earthed systems, common in many countries' medium-voltage networks, a single-phase fault will result in a voltage up to about 180% in the non-faulted phases. These can result in premature aging of cable insulation, but it does not impact any end-users because of the delta-star-connected transformers between medium and low-voltage networks.

7.4 SHORT AND LONG INTERRUPTIONS

What is a short interruption?

Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

Causes of Short interruption

Mainly due to the opening and automatic reclosers of protection devices, to decommission a faulty section of the network; the main fault causes are insulation failure, lightning and insulator flashover

Consequences of Short Interruptions

Tripping of protection devices, loss of information and malfunction of data processing equipment, Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they are not prepared to deal with this situation

What is a Long Interruption?

Total interruption of electrical supply for duration greater than 1 to 2 seconds

Causes of Long Interruption

Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines or poles, fire, human error, bad coordination or failure of protection devices.

Consequences of Long interruptions: Stoppage of all equipment

Thus, the distinction between long and short interruptions is in their duration. Interruptions are a concern for all customers. The longest interruptions are often the ones, which have their origin in the low-voltage networks. One of the reasons for this being, it takes longer for them to be reported, as only fewer customers are impacted. The main contribution to the unreliability comes however from inter-ruptions that originate in medium-voltage networks. Medium-voltage network are more extended, creating more opportunities for things to go wrong. Contrary to high-voltage networks, medium volt-age network are typically radially operated, without remote-control switching, so that any fault results in an interruption. Interruptions originating at High or Extra-High Voltage levels (sub-transmission or transmission) are rare as these networks are operated meshed (in a ring) and monitored continuously from a control room. However, once an interruption occurs at these higher voltage levels, many cus-tomers are affected and it may take many hours for the supply to be restored.

Short interruptions are mainly related to automatic reclosing, after a fault in medium or low-voltage overhead lines. Some of the reclosing schemes (like "fuse-saving") give a reduction in the number of long interruption but at the expense of increased short interruptions. The total number of interrup-tions (long and short) can be, for some customers, several times higher than the number of long inter-ruptions in no-reclosing case. For industrial customers, a short interruption can be almost as bad a long one. Hence, such reclosing schemes are not always popular with industrial customers.

Overvoltage has been observed at the start of interruptions, two examples are shown in Figure 7-7. In both cases, the interruption was due to the opening of a breaker, without any fault causing this. An example of an interruption due to a fault is shown in Figure 8, the voltage dip that precedes the inter-ruption and the motor load keeping up the voltage for a while, is clearly visible.

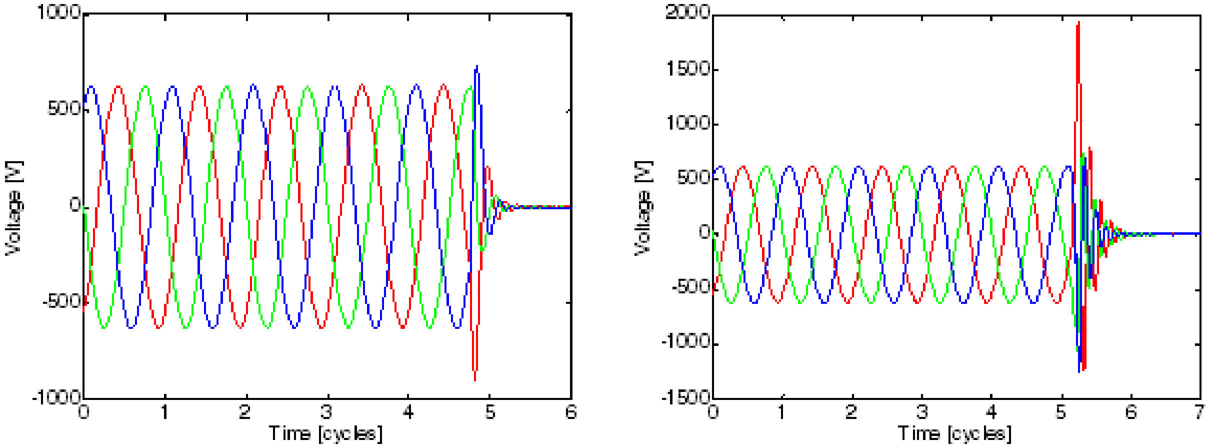


Figure 7-7: Overvoltages with the start of a non-fault interruption.

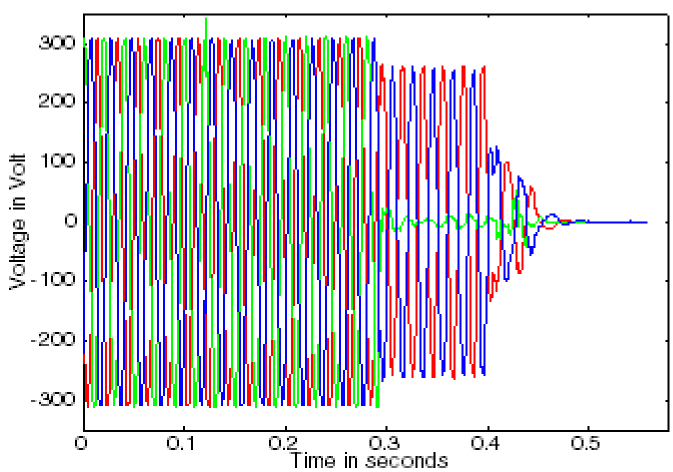


Figure 7-8: Voltage dip and motor contribution at the start of an interruption due to a fault

The occurrence of overvoltage can result in equipment damage. Another possible cause of equipment impact (beyond the actual interruption) is the presence of heavy voltage distortion, after the interrup-tion. This is due to the saturation of transformers which are energizing when the voltage is restored; an example is shown in Figure 9. Even two seconds after the voltage recovery, heavy harmonic voltage distortion remains.

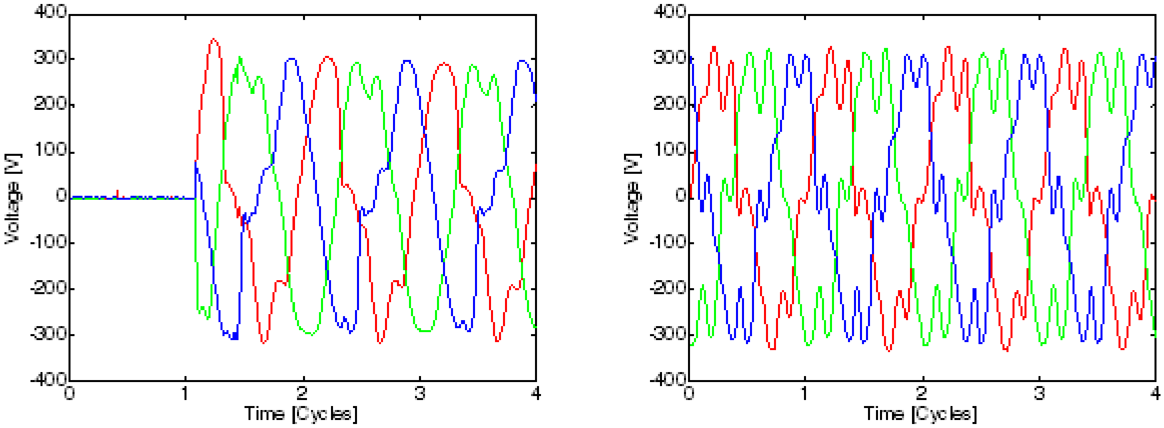


Figure 7-9: Heavy waveform distortion due to transformer saturation after an interruption: upon volt-age recovery (left) and two seconds later (right).

7.5 SLOW VOLTAGE MAGNITUDE VARIATIONS

What is a Slow Voltage Magnitude Variation?

A slow voltage magnitude variations, also defined as supply voltage dips, is the sudden reduction in supply voltage to a value between 90% and 1% of the nominal voltage value followed by the recovery, after a short period of time. Conventionally the duration of dip is between 10ms to 1 minute.

Every electrical equipment or appliance is designed for operating at a rated voltage level with an ac-cepted tolerance level, and the rated voltage is essential for ensuring constant output power level, from each equipment. Studies have shown that variation of voltage levels by 10% increases the slip of induction motors, a major industrial load, by up to 21% and also reduction in torque.[1]

Variation in voltage and frequency has been an age old problem in electric distribution system. The dip in voltage and frequency with starting of large induction motors are common in industries, but the advent of new generation starters has solved these sudden voltage dips to a great extent. As the grids got interconnected and system stability increased, residential and commercial consumers were largely protected from the menace of sudden voltage variations. However, with increase in penetration of distributed generation systems and micro-grids where generation and storage capacity are limited, the voltage variation with change in load distribution has to be a major consideration while evaluating the power quality.

In India, the Technical Standard for Connectivity to Grid Regulations 2012 mandates voltage regulation of + 5% of nominal value and the flicker limits as per IEC 61000[2]. Voltage characteristics in public distri-bution system as defined by EN 50160 requires the voltage magnitude Regulation to be within + 10% for 95% of a week, when measured as the mean of 10 minutes rms values.

ICE 61000 defines two aggregated intervals for variations in rms voltage: a 3 second "very short time" and a 10 minute "short time" interval and only the 10 minute values are used to quantify the system

[1]Bonnet A H and Boteler R, "The impact that voltage variations have on AC induction motor performance" , available at http://aceee.org/files/proceedings/2001/data/papers/SS01_Panel2_Paper27.pdf

[2]Technical Standard for Connectivity to the Grid (Amendment) Regulations 2012, available at http://www.cea.nic.in/reports/regulation/grid_connectivity_12112013.pdf

performance. As per IEC 50160, slow voltage magnitude variations, also defined as supply voltage dips, is the sudden reduction in supply voltage to a value between 90% and 1% of the nominal voltage value followed by the recovery, after a short period of time. Conventionally the duration of dip is between 10ms to 1 minute and voltage variations up to 90% of the nominal value is not considered to be dips.

In India, the variation in distribution voltage is a concern, especially in rural areas. The voltage profile comparing three different areas shown in Figure 10 indicates the variation in voltage during evening peak. Distribution losses combined with lack of adequate compensation system are the major reasons for an unhealthy distribution voltage profile.

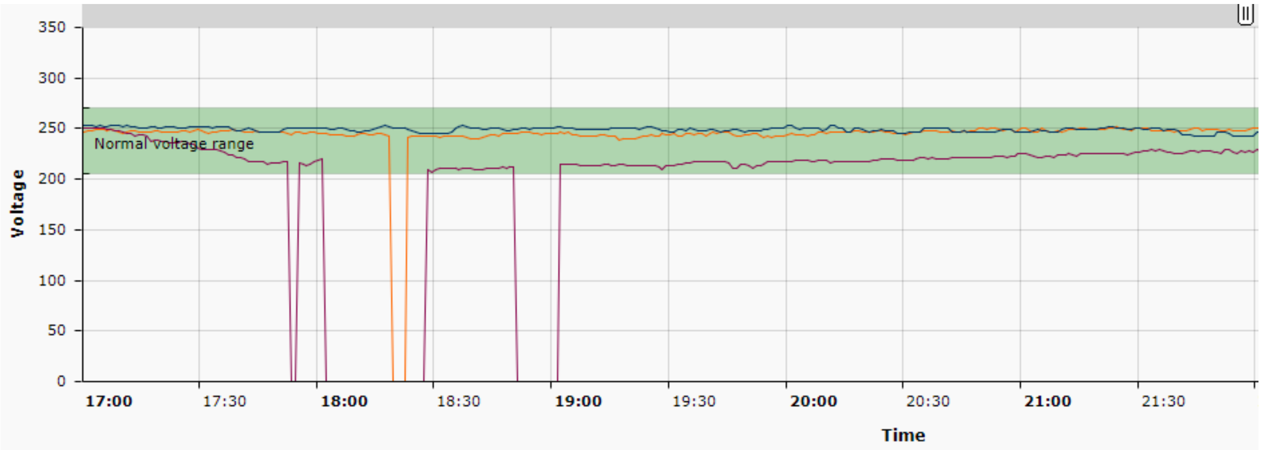


Figure 7-10: Voltage variations during evening peak in metro, municipality and village areas.

Distributed generation systems with smart grid technologies can alleviate the slow voltage variations in rural India, to a great extent. These small capacity generation units, mainly solar, wind and small hydro, located near to rural load centres can supplement the grid power, during peak hours and improve the voltage profile on remote located village areas, without any concern of very short variation in grid voltage.

However, the increased penetration of solar and wind based distributed generation systems integrat-ed with the grid may lead to slow voltage variations in the grid, mainly owning to the variation in wind speed and insolation levels[3] (exposure to Sun rays). The effect of slow voltage variations is felt the most, when the distributed generation systems are connected to the low-voltage distribution network and as a result, integration of these systems at high-voltage levels is recommended.

Demand Side Management (DSM), which is an integral part of smart grid, can also offer solution to slow voltage variation through load management (or curtailment) in response to power generation variation due to change in wind speed and insolation. In a smart grid integrated system, the predictive control for solar and wind would also play a significant role in minimizing the effect of slow voltage var-iations with change in weather parameters.

[3]Lennerhag O et al., “Very short variations in voltage (timescale less than 10 minutes) due to variations in wind and solar power”, 23rd International Conference on Electricity Distribution, June 2015, Lyon.

7.6 FAST VOLTAGE MAGNITUDE VARIATIONS

What is a fast Voltage Magnitude Variation?

Change in rms voltage on a time scale of 1 second or less is typically defined as fast voltage magnitude variations. This change can be continuous rapid voltage variations, also known as flicker or individual rapid voltage changes similar to a voltage step.

Transients, on the other hand, are large and sudden deviation from normal voltage levels at time less than one cycle. Unlike slow voltage variations, fast voltage variations are easily detected by human eye in the form of flicker or sudden change of luminosity of light sources. On application level, effect on performance of major industrial loads (induction motors) is limited due to their large inertia. However, large variations in voltage magnitude due to voltage step can change the power output. Also, the stress on electrical components due to fast change in voltage magnitude, which can deteriorate their performance over time, is another important operational parameter to be considered.

Large scale integration of renewable energy sources, particularly solar, with the conventional power grid may cause both frequency and fast voltage variations, resulting in significant impact in terms of power quality. PV generators have no mechanical inertia and cloud transients can result in instantane-ous fast voltage variations, in a grid with high penetration of PV generators. Wind, on the other hand, is less susceptible to fast voltage variations due to change in wind speed owing to the large inertia of rotor blades.

7.7 HARMONIC DISTORTION

What is Harmonic Distortion?

Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency.

Causes of Hramonic Harmonic Distortion

Classic sources: electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors.

Modern sources: all non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.

Consequences of Harmonics

Increased probability in occurrence of resonance, neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, errors in measurements when using average reading meters, nuisance trip-ping of thermal protections

Modern devices (non-linear loads in nature) such as SMPS based devices, Computers, Televisions, Washing Machine, Freezer, Refrigerator, Air-Conditioners, Lighting (mainly CFL), Resistance heaters, Furnaces, VSD, LED, Inverter, UPS, battery charger, Traction, digital protection devices have a major drawback of introducing of harmonics to the local distribution network. Due to presence of harmonics there is a distortion in sinusoidal voltage and current waveforms, which raises concerns regarding the power quality pollution in the electric grid.

Impact of Modern Non-Linear Loads on Grid

- Creates large load currents in the neutral wires of a 3-phase balanced system, thereby causing overheating. This may be a cause of potential fire hazard, as conventional circuit breakers or fuses do not protect the neutral wires.
- Causes overheating of electrical supply of transformers, which shortens the life of the important asset.
- Causes high voltage distortion exceeding IEEE Standard 1100-2005 “Recommended practice for Powering and Grounding Electronic Equipment” and manufacturer’s equipment specification.
- Causes high neutral-to-ground voltage to often exceed 2 volts exceeding IEEE Standard 1100-2005.
- Causes high voltage and current distortions exceeding IEEE Standard 519-1992 (revised further in 2014) “Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems”.
- Results in poor power factor conditions giving false sense of good level of power factor based on average power factor monitoring generally in vogue
- Causes higher apparent power demand (kVA) for the same effective power (kW) demand output.
- Causes resonance that produces over-current surges resulting in destroying capacitors and their fuses and damaging surge suppressors that will cause an electrical system shutdown.
- Causes false tripping of branch circuit breaker.
- Responsible for more heat generation, thus more energy is required to keep the system cool.
- Generator Heating: The harmonic currents produce high frequency flux change and results in heating of stator cores. The harmonic currents in the stator induce currents in the pole faces and armature windings (Higher magnetic core temperature result in higher winding temperature.

The term “waveform distortion” refers to the situation, when the voltage or current is not sinusoidal. In power-quality terms, waveform distortion is a variation, it is present all the time and it can be meas-ured at any moment or over any window of time. Main concern for network operators and consumers is in maintaining the harmonic distortion levels below the objective values that are set in the Standards and Regulations. When a large installation (like a wind park or an industrial installation) is connected to the grid, it is necessary to do an assessment of the harmonic situation after connection. Harmonic volt-ages and currents after connection are, compared with the objective values. When the values are ex-ceeded there is a the need to take measures.

An example of the voltage measured in an office building is shown in Figure 7-11. The voltage wave-form is close to sinusoidal, but it is not completely sinusoidal. For example, some small deviations occur around the voltage maximum. The spectrum of the voltage or current is typically used to quantify the distortion. As shown in Figure 7-12 for the same office building, the spectrum indicates which frequen-cy components are present in the voltage waveform Adding all the frequency components, with the right phase angle, would result in the original waveform.

The voltage in the office building is shown to contain 0.7% (percent of the fundamental voltage) of harmonic 7, 0.5% of harmonic 9, etc. The harmonic voltage distortion varies a lot between different locations as shown in Figure 7-13.

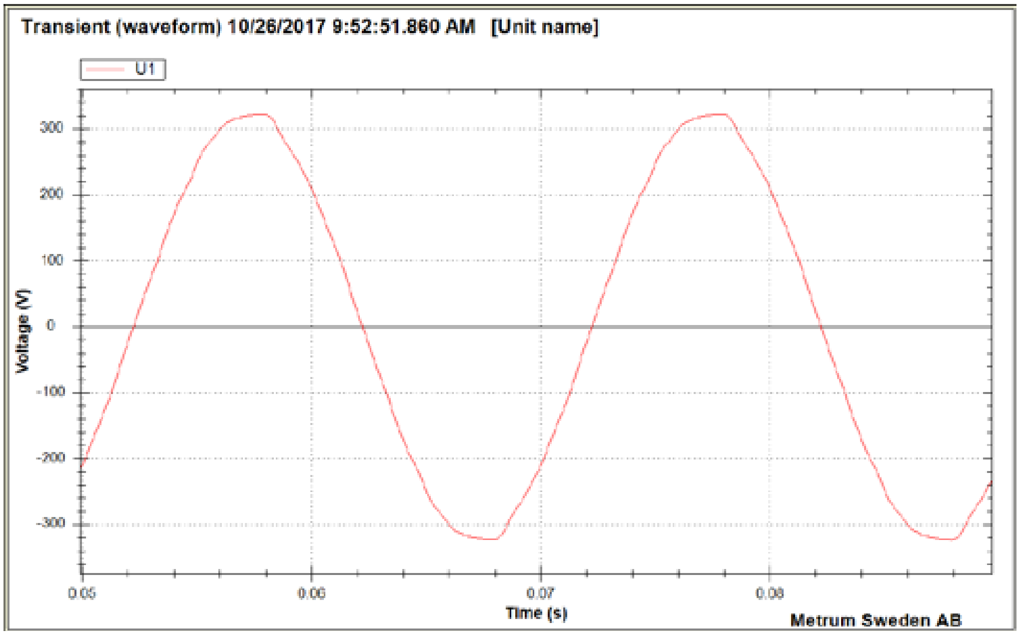


Figure 7-11: Voltage waveform measured in an office building in Sweden

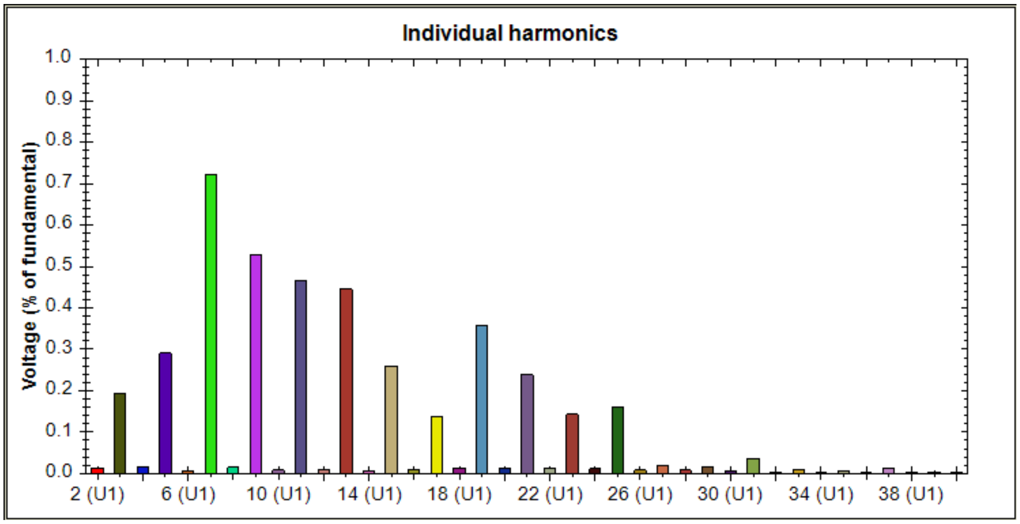


Figure 7-12: Spectrum of the voltage for an office building in Sweden.

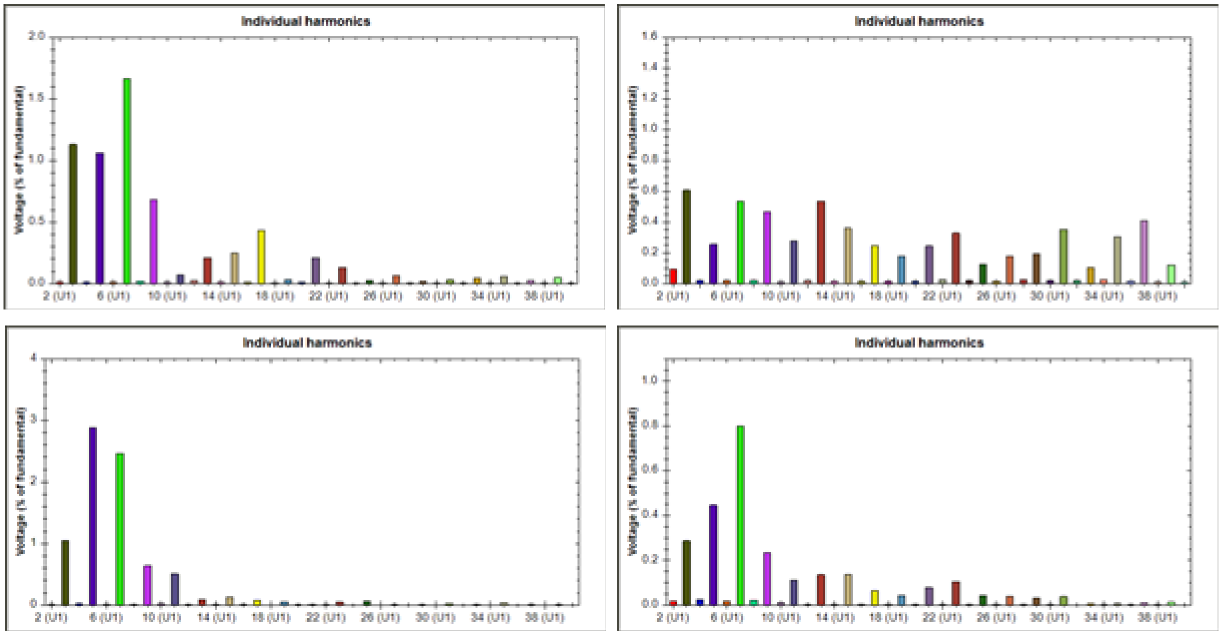


Figure 7-13: Apartment Gothenburg (top left), office building Mumbai (top right), airport Munich (bot-tom left); hotel Stockholm (bottom right). Note the differences in vertical scale.

Harmonic voltage distortion, as shown in the above figures, is due to harmonic current distortion, typically from end-user equipment. A typical example of the current to a computer screen some 15 years ago is shown in Figure 7-14. The Figure 7-15, is showing the spectrum of a modern television. The emission (distortion of the current) has become lower for the low-order harmonics, but new emission appears at higher frequencies. These higher frequencies, are called as “supra-harmonics”.

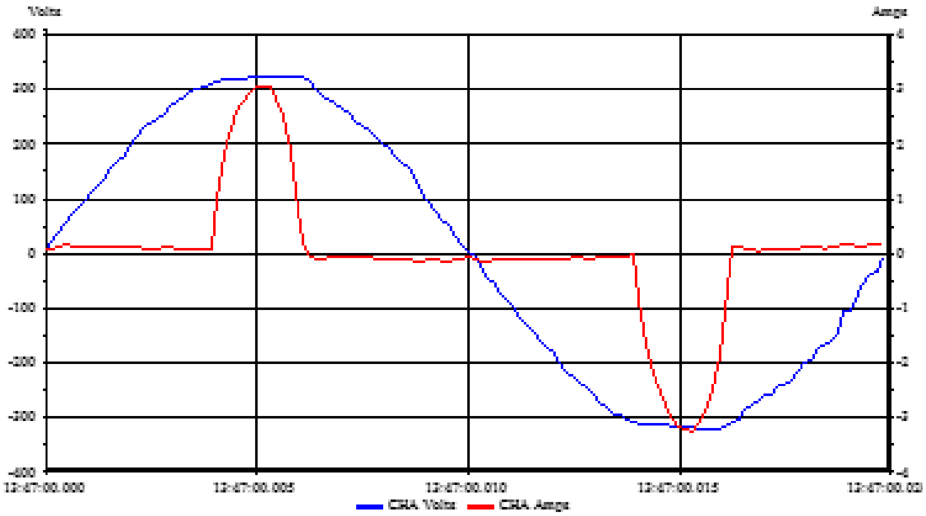


Figure 7-14: Current waveform (red) and voltage waveform (blue) at the terminals of a single-phase diode rectifier.

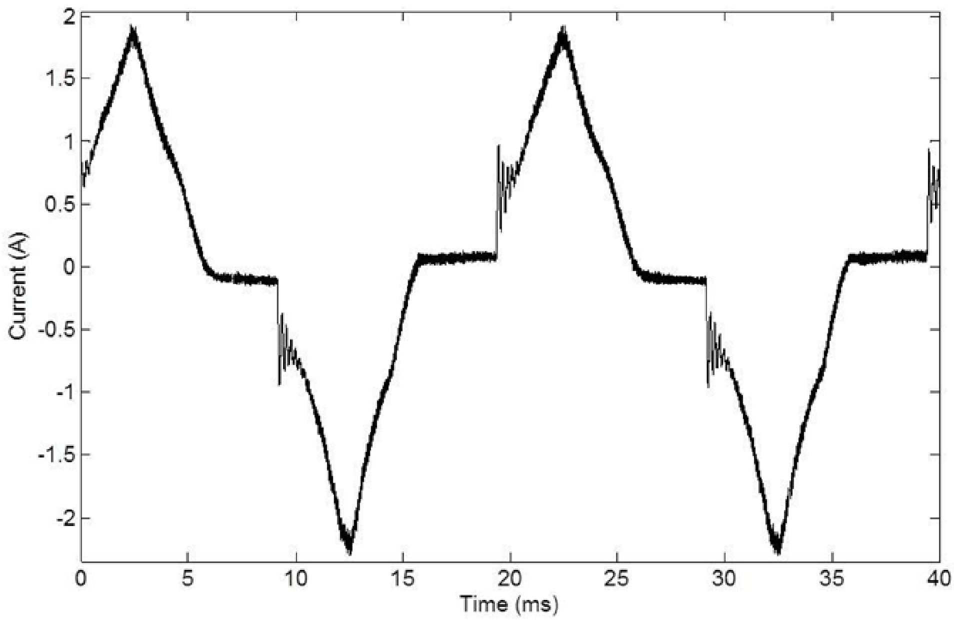


Figure 7-15: Current waveform for a device with active-power-factor-correction. (Source: Sarah Rönn-berg)

LED lamp, with a heavily distorted waveform is shown in Figure 7-16. The current waveform is shown for four different types of lamp. None of them shows a perfect sinusoidal waveform, but all of them are distorted. Here it should be noted however that the fundamental current for such lamps is small, so that their total contribution to the emission of an installation remains low. When replacing all incan-descent bulbs by LED lamps in an installation, the harmonic currents for the whole installation do not show much change. But again, high frequency "supra-harmonics" are injected, by most of these lamps.

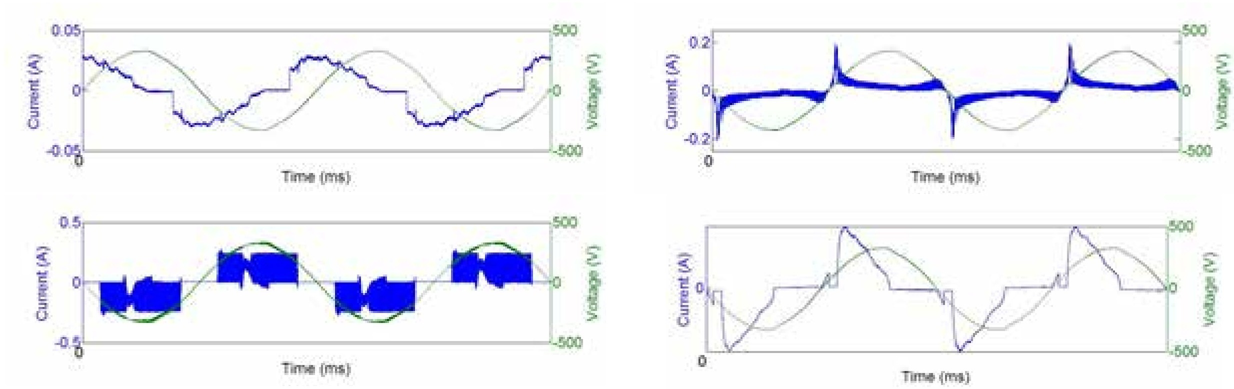


Figure 7-16: Examples of waveforms for different LED lamps

(Source: Sarah Rönnberg)

Harmonic waveform distortion impacts both network operators and customers. Brief list of problems that one typically can expect, when harmonic voltage or current distortion is high, (i.e. exceeding the objective values set in various Standards and Regulations) are given below:

Impact of High harmonic voltages in the grid:

- High currents through capacitor banks with fuse blowing or protection tripping as a result. Los-ing the capacitor bank can give higher reactive-power consumption or even voltage collapse.
- Forming of hot-spots in synchronous generators, resulting in derating of the Generators.

Impact of High harmonic currents in the grid:

- Forming of hot spots in transformers resulting in derating of the transformer.
- Overloading of the neutral conductor because of triplen harmonics. (Odd multiples of 3rd Har-monics i.e. 9th, 15th, 21st etc.)
- Magnetic fields, stray currents and telephone interference.

High harmonic voltages with end-user equipment can result in:

- Equipment tripping or mal-operation with multiple zero crossings.
- Inductive and capacitive coupling to electronic circuits through the power supply.
- Inter-harmonics and supra-harmonics creating noise in Power-Line Communication.
- Reduction in efficiency for rectifiers due to flattening of the waveform.
- High currents through capacitors in EMC filters leading to loss-of-life, especially due to high-order harmonics.
- Forming of hot stops in capacitors and in rotating machines, especially to low-order harmonics.
- High crest factor putting higher stress on insulation (being a concern at higher voltage levels)
- Incorrect protection operation, especially for solid-state relays.
- Incorrect values given by remotely-read energy meters, especially due to higher-order har-monics.

The spread of harmonics through the grid, from the emitting source to a device that is sensitive to harmonics, is ruled by resonances between capacitances and inductances. High levels of harmonic voltage or current distortion are related to resonances close to harmonic frequencies. An example of a resonance due to an industrial capacitor bank is shown in Figure 17. When the capacitor bank is con-nected, the reactive power consumption is low. But at the same time both voltage and current distor-tion are high at seventh harmonic. The correlation between low reactive power consumption and high harmonic distortion is clearly visible from the plots.

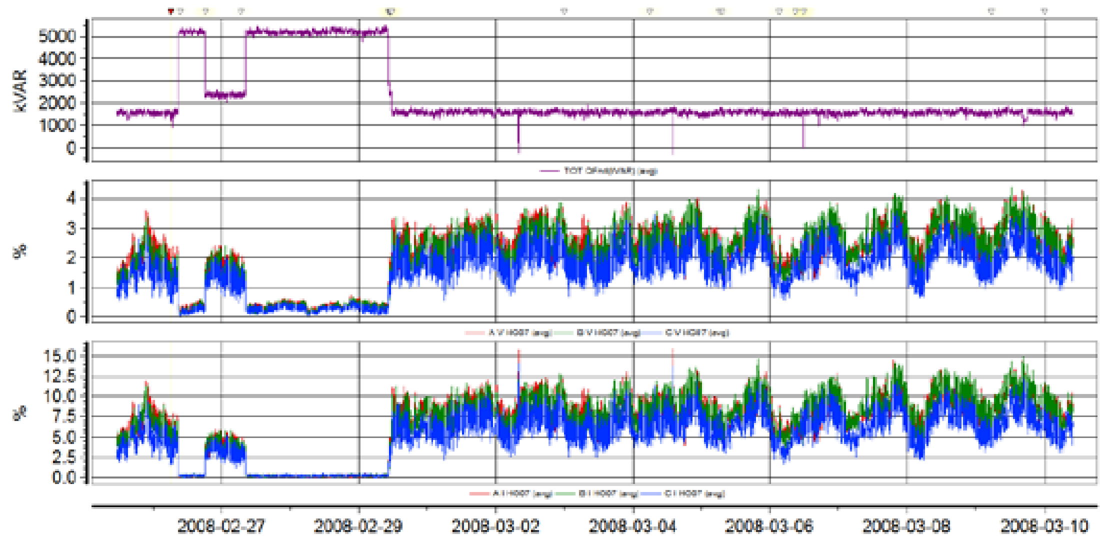


Figure 7-17: Reactive power consumption (top), seventh harmonic voltage (centre) and seventh har-monic current (bottom) at the terminals of an industrial installation

7.8 SUPRA-HARMONICS

What is a Supra-harmonics?

Supra-harmonics are waveform distortion at frequencies between 2 kHz and 150 kHz (> 40th Harmon-ics). The term "supra-harmonics" It is the same as "high frequency distortion", "high frequency har-monics", "low-frequency EMC" and "converter harmonics".

Several examples of supra-harmonics were shown in the section on harmonics. The study of equip-ment for mainly domestic customers showed that more than half of the devices emitted a significant amount of supra-harmonics. Active switching in the power-electronic circuit has become the easiest way of limiting harmonic emission to below the limits set in product standards. Some examples of equipment emitting supra-harmonics, and the most common frequencies found are:

- PWM converters (around 3 kHz)
- Industrial size converters (9 to 150 kHz)
- Oscillations around commutation notches (up to 10 kHz)
- Street lamps (up to 20 kHz)
- EV chargers (15 kHz to 100 kHz)
- PV inverters (3 kHz to 20 kHz)
- Household devices (2 to 150 kHz)
- Power line communication, AMR (9 to 95 kHz)

Four examples are shown in Figure 18. The figure shows the "spectrogram" which is also known as "time-frequency representation" or "short-time-Fourier transform". The horizontal scale shows time and the vertical scale frequency; the colour indicates the magnitude of the emission at each frequency and point in time, where red is highest emission and dark blue lowest emission (a so-called “heat scale”). The emission for most devices changes a lot within one cycle of the power-system frequency.

There are several possible sources of supra-harmonics, like VSC-based HVDC and wind turbines, con-nected to higher voltage levels. But measurement of supra-harmonics at those voltage levels is diffi-cult.

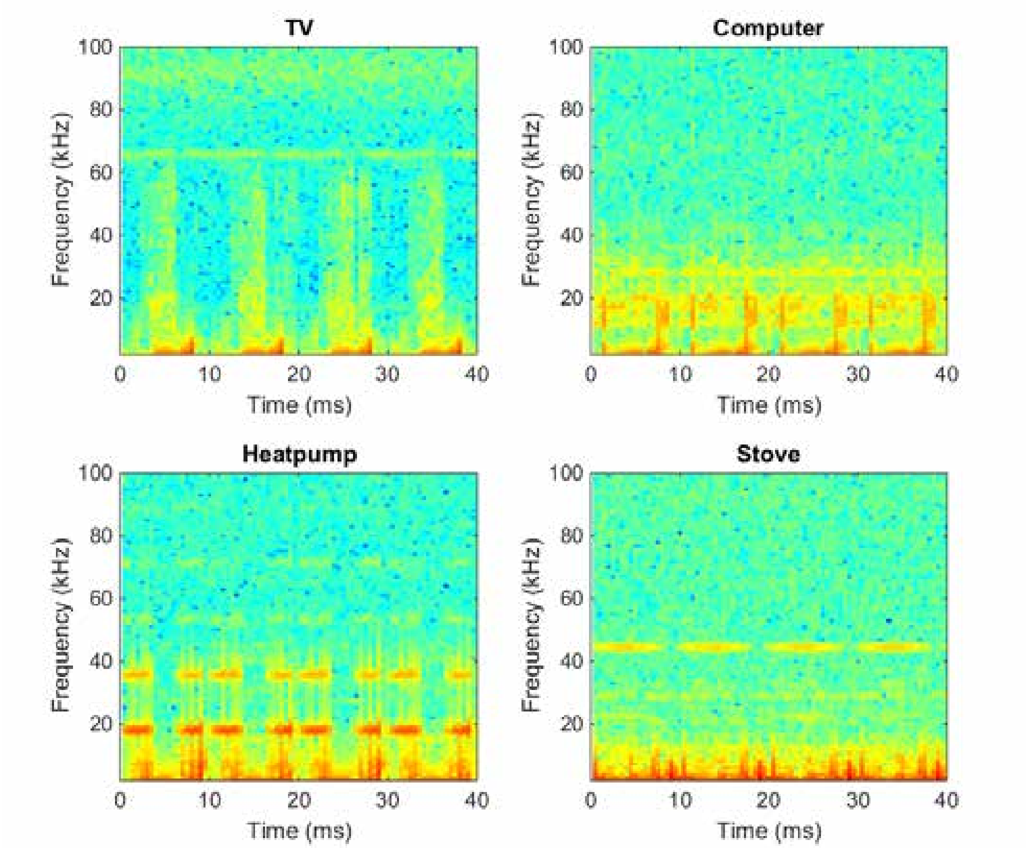
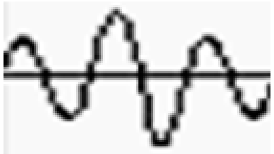


Figure 7-18: spectrogram showing changes in supraharmonics emission at millisecond timescale for four different devices. (Source: Sarah Rönnberg)

Supra-harmonics have the tendency to spread between equipment, but during resonances the spread may be different. Resonances are very common at supra-harmonic frequencies, so that it becomes even more difficult to draw general conclusions. The research on supra-harmonics has only recently started, on a wider scale and more research is needed for a broader and deeper understanding

7.9 ADITIONAL THREE IMPORTANT POWER QUALITY ISSUES (CHAL-LENGES)

7.9.1 VOLTAGE FLUCTUATION



What is a Volatge Voltage Fluctuation?

Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz

What are Causes of Voltage fluctuation?

Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads

What are the Consequences of Voltage Fluctuations?

Most consequences are common to under-voltages. The most perceptible consequence is the flicker-ing of lighting and screens, giving the impression of unsteadiness of visual perception.

7.9.2 NOISE

What is the Noise?

Superimposing of high frequency signals on the waveform of the power-system frequency.

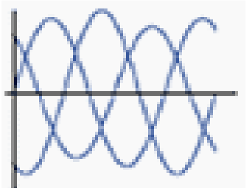
What are the Causes of Noise?

Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment Improper grounding may also be a cause

What are the Consequences of Noise?

Disturbances on sensitive electronic equipment, usually not destructive, May cause data loss and data processing errors

7.9.3 VOLTAGE UNBALANCE



What is Voltage Unbalance?

A voltage variation in a three-phase system in which the three voltage magnitudes or the phase angle differences between them are not equal

What are the causes of Volatage Unbalance?

Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault).

What the consequences of the Voltage Unbalance?

Unbalanced systems imply the existence of a negative sequence that is harmful to all three- phase loads. The most affected loads are three-phase induction machines

7.10 CHALLENGES IN POWER QUALITY

Several changes that have a potential impact on the power quality occur in production side and also consumption side or in the electricity grid. For power quality, probability of interference is very im-portant. As long as this probability does not increase, it doesn't matter. Increase in interference can occur due to increase in emission of disturbances; decreased immunity; or increased transfer through the grid. All three could be impacted by changes and some examples are shown in Figure 19 to 22. The different cells indicate which specific changes impact emission, immunity or transfer for a certain type of disturbance.

For example, switched capacitor banks will be part of advanced voltage control in the smart grid (Fig-ure 7-19). This will impact resonant frequencies: they will move to lower values and show more regular changes. This impacts the transfer on harmonics and the oscillation frequency of switching transients. Continuous control methods, like converter-based reactive-power control, will result in emission of supra-harmonics. Discrete control methods, like tap-changers and switched capacitor banks will result in more voltage steps.

	Emission	Immunity	Transfer
Harmonics			Switched capacitor banks
Interharmonics			
Supraharmonics	Continuous control methods		
Fast volt variations			
Voltage steps	Discrete control methods		
Switching transients	Switched capacitor banks		Switched capacitor banks

Figure 7-19: Changes in power-quality due to advances in voltage control as part of smart grids

The increased use of microgrids (Figure 7-20) will result in emission of supra-harmonics from battery storage installations and higher harmonic levels because of a generally weaker source during island operation.

	Emission	Immunity	Transfer
Harmonics			Change in source impedance
Interharmonics			
Supraharmonics	From storage installations		
Fast volt variations			
Voltage steps	to and from island operation		
Switching transients	to and from island operation		

Figure 7-20: Changes in power quality due to island operation of microgrids

New sources of production can impact the power quality in many different ways (Figure 21): for ex-ample: emission of inter-harmonics from wind and solar power installations; supra-harmonics from voltage-source converters; over-voltages due to connection of PV to low-voltage networks and switching transients associated with cables in wind parks.

Recent events have shown that wind-turbine controllers in large parks could become unstable due to high levels of harmonics or inter-harmonics. Similar problems were observed several years ago with PV installations.

	Emission	Immunity	Transfer
Harmonics		Harmonic instability	Change in resonance
Interharmonics	Wind and solar power	Interharmonic instability	Change in resonance
Supraharmonics	Voltage-source converters	Supraharmonic instability	
Fast volt variations	Variations in sun and wind		Weak transmission grids
Slow voltage variations	Overvoltages becomes a serious problem		
Switching transients	Long cables and wind parks		Weak transmission grids

Figure 7-21: Changes in power quality due to new sources of production

The general shift to more active power-electronics control in equipment connected to the grid will create large uncertainties in the immunity of new equipment. Harmonic emission will generally re-duce, but at the expense of the emission of supra-harmonics. Most such equipment contains an EMC filter with a grid-side capacitor. The combined effect of all these capacitances is a lowering of the reso-nant frequencies, especially in the low-voltage network.

	Emission	Immunity	Transfer
Harmonics	In general a reduction	Unknown for new equipment	Adding capacitance
Interharmonics		Unknown for new equipment	Adding capacitance
Supraharmonics	Active interface	Unknown for new equipment	Multiple local resonances
Fast volt variations			
Voltage steps			
Switching transients		Unknown for new equipment	Adding capacitance

Figure 7-22: Changes in power quality due to increased number of power-electronic interfaces with active switching

The overall conclusions are:

- Increasing amounts of capacitance connected to the grid will result in a shift of resonances to lower frequencies
- New types of disturbances will occur: supra-harmonics are expected everywhere; more equipment than before will emit even harmonics, inter-harmonics, DC and quasi-DC. Also the level of voltage magnitude variations at the time scale between a few seconds and a few minutes is expected to increase.
- More switching actions will occur, with more transients, voltage steps and changes in resonant frequency, as a result.
- Immunity of modern equipment is less understood.

7.11 POWER-QUALITY MONITORING

Measurement of voltage and current has been a common part of power-quality studies from the be-ginning. Those measurements were in almost all cases only initiated after serious cases of interfer-ence; the oscilloscope and the universal (voltage and current) meter were the tools being used. Around 1990 it became practically and economically possible to measure voltages and currents perma-nently and record the data for analysis afterwards. Such measurement equipment (which soon be-came referred to as "power-quality monitors") were very expensive in those days and were typically used for trouble shooting.

Barrier against the widespread use of power-quality monitoring was the high costs of data transfer and storage. This barrier has since disappeared by developments within communication and computing fields. A huge step forward in power-quality monitoring was made by the publishing of the IEC power-quality standard IEC 61000-4-30. The document solved several of the definition issues that had kept the power-quality community busy for many years. It defined a standard method for processing and recording voltage and current to obtain power-quality information. This method is referred to as “Class A”. The alternatives (Class B and later Class S) where introduced as a transitions to allow existing moni-tors to remain on the market. Class A allowed for the first time a comparison of results between dif-ferent manufacturers. It also made it much easier for new manufacturers to enter the market, which resulted in a broadening of the market and a reduction in price.

Around 2010 instruments for power-quality monitoring had become cheap and it became justifiable to install them permanently, for monitoring of the supply. Recommendations for such permanent moni-toring programs were issued by the European Energy Regulators, in 2013, and by an international working group under CIGRE (an organisation where the network operators play an important role), in 2014.

Both EE Regulators & CIGRE indicated that a power-quality monitoring program is important for a mod-ern utility or network operator & both gave recommendations on where to place the monitors (at least at every MV side of an indeed from the transmission grid), what to monitor (basically everything following Class A), and how to publish the results (at least annually). Even with the shift to the smart grid, Power quality, together with reliability, will define the performance of the smart grid.

7.11.1 POWER QUALITY MONITORING: INDIAN SCENARIO

CERC and SERCs have notified Regulations on power Quality however, the implementation is not strict-ly enforced. Frequency and Average Power Factor are the only monitored parameters of the electrici-ty supply. Frequency regime is implemented through CERC Regulations and consistently is followed across the country. Power factor is also largely maintained at optimum levels and implemented through incentives and penalties in tariff determined by the SERCs. However in absence of true power factor measurement the impact of distortion in waveform due to nonlinear loads remain unknown.

The chart on the next page gives a comparative analysis of power quality Regulations in different states.

Maharashtra

Monitoring:
Consumer is responsible for taking corrective action for preventing harmonics and injection.

Compensation:
Penalty and incentive for harmonics as per the state commission orders, however no such penalty or incentive is ever specified so far.

Gujarat

Monitoring: No clarity in monitoring and implementation methodology for Harmonics and Voltage.

Compensation: No compensation on account of failure to maintain voltage and harmonics within prescribed limits.

Tamilnadu

Monitoring:
DISCOMs need to monitor the voltage, frequency and power factor at peak and off peak hours and take reasonable measures for improvement of the same in coordination with users. No monitoring provision for other Power Quality parameters.

Compensation:
No compensation on account of failure to maintain voltage within prescribed limits. Consumer is liable to pay compensation at 15% of the respective tariff when it exceeds harmonics injections limits specified

Madhya Pradesh

Monitoring:
No clarity in monitoring and implementation methodology for Harmonics and Voltage. DISCOM need to monitor the harmonics at regular interval at strategic points where it is prone to harmonics voltage generation.

Compensation:
No regulations specified for compensation in Madhya Pradesh.(Forum of Regulators)

Andhra Pradesh

Monitoring: DISCOMs need to monitor voltage and harmonics as per prescribed limits. But no clarity on method of recording harmonics.

Compensation:
Compensation to consumers applies in case of default in voltage regulations. However, No compensation on account of voltage fluctuation payable to industrial and agricultural consumers who do not provide capacitors to prescribed extent

Karnataka

Monitoring: No clarity in monitoring and implementation methodology for Harmonics and Voltage.

Compensation: No compensation on account of failure to maintain voltage and harmonics within prescribed limits.

Delhi

Monitoring: No clarity in monitoring and implementation methodology for Voltage and Harmonics.

Compensation: No compensation on account of failure to maintain Voltage and Harmonics within prescribed limits.

Although the Regulations specify the Power Quality norms like voltage variation at point of supply and inter connection points; and norms for harmonics and voltage unbalance, these parameters are not strictly monitored and implemented. The penalty specified in the Regulations in most of the States is insufficient to compensate users for the production loss or equipment failure due to voltage variation from upstream. Tamilnadu has specified provisions and mechanisms for penalizing the consumers defaulting on harmonics injection limits specified by CEA. Maharashtra also has similar regulatory provisions.

7.11.2 INTERNATIONAL PRACTICES FOR POWER QUALITY MONITORING

I. BENCHMARKING OF POWER QUALITY IN EUROPEAN COUNTRIES (CEER BENCH-MARKING)

In European Countries continuity of supply and voltage monitoring are used as evaluating factor for assessing the performance of Discoms. Most of the Europeans countries have adopted EN50160 standard as power quality standard.

Table 7-1: Standard EN 50160 Summary

Voltage Disturbance	Voltage Level	Voltage Quality Index (Limit)
Supply Voltage variation	LV	95% of the 10 minute mean r.m.s values for 1 week (±10% of nominal voltage). 100% of the 10 minute mean r.m.s values for 1 week (+10% / -15% of nominal voltage).
	MV	99% of the 10 minute mean r.m.s values for 1 week below +10% of reference voltage and 99% of the 10 minute mean r.m.s values for 1 week above -10% of reference voltage. 100% of the 10 minute mean r.m.s values for 1 week (±15% of reference voltage).
Flicker	LV,MV,HV	95% of the Plt values for 1 week.
Unbalance	LV,MV,HV	95% of the 10 minute mean r.m.s values of the negative phase sequence component divided by the values of the positive sequence component for 1 week (0% - 2%).
Harmonic Voltage	LV,MV	95% of the 10 minute mean r.m.s values for 1 week lower than limits provided by means of a table. 100 % of the THD values for 1 week (≤8%).
	HV	95% of the 10 minute mean r.m.s values for 1 week lower than limits provided by means of a table.
Mains signaling voltage	LV,MV	99% of a day, the 3 second mean value of signal voltages less than limits presented in graphical format.

Majority of the European countries have developed voltage quality monitoring systems using measur-ing units installed at EHV/HV, MV an LV level. Many countries have initiatives for Voltage Quality moni-toring for statistics, Regulations, Research and Development, monitoring and network development. The cost of voltage quality monitoring is the responsibility of distribution and transmission companies, which is passed to all connected customers through the tariff.

7.12 CONCLUSIONS

The term "Power Quality disturbance" is defined as "any deviation from the ideal voltage or current waveform, magnitude or frequency". Power quality is important for several stakeholders in the elec-tric power system. The ones most impacted by poor power quality are the consumers of electric pow-er. But the current quality and even the voltage quality can have an adverse impact on the network operator as well.

The most common types of Power Quality challanges challenges are Voltage sag (or dip), Very short interruptions, Long interruptions, Voltage spike, Voltage swell, Harmonic distortion, Voltage fluctua-tion, Noise, Voltage Unbalance. The voltage variation beyond stipulated standards and interruptions are major Power Quality issues faced by the end users at the points of supply.

Harmonics are gradually becoming a key issue, arising out of customer's power utilisation. However there is no effective monitoring and or regulating harmonics level at consumer metering end. Power quality issues such as availability related issues are recognized by the Regulators and the Regulations have been notified to address these issues. However, there is a need to monitor power quality indices in the performance evaluation of Discoms, which needs to strengthen and enforce the Regulations. Finally such proactive Regulations & strict monitoring of Power Quality indices will only motivate the Discoms to adopt Power Quality monitoring systems across the network to monitor and control the quality of power supply at an optimum level.

Both European Energy Regulators & CIGRE have indicated that a power-quality monitoring program is important for a modern utility or network operator and both organizations gave recommendations on where to place the monitors (at least at every MV side of an indeed from the transmission grid), what to monitor (basically everything following Class A), and how to publish the results (at least annually). These documents can be utilized by all Stake-holders in Indian Power Sector to frame National guide-lines for Power Quality Monitoring.

MODULE 8

MICROGRIDS

Abstract

This module starts with a discussion of mini and micro grids including the characteristics, components, benefits, Indian scenario and business opportunities. Details of Low voltage DC microgrids are then discussed. The module concludes with three case studies of microgrids in India, Scotland and USA.

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8 MICROGRIDS

8.0 INTRODUCTION

Depending upon the user's needs and type of distribution generation resource to be used, various types of microgrids can be constructed. These can be used to supply power to various end users in commercial, residential and also industrial sectors. Microgrids are generally supplied by the locally installed distributed generation sources and hence, can prove to be feasible and efficient, technically and economically and in some cases environmentally. In a micro grid, there may be conventional generation sources used to produce power for a DG plant like Diesel, Natural Gas, Kerosene, etc., which can be used to run various combustion engines and micro-turbines or, there may be non-conventional sources of power generation which uses the renewable front of the power generation (Solar, Wind, Bio Fuels, etc.).

In-depth research has been and is still being carried out on the demand side of the electrical network, also known as demand side management (DSM), which deals with the most intensive energy efficiency measures applicable to reduce the consumption on the consumer's side without hampering the overall productivity of the organization or a household. Keeping this in mind, along-with the constraints of the national transmission network to provide power to every corner of the country at present, the concept of Microgrid presents a good case for itself to accommodate the energy needs of remotely located consumers specifically. This report focusses on the use of microgrids in such inaccessible areas and their equally large potential in the urban and peri-urban sectors.

The Smart Grids of the future will be a dynamic network of power systems, information technology and operational technology that listen and cater to the energy needs of the consumer. Increasing popularity of renewable energy, electric vehicles and storage technologies are forcing utilities to rethink their strategies and invest more in advanced grid modernization technologies to be able to successfully manage the ever-increasing complexity of the electric grid.

To manage these changes in a more efficient manner Microgrids are a key player. A Microgrid is one such aspect of a smart grid that is defined as a local grid with integrated energy systems that intelligently manages interconnected loads and distributed energy resources within clearly defined electrical boundaries.

It acts as a single controllable entity with respect to the grid and can operate in parallel with, or independently, from the existing main grid, i.e. the generation and distribution of power can be operated in island mode or grid connected mode.

Depending upon the user's needs and type of distribution generation resource to be used, various types of microgrids can be constructed. These can be used to supply power to various end users in commercial, residential and also industrial sectors. Microgrids are generally supplied by the locally installed distributed generation sources and hence, can prove to be feasible and efficient, technically and economically and in some cases environmentally. In a micro grid, there may be conventional generation sources used to produce power fROM a DG plant like Diesel, Natural Gas, Kerosene, etc., which can be used to run various combustion engines and micro-turbines or, there may be non-conventional sources of power generation which uses the renewable sources like (Solar, Wind, Bio Fuels, etc.).

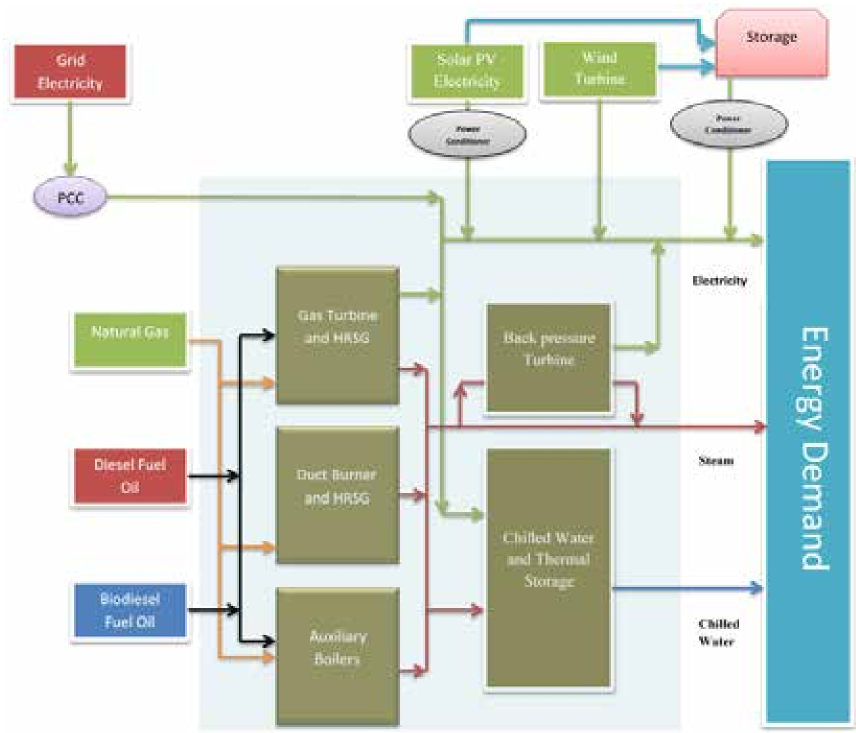
In-depth research has been and is still being carried out on the demand side of the electrical network, also known as demand side management (DSM), which deals with the most intensive energy efficiency measures applicable to reduce the consumption on the consumer's side without hampering the overall productivity of the organization or a household. Keeping this in mind, along-with the constraints of the national transmission network to provide power to every corner of the country at present, the concept of Microgrid presents a good case for itself to accommodate the energy needs of remotely located consumers specifically. This report focusses on the use of microgrids in such inaccessible areas and their equally large potential in the urban and peri-urban sectors.

SUMMARY: The term "microgrid" is used for electrical power systems that:

- have distributed energy resources (DERs) and load,
- can disconnect from and be parallel with the local grid when required

8.1 MINI/MICROGRIDS

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as single controllable entity with respect to the grid. If desired, a microgrid can connect and disconnect from grid to enable it to operate in both grid-connected or island-mode [8]. Internationally, the number of households specifies the designation of a "local Distribution, Generation and Supply (DG&S)" to be mini- or microgrid to supplied electricity. In India, MNRE defines microgrids as "renewable-based distribution generation under 10 kW, which can operate on a stand-alone basis or connected to the central-grid". Systems having generation potential and capacity of more than 10 kW are called Mini-grids. Uttar Pradesh (UP) has released a policy on mini-grid, which limits the capacity of microgrids to 500 kW for supplying rural households/hamlets. An example of Princeton University Microgrid is shown in Figure 8-1.



An efficient on-campus power generation and delivery network that draws electricity from gas-turbine generator and solar panel field. Capable of producing 15 MW of electricity. The micro-grid is able to disconnect from the utility in times of crisis and generate all power for the campus.

Figure 8-1: Microgrid in Princeton University

8.1.1 DEFINING CHARACTERISTICS OF MICROGRID

- Grouping of interconnected loads and distributed energy storage.
- Can operate in island mode or grid-connected mode as/if desired (Can connect and disconnect from grid as/if desired).
- Can act as single controllable entity to the grid.

8.1.2 MAJOR COMPONENTS OF MICROGRID

The major components of a microgrid are: Distributed generation resources, controller, communication infrastructure and storage system (if present). These are described in the following sections. The Figure 8-2 illustrates major components in a microgrid

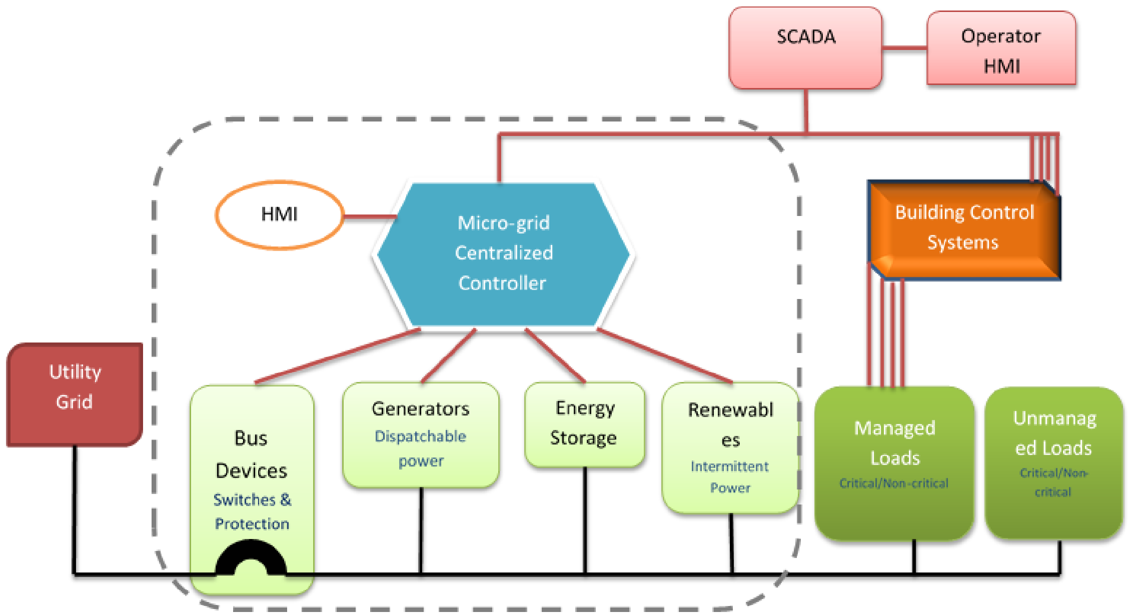


Figure 8-2: Major Components of Microgrid (source: Lockheed Martin, 2011)

I. MICROGRID MASTER CONTROLLER

The basic functions of the master controller are:

- Match the load with Generation- in both island mode or grid-connected.
  - Optimize integration, dispatching and control of DER and loads.
  - Ensures combination of Distributed Energy Resources (DERs) improves economics.
  - Maintains reliability and manage frequency and voltage.
- Real-time response and fault protection.
- Connect and disconnect from the grid.
- Predictive and forecasting analysis.

II. FAST AND SECURE COMMUNICATION TO MONITOR REAL-TIME NETWORK STATUS

The Basic Functions are:

- Optimize operations and control of DERs and loads.
- Connect to buildings via EMS.
- Continued monitoring and trends of microgrid component's health[1].
- Smart metering to obtain load and DERs profile.
- Electricity pricing and demand response capabilities.
- Continuous communication to utilities and energy markets.

[1]The two-way smart communication system between the source and load provides information of the micro-grid's overall operating condition.

III. ADVANCED METERING INFRASTRUCTURE

AMI (Advanced Metering Infrastructure) is the collective term to describe the whole infrastructure from Smart Meter to two way-communication network to control center equipment and all the applications that enable the gathering and transfer of energy usage information in near real-time. AMI makes two-way communications with customers possible and is the backbone of microgrids. This infrastructure built extensible and persistent information network in microgrids.

IV. DISTRIBUTED ENERGY RESOURCES

Distributed Energy Resources (DERs) provide on-site generation for electricity consumers. Microgrid not only allow DERs to operate as dispatchable assets to provide power to the microgrid when appropriate, but also to aggregate several DERs and energy storage devices to optimize their use on behalf of the electricity users. When one DER goes down, the microgrid can reduce energy usage in other locations and utilize other DERs to adjust for the electricity generation capacity loss.

V. ENERGY STORAGE IN MICROGRIDS

To counteract power imbalances between demand and supply, energy storage unit functions as energy buffer or backup.

Some key energy storage technologies for Microgrids:

- **Batteries**: Batteries store energy in electrochemical form, available in different size and storage capacity ranging from less than 100 W to several megawatts. The overall estimated efficiency of battery storage is in the range from 60% to 80%, depending upon the operational cycle and the electrochemistry type within the batteries.

  There are four principle types of battery storage suitable for microgrid implementations, wiz., Lead-acid, Nickel-iron, Nickel-Cadmium (NiCd), Nickel-Metal hydride (NMh). Lead acid battery is the most mature and cheapest energy storage device of all the battery technologies available. However, the limited cycling capability of lead acid results in unacceptable scenario of the economy of the overall system. Nickel-iron and nickel-Cadmium batteries contain toxic materials and thus are environmentally unfriendly. As for Nickel-Metal hydride batteries, they contain mild toxins and have 30-40 % higher capacity over a standard Ni-Cd battery, but have limited service life.

- **Sodium-Sulphur (NaS) batteries**: Compared with other lead-acid batteries, NaS battery shows much more attractive energy density (four times that of lead-acid battery) and much lower costs along-with long cycle capability (2500 plus cycles upon 90% depth of discharge, or several hundred thousand cycles at 10% depth of discharge) and a millisecond response for full charging and discharging operation. This technology has high cell efficiency of 89% without self-discharge, minimal maintenance and long cell life up to 15 years. However, large capacity in a single cell and reliable operation at high temperature of 300 centigrade and above are still main obstacles in manufacturing process.

- **Flywheel energy storage (FES)**: A FES unit stores electrical energy in form of rotational kinetic energy. It makes use of electrical energy to rotate a rotor at a very high speed preferably for providing short-term energy boost (10-30 s). FES has much higher power density, is environmentally friendly and be used with unlimited number of charging cycles. The disadvantages of a FES lie in difficulty in storage expansion, large dimension size, low energy density and high standby loss.

- **Supercapacitor**: It stores energy in two series capacitors of the electric double layer (EDL), which forms between each of the electrodes and the electrolyte ions. Supercapacitors are also called ultracapacitor or electric double layer capacitor (EDLC). The response time is very small as electrical energy can be stored directly without any chemical process. The capacitance and energy density of these devices are thousand times larger than that of electrolyte capacitors. Compared to a Lead-acid battery, the energy density is low but it has tens of thousands time longer cycles, and is much more powerful than batteries for fast charge and discharge capability. The disadvantage is that the cost of these supercapacitors is five times the Lead-acid batteries and may give rise to problem of imbalanced cell current and voltage during charging due to low cell voltage.

- **Superconducting magnetic energy storage (SMES)**: In a SMES unit, energy is stored in a magnetic field created by the DC flow in a superconducting coil. The system has very high efficiency up to 95% and has very short tie delay during charging or discharging process. It supplies almost instantaneous power output and large power capacities are achievable. The SMES systems, currently used just for short duration energy storage due to their requirement of power for refrigeration, include high costs of superconducting wires. SMES can specifically be used to ameliorate local power quality, such as power factor improvement, frequency stabilization and UPS implementation.

Table 8-1: Comparison of several types of Energy Storage Systems [12]

Type	Efficiency (%)	Energy Density (Wh/kg)	Power Density (W/kg)	Response time (ms)	Cycle Life (time)	Cost ($/kW h)
Battery	60-80	20-200	25-1000	30	200-2000	150-1300
SMES	95-98	30-100	1e4-1e5	5	1e6	High
Flywheel	95	5-50	1e3-5e3	5	>20,000	380-2500
SuperCap	95	<50	4000	5	>50,000	250-350
NaS	70	120	120	<100	2000	450

Table 8-2: Microgrid Controller and Stakeholders

Type	Efficiency (%)	Energy Density (Wh/kg)
Local Grid	System	The local grid that serves the microgrid through the PCC
EMS	System	The Energy Management System acts as an interface between the loads and the microgrid. It communicates with the smart meters and other devices to smartly manage the microgrid.
Microgrid Controller	System	A control system that dispatches the various microgrid assets such as opening and closing of switches, switching control among generator and load sources etc
Consumer	Individual/Organization	Utility scale Residential society Large campus/university Defense areas such as army, air and naval bases Islands Airports/ Ports Village/small community

Type	Efficiency (%)	Energy Density (Wh/kg)
DER Owner	Individual/Organization	The DER owner that operates the DER connected to the microgrid
Storage owner	Individual/Organization	Owns the storage unit connected to the microgrid
Aggregator	Organization	Market player that buys and sells electricity products on behalf of the consumer
Grid Operator	Organization	The Transmission grid operator
Distribution Company	Organization	Distribution utility
DER Unit	Device	Includes Solar PV, Wind, Diesel gensets etc
Smart Devices	Device	Includes sensors, breakers, switches etc
Storage Unit	Device	Includes batteries, flywheels, compressed air etc

8.1.3 BENEFITS OF DISTRIBUTED GENERATION, ENERGY STORAGE SYSTEMS IN MICROGRIDS

The essential role of energy storage in a Microgrid is to maintain stability, facilitate integration of renewable energy into the grid and improve power quality. Typical benefits of Distributed Generation and Energy storage system in microgrid-based applications can be deduced as follows.

I. SHORT TERM POWER SUPPLY

Power unreliability may result in substantial impact on economy. A study from FICCI reports that, companies across the country lost approximately INR 40,000 on an average per day during the blackout on July 30 and 31 of the year 2012, due to the failure of Northern, Eastern and North-Eastern grid. Momentary outages are precisely where energy storage is most cost effective and other solutions are least applicable. A microgrid may either work in grid connected mode or islanded mode. When a power failure occurs in the utility grid or the power quality requisites are not satisfied, the microgrid will disconnect from the utility grid and start to operate in islanded mode. Then the instant power shortfall, as the microgrid gets disconnected from the utility grid and gets transferred to islanded mode, can be compensated by distributed generation and energy storage system boost. Energy storage can implement a seamless transfer of the microgrid between different modes along-with acting as emergency power buffer for critical customers during fault situation, and facilitates black start of the entire power systems.

II. FACILITATING INTEGRATION OF RES

As major renewable source, the solar and wind power are intermittent and unstable, resulting in varying power supply to the microgrid. Combining energy storage with renewables can buffer the power output by storing surplus energy during high availability and re-dispatching it while there is power shortage, helping high penetration of renewables in to the microgrid. ESS facilitates optimized operation of the power sources within a microgrid. Further studies are mandatory to determine the appropriate capacity of ESS for an optimized operation.

III. ARBITRAGE

India follows a time of use approach for setting up the tariff for power usage in peak and off-peak hours. The spread between the peak and off-peak prices provides an opportunity for resources that can economically store energy for hours or days. So, arbitrage can easily be attained in a microgrid with energy storage asset. Given the price of ESS technologies and the overall system cost, it is very strenuous presently to establish an economic justification for the utilities to store energy with ESS during off-peak hours and supply power during peak hours.

IV. OPTIMIZATION OF POWER SOURCE IN MICROGRID

Smooth power transition can be attained with energy storage system in place, when some DG units operate abnormally within a microgrid. As most power sources in microgrid experience relatively long response time, energy storage is an ideal substitute to provide a smooth transition. Accompanied by abnormal operation, constantly changing demand from the customers makes the use of energy storage indispensable, resulting in improved reliability and efficiency.

V. POWER QUALITY IMPROVEMENT

A microgrid must comply with strict power quality requisites when being integrated into the utility grid, to maintain the high power factor and suppress any harmonics distortion, etc. Being controlled by power electronic-based interfaces, energy storage system acts as a power quality regulator to output specified active or reactive power from customers. Some energy storage systems can quickly absorb or release energy of high density, suitable to tackle transient issues like instantaneous voltage swells or swags.

VI. ANCILLARY SERVICES

Ancillary services generally cover load following, operational reserve, frequency regulation and fast response power plants. Power plants or large pumped-hydro energy storage systems provide most ancillary services. A microgrid comprising of large distributed energy resources such as wind turbine and/or PV, may provide ancillary services with integration of large ESS. Microgrids can also serve as reserve to the utility when the utility has surplus power, thus negating the wastage of resources.

VII. NET METERING

While there is surplus power in the microgrid, net metering provides the microgrid operators an appealing technique to earn through the installed system. Net metering allows the microgrid to sell surplus power to the grid and bank[2] the power with utility, so that it can be used at later hours, when the microgrid area needs it. Thus, a microgrid with net metering in place can also act as a source of income alongside being a source of continuous and reliable power.

8.1.4 MAIN CHARACTERISTICS OF A MICROGRID

The defining characteristics of a microgrid are:

- Geographically delimited or enclosed within clearly defined electrical boundaries
- Connected to the main utility grid at a point of common coupling (PCC)
- Can automatically make the transition to/from a synchronised grid connected mode to islanded mode and is compatible with system protection devices

[2]Banking surplus power with the utility is an option for micro-grid operators, where-in excess power is sent to the utility and same amount of power can be harnessed whenever required by the micro-grid area.

- Has DERs, including renewables, fossil fuel based generators such as diesel gensets, and/or integrated energy storage
- Can perform real-time switching among various generation and load sources to balance supply and demand quickly, manage power exchanges and participate in demand response
- Includes power and information exchanges between the microgrid and the main grid

8.1.5 BENEFITS

Table 8-3: Benefits to utilities and end users

Benefits to utilities	Benefits to end users
Electrification at lower investment	24*7 un-interrupted power for essential needs
Self-healing to avoid blackouts	Improves life style and economic activity
Seamless integration with renewables and existing grid	Reduction in bills – through participation in DR programs and other markets
Energy efficient- distribution losses reduction	Secure power supply
Power demand reduction – peak shifting and shaving	Reliable power supply even during outages and other contingencies
Remote monitoring and troubleshooting – for easy maintenance	Elimination of fossil fuel (kerosene) – local DER usage
Sustainable business model based on renewable energy	

Price Stability: Microgrids help provide protection from market fluctuations. Since it is self-sufficient and does not rely on the grid, it is not affected by the price instability caused by fluctuations in crude oil and coal prices. Also, it is not driven by the power markets and remains insulated from energy shocks.

Efficiency: Microgrid has the ability to operate, command and control the system assets – generation, storage, loads etc. through a smart microgrid controller that monitors and manages the entire system. This minimizes theft and since power is being consumed close to where it is generated, the system has less losses.

Reliability: Microgrids can be customized for a fixed territory, which allows the system to be more reliable than the main grid that is designed for large territories and a diverse customer base. Microgrids can disconnect from the main grid when outages occur and continue to provide un-interrupted power to the customers.

Energy Security: Microgrids ensure supply for the must-run critical loads using locally available generation and storage and can meet peak demands more quickly. Even if the main grid fails, microgrid can shut itself off from the main grid (islanding) making it less vulnerable to outside attacks.

Economic Savings: It enables hedging against energy cost fluctuations, reduction of cost of electricity and effective energy management with higher control and monitoring of connected loads.

Generates Revenue: Consumers and businesses can act as prosumers (producers + consumers) and supply to the grid in return for payments from the utility company. Microgrids enable peak shaving and peak load shifting by participating in demand response and dynamic pricing programs that save the main grid from over-loading. In the future microgrids can also offer balancing support for variable RE sources through voltage support, capacity support, and spinning reserve etc. These smart microgrids also set the stage for additional consumer revenues from distributed power generation, plug-in electric vehicles and carbon credits.

Sustainability: Distributed generation based microgrids are an ideal source of power for far flung areas where the main grid cannot reach. In these cases the microgrid model is sustainable and can be replicated to supply power to large sections of people spread across various regions.

Cyber Security: As the dependence on modern communication technology increases (wireless, cloud computing, etc.), power systems are vulnerable to cyber-attacks and hackers. In some specific customer segments, such as the military and research labs, there is significant value in a secure network. Microgrids are an ideal solution for these kinds of applications that offers the option to island from the main grid in case of a grid threat.

8.1.6 MICROGRIDS FOR INDIA

The Smart Grid Vision and Roadmap for India envisions 1000 microgrids by 2017; 10,000 microgrids by 2022 and 20,000 microgrids by 2027. A National Smart Grid Mission (NSGM) is soon to be released that would serve as the implementation body of these projects.

Development of medium sized microgrids are one of the indicative components of the NSGM with a total outlay of Rs. 27 crores in the 12th Five Year Plan. The World Bank is also in the process of rolling out implementation of microgrids in 7 districts in Uttar Pradesh.

In order to promote microgrids at such a fast pace, several demonstration projects need to be undertaken and appropriate and sustainable business cases and technology selection guidelines are to be developed. Scope of such demonstration projects would be to conceptualize, design and implement cost effective Smart Microgrids in:

- Remote villages/islands that integrates renewable energy generation and energy storage systems and can provide lifeline supply to all the households and public institutions in the village/island;
- Industrial parks/gated communities that integrates renewable energy generation, EV charging infrastructure, energy storage etc and can island from the grid whenever the situation demands
- Campuses or large institutional buildings that integrates renewable energy generation, energy storage, Building Management System(BMS), the utility's Distribution Management Systems (SCADA/DMS) etc and facilitate active participation in the Demand Response and Ancillary Services markets, create enabling platform for roll out of Electric Vehicles (EV) and transition to Net Zero Energy Buildings (NZEB)
- Defense areas
- Airports, Ports, Railway stations and Metro stations

8.1.7 BUSINESS OPPORTUNITIES IN MICROGRIDS

Even if 70% of the rooftops are used for setting up solar PV systems with net metering, along with energy efficiency measures, a major share of the load would be shaved off. With most people travelling by cars, building EV charging infrastructures would encourage more EV users. Also, given

> The All India Institute for Medical Sciences (AIIMS) ran up annual electricity bills of nearly INR 30 Crores before deciding to setup cogeneration plants

the number of buses and other light vehicles used in airports and defense areas, fast charging electric buses, four wheel drives and light commercial vehicles can be developed. These can be charged within hours and can be used to save on expensive fuel and also used as sources of power during outages and other exigencies.

8.2 LOW VOLTAGE DC MICROGRIDS

The depleting fossil fuels, ever-rising energy demand and concern over adverse climate change necessitate a substantial amount of power be generated by renewable energy sources. However, dispensing electronic loads, variable speed drives and LED loads from renewable sources require multiple

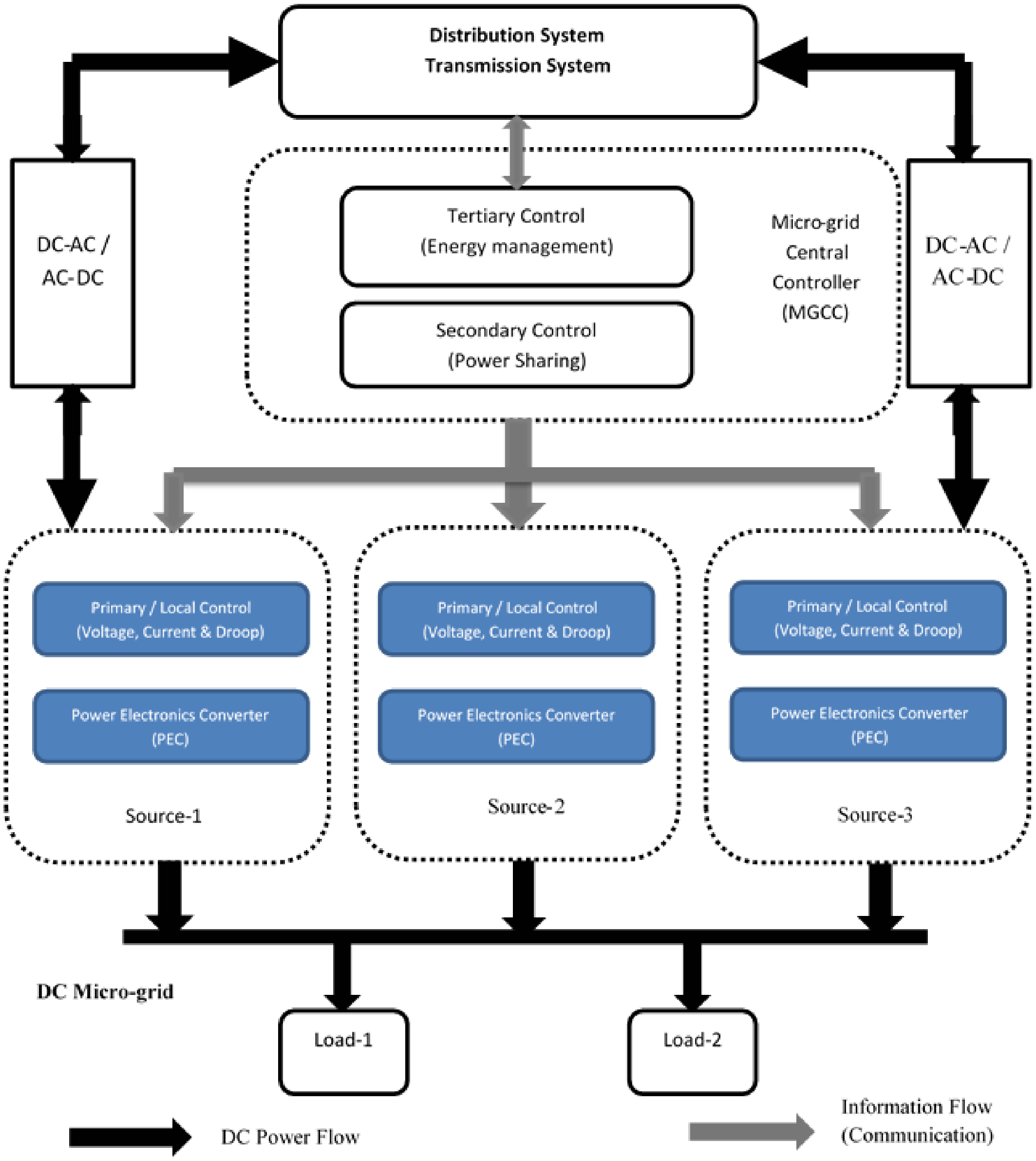


Figure 8-3: An LVDC Distribution system with Utility linkage

AC-DC and dc-ac conversions, which accounts for substantial energy wastage before end-use. To address this limitation, dc system for a microgrid is advisable, offering high efficiency and reliability [13].

8.2.1 CONCEPT OF LVDC AND WORKS DONE IN INDIA

The technical and economic developments in the past decades have constituted the opportunity to develop a new competitive distribution system relying on modern power electronic technology. From a technological point of view, the DC distribution is a new concept in electrical distribution systems and it paves the way for a new area of business to power electronic device manufacturers. Low Voltage Direct Current has secured remarkable importance as it furnishes broader scope for generation and distribution of electric power with viable large-scale employment of renewable energy resources amidst widespread global concerns like depleting fossil fuels, energy conservation, clean environment and continuously rising demand of electricity. Additionally, developing countries like India have a national obligation and priority of providing electricity access to the remote villages where currently grid power is unavailable. All these issues and concerns can be well addressed with the deployment of LVDC generated through renewable resources. Along-with aforementioned issues, most of the modern equipment run on low voltage DC and the installations of power converters for AC to DC conversion can be eliminated from the system resulting in less investment in the supporting infrastructure for the conversion, eliminating the losses and heat generation in conversion, thereby increasing the efficiency of the whole system.

The International Electrotechnical Commission (IEC) has established System Evaluation group (SEG) to sort out the gap of standardization in the LVDC field. In India, the IEC and Bureau of Indian Standards (BIS) have jointly organized International conference titled "LVDC: Redefining Electricity" in New Delhi on 26-27 October 2015 in order to deliberate extensively on the subject as an enabler to electricity access and solution to 21st century. Many notable global experts, speakers, practitioners and other stakeholders attended the conference. The conference highlighted LVDC applications and trends that would enable a stakeholder to review standardization efforts for a faster and cost effective development of LVDC.

8.2.2 ISSUES ARISING DUE TO LOW VOLTAGE POWER PRODUCTION

- Low voltage power production means that the current gets increased for transmission of same amount of power leading to increase in thermal loss, which causes a voltage drop over the given transmission line and result in power losses in conductors.
- Along with thermal losses, the nominal power properties of loads should also be met by the low voltage power produced from the generation source. Any mismatch between the two causes frequency imbalance in the network.
- In case of small-scale production, three different inverter systems have to be deployed for one installation to supply to the three-phase loads, which will lead to phase asymmetry in the system [14].
- Moreover, due to the low-voltage, DC circuits will experience limitation of short-circuit currents due to the absence of self-inductance voltages.
- Due to the absence of zero-crossings, it is more difficult to interrupt DC currents than AC currents [15].

8.2.3 PROTECTION OF LOW-VOLTAGE DC MICROGRID

To ensure reliability in operation of a LV microgrid, well-designed protection system must be in place. The system consists of protection devices (current interruptions), protective relays, measuring equipment and grounding. When connected with the utility grid, there will be another protection system for the ac network. Possible types of faults in a LV dc microgrid can be Pole-pole faults, pole-to-ground faults, bus faults, feeder faults and ground faults. Following protective measures are to be taken up while designing a low-voltage microgrid [16].

- **Grounding**

  Grounding is used for detecting ground faults and for personnel and equipment safety. Due to the ground-fault-current, metal enclosures of the system may get energized, so grounding with pre-assessed requirements is necessary for a LVDC microgrid.

- **Protection Devices**

  Commercially available protection devices for LV dc systems are fuses, molded-case circuit breakers, LV power circuit breakers and isolated case circuit breakers.

- **Protective relays and measurement equipment**

  Mechanical instantaneous overcurrent tripping devices are incorporated in high-speed dc circuit breakers, which are set up to trip the breaker if the current exceeds the rated limit of the system. However, tripping of CB due to events other than over-current requires installation of relays.

8.3 CASE STUDIES

8.3.1 VILLAGE DHARNAI, JEHANABAD DISTRICT, BIHAR

Greenpeace India has installed a 100 kW plus expandable pilot smart microgrid based on renewable technologies. It uses 280 solar panels to generate more than 100 kW of electricity that powers more than 400 households who have applied for connections. The project is led by the electrification committees, which consist of members of the village community using the microgrid. Greenpeace has involved BASIX[3] and CEED as co-implementers of the project overlooking the technological and financial wing and community interface with the villagers, respectively.

The basic package includes one light connection and a charging point totaling 18 watts per household. The second package includes three lighting points and a mobile charging point with usage totaling to 30 watts, including connections for televisions and fans. The third package is for the commercial customers that includes one lighting point, one charging point and a streetlight, totaling usage to 18 watts of electricity. Other than this the microgrid also includes 10 solar-powered water pumps of 3 horsepower capacity for irrigation and 60 solar street lights.

The microgrid runs on rooftop solar-powered PV panel system, installed on Government, residential and commercial buildings. Battery bank has been provided for each cluster of 20 kW each. The operation and maintenance of the system is taken care by BASIX Urja's trained local technician on a daily basis. Revenue collection is being done through different channels like payment of bills post-usage, using energy meters, or, pre-payment as applicable to reduce transaction costs and increase payment rates and revenues.

[3]The Holding Company of BASIX Group is called Bhartiya Samruddhi Investments and Consulting Services (BASICS Ltd.)

8.3.2 FAIR ISLE, SCOTLAND

One of the most remote islands in the UK, Fair Isle is not connected to the main UK transmission system. Prior to 1982, electricity was supplied by two diesel generators for a limited number of hours in the day. In addition, the cost to buy and import diesel became far too steep for the island to maintain its electric supply at low costs, and so alternative energy sources were studied. Wave, wind and hydroelectric power were all taken into consideration to support the island's diesel system. Henceforth, after testing, conclusion was that wind was the only viable option due to the average wind speeds of over 9m/s.

Currently, Fair Isle's microgrid incorporates two wind turbines with additional support from the pre-installed diesel generation for back-up. A double network system provides greater control over the energy consumption and distribution within the island. There are two separate services being catered by the microgrid; heating and power supply (services), where heating load is always regarded secondary load. Hence, if wind strength diminishes, the heating load is forced to reduce so as to maintain the integrity of the power supply to primary service load.

8.3.3 PRINCETON UNIVERSITY, NEW JERSEY, UNITED STATES

Acknowledged among the best-in-class microgrids, Princeton's gas-fueled CHP plant continued supplying heating, cooling and electricity for the campus during the hurricane Sandy in October, 2012, keeping the university up and running when considerable parts of the state were in dark. Initially, the cogeneration plant was to reduce the lifecycle costs and create low-carbon footprint along-with higher reliability. The core of Princeton's microgrid is a gas turbine which produces 15 MW of power. With this, there is a 4.5 MW solar field which supplements the microgrid on sunny days. The microgrid is synchronized with the utility grid which benefits the university and the local ratepayers too. When the cost of power from the utility is less, the university draws power from the grid. When the university's microgrid produces power at rates less than the utility, it runs to meet the maximum possible electricity needs of the campus. During surplus power generation, when the power produced by the microgrid is cheaper than the utility, the extra power is exported t to the utility and earns revenue for the university, while lowering the net price of power for all other grid participants.

Post-creation of the new ancillary services markets, Princeton University is able to use its existing co-generation asset to produce new revenue lines by selling voltage and frequency-adjustment services back to the larger power grid. This proves to be less costly for the utility rather than building up its own power grid infrastructure and increasing generation at its plant, while not reducing area's reliability.

8.3.4 LONGMEADOW, JOHANNESBURG, SOUTH AFRICA

South Africa has the highest electricity consumption in the sub-Saharan region, with demand continuing to outpace supply. Businesses across the country face disruptions due to regular power shortages. Typically, companies use backup diesel generators to cope with these shortfalls. The result is an increase in consumption of expensive and polluting fossil fuels.

ABB, a power and automation company, installed a microgrid at their 96,000 square meter Longmeadow industrial facility to ensure a reliable, 24/7 power supply.

A central feature of the microgrid solution developed by ABB is the 750 kWp solar PV plant located on the Longmeadow facility's rooftop. During normal operations, power generated from the PV system supplements electricity from the grid. The PV plant helps minimize usage of two 800 kVa diesel-powered generators that were previously used for backup power.

The second key element in the microgrid is a 1 MVA/ 380 kWh lithium-ion battery that helps stabilize the microgrid against fluctuations in frequency and voltage by rapidly absorbing or injecting power. This provides a smooth transition from grid to back-up power during outages. It also enables peak shaving during peak consumption times. A microgrid control system ensures that the power supply is well-balanced between fossil-fuel and renewable energy sources. The system enables cloud-based remote monitoring to access key performance indicators anytime.The microgrid is helping reduce consumption of both grid-provided electricity and diesel fuel. Its combination of innovative battery technology and a bespoke control system enables a seamless transition between grid-connected and islanded modes. As a consequence, should a power quality issue arise or an outage of the main grid occur, there is no disruption to loads. The system also ensures that the Longmeadow facility is now no longer fully dependent on costly diesel fuel during blackouts or dips in power, which prior to the microgrid installation occurred every three days on average.

In total, the addition of solar-generated electricity has caused annual diesel consumption to decrease from around 52,000 liters to 38,000, a fall of 27 percent. Thanks to the microgrid solution, the facility's generators now run for only 106 hours annually, down 76 percent compared to 433 hours beforehand. In cost terms, this translates into an overall drop in energy costs of US$150,000 per year, to US$460,000. This environmentally-friendly solution has also seen overall carbon emissions reduce by an estimated 1,000 tonnes per year.

India Smart Grid Forum

MODULE 9

ENERGY STORAGE

Abstract

This Module attempts to give an introduction to Energy Storage and gives briefs about the technology outlook, state of energy storage in India, Role of energy storage technologies in India's Power system and Smart Grids and opportunities due to large share of renewables are discussed in detail. To conclude possible solutions and successful international case studies are analyzed.

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9 ENERGY STORAGE

9.0 INTRODUCTION

Energy storage is a three-step process that consists of drawing energy, storing it and returning it at a later stage. It consists of two dimensions: the power capacity of the charging and discharging phases, which defines the efficiency of the storage system to withdraw or inject energy instantaneously from or into the grid; and the energy capacity of the storing phase, which measures how much energy can be stored and for how long.

The term "energy storage" applies to many different technologies, including batteries, flywheels, and pumped hydroelectric storage. All technologies can store energy during periods when the cost is low and then make the energy available during a period when the costs are higher. Energy storage can absorb energy from renewable resources, such as solar power, that may over produce in certain periods and then use it in later periods when it is more valuable to the customer and the power grid.

Energy storage technology has great potential to improve electric power grids, to enable growth in renewable electricity generation, and to provide alternatives to oil-derived fuels in the nation's transportation sector. Energy storage in electric applications can provide two significant benefits to the nation's energy system. First, it can improve the technical and economic performance of the electric power grid, increasing reliability and potentially decreasing costs while allowing greater penetration of intermittent sources like solar and wind generation. Second, it enables a potential transition from an oil-based transportation system to one based on an array of domestically sourced electricity options, greatly reducing dependence on petroleum. In both cases, a reduction in the burning of fossil fuels could result in lower overall carbon emissions and conventional pollutants.

9.1 ENERGY STORAGE IN INDIA

Government of India has set up aggressive renewable energy (RE) capacity addition target of 175 GW by 2022. The primary focus of Government is on the promotion and scaling up of electricity generation from the renewable energy. High intermittency of renewable energy make it difficult to forecast and schedule for dispatches. Higher penetration of RE resources will ultimately (with rapid deployment) result in a stage where the grid will become unstable. One of the most effective solutions for addressing this high intermittency while allowing scale up of these resources is the use of energy storage technologies as energy storage can act as a capacity in the entire energy value chain i.e. - generation, transmission, distribution and loads.

Large-scale storage facilities can arbitrage base load generation by storing electricity during non-peak hours and providing power in long-duration discharges and also provide low-cost ancillary services such as load following and spinning reserves. Large scale energy storage helps on both the supply and demand side of the wholesale generation market. Although they do help offset the need for additional peaking capacity, large-scale storage facilities are focused more as system optimizers rather than generation replacement.

9.2 ENERGY STORAGE TECHNOLOGIES - TYPES AND FEATURES OF ENERGY STORAGE SYSTEMS

Different types of Energy Storage Technologies and their features are described in this section. A brief classification is followed by a description of the various technology types with their advantages and disadvantages.

There are many different kinds of energy storage technologies with various capabilities. While all technologies store energy, the way in which each operates can differ. Thus, the variety of technologies provides flexibility in matching energy storage solutions to diverse energy related challenges faced by the consumer and the power grid operator.

Batteries, pumped storage systems, ice storage, and heat-based thermal storage make up some of the more common types of energy storage. Pumped Hydro Storage is often referred to as “conventional energy storage”. More recent emerging forms of energy storage, such as batteries, flywheels, and new compressed air energy technologies, are often referred to as “advanced energy storage”. Energy storage technologies can be broadly classified as: mechanical, electrochemical, thermal, electrical and chemical storage. See Figure 9-1 for the many storage technologies contained in each category.

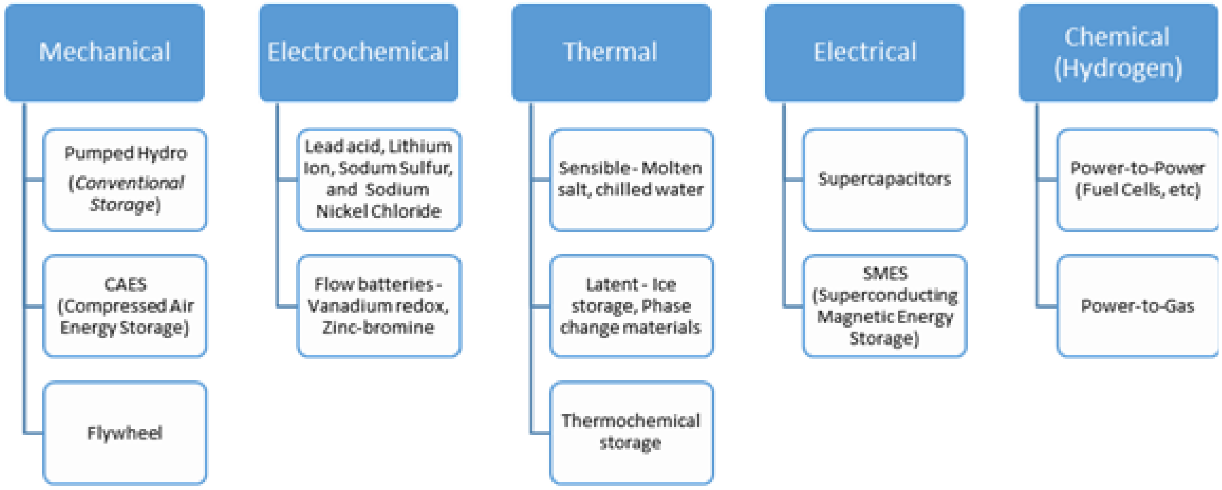

Figure 9-1: Classification of Energy Storage Technologies

9.2.1 MECHANICAL STORAGE SYSTEM

Mechanical Storage includes Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES) and Flywheels:

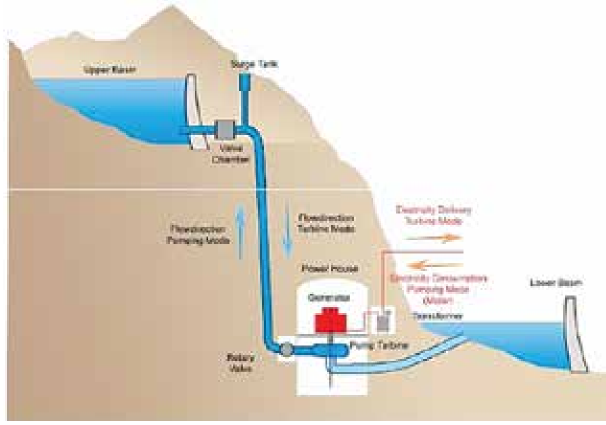

Figure 9-2: Mechanical Storage System

I. PUMPED HYDRO STORAGE (PHS)

Pumped Hydro Storage (PHS) stores electrical energy as the potential energy of water. Generally, this involves pumping water into a large reservoir at a high elevation—usually located on the top of a mountain or hill. When energy is required, the water in the reservoir is guided through a hydroelectric turbine, which converts the energy of flowing water to electricity. PHS is often used to store energy for long durations for use in a future period. The location of these systems is dictated by the presence of the required geology. Proposed pumped storage projects are also subject to rigorous environmental clearances, which can add significantly to the time required for the installation of such a system. Projects can take five to fifteen years to be sited, permitted and built.

II. COMPRESSED AIR ENERGY STORAGE (CAES)

Compressed Air Energy Storage (CAES) converts electrical energy into compressed air, which is stored either in an underground cave or above ground in high-pressure containers. When excess or low cost electricity is available from the grid, it is used to run an air compressor, which compresses air and stores it. When electrical energy is required, the compressed air is directed towards a modified gas turbine, which converts the stored energy to electricity. A recent advancement that is maturing through research and development by several start-ups is storage of the heat produced during the compression. This type of CAES does not use natural gas to reheat the air upon decompression and is therefore emissions-free, as well as more efficient overall. Similar to pumped hydro, CAES systems are used for storing energy over longer periods.

III. FLYWHEEL ENERGY STORAGE (FES)

Flywheel storage systems store electrical energy as the rotational energy in a heavy mass. Flywheel energy storage systems typically consist of a large rotating cylinder supported on a stator. Stored electric energy increases with the square of the speed of the rotating mass, so materials that can withstand high velocities and centrifugal forces are essential. Flywheel technology is a low maintenance and low environmental impact type of energy storage. In general, flywheels are very suitable for high power applications due to their capacity to absorb and release energy in a very short duration of time.

In flywheel energy storage, rotational energy is stored in an accelerated rotor, a massive rotating cylinder. The main components of a flywheel are the rotating body/cylinder (comprised of a rim attached to a shaft) in a compartment, the bearings and the transmission device (motor/ generator mounted onto the stator). The energy is maintained in the flywheel by keeping the rotating body at a constant speed. An increase in the speed results in a higher amount of energy stored. To accelerate the flywheel electricity is supplied by a transmission device. If the flywheel's rotational speed is reduced electricity may be extracted from the system by the same transmission device.

9.2.2 ELECTROCHEMICAL STORAGE SYSTEMS

In this section, various types of batteries are described. Most of them are technologically mature for practical use. Electrochemical storage includes various battery technologies that use different chemical compounds to store electricity. Each of the numerous battery technologies have slightly different characteristics and are used to store and then release electricity for different durations ranging from a few minutes to several hours. There are two main categories of batteries: (1) traditional solid rechargeable batteries where the chemical energy is stored in solid metal electrodes, and, (2) flow batteries where chemical energy is stored in varying types of flowing liquid electrolytes kept in tanks separate from the actual electrochemical cells.

I. SOLID RECHARGEABLE BATTERIES:

- Lead Acid: Lead acid batteries have been in commercial use in different applications for over a century. Lead acid is the most widely used battery technology worldwide. High performance variations of lead acid batteries are classified as advanced lead acid and are known to have a longer life.
- Lithium Ion batteries are increasingly used in many applications in buildings, computers, automobiles and aeroplanes, consumer electronics and on the power grid. They include various types of chemistries, and include lithium combined with cobalt, nickel, manganese and phosphate based cathodes. They can be adapted to many different use cases and are quickly becoming a dominant technology for new energy storage projects.
- High Temperature Sodium: This type of battery is made from inexpensive, non-toxic materials. The battery operates at a high temperature (above 300oC) and has been shown to have a long cycle life.
- Zinc-based batteries combine zinc with various chemicals and are earlier in their development stage than some of the other battery technologies. Historically, zinc batteries were not rechargeable but developers are overcoming challenges to produce fully rechargeable zinc-based chemistries. This technology is known for being lightweight, low-cost, and non-toxic.

II. FLOW BATTERIES

- Flow batteries differ from conventional batteries in that energy is stored in the electrolyte (the fluid) instead of the electrodes. The electrolyte solutions are stored in tanks and pumped through a common chamber separated by a membrane that allows for transfer of electrons—flow of electricity—between the electrolytes.
- There are many different types of flow batteries, of which at least three varieties are currently commercially available: vanadium redox flow batteries, zinc-iron flow batteries, and zinc-bromine batteries. Variations such as zinc-iron flow batteries and hydrogen-bromine flow batteries are also under development.

9.2.3 THERMAL ENERGY STORAGE SYSTEMS

Thermal energy storage includes ice based storage systems, hot and chilled water storage, molten salt storage and rock storage technologies. In these systems excess thermal energy is collected for later use. Examples include storage of solar energy for night heating; summer heat for winter use; winter ice for space cooling in the summer; and electrically generated heat or cooling when electricity is less expensive, to be released in order to avoid using electricity when the rates are higher.

9.2.4 ELECTRICAL ENERGY STORAGE SYSTEMS

Electrical Storage include supercapacitors and superconducting magnetic energy storage (SMES) systems which store electricity in electric and electromagnetic fields with minimal loss of energy. A few small SMES systems have become commercially available, mainly used for power quality control in manufacturing plants such as microchip fabrication facilities. These technologies are ideal for storing and release high levels of energy over short bursts.

9.2.5 CHEMICAL ENERGY STORAGE SYSTEMS

Chemical storage typically utilizes electrolysis of water to produce hydrogen as a storage medium that can subsequently be converted to energy in various modes, including electricity (via fuel cells or engines), as well as heat and transportation fuel (power–to-gas).

9.3 TECHNICAL COMPARISON OF ENERGY STORAGE TECHNOLOGIES

Different applications with different requirements demand different features from energy storage. Hence a comprehensive comparison and assessment of all storage technologies is rather ambitious. Figure 9-2 provides a comparison of different technical parameters, such as operating costs and technology maturity, as well as practical considerations, such as space requirements and development and construction periods for different energy storage technologies.

The C-rate of the system is an important parameter that varies significantly between different energy storage types particularly electrochemical batteries. C-rate is an inverse measure of the rate (length of time) over which a system can provide its maximum rated power. The range of discharge duration is therefore directly linked to the C-rate. It is normally expressed in terms that look like 1C, 2C or C2 etc. For instance, a system with a C-rate of 2C can supply all its stored energy in ½ hour while a system with a C-rate of 1C can do it in one hour and a system with a C2 rate can do the same in 2 hours.

Table 9-1: Parameters for Select Energy Storage Systems (ESS)[1]

Energy Storage System Attributes	Lead Acid	Li –Ion	NaS	Flow Batteries	Flywheel	CAES	Pumped Hydro
Round Trip Energy Efficiency (DC-DC)	70-85%	85-95%	70-80%	60-75%	60-80%	50-65%	70-80%
Range of Discharge Duration	2-6 Hours	0.25–4+ Hours	6-8 Hours	4-12 Hours	0.25-4 Hours	4-10 Hours	6-20 Hours
C Rate	C2 – C6	4C – C6	C6-C8	C4-C12	4C-C4	N.A.	N.A.
Cost range per energy available in each full discharge ($/kWh)	100-300	400-1000	400-600	500-1000	1000-4000	>150	50-150
Development & Construction Period	6 months - 1 year	6 months - 1 year	6 months - 1.5 year	6 months - 1 year	1-2 years	3-10 years	5-15 years
Operating Cost	High	Low	Moderate	Moderate	Low	Moderate	Low
Estimated Space Required	Large	Small	Moderate	Moderate	Small	Moderate	Large
Cycle life: # of discharges of stored energy	500-2000	2000 -6000+	3000-5000	5000 - 8000+	100,000	10,000+	10,000+
Maturity of Technology	Mature	Commercial	Commercial	Early - moderate	Early - moderate	Moderate	Mature

[1]DOE-EPRI Energy Storage Handbook, and Customized Energy Solutions Analysis

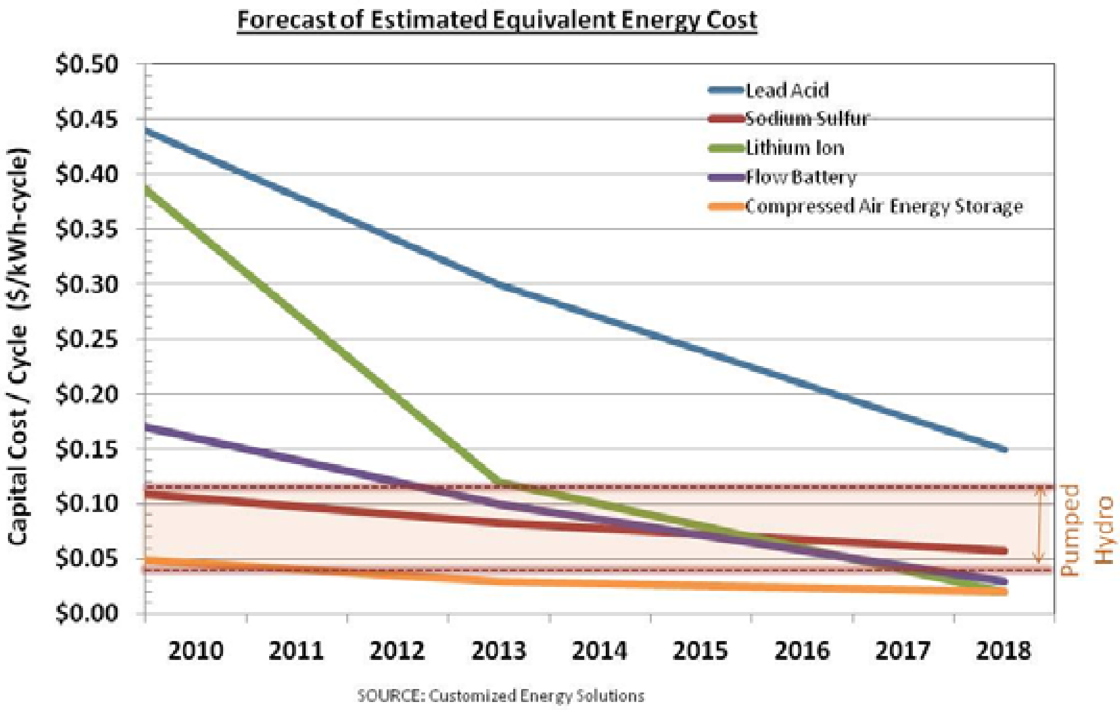

Figure 9-3: Forecast of Estimated Capital Costs by Storage Technology and Type[2]

9.4 APPLICATIONS AND ROLE OF ENERGY STORAGE IN POWER SYSTEM

- Penetration of renewable energy requires more frequency control capability in the power system. Energy storage can be used to enhance the capability through the control of charging and discharging from network operators, so that the imbalance between power consumption and generation is lessened.
- In some cases, energy storage can reduce investment in power system infrastructure such as transformers, transmission lines and distribution lines through load levelling in certain areas at times of peak demand. ENERGY STORAGE for this purpose may also be used to enhance frequency control capability.
- A further option is so-called demand-side management, involving smart grids and residential users. With intelligent consumption management and economic incentives consumers can be encouraged to shift their energy buying towards periods when surplus power is available. Users may accomplish this shift by buying and storing electricity for later use. Electrochemical storage types used in smart grids are basically lead acid and NaS batteries, and in some cases also Li-Ion batteries. For this application redox flow batteries also have potential because of their independent ratio of power and energy, leading to cost-efficient storage solutions.

[2]Customized Energy Solutions and India Energy Storage Alliance analysis.

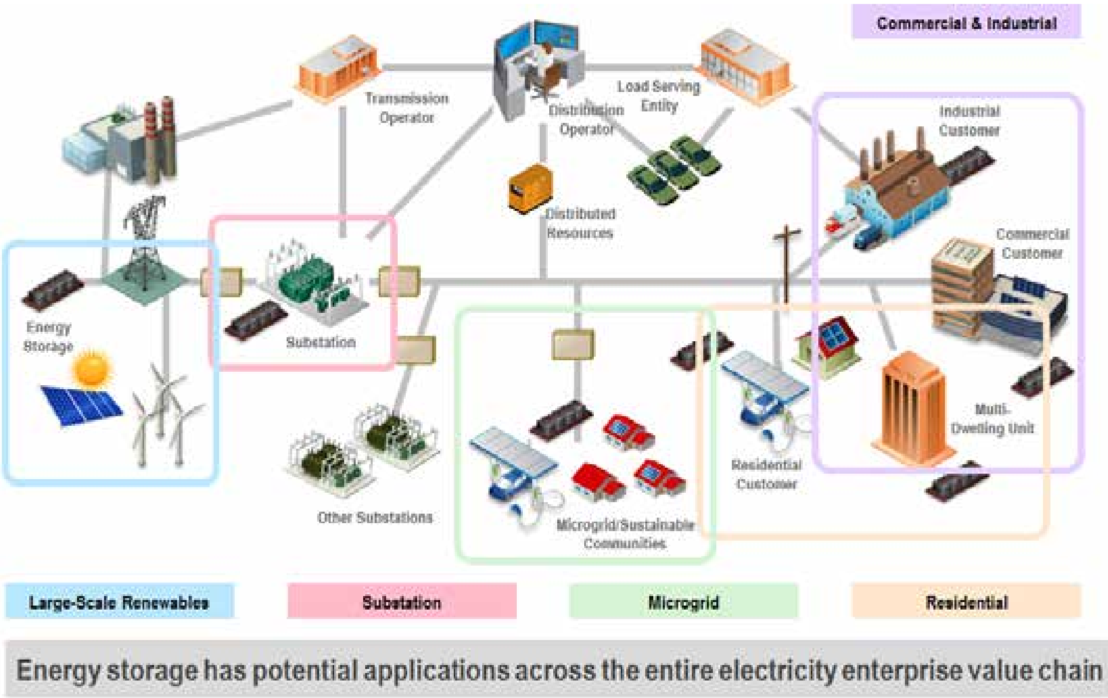

Figure 9-4: Representation of the Diversity of Potential Storage Grid Locations

(Source: EPRI)

9.4.1 SERVICES AND FUNCTIONS OF BATTERY ENERGY STORAGE FOR GRID OPERATORS

Battery Energy Storage (BES) systems offers a wide range of primary and ancillary services and functions for grid operators. These include:

Peak shaving in low voltage grid - Typical duration is 2 hours, with 1 to 2 cycles per day BES can store energy in periods of low demand, and release that energy during periods of high demand. This reduces peak demand in low voltage (LV) electricity grids, and allows grid operators to defer investment into upgrading their network capacity.

Load levelling in LV grid - Typical duration would be up to 8 hours BES can help grid operators to avoid a fatal overload in power of grid devices, by shifting load from peak to base load periods in order to reduce the maximum currents flowing from the high voltage grid through constrained grid assets.

Integration of renewable energy into the grid (Numerous small cycles per day)- BES can provide control power to limit fluctuations of feed-in electric power into the low voltage grid, and potentially also for large photovoltaic farms in the middle voltage grid. It can also shave off renewable peak generation in times of high production and low consumption, minimising grid congestion and/or RES curtailment. This function also provides voltage support on distribution feeder lines. This may allow for the deferral of any necessary grid upgrade or extension.

Frequency regulation - Numerous small cycles per day, quick response time BES can store energy or feed in energy in order to balance a grid area with high frequency instabilities. This defers the need for grid upgrade or extension. BES can also provide primary reserve capabilities to wind and solar generators, which is crucial in grids with high renewable penetration and subsequent low inertia due to a lack of conventional generation. BES can also optimise reserve power generation from conventional generators.

Voltage control - Numerous small cycles per day, quick response time BES can help to maintain the voltage profile within a defined range, with the aim to guarantee standard of supply. BES achieves this by storing energy when the voltage is high, and feeding in when voltage is low.

9.4.2 ENERGY STORAGE FOR HOMES AND BUILDINGS

Small and medium-size users (i.e. households, industry) which use tailored BES as a component in their smart system can benefit in the following ways (non-exhaustive list):

Time-shift for self-consumption - Typical duration is 1-6 hours, with typically 1 cycle a day BES can provide power during RES non-generation hours, allowing the household or building to decrease the dependency on the electrical-grid. In the mid-term, this could reduce the overall electricity price by smart-metering, where stored energy is discharged during peak load hours when electricity prices are high.

Smoothing of RES feed - Typical duration ranges from milliseconds to a few minutes, with numerous small cycles per day BES has the capacity to smooth RES generation by providing, absorbing and delivering power to limit fluctuations of feed-in electricity in the low voltage grid. This will improve overall grid conditions, with higher shares of renewable energy deployed. Appropriate energy sources are photovoltaic and wind energy.

Uninterruptible Power Supply (UPS) - Typical duration is 15 minutes to 1 hour, with the number of cycles depending on the grid stability. BES allows for increased power safety in areas with weaker low voltage grids. It has the capacity to provide backup power through the entirety of a power outage period. The number of cycles is dependent on overall grid stability.

9.5 MARKET POTENTIAL FOR ADVANCED ENERGY STORAGE

9.5.1 GLOBAL MARKET POTENTIAL FOR ADVANCED ENERGY STORAGE

Globally, the total of energy storage projects in 2016 amounts to almost 2 GWs, not including pumped hydro (see Figure 9 5). Energy storage deployments are growing around the world — particularly in the United States, Spain, Germany, the UK, Canada, France and Japan.[3]

[3]U.S. Department of Energy, DOE Global Energy Storage Database, Top 10 Countries, May 12, 2016; http://www.energystorageexchange.org/projects/data_visualization

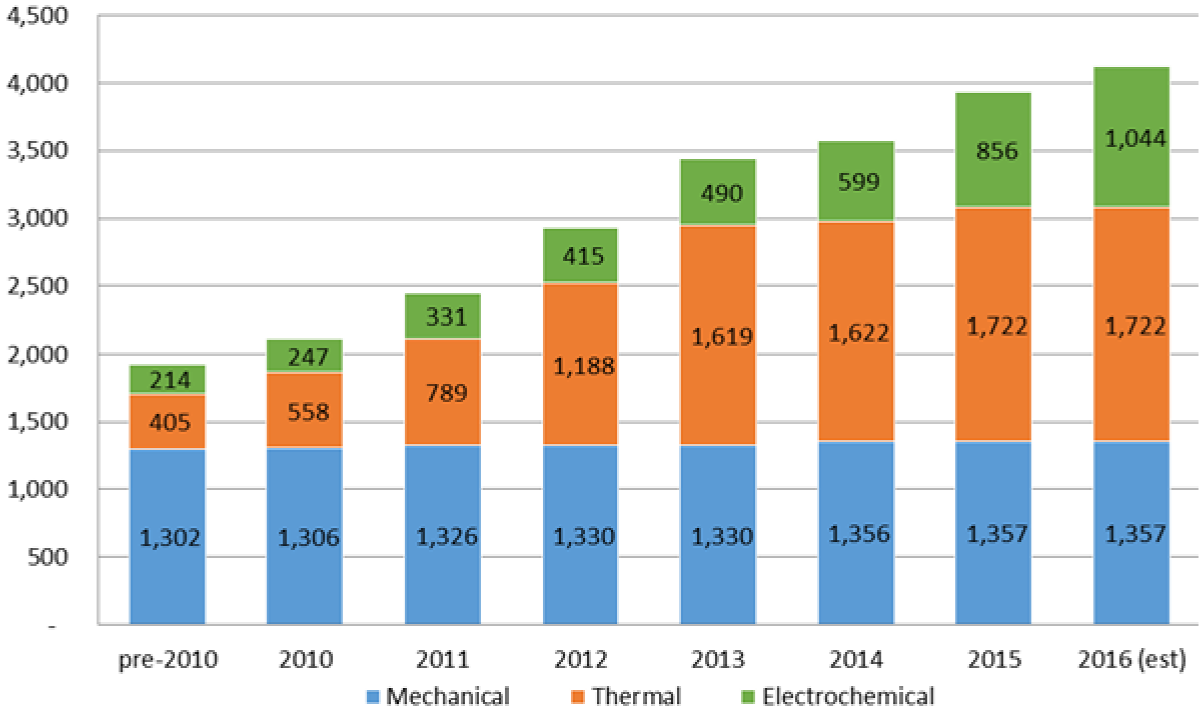

Figure 9-5: Operational Advanced Energy Storage Globally in Megawatts, by Commissioning Year[4]

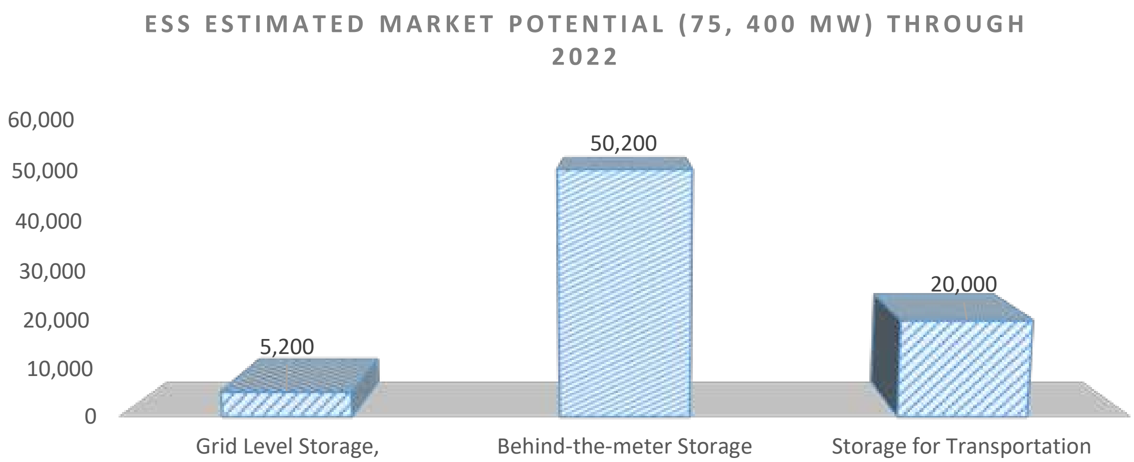

Figure 9-6: ESS Estimated Market Potential (75,100 MW) Through 2022

[4]Source: DOE Global Energy Storage Database, March 23, 2016: www.energystorageexchange.org

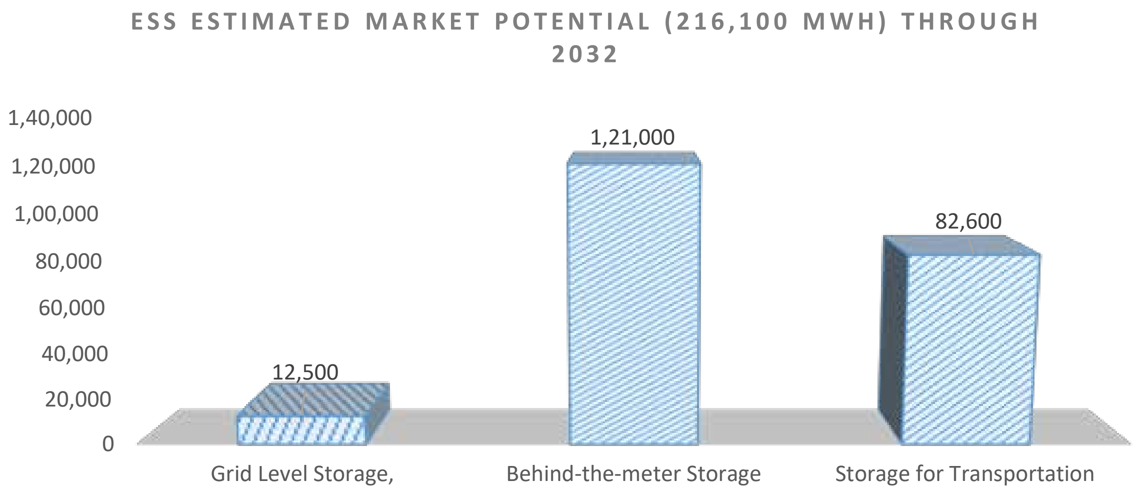

Figure 9-7: ESS Estimated Market Potential (216,100 MWH) Through 2032

Source - IESA

9.5.3 APPLICATION-WISE INDIAN ESS MARKET POTENTIAL (IN MWH)

Application	Capacity (MWh)
Solar Integration	3207
Wind Integration	2812
Frequency Regulation Ancillary Services	202
T&D Deferral	6280
Commercial & Industrial Backup	14095
Residential Power Backup	31185
Telecom Towers	23496
Power Backup in Rural Areas	17866
Peak Management - Thermal Storage	9411
Rooftop Solar	8651
Diesel Replacement	9640
Rural Microgrids and off-grids	5162
Peak Management - Electrical Storage	1382
Electrical Vehicles	66324
Indian Railways	5960
MHE	10336
Total	**216009**

Source - IESA

REFERENCES:

- DOE-EPRI Energy Storage Handbook,
- IESA Analysis
- DOE Global Energy Storage Database, March 23, 2016

India Smart Grid Forum

MODULE 10

ELECTRIC VEHICLES

Abstract

The module is designed to give an overview of the Electric Vehicle(EV) and charging infrastructure technologies, and grid-connected services that can be provided by EVs and their barriers to adoption. It summarizes the international field-study projects and best practices undertaken for the accelerated deployment of clean transportation and clean energy objectives in India.

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10 ELECTRIC VEHICLES

10.0 INTRODUCTION

Transportation accounts for more than 30 percent of the world's energy consumption and nearly 72 percent of global oil demand. According to a report by International Energy Agency (IEA), fossil fuel based transportation is the second largest source of CO2 emissions globally. It was also projected that the global energy consumption is likely to rise by 53% from 2006 to 2030, and about three quarters of the projected increase in oil demand will come from transportation. However with electric vehicles becoming popular, we expect a change in this trend.

India largely imports oil to meet its energy needs. The percentage of oil imported by India has risen from 57% in 1997 to 85% in 2010; this is likely to reach 92% of the total demand by 2020. The transportation sector accounts for about one-third of the total crude oil consumption with road transportation alone accounting for more than 80% of this. The annual demand for passenger vehicles, commercial vehicles and two wheelers in India is estimated to rise to 10 million, 2.7 million and 34 million units respectively by 2020, thereby making India the third largest vehicle market in the world (Department of Heavy Industries, 2013). This expected growth of vehicles coupled with the fact that the present level of vehicle penetration in India is amongst the lowest in the world as well as import dependency for fossil fuel, raises major concern on the sustainability of future transport system. This has initiated a quest to find alternate sustainable modes of transport.

Although a variety of clean vehicle technologies and fuels are being developed, electric vehicles (EVs) represent one of the most promising technology pathways for cutting oil use and CO2 on a per-kilometer basis. With a moderately clean electric grid, EVs can achieve 50 grams of CO2 per kilometer, well below today's most efficient cars, which emit between 100 and 150 grams of CO2 per kilometer (OECD, IEA, 2010). EVs also have huge potential of leading innovation and creation of new advanced industries that could spur job growth and enhance economic prosperity. EVs also have the ability to be an independent distributed energy source for the electricity grid. However, the mass deployment of EVs will require transportation systems capable of integrating and fostering this new technology. Electric vehicle technology must pass through several stages of market development, optimization and scale-up. At present there are substantial technical, social, and economic barriers to widespread adoption of electric vehicles, including vehicle cost, small driving range, long charging times, and the need for a charging infrastructure. In addition, people are unfamiliar with electric vehicles, are uncertain about their costs and benefits, and have diverse needs that current electric vehicles might not meet. Charging an EV is analogous to filling the fuel tank of a conventional vehicle with gasoline, but at a much lower rate. Hence extensive support infrastructure is required to build up the volume for EVs (National Academy of Sciences, 2013)

Electricity Distribution Companies (Discoms) and the Electricity Regulatory Commissions would be one of the most critical stakeholders in the EV landscape in India. The planned promotion of EVs by Central Government is likely to help improve the number of EVs on the road. As more EVs populate roads, utilities are likely to become increasingly concerned with managing and making use of these "mobile assets." Especially when only 81% of the total population has access to electricity in India and utilities are struggling to provide electricity connections to a large percentage of rural population (WEO, 2015). Utilities thus, need to be educated about the benefits that they can derive from EVs and about the innovative mechanism that they can devise to avoid adding stress to the grid from charging of the EVs. Utilities should not perceive EVs as an additional burden on the grid which would otherwise hinder the adoption of EVs at large scale. Similarly, regulators need to create enabling framework and attractive and optimal rate structures for electricity required for charging such that the peak hour charging is avoided and shifted to off-peak hours.

Hence it is very important to equip both regulatory and utility personnel with technical and managerial aspects of EV ecosystem. This module is intended at providing basic understanding, status and functioning of EVs as well as exploring the synergies between EVs and the Grid, international pilots/researches being undertaken in this regard and finally identifying possible opportunities for the electric grids.

10.0.1 BASIC ELECTRIC VEHICLE TECHNOLOGY DESCRIPTION

An EV uses chemical energy stored in rechargeable battery and converts it into electrical energy to power the electric motor which powers the wheels of the EV, unlike Internal Combustion Engines (ICEs) that use petrol or diesel. The batteries are charged through the electricity from the grid and from the regenerative braking where the energy generated from applying brakes is sent to the batteries, instead of being wasted as heat. EVs are of following types: **battery electric (BEV), hybrid electric (HEV or hybrids), and fuel cell electric (FCEV). BEVs** have an electric motor and rechargeable battery instead of an ICE and runs purely on electrical energy. **HEVs** use two sources of power viz. the ICE as well as electric motor to improve fuel economy. Hybrid systems do not require external charging and the batteries are charged through regenerative braking. The HEVs can vary from mild hybrids – which simply reduce the engine size and boost acceleration with an electric motor to full hybrids – that can run solely on the engine, the batteries, or a combination of both (Boschert, 2006).

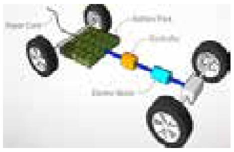
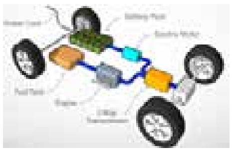
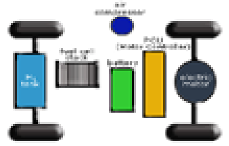
Hybrids can be classified into three categories based on the method by which power is supplied to the drive-train (EV World, 2014).

- **Series Hybrid System:** In this system Engine drives a generator to generate electricity, an electric motor then uses this electricity to drive the wheels.
- **Parallel Hybrid System:** In this system both the engine and the electric motor drive the wheels, and the power from any of these two sources can be utilized according to the prevailing conditions.
- **Series/Parallel Hybrid System (SPHS):** This system by combining both the series hybrid system and the parallel hybrid system, maximizes the benefit of both systems. It has two motors, and depending on the driving conditions, it can use only the electric motor or both the electric motor and the engine, to achieve the highest efficiency.

Another type of hybrid system is plug-in hybrid **(PHEV)** that combines the characteristics of both a HEV by having an electric motor and an ICE; and of a BEV by being able to connect to the grid to recharge the batteries, because the combustion engine works as a backup when the batteries are depleted.

Fuel Cell Electric vehicles (FCEV) use fuel cells (FC) to generate electricity based on a chemical reaction between hydrogen and the oxygen present in the air and this electricity is supplied to the electric motors that propel the vehicle. Table 1 gives a comparison of all the electric vehicle technologies (Webber, 2013).

Table 10-1: Various EV technologies

Technology/ Protocol	BEV	HEV	PHEV	FCEV
Propulsion	Electric Motor	ICE/ Electric Motor	ICE/ Electric Motor	Electric Motor
Drive train				
Battery Charging	Plug-in	Regenerative braking	Plug-in	Electricity generated by fuel cell
Fuel	Electricity	Petrol or Diesel	Petrol or Diesel & Electricity	Hydrogen
Infrastructure	Electric Charging facilities	Re-Fuelling stations	Re-Fuelling stations & Electric Charging facilities	Hydrogen production and transportation facilities
Tailpipe Emissions	No	Yes (low)	Yes (low)	No
Other Characteristics	• High efficiency • Independence from crude oil • Commercially available	• Low emission • Better fuel economy as compared to ICE vehicles • Commercially available • Range	• Low emission • Better fuel economy as compared to ICE vehicles depending on use of motor and driving cycle • Commercially available	• High energy efficiency • Independence from crude oil if hydrogen not produced from fossil fuel • Under development
Challenges	• High cost as compared to ICE vehicles • Lack of charging infrastructure • Relatively short range • Battery and battery maintenance	• High cost as compared to ICE vehicles • Battery sizing and management • Longer Range	• High cost as compared to ICE vehicles • Battery sizing and management • Lack of charging infrastructure • Longer range as compared to conventional hybrids	• Fuel Cell cost, reliability, safety • Hydrogen infrastructure

10.0.2 BATTERY TECHNOLOGY, CHARGING INFRASTRUCTURE AND INTERNATIONAL STANDARDS

I. BATTERY TECHNOLOGY

Batteries are the most important component in an EV and constitute approximately 50-60% of the cost of the EV. Battery in an EV should be robust enough to handle high power, should have high energy capacity, should be stable and ideally be lightweight in order to reduce the deadweight in the vehicle which impacts the fuel efficiency.

Today, Lithium Ion Batteries (LIB) are used in all EVs. There are different battery chemistries in the LIB family but the ones popular with most EV manufacturers are:

- Lithium Iron Phosphate Oxide (LiFePO 4) or simply called LFP for Lithium Ferro Phosphate
- Lithium Nickel Manganese Cobalt (LNMC) or popularly known as NMC
- Lithium Titanate Oxide (LTO)

The performance, durability and cost are key consideration in selection of batteries.

II. CHARGING INFRASTRUCTURE

Understanding the electric mobility systems and their interface standards represent an opportunity to provide cost-effective and secure interoperability with a diverse set of technologies and business models. Standards are key enablers for open interoperable systems and encourage innovation because it enables new business models and services. The benefits of interoperability standards for customer-side transactions are well studied and deployed in commercial programs in many countries. EV batteries as distributed energy resource (DER) systems, requires integration among all three power-flow domains: grid operators, electricity service providers, and customers. The standards can be de-facto, which are uniformly adopted by the industry, or de-jure, which are developed by an accredited standards development organization (SDO) and adopted by the industry. The standards can also be at various levels—for data models, transport mechanisms, and physical communications. This module lists the SDO-supported data model standards for EV charging infrastructure that includes EV supply equipment (EVSE) or charging stations, EVs, and grid interconnection at the key interfaces, as shown in Figure 10-1. Open standards refers publicly available standards with no intellectual property (IP) or pre-agreed IP terms. The module also lists power standards for different EVSE types.[1]

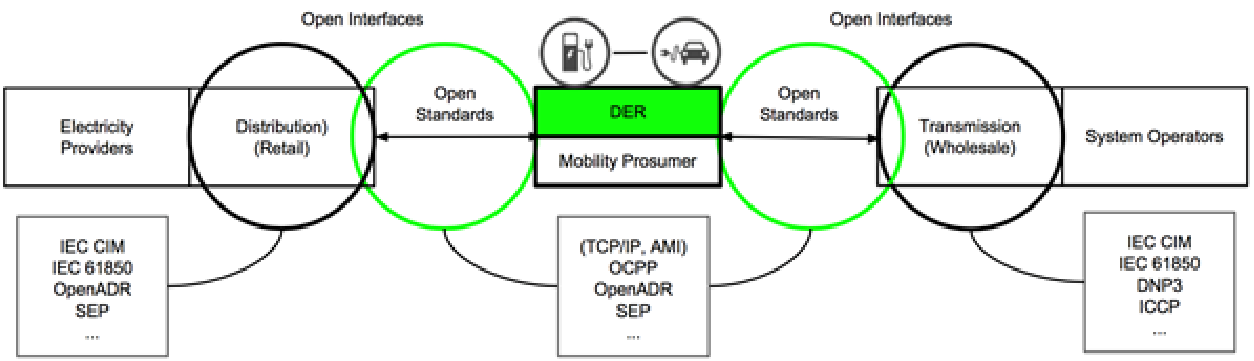


Figure 10-1: Electric Mobility Interoperability with Power Systems and Electricity Markets

[1] *Ghatikar G; Decoding Power Systems' Integration for Clean Transportation and Decarbonized Electric Grid, Proceedings of the ISGW 2016. New Delhi, India.*

The standards governing low voltage AC and DC systems are quite different. The established Low Voltage AC (LVAC) standard voltage limit is 1000 V AC internationally, while the IEC Low Voltage DC (LVDC) standard voltage limit is 1500 V DC[2]. The Bureau of Indian Standards (BIS) has embarked upon its own LVDC standards with two collaborations (1) An Memorandum of Understanding (MoU) with IEEE for LVDC micro grids and (2) with IEC as a part of their membership in LVDC SEG4 and LVDC Sys Committees. The BIS has set up two technical committees ETD-50 (LVDC Power Distribution Systems) and (2) ETD-51 (Electro technology in mobility). The ETD-50 has published standards for DC microgrids in November 2017; but the work of ETD-51 is under progress. Further, the BIS Group 5.5 has standards for various batteries but none for Lithium Ion chemical variants. Thus, in the short-term, the standards governing EVSE and/or the EV batteries in India will likely be governed by major international standards such as the IEC or the IEEE.

The EV charging infrastructure comprises of the following:

- Electricity supply infrastructure - transformers, meters, panels, conduits and wires that is required to provide reliable electricity supply to the vehicle chargers.
- Electric Vehicle Supply Equipment networking requirements to enable efficient EV charging and other services among EVSE owners and EV drivers
- EVSE and EV integration for automated communications and EV identification
- EVSE/EV communication with electricity service provider and/or grid operators for effective monitoring and management of EV, as a grid resource

There are two basic EVSE options for charging an electric vehicle: wired or conductive charging and wireless or inductive charging. Considering that the wireless charging is still in early stages of development and widespread acceptance, the focus is on wired charging. Wired charging is primary option wherein commercially ready solutions are widely available for EVs and EVSEs. The EVSEs are classified into several types and categorized by the current flows and the power ratings at which the EV batteries are charged.

The EVSE current follows are categorized, as alternate current (AC) and direct current (DC) charging. Charging with AC is used for low- and medium-power charging at homes and offices or workplaces, and at public spaces. Charging with DC is used for fast-power and are called DC Fast Charging (DCFCs), while AC Pulse Charging (ACPC) is enabled through the deployment of Ultra Capacitors. The global deployments of public charging infrastructure are dominated by AC chargers and DCFCs. The advantage of Pulse Charging is that the grid power supply intake is much less even though the DC pulse charge (often less than a second) can be twice as much as DCFC levels.

Considering that all EV batteries require DC power to be charged, the grid-supplied AC power has to be converted to DC. An AC/DC convertor is needed to charge the battery using grid power. In the AC EVSEs the converter is on-board the EV, while the DC EVSEs (DCFC) and the ACPC (AC Pulse Chargers) have integrated converters. At higher power DC charging levels, a more expensive converter is needed that is not a standard practice by majority of the car manufacturers. These converters are therefore incorporated in the EVSEs and DC power is delivered to the EV. The same is true of Pulse Chargers as well.

Table 10-2: Different EVSE types for AC and DC, their typical voltage and current levels

Power Levels	Grid Voltage/Current (in Amperes) Input	DC Power to Battery (kW)	Applicable Vehicles
AC Level 1	108-120/15-20	~1.4 to 2.4	2W, 3W, 4W
AC Level 2	208-240//≥30	~7.2 to 19	3W, 4W

[2] *Note that the various national standards as it exists today limit the DC voltage between 400V – 1000V*

Power Levels	Grid Voltage/Current (in Amperes) Input	DC Power to Battery (kW)	Applicable Vehicles
DC Level 3 (DCFC)	400-800/≥120	≥50 (up to 150)	4W, LDV, HDV
AC Level (ACPC)	400/60	450-600	HDV

HDV: Heavy Duty Vehicle; LDV: Light Duty Vehicle

The EVSE types vary for each type of EVs for example, 4 wheelers primarily use dedicated EVSEs in non-residential charging, while buses can be charged with overhead (pantograph based) charging. While the power standards for EVSEs are mature for 3W, 4W and LDVs, the same is not true for bus charging infrastructure.

It may be noted that battery chemistry variant dictates the limitations to the type of charging method (and hence chargers) that can be used. While this is taken care in the case of the AC Level-1 and AC Level-2 chargers (being on board the vehicle), in all other cases where the charger converter is external to the vehicle, the selection of third party chargers needs careful consideration of battery chemistry[3] used in different types of EVs.

AC Pulse Chargers cannot typically adjust their outputs to respect Demand Response (DR) signals nor VGI signals due to their internal "pulse booster circuitry designs which keep the battery "off-circuit" from the grid. These type of chargers are not widely used.

III. EVSE POWER STANDARDS

For both AC and DC charging, multiple plug designs and charging modes have been developed and have been deployed throughout the world. Some of the major charging standards followed around the world are described below:

a. MODES

The charging mode refers to power levels that charger and its connectors are rated for. IEC 61851-1 Committee on "Electric vehicle conductive charging system" has defined 4 Modes of chargers, concerning:

- Mode 1: slow charging from a household-type socket-outlet in AC
- Mode 2: slow charging from a household-type socket-outlet with an in-cable protection device in AC
- Mode 3: slow or fast charging using a specific EV socket outlet with control and protection function installed in AC
- Mode 4: fast charging using an external charger in DC

b. PLUG TYPE

i. AC CHARGING STATIONS

Both 3 and 4 wheelers can primarily use the AC EVSEs, depending on the EV manufacturers' preferences.

[3] Popular battery chemistry for EV batteries and its properties are Lithium Titanate Oxide (LTO); Lithium Manganese Cobalt (LMNC); Lithium Phosphate Oxide (LFP); Lithium Polymer (LP). Each one has its own charging and discharging advantages and limitations. While some of them can be fast charged up to 10C, others are at 5C or below. (1C denotes 1 hour of charging to 100% State of Charge; therefore, a 10C rating would full charge in 6 minutes; this would apply equally for discharge rate as well).

The IEC committee has defined three types of socket outlets:

- **IEC 62196-2 "Type 1"** - single phase vehicle coupler - reflecting the SAE J1772/2009 automotive plug specifications
- **IEC 62196-2 "Type 2"** - single and three phase vehicle coupler - reflecting the VDE-AR-E 2623-2-2 plug specifications
- **IEC 62196-2 "Type 3"** - single and three phase vehicle coupler with shutters - reflecting the EV Plug Alliance proposal

ii. DC CHARGING STATIONS

Both 3 and 4 wheelers, and buses can primarily use the DC EVSEs,[4] depending on the EV manufacturer's preferences, based on the battery chemistry. There are four different standards for DCFCs in practice today as briefed below:

CHAdeMO

To define a standard for DC charging, Japan set up the CHAdeMO association (Charge de Move) in 2010. CHAdeMO charging station can only be used for cars with a matching CHAdeMO inlet and that it is not possible to use alternative cables such as for AC charging. The plug design is however not (yet) recognized as such by the IEC even though its power and safety ratings comply with the IEC 62196 norms. A major drawback of the CHAdeMO standard is that it prescribes a separate vehicle inlet that is used for DC charging exclusively. The CHAdeMO equipment is typically rated for 125 A and 500 V DC, which translates to 62.5 kW, albeit recent updates allow the peak power charging upwards of 125 kW.

Combined Charging System (CCS)

The Combined Charging System (CCS) or Combo was developed by the Society of Automotive Engineers (SAE) for EVs with DC charging requirements. Similar to CHAdeMO, the CCS-supported EVSE can only be used for cars with a matching CCS inlet. There are two versions of the CCS connector: (1) The U.S. version combines the Type 1 Yazaki AC design with the additional DC pins, and (2) The European version combines the DC pins with the Type 2 Mennekes AC design. Type 1 is available for sale rated up to 200 A and 600 V on the DC lines, which translates to 120 kW peak power at best. European Type 2 seems much more capable with 200 A and 850 V, which in theory gives 170 kW peak power.

GB/T

GB/T is a Chinese standard (20234), which can run up to 250 A and 750 V, which means that it is actually the most powerful DC fast-charger in the world with 187.5 kW capacity. This standard is yet to be accredited by the international standards development organisations.

Tesla SuperCharger

Tesla began its adventure from 90 kW level, then increased to 120 kW in North America. The connector in North America is unique. Tesla SuperChargers in Europe have a different connector which looks like Level 2 AC connector.

[4] *http://archive.northsearegion.eu/files/repository/20140805153226_StandardizationofEVRecharginginfrastructure.pdf*

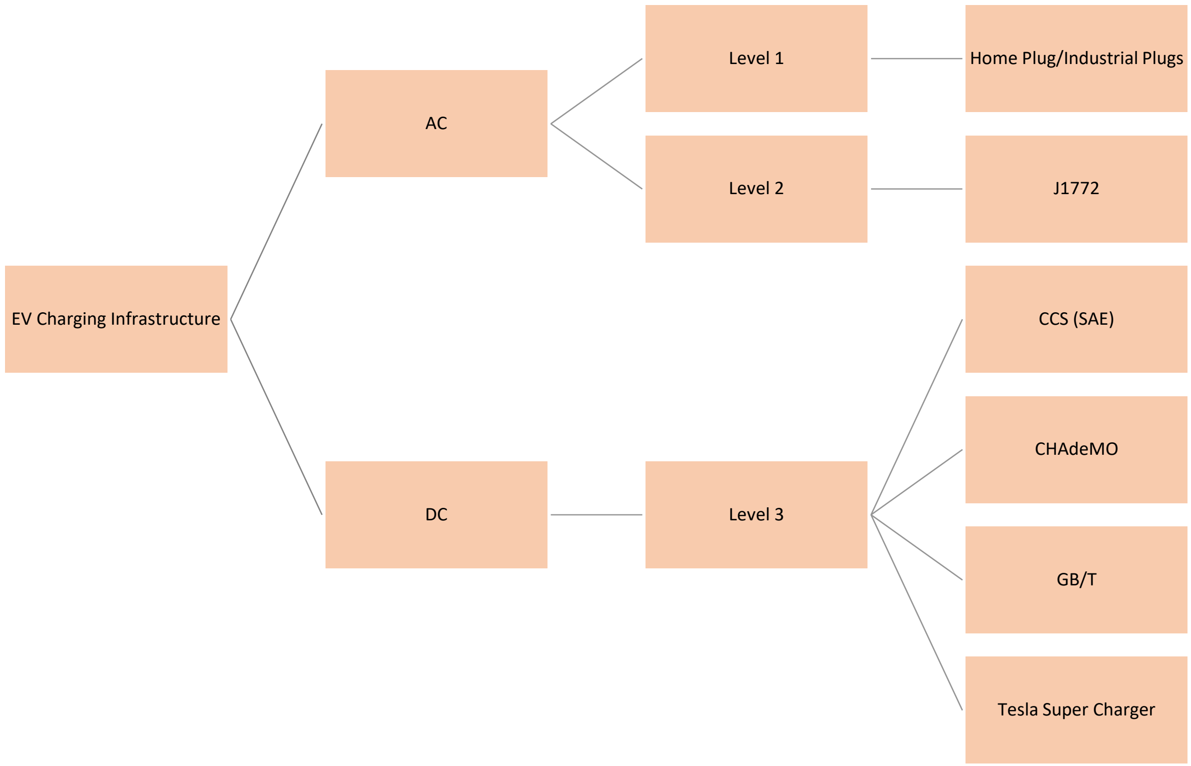


Figure 10-2: Charging Standards for Alternate and Direct Current Charging Infrastructure

Table 10-3: Popular EVs and their DCFC Standards

EV Models	DCFC Standards
Nissan LEAF, Mitsubishi,	CHAdeMO
Chevy Volt, BMW, Ford, Mercedes	CCS
Tesla	Super Charger
GB/T	GB/T

For buses, the EVSE types can also be overhead or pantograph based. Considering that the battery capacities for buses are typically much larger than those of 3 or 4 wheelers, a significantly higher level of charging will be required. The U.S. Society of Automotive Engineers (SAE) is considering charging voltage (V) limits in the range of 500 V to 1000 V and current ampere (A) limits from 200 A to 350 A, which provides a maximum 350 kW DC charge. For buses, the following standards are under consideration[5]:

- Manual 3 phase AC at high power—SAE J-3068
- Manual DC connection at high power—SAE J-1772
- Overhead or pantograph connection at high power—SAE J-3105

iii. AC PULSE CHARGING STATIONS

These chargers are typically deployed on heavy duty vehicles (buses and trucks) mostly through the use of pantograph style connectors due to the heavy pulsed charging currents involved. This method allows for charging en-route (and not just at depots) as well due to its short duration. The cost of the charger is high due to its use of Ultra Capacitors and DC-DC pulse boosting converters.

[5] *EPRI IWC Bus and Truck Charging WG*

IV. EVSE COMMUNICATION STANDARDS

While power standards are key to determine interoperability to charge different makes of EVs, with different makes of EVSEs, their management and use for services to respective owners is the key function of the standardization of communication standards. Figure 3-3 shows the communication requirements between EV and EVSE and EVSE/EV with the electric grid through electric utilities and EVSE service providers (EVSP). These communication standards are further described below.

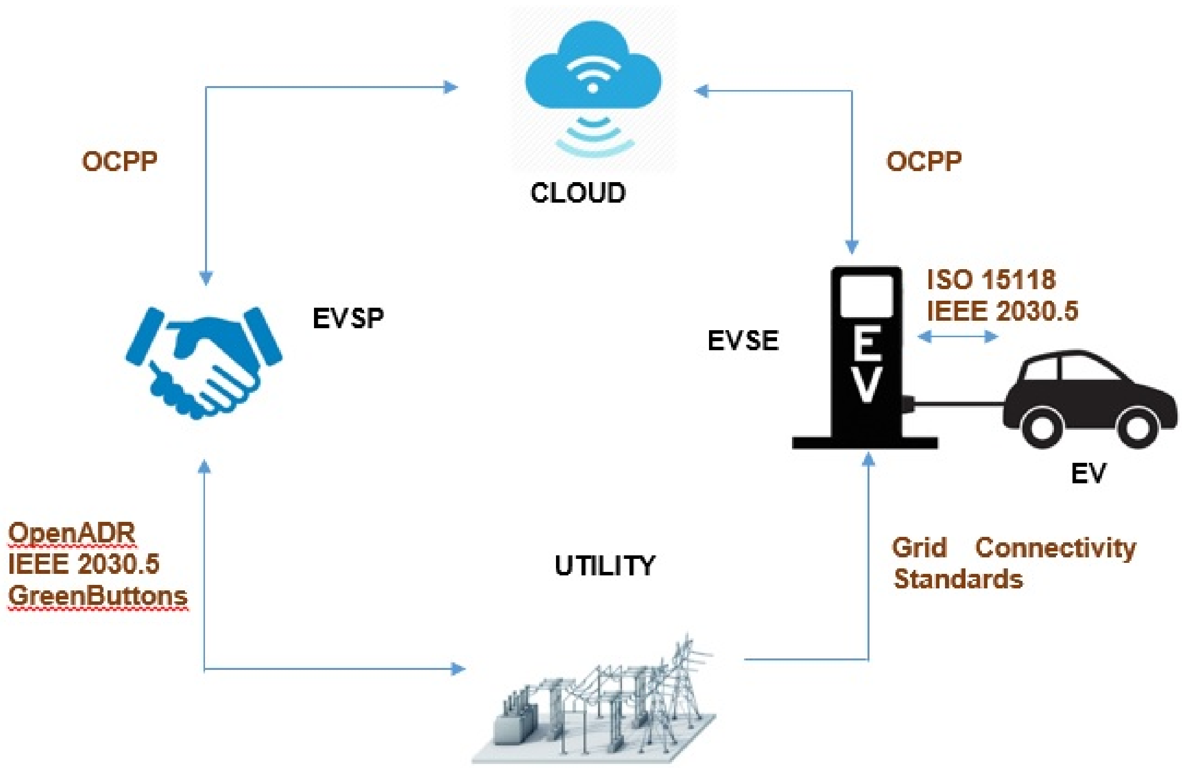


Figure 10-3: Few Globally Available Information Exchange Standard

EVSP: EVSE Service Provider; EVSE: Electric Vehicle Supply Equipment; OCPP: Open Charge Point Protocol

Open Charge Point Protocol (OCPP)

EVSE communicate through the internet to management software for the purposes of operating and controlling the charging stations. The Open Charge Point Protocol (OCPP) is an internationally established open protocol for the communication between EV charging stations and charging station networks (akin to a cell phone service provider). OCPP tells the charging station to communicate and send data to a particular EVSE service provider (EVSP) or operating company's charging station management software. That charging station management software is the major component of an EV charging "network".

An EV charging station network is necessary to monitor charging station up-time, control access to charging, enable payment processing, capture driver and usage data for reporting, and to integrate with enterprise software systems beyond the charging station network – including utilities, building management systems, HR systems, customer loyalty programs, and other charging station networks.

ISO 15118

ISO 15118 specifies the communication between Electric Vehicles (EV) and the Electric Vehicle Supply Equipment (EVSE). As the communication parts of this generic equipment are the Electric Vehicle Communication Controller (EVCC) and the Supply Equipment Communication Controller (SECC), ISO 15118 describes the communication between these components. The ISO 15118 can be applied to any vehicles that wishes to communicate with the supporting EVSE in a standardized fashion.

ISO 15118 does not specify the vehicle internal communication between battery and charging equipment and the communication of the SECC to other actors and equipment (beside some dedicated message elements related to the charging). All connections beyond the SECC, and the method of message exchanging are considered to be out of the scope as specific use cases.

OASIS Energy Interoperation (or OpenADR 2.0)

OpenADR is commonly being used in peak load management programs in electric utilities. The last few years have seen an increasing uptake of this standard for fast demand response (DR) programs and auxiliary service which deploy DR resources within seconds to balance inconsistent generation from renewables. Distributed energy resources (DER) management and electric vehicle charging are also key aspects in many recent trials. OpenADR 2.0 can communicate event messages, reports, registration services, and availability schedules for price- and energy usage-based programs[6].

IEEE 2030.5 (or Smart Energy Profile)

IEEE 2030.5 is a standard for communications between the smart grid and electricity customers. The standard is built using Internet of Things (IoT) concepts and gives consumers a variety of means to manage their energy usage and generation. Information exchanged using the standard includes pricing, demand response, and energy usage, enabling the integration of devices such as smart thermostats, meters, plug-in electric vehicles, smart inverters, and smart appliances.

Energy Services Provider Interface (or GreenButton)

The GreenButton initiative is an industry-led effort that responds to a White House call-to-action to provide utility customers with easy and secure access to their energy usage information in a consumer-friendly and computer-friendly format. Customers are able to securely download their own detailed energy usage with a simple click of a literal "Green Button" on electric utilities' websites.

The GreenButton initiative was officially launched in January 2012. This ensures homes and businesses to securely access their own energy information in a standard common, machine-readable format.

V. EV CHARGING AND GRID CONNECTIVITY GUIDELINES

The electrical code in India provides connectivity guidelines (both Low Tension (LT) and High Tension (HT) connections). It also articulates the technical details of the load connection to be submitted to the local Distribution Companies (DISCOMs) for review. The DISCOM reviews these details primarily for determining electrical capacity requirement to feed the stated load as well as impact on power quality aspects. It then selects the rate class under which the applicant would be billed (demand charges and energy tariff).

All charging infrastructure (AC, DCFC, ACPC) falls under the electrical code purview. If the charging infrastructure is a HT connection (11 kV or higher) the captive substation design details must be submitted to the DISCOM for review (location, public safety, electrical protection/relaying, etc.) and approval.

[6] *https://openadr.memberclicks.net/assets/using%20openadr%20with%20ocpp.pdf*

Substations that are located in proximity of public spaces require other municipal clearances like fire, water, noise, fence clearance surroundings, underground, etc. These approvals are required for each location of a charger to be installed by a third party (other than DISCOM). To the extent such charging infrastructure is drawn from an existing source point (e.g. DT), then such process is much simpler. Addition of new captive DT (415V application) is much like a new application and will go through the DISCOM approval process.

Typically, capacity requirements under 600 kVA could be delivered either through an existing DT or through the provision of a captive DT. All load capacity requirements above 600 kVA and up to 1500 kVA will require an 11 kV connection with the applicant providing necessary voltage step down transformers and a functioning substation that interfaces with the charging equipment. The impulse characteristics of fast chargers (typically 3C and above) are to be studied for power quality impact and if significant, the charging station may be connected to 33 kV (instead of 11 kV) or require customer-owned mitigation equipment to reduce impact from impulse.

The fleet operator (or third party operator) who owns and operates charging facilities will be given an electrical licence to operate under the requirements of the electrical code. The code stipulates ongoing upkeep and safe operations of such charging facilities.

Necessary Regulatory Provisions

As a customer connected to the LT or HT grid, and duly supplied by a DISCOM, the state regulatory provisions and approved codes shall apply. The DISCOM has no powers of waivers over regulatory matters, imposed tariff structure or rates. The DISCOM merely administers the regulatory codes and regulations. The regulatory powers are in turn delivered through state or central legislation via the Electricity Act or other legislative directives.

Since the charging infrastructure for public bus fleets is a monopoly asset for the public good, the DISCOMs themselves may agree to own and operate these assets. To do this, they need to apply to the regulatory process for such acquisitions and an approved a rate recovery. If approved, a new rate class may be prescribed by the regulator or merely directed under an existing rate class.

b. Connectivity Norms/Standards—Charging Management, Batteries, and Demand Response

All charging equipment in India shall be either covered/certified to relevant standards set by the Bureau of Indian Standards (BIS). These include the following subsystems of a typical charging infrastructure:

- Battery type, enclosure, battery management system (BMS) and all DC connection gear /equipment
- The AC/DC power converter, associated control and protection equipment
- Drivetrain controls, motor and all AC and DC electrical equipment such as substation that feeds the power converter
- Others such as fire protection, anti-flooding, public safety, etc.

All batteries require a select methodology of charging to ensure its internal chemistry as well as physical parameters (thermal, mechanical, etc.) are not damaged due to an aggressive charging process. The BMS acts as safeguard here.

All batteries have a stated depth of discharge (DOD) beyond which its life is reduced. For most Lithium Ion batteries the DOD is 70% (max). The various states of charge (SOC) between 100% full charge and the maximum DOD (70%) governs the battery performance and this function is not linear. For example, a 100 kWh battery should not be discharged below a residual 30 kWh level. As the residual power in the battery decreases towards the DOD levels, the stress on the battery increases. Suitable third-party fast chargers are typically recommended by the battery vendor (through EV OEM) for suitability as otherwise it may be detrimental to the battery employed. Also, the drivetrain is also mated with a particular battery type and size for optimum performance.

Smart chargers may have communications connectivity at the grid side to DISCOMs to be able to reduce charging power levels under voluntary /subscription based participation in a Demand Response program. The charging power levels set by the fleet operator to optimize the charging process may be given precedence over participation in the DR program.

For an effective performance and successful operation Electric Vehicle (EVs) require an extensive charging infrastructure for easy access. Charging Infrastructure or Electric Vehicle Supply Equipment (EVSE) refers to the elements that supply electric energy for the recharging of EVs. The charging infrastructure includes the hardware and software which ensures that energy is transferred from the electric grid to the vehicle. It can be categorized by location, power level and charging time strategy.

Charging infrastructure plays a pivotal role in EV deployment, and in the absence of a proactive plan and schedule, is a major impediment to mass market adoption. Infrastructure limitations are particularly pertinent to EVs due to their sole dependency on electricity. The charging stations can be built in homes; offices and public places like petrol pumps, bus depots, shopping centers, restaurants, entertaining places, highway rest areas, parking lots.

The charging infrastructure broadly includes level 1 terminals, level 2 terminals (fast chargers) and level 3 terminals (rapid chargers). The typical time taken for charging by these chargers is 6-8 hours, 3-4 hours and less than 30 minutes respectively. These chargers also vary substantially in their costs; therefore, the charging terminals need to be created as per the requirement of the location. The electric vehicles can be charged externally via:

- Electric cable
- Wireless charging, that uses Electromagnetic field to transfer energy between 2 objects.
- Battery Swapping

VI. INTERNATIONAL STANDARDS

SAE International (Society of Automotive Engineers) has defined 240 V AC charging as level 2 and 500 V DC high current charging as DC fast charging (level 3). Level 2 chargers can be installed at home. A number of standards have been formulated for energy transfer, connection interface and communication for EV charging. These standards are given in Table 11.2

Table 10-4: International Standards for EV chargers

Country	Power Standards
Americas	SAE J1772 Level 1 and 2 for Alternate Current (AC)
	SAE J1772 Combo Coupler Standard (CCS) Direct Current (DC)
	CHAdeMO (DC)
	Tesla Supercharger (DC)

Country	Power Standards
Europe	SAE J1772 Level 1 and 2 for Alternate Current (AC) SAE J1772 CCS DC CHAdeMO (DC) IEC 61851
Asia (China)	GB/T (DC) IEC 61851

SAE standards are industry-accepted standards developed through technical consultations carried out by the SAE International (www.sae.org) a global association representing aerospace, automotive and commercial vehicles industry experts. In addition to SAE standards, the International Electrotechnical Committee (IEC) and CHAdeMo, industry association with a mission to set-up fast charging infrastructure too have developed standards (Young, 2013).

Table 10-5: EV Charging levels

Charging Level	Typical charging power	Voltage	Charging time	Suitable Location	Price (USD)
Level I	1.5 kW	120 V AC	6-8 hours	Home, offices, parking areas	~550-600
Level II	6.6 kW	240 V AC	3-4 hours	Malls, railway station, airports	~5000
Level III	40 kW and above	500 V DC	<30 min	Petrol pumps	~25000

Source: http://iopscience.iop.org/article/10.1088/1748-9326/11/6/064010/pdf

VII. EVSE STANDARDS IN INDIA

Automotive Research Association of India (ARAI) has also developed standards for type approvals of EVs available in Indian market and for hybrid electric conversion kits. It is currently in process of defining standards for charging stations and chargers.

- AIS-102 (part 1): Applicable for hybrid vehicle less than 3500 kg. The standard specifies applicable type approvals under Central Motor Vehicle Rules for HEVs
- AIS-102 (part2): Applicable for hybrid vehicle more than 3500 kg. The standard specifies applicable type approvals under Central Motor Vehicle Rules for HEVs
- AIS-123: Standard for Vehicles Retrofitted with Hybrid Electric System. AIS-123 defines the type approvals required for such retrofitted vehicles.

Apart from this, ARAI has formulated draft standards for Electric Vehicle Charging Infrastructure as well:

- AIS 0138 (Part 1): Electric vehicle conductive AC charging system
- AIS 0138 (Part 2): Electric vehicle conductive DC charging system (Under Preparation)

In May 2017, a committee appointed by Department of Heavy Industries, GoI prepared charger specifications for EVs (do not cover buses).[7] These specifications includes following type of chargers:

[7] *Committee Report on Standardization of Public EV Chargers; DHI, GoI http://dhi.nic.in/writereaddata/UploadFile/Standardization%20of%20protocol.pdf*

- AC Chargers
- AC Public off-board Chargers up to a maximum charging rate of 2.5 kW or 3 kW.
- DC Public off-board Chargers
- Level 1 DC Chargers
- Level 2 DC Chargers

Bureau of Indian Standards (BIS), the national standards body has constituted a technical Committee (ETD-51) which is presently preparing standards for EVSEs for India which is expected to issue draft standards early next year.

Aggressive electric mobility adoption has potential for grid services, using the framework for electric mobility infrastructure and electric power systems integration. To best integrate EVs, Regulators should mandate grid interoperability using open standards that have been adopted by the electric grid participants and technology providers in other countries. This will address industry issues with vendor lock-in, and cost-effectively connect EVs with all charging network types, metering, and Smart Grid domains, to encourage innovation and advance the industry/customer experience.

List of globally available standards for Electric Vehicles are provided in Annexure to this Module

10.0.3 EV- IMPACT ON ENVIRONMENT AND ENERGY SECURITY

As already stated in the beginning of this module, India imports most of its crude oil demand. The crude oil import can be avoided to large extent by increasing the penetration of EVs in the transportation fleet.

EVs have virtually no tailpipe emissions. However, owing to the fact that the Indian Electricity Grid is still dominated by coal-based thermal power plants which has a high CO_2 emission factor the life cycle emissions from EVs become positive. Hence, coupling the EVs with renewable energy will make EVs a zero emission technology and it will also open up new avenues for promotion and increase in share of RE in the grid.

EVs are important not only with respect to reduced fuel imports and the subsequent reduced burden on the Government, but also from the perspective of reduced GHG emissions and associated health benefits from reduced curb-side pollution. EVs can work as energy storing device to absorb renewable energy, so the problem of intermittency and non-dispatchability of this power can be worked out (Bellekom, Benders, Steef, & Moll, 2012). Furthermore, EVs can sell the stored electricity back to the grid through the technology of Vehicle-to-Grid (V2G) (Zhang, Xie, Rao, & Liang, 2014)

10.0.4 INTERNATIONAL EV MISSIONS

International Energy Agency (IEA) has developed electric and plug-in hybrid vehicle roadmap for the world which aims to attain a combined EV/PHEV sales share of at least 50% of Light Duty Vehicle (LDV) i.e., passenger cars sales worldwide by 2050. IEA Energy Technology Perspectives BLUE Map scenario, targets an ambitious 50% reduction in global CO_2 emissions by 2050 relative to 2005 levels. Transport sector targets a 30% GHG reduction which will be mainly accomplished by rapid market penetration of EVs and PHEVs. This translates into combined EV and PHEV sales of 2,500,000 electric cars by 2030 from India in comparison to 1,275,000 HEV/PHEV and 170,000-320,000 BEV sales in 2020 as envisaged in National Electric Mobility Mission Plan (NEMMP). Other countries like US, UK, Germany, China, and South Korea have also taken up ambitious EV implementation targets which are summarised below.

The characteristics of purchase incentives are explored in the list below, focusing primarily on countries with higher-than-average EV market shares.[8]

- Electric cars in **China** enjoy an exemption from acquisition tax and from the excise tax, normally based on engine displacement and price (Mock and Yang, 2014). The value of the incentives was in the range of 35 000 Yuan renminbi (CNY) to CNY 60 000 (USD 6 000 to USD 10 000) to purchase electric cars (Lutsey, 2015).
- **France** began offering in 2013 purchase incentives of 6 300 euros (EUR) (USD 7 100) for BEVs (cars emitting less than 20 grammes of CO2 per kilometre [g CO2/km]) and EUR 1 000 (USD 1 100) for PHEVs (vehicles emitting between 20 g CO2/km and 60 g CO2/km) through its bonus/malus feebate scheme (MEEM, 2016a). Scrapping diesel vehicles allows a supplementary bonus of EUR 10 000 (USD 11 000) for BEVs and EUR 3 500 (USD 4 000) for PHEVs (MEEM, 2016b).
- **Japan** subsidies are based on the price difference between an EV and a comparable gasoline car, with a maximum of 850 000 yen (about USD 7 800). Mock and Yang (2014) indicated that incentives amounted to EUR 3 000 to EUR 5 000 (USD 3 300 to USD 5 500) for typical BEVs and PHEVs.
- **Netherlands**, in 2016, cars emitting zero CO2 at the tailpipe are exempt from paying registration tax. For other cars there is a differentiated taxation scheme with five levels of CO2 emissions with progressively increasing taxation per g CO2/km. PHEVs qualify for the first level (below 80 g CO2/km) and pay EUR 6 per g CO2/km. Diesels emitting more than 70 g CO2/km Beyond one million electric cars also pay EUR 86 per g CO2/km (EVI, 2016a and Energielabel, 2016). This kind of structure provides significant benefits for both BEVs and PHEVs compared with vehicles powered by ICEs, with a steep growth for models having ICEs with emissions ratings above 106 g CO2/km. The condition for exemption from the registration tax has become stricter since 2013, when it started to be fully coupled with CO2 emission performances (Energielabel, 2016).
- In **Norway**, EVs are exempt from purchase taxes (about 100 000 kroner [NOK] – USD 12 000) (OECD, 2015). BEVs are also exempt from VAT (set to 25% of the vehicle price before tax). The VAT exemption does not apply to PHEVs (Mock and Yang, 2014).
- In **Portugal**, BEVs are exempt from vehicle registration (about EUR 1 250, or USD 1 400) and circulation taxes (Saldopositivo, 2014). Scrapping existing vehicles for a selection of BEVs also entitles buyers to a bonus of EUR 4 500 (USD 5 000) (Apambiente, 2016; IMT, 2016). PHEVs are not eligible for specific incentives.
- In **Sweden**, passenger vehicles with emissions levels lower than 50 g CO2/km have been granted a 40 000 kronor (roughly EUR 4 000 or USD 4 400) rebate since 2011.
- Germany, in 2016 announced that ICE production and sales will be stopped in 2030
- In the **United Kingdom**, BEVs receive a purchase incentive up to 4 500 pounds (GBP) (USD 6 300) for cars and GBP 8 000 (USD 11 200) for light commercial vehicles; PHEVs below GBP 60 000 (USD 84 000) receive incentives equal to GBP 2 500 (USD 3 500) (GOV.UK, 2016a).
- In the **United States**, EVs enjoy tax credits capped at USD 7 500 at the national level. PHEV models with all-electric ranges (18 km to 40 km) receive credits of USD 2 500 to USD 4 000; BEV models and some PHEV models with relatively high all-electric range (e.g. Chevrolet Volt) receive the maximum USD 7 500 credit (Lutsey at al., 2015). States also apply purchase incentives (AFDC, 2016). For instance, California offers incentives of USD 2 500 for EVs and USD 5 000 for FCEVs (or more for low-income consumers); Colorado offers an income tax credit of up to USD 6 000; Connecticut offers up

[8] *IEA Global EV Outlook, 2016*

to USD 3 000 in rebates and Delaware up to USD 2 200. Jin, Searle and Lutsey (2014) estimated a range between USD 1 000 and USD 6 000 for BEV and PHEV purchase incentives at the state level, and an average value for the incentive offered to EV purchasers across the United States close to USD 1 000, both for BEVs and PHEVs.

***Government of India** has also unveiled its National Electric Mobility Mission Plan 2020 as a commitment for reducing the carbon footprint of the automotive sector as well as to reduce its imported oil dependency. Under the NMEM (National Mission for Electric Mobility), Government has set an ambitious target of xEVs sales of 6-7 million by 2020 which corresponds to penetration of EVs of 15% in 2W and 19% in passenger car markets. In 2015-16, Government of India allocated INR 75 crore for the FAME scheme launched as a part of this mission; in 2016-17, Government of India allocated INR 122 crore for FAME and in 2017-18 budget, Government of India allocated INR 175 crore for Electric Vehicles.*

Electric vehicles present potential benefits to energy security and environment. EVs have not gained a significant interest and attraction since none of the current EVs available in the market are capable of perfectly replacing the service provided by a conventional petrol or diesel vehicles owing to variety of teething troubles. Moreover, EV recharging takes longer than conventional refueling; affordability and range still remain deterrents for consumers. On the other hand, Electric motors are inherently more efficient than internal combustion engines (ICEs), EVs have no tailpipe emissions, and at current given prices of fuel and electricity it generally costs less to run vehicle on electricity than on petrol or diesel. In the last 10 years the world has again considered vehicle electrification in light of increasing and volatile oil prices, deteriorating urban air quality, and climate change. International Energy Agency (IEA) in its Energy Technology Perspectives 2012 has clearly spelt out potential of CO2 reduction from transport sector. A great amount of research and development is underway to standardize, battery and chargers, create charging infrastructure and reduce the costs. An electrical vehicle fleet would make plausible such long-term futures options as (Kempton & Tomic, 2005):

- EVs serving as a power generation/balancing resource for the grid
- Storage of a high proportion of intermittent renewables in the battery-EV fleet

10.1 VEHICLE GRID INTEGRATION (VGI)

10.1.1 POTENTIAL GRID SERVICES FROM VGI

Studies have shown that most vehicles are parked almost 95% of the time and when parked they can be connected to grid to either charge from the grid or to deliver the energy stored in their batteries, similar to large scale grid energy storage systems (Guille & Gross, 2009). The use of vehicles to deliver the grid services are collectively referred as **Vehicle-Grid Integration** (VGI). Different categories of VGI exist based on the type of electricity market that vehicles are offering services in, and whether vehicles are controlling 1-way charging only (V1G) but doesn't discharge the battery to the grid, or **Vehicle-to-grid** (V2G) where there is capability of controllable, bi-directional electrical energy flow between a vehicle and electric grid. As a controllable load, V1G can likely take advantage of the existing regulatory framework e.g. Demand Response and provide grid services by controlling the state-of-charge of the battery. However, V1G can only provide grid value when the vehicle is charging. Bi-directional flow of electricity enables a V2G capable vehicle to discharge its battery power to the grid and provide grid services whenever it is plugged-in and communicating with the grid.

With large scale penetration and its integration with grid, EVs can potentially provide following services to the grid (Kadurek, Ioakimidis, & Ferrao, 2009):

- Ancillary services such as peak power shaving, spinning reserve, voltage and frequency regulations
- Reactive Power Regulation
- Integration of large scale renewable energy sources (RES)

The possible grid services by EVs can alleviate technical and economic challenges for the grid, and enable drivers to receive a stream of money for the grid services that their vehicles offer, however the understanding of the value of these vehicle-grid services is still in an evolving stage.

I. EVS AND ANCILLARY SERVICES MARKET

It has been studied that most of the vehicles are parked for over 95% of their time. If connected to the grid during this idle time the batteries and chargers of EVs could be used to transmit active and reactive power from the vehicle and internal capacitors back to the grid. The prerequisite for such function is a bidirectional EV Supply Equipment (EVSE or EV Charger) which can be optimally designed for providing support to the grid during critical conditions: active power ride-through, regulation of reactive power, and sending active power back to the grid for peak shaving (Kisacikoglu, Ozpineci, & Tolbert, 2011). With the bidirectional charging capacity integrated with intelligent and smart charging features, EVSE can be programmed to charge the vehicle during off-peak hours of the local distribution system, which also serves to support the grid to flatten the load shape.

The ancillary services from VGI can be divided into peak power shaving, spinning reserves, and voltage and frequency regulation (Ehsani, Falahi, & Lotfifard, 2012).

Peak Shaving: Injection of active power stored in the batteries of EVs during peak load hours can help lowering the peak power demand of the distribution system. However, in order to act as a reliable peak power source, utility needs to know the exact location of the available source. Therefore, larger fixed charging stations present in public, commercial or industrial areas need to be created which can be used as distributed generation source by the utility during peak hours.

Active Power Regulation can be used for maintaining the frequency of the grid at 50Hz (or 60Hz where relevant) and to minimize voltage fluctuations. The grid operator uses a real-time communication signal to request active power regulation. Therefore, a unit with short response time and high ramp rate is required to provide this service. EVs with power electronics chargers have fast response time and high ramp rate, which makes them suitable for regulation and batteries can be used for active regulation if connected to grid through a high power DC/AC inverter. Sizing of the battery and the AC/DC interface is important for regulation.

Spinning Reserve is provided by online generators that can change their output instantly in response to major transmission outages. These units are equipped with advanced telecommunication facilities and can reach their full output within minutes. Spinning reserves should be capable of sustaining their response for few hours. Spinning reserve is required less frequently than active regulation. Batteries of electric vehicles are perfectly suited for this service. However, similar to peak shaving services the utilities need to know the exact location and capacity connected to the distribution system at any given time.

II. REACTIVE REGULATION

Modern residential appliances such as microwaves, washing machines, air conditioners, dishwashers, and refrigerators consume reactive power for which, even though the residential consumers do not pay, but the utility is responsible to deliver. This reactive power is generated at energy source end and is transmitted through the transmission and distribution system, which causes increased energy losses and decreased system efficiency. Therefore, reactive power is best utilized when it is generated close to user end. EVs can readily supply this reactive power locally. The charger can supply reactive power at any time even during charging. However, the selected topology and the effect of the reactive power on the operation of the charger and the battery should be well analyzed. There is a need for further technical analysis and research on topologies suitable for reactive power operation and its effect on both the charger design and battery charging cycle (Kisacikoglu M. C., 2013).

III. RE INTEGRATION

Renewable energy sources go through transients due to fault or weather conditions. EVs connected with a charger to the grid can support the grid fault and Low Voltage Ride Through (LVRT) conditions. EVs can also be charged from the excess energy generated from RE (solar and wind) sources instead of backing down conventional generating stations to keep the grid balanced. This stored energy can be used for driving needs or to provide power at a later time (Ehsani, Falahi, & Lotfifard, 2012), (Clement-Nyns, Haesen, & Driesen, 2011).

10.1.2 CHALLENGES ASSOCIATED WITH VEHICLE GRID INTEGRATION

Integration of EVs with the grid pose numerous challenges for becoming commercially viable; ranging from overheating power transformers to incurring new investments of power distribution facilities. Some of the key concerns are listed below:

- **Coordination of several vehicles** is required to be presented to the utility as a single storage device. Since utilities will not own or operate the storage system, it would be difficult to forecast the total amount of storage that will be available at a given time.
- **Impact of vehicle range:** Utilities would require the flexibility of drawing energy from the batteries as well as storing excess energy when it is produced, which would, not be possible if the batteries are completely discharged or completely full respectively. Therefore, the vehicle batteries must be kept at about 75-80 percent of their capacity when being used for V2G functionality, which would impact the vehicle's range for driving.
- **High costs of upfront infrastructure including** upgrades to distribution circuits to support the increased load from EVs.
- **Peak load impacts of uncontrolled charging** which would likely have a de-stabilizing effect on the grid.
- **Local distribution system impacts from clustering of EVs** from the clusters of EV connected on the same distribution transformers.
- **Billing issues** with respect to the tariffs to be charged on slow and fast chargers. Further, the electricity used for transportation requires separate metering and discrimination from electricity used for residential and commercial uses. Clarifications in the regulation are necessary in terms of meter accuracy, meter accessibility, billing calculation and accuracy and dispute resolution.

- **Structuring of battery warranty and the compensation model** for vehicle owners. At present it is also difficult to predict the potential effect on battery life given the uncertainty of how frequently the utility will actually use the battery.
- **Third party charging stations** selling electricity to grid might fall into the regulated business of electricity transmission and distribution and might have to face the regulatory challenges to enter in to the market.
- **Utility ownership of EVSE** needs to be defined to resolve the uncertainty around utility ownership of charging infrastructure.

10.1.3 MOTIVATION FACTOR FOR ADOPTION OF VGI

Despite the numerous challenges in Vehicle to Grid Integration, a number of motivational factors also exist for utilities and regulators to promote VGI.

I. UTILITIES

The bidirectional power flow feature of EVs is promising for Utilities for two main reasons:

- for storage and balancing for intermittent renewable energy and
- for providing grid support/ancillary services

II. REGULATORS/GOVERNMENT

State Regulators are under pressure from rate payer advocates (Consumer Representatives) and state/ municipal governments to maintain reasonable electric rates and to ensure reliable electricity service. EVs can provide grid support services which would be beneficial for the overall system. Forward-looking Regulators would like to promote policies that will support rapid advancement of the VGI business models. For example, the Federal Energy Regulatory Commission has created various market-driven systems that incentivize participants to provide the required energy and capacity services to keep the grid cost effective, stable and reliable and it considers VGI as a viable mechanism to help promote the wider adoption of both EVs and renewable energy integration. It can create a market for readily available ancillary services.

California, for example, has issued Legislative Order 626, directing the California Public Utilities Commission to lower barriers to widespread adoption of EVs, which includes allowing and empowering third-party providers to deliver innovative business models such as V2G (Briones, et al., 2012). Following figure summarises major drivers and restraints for uptake of EV technology.

Drivers

Incentives by legislatures and regulators
Zero tail-pipe emissions
Lower operating costs
Time and monetary savings
Reduced dependency on foriegn oil
Improved energy security
Downsizing of the engine while retaining performance

Restraints

Cost of EVs
Safety and reliability of battery technology
Space constraints owing to larger battery and motor size
Other alternative and competitive technologies
Sources and availability of electricty

Figure 10-4: Drivers and restraints for EV technology uptake

10.1.4 TYPICAL COMPONENTS FOR V2G

There are three basic components in a V2G model for recharging a vehicle or discharging energy from the vehicle to the electrical grid:

- Point of grid interconnection
- EVSE
- EV and the BMS (Battery Management System) that manages the operations

The vehicle has several important components that manage and regulate the charging and discharging functionality of the battery and the battery itself (Marnay, et al., 2013). A brief description of these components is given below:

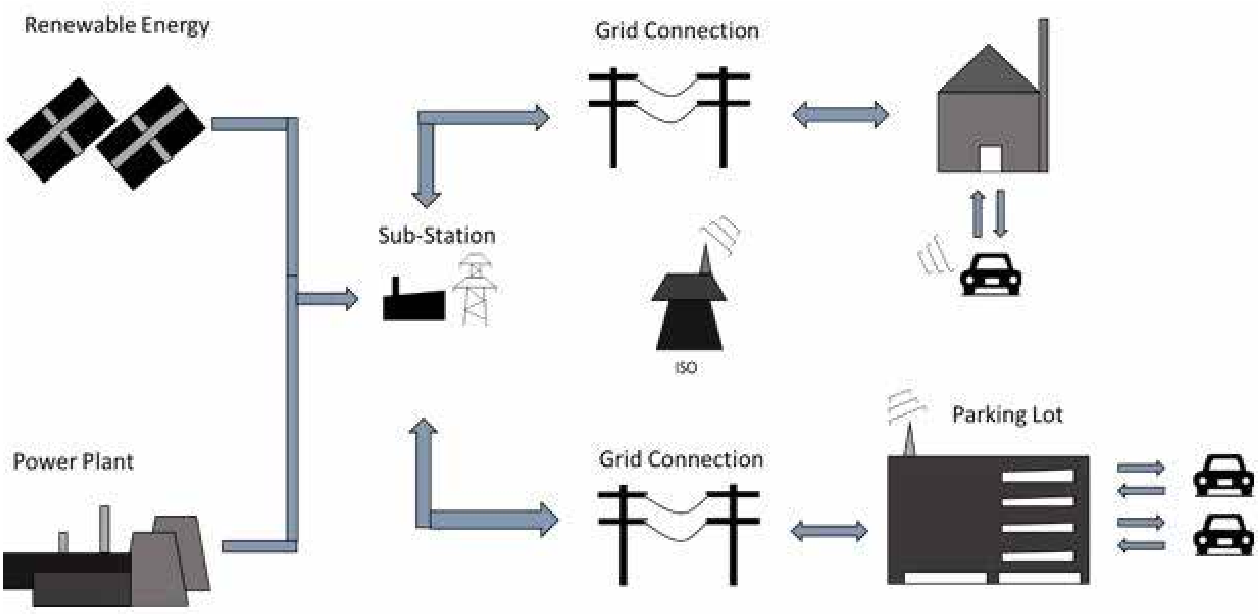


Figure 10-5: Components in a VGI system (Tomi & Kempton, 2007)

I. V2G CAPABLE VEHICLE

Most essential element is an electric or plug-in hybrid vehicle with the capability to connect and communicate with grid. A schematic of V2G capable vehicle is shown in Figure 11.3

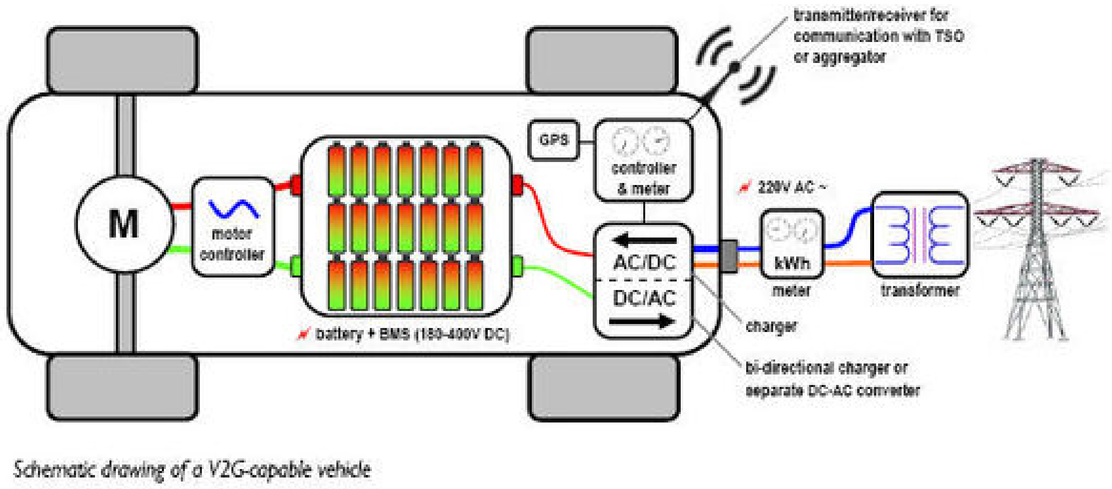


Figure 10-6: Schematic of a V2G capable vehicle

II. BATTERY

PHEVs have advanced batteries with a storage capacity of 4 to 15kWh, giving the vehicle an electric-only range of 15-80km. BEVs generally have 15 to 50kWh on board, for a range of 80-300km.The DC voltage of the batteries is generally between 180V and 400V DC.

III. BATTERY MANAGEMENT SYSTEM (BMS)

The batteries in an EV have modular configuration with each battery comprising hundreds to thousands of individual battery cells. Each cell has a voltage ranging from 1.2V to 3.6V. These modular, high-energy battery pack requires intricate electronics and software to manage voltage, current levels and temperatures for each individual (module of) cells. This system is called the Battery Management System (BMS). The BMS also manages the state-of-charge (SOC) of the battery, and controls the maximum power level of the charger and the maximum regenerative breaking level.

IV. BATTERY CHARGER (AC-DC) & INVERTER (DC-AC)

The Battery chargers generally have an output voltage of 180-400 Volt DC. If they are rated for a standard 220V AC socket, their maximum (dis-)charge power in Europe is generally ±3.5kW while in the US, the residential socket output is 110V, and hence maximum power output is ±1.5kW. However, if a two-phase AC outlet is used, a much higher charge power can be drawn (15-20kW is the current norm).

Most of the current research assumes that future chargers will have a (dis-)charge power level of 10-20kW, and that there will thus be dedicated EV charging connections installed in the house of (PH)EV owners.

The BMS controls the maximum charge level of the charger, which is usually connected via a CAN-interface (Controller Area Network-interface). In order to achieve the V2G functionality, either the charger needs to be bi-directional, or a separate DC-AC inverter is required.

V. CONTROLLER, GPS & ELECTRICITY METER

A communication signal is required to be sent to a remotely controlled regulation device (controller) to regulate the power taken from or fed into the grid by the vehicle. The signal can be provided in the following ways:

- via the cellular phone network
- via a radio signal
- via the 'Internet' (last part WLAN connection)
- via a 'smart meter' network (last part wirelessly, first part Internet or cellular phone network)
- via the power grid (TSO signals)

Ideally, a GPS device keeps track of where the vehicle is and an on-board electricity meter measures in- and outflow of electricity. However, in a less advanced V2G scenario, it is not the on-board meter that measures electricity consumed and generated by the vehicle, but a (smart) residential electricity meter (Sarkar, 2015).

10.1.5 BUSINESS MODELS FOR ELECTRIC VEHICLES

Various business models for grid integration have been proposed and studied. The most common is aggregator model which is explained below:

I. AGGREGATOR MODEL

The aggregator is the coordinator between system operator, EV owner and distribution utility. The aggregator collates EVs and create a potential source of energy that can be used by the utilities and system operator during the periods of high demand-supply gap.

II. OWNER MODEL

Another possible model is to integrate large EV fleet through individual vehicle owners who then directly participate in the energy market. In this model, the EV owner will receive signals and directly manage the requests from utilities and system operators with the help of the two-way communication and control systems. This can be achieved by optimizing charging price so that the EV owner can minimize the charging cost at all times while reducing the stresses on the power grid. However, this integration scheme is not reliable and efficient because dealing with each individual EV owner increases the complexity in energy planning, security and control (Kempton & Tomic, 2005).

III. DISCOMS

In this model, the DISCOMs shall be the owners and operator of charging facilities under a separate deregulated model. Several DISCOMs consulted have shown an interest in this business

IV. BUS DEPOTS

In this model, the STUs themselves shall be the owners and operators of charging facilities for their own buses as well as their franchisee private bus operators

V. BATTERY SWAPPING

In this model, the battery charging could be at public facilities or at their own captive industrial establishments from where charged batteries can be delivered at strategic locations within the city

VI. FRANCHISEES AT PARKING LOTS AND MUNICIPAL FACILITIES

In this model, the Franchisees of DISCOMs will own and operate charging facilities at premised allotted by City Governments/Municipalities or leased from the landlords.

10.1.6 FUTURE OF EV AND VGI

The future scenarios for EVs cannot be predicted with accuracy due confluence of many technical, economic, environmental and social factors. However, following improvements and developments are expected going forward (Damiano, Gatto, Marongiu, Porru, & Serpi, 2014):

- A whole range of new EVs models will be available to match different owners' needs and electric grid requirements (Shahidinejad, Filizadeh, & Bibeau, 2012).
- Cost of batteries which constitute the major portion of the cost of EVs is expected to decrease by 50% by 2020, owing to economies of scale and technological innovations, which will allow share of EVs to rise (Rios, Goentzel, & Siegert, 2012).
- Improvements in range of EVs is also expected owing to improvements in battery technology to 160 km at least (Tuttle & Baldick, 2012).
- The capacity and power of the battery is expected to go up to 70 kWh and 20 kW respectively, and the recharge time is expected to reduce further (Guille & Gross, 2009).

Researchers from University of Cagliari, Italy have quoted four step evolution process for PEVs

First Stage EVs: The EVs in their present form are in nascent stage and are not as matured as ICE vehicles but they would give important feedbacks to manufacturers to direct further and future research. Most of the current EVs only allow unidirectional power flow and manual programmable charging operation, with modest communication capabilities. "In the US vehicle market, all manufacturers agreed to equip their vehicles with a common plug SAE J1772, available at level-1 (120 V) or level-2 (240 V)" (Tuttle & Baldick, 2012).

Second Stage EVs: These would be similar to the first-generation EVs but with better battery control and efficiency to increase their range and decrease their costs and also with better communication capability in order to implement more sophisticated charging strategies. Consequently, second generation EVs will be able to provide ancillary services by V1G mostly (Tuttle & Baldick, 2012).

Third Stage EVs: The third generation EVs would be considerably different from the first two generations and will be characterized by high rated power and a bidirectional power flow charger. It is expected that charging will be performed at 50-100 kW, significantly reducing the recharge time. This will initiate V2G capability at a preliminary level.

Fourth Stage EVs: EVs of the fourth generation will have a well-developed V2G capability. They will also be equipped with an advanced and reliable communication system, guaranteeing their aggregation (Guille & Gross, 2009)

10.1.7 POLICY OPTIONS FOR PROMOTION OF EV AND VGI

A number of policies have been suggested that can be adopted by policy makers in India to promote VGI:

- Creating separate electricity tariff for EV charging which may be dynamic and concessional based on grid situation and use of differential pricing for different times of day and night. Differential pricing for EV charging could also help renewable energy integration – subsidised rates when surplus generation from RE resources on the grid.
- Evolving payment settlement mechanisms for the EV aggregator/owner: An EV owner/aggregator may be charged with or incentivised on net consumption (import-export) basis. The payments for grid servicing can be done through cash or mobile/internet based payment gateway (e.g. prepaid cards issued by Discoms/third parties, Credit/Debit cards, Mobile wallets, Reward points).
- An adequate infrastructure of charging stations, also called Electric Vehicle Supply Equipment (EVSE), is a key enabler for EV adoption and Vehicle to grid integration. An EVSE can be coupled with interoperable communication and networks, to enable operators and EVs with cost-effective management services and ease their integration with grid management systems. Such features will ensure utilities and owners to eliminate stranded assets, which can result from proprietary technologies. Open standards such as Open Charge Point Protocol (OCPP) for EVSE network management, can be used to manage this requirement. Technology integrators can access data to provide innovative solutions such the availability of the nearest charging station, charging costs, track energy usage, etc. (India Smart Grid Forum, 2015) (Damiano, Gatto, Marongiu, Porru, & Serpi, 2014)

Specific activities/actions that can be taken by the Regulators (Both Central and State Level) are (California ISO, 2014).

- Developing coherent policies/regulations in line with NEMMP and national standards
- Defining V2G related products and programs including product eligibility
- Establishing V2G related product and program requirements
- Establishing settlement processes,
- Defining verification and conflict resolution protocols
- Defining signals and messaging protocols

The CPUC for example has undertaken a number of policy initiatives to promote the demand for Vehicle Grid Integration (VGI) services, the means for implementation, and means for compensation. These include creating rules about storage procurement targets that include EVs as a possible resource, to ones concerning mechanisms to access wholesale market programs, and payment for frequency regulation services, depending on speed and accuracy in response to market signals (California ISO, 2014). The policies of CPUC are given in Annexure 1.

10.1.8 ROLE OF SMART GRID IN EV INTEGRATION

A large scale EV fleet charging might increase the burden on the existing power distribution grid. If uncontrolled, it can result in malfunctioning of the power system equipment and tripping of the relays under rigorous overload conditions. Hence the integration needs to be well planned and should conform to the power system operational standards. Electric vehicles can be integrated into power systems and operate with different objectives such as the dynamic loads by drawing power from the grid (during charging) or dynamic Energy Storage System (ESS) by feeding power to the electric grid when called for. Extensive safety protection measures such as anti-islanding and system cost are among the demerits reported by studies which reduce full potential that can accrue to the system (Francis Mwasilu, 2014).

A smart grid platform can provide solutions for integration of EVs into the grid and creating a functional V2G technology through an accessible advanced communication infrastructure. An EV through the electric vehicle management system (EVM) built in the vehicle can receive and send information to the aggregator or the owner and vice versa. The smart meters (SM) can be embedded in EVM to facilitate real time energy measurement, communication and control, and creating a smart charging schedule to optimize the available grid power through the advanced bidirectional data exchange (Francis Mwasilu, 2014).

VGI is a promising solution in providing ancillary services, such as load leveling, regulation and reserve. Moreover, it can also support large scale penetration of RES. In Future, if a viable and competitive market can be created for EVs to provide such services, owners may be able to capture additional value by providing services to the grid. At the same time, for grid operators and utilities, this could provide a cost-effective grid resources to help them meet the evolving energy demands of 21st century. Increasing the pace of growth of EV market requires a coordinated evolution in both technology and policy sectors. Supportive policies should work to ensure that EV owners are able to capture the full economic value of their decision to switch to EVs, including any benefits to the grid operator, along with capturing any emission reduction benefits. Indian Regulators need to pro-actively develop the policies for integration of EVs and create tariff structures to encourage participation of V2G technologies at large scale.

10.2 DETAILED CASE STUDIES

This section illustrates some of the VGI pilots carried out world-wide and presents the regulatory framework that supported the pilots and research

10.2.1 V2G PILOT AT LOS ANGELES AIR BASE, CALIFORNIA, US

I. PROJECT DESCRIPTION

Los Angeles Air Force Base (LAAFB) is a non-flying United States Air Force Base located in El Segundo, California. A proof-of-concept for demonstrating that battery storage of Plug-in Electric Vehicle (PEV) fleets can provide energy and ancillary services to the California Independent System Operator (CAISO) markets to generate additional revenues has been undertaken at the base. The project started in February, 2012. The project being in a sensitive zone, the system architecture was carefully designed to lie entirely outside the base firewall and use its own internet service provider (ISP) access (Marnay, et al., 2013).

The fleet has 42 vehicles: 13 Nissan LEAF sedans; 13 VIA plug-in hybrid vans; five Ford F-150 pickup trucks retrofitted with EVAOS hybrid electric kits; four Ford C-MAX Energi sedans; four EVI hybrid trucks (two stake beds and two box trucks); two Chevrolet Volt sedans; and one Phoenix Motorcars shuttle bus (Concurrent Technologies Corporation, 2015). Of the entire fleet, 34 vehicles have V2G capability with 655 kW instantaneous demand or capacity (Southern California Edison, 2016). The charging stations to power these vehicles are 15-kilowatt (kW) AC chargers from Eaton, 15-kW DC chargers from Princeton Power Systems, and 15-kW AC chargers and 50-kW DC charging stations from Coritech Services. Concurrent Technologies Corporation (CTC), an independent not-for-profit organisation has installed 13 vehicle-to-grid plug-in electric vehicle (V2G-PEV) charging stations and infrastructure at the LAAFB which will be supplied by Princeton Power Systems (PPS). The Charging stations are bidirectional V2G charging stations, based on PPS's UL-listed Grid-tied Inverter (GTIB) product. The GTIB is a bidirectional, UL -1741 listed inverter with an available option for CHAdeMO compliant DC car charging that includes communications, safety features, and a hose with a connector and is also capable of exporting power from the car to the grid. The output of the stations will be monitored and controlled by a PPS Site Controller and has built-in functionality for frequency regulation, demand response, and other grid-support features (Princeton Power Systems, 2014).

II. PROJECT DESIGN AND UTILITY SUPPORT

Southern California Edison (SCE) the utility partner for the program, identifies behind the meter (BTM) V2G resource to provide customer (retail) benefits. The project intends to demonstrate retail peak shaving for the Air Force Base as well as wholesale benefits by participating in the wholesale market as a Non Generating Resource (NGR) providing ancillary services. However, allowing BTM participation as an NGR resource is significantly more complex than participation as a Proxy Demand Response (PDR) resource. The entire load of the air base – both "regular load" and PEV load – receives electricity behind one point of interconnection to SCE's distribution system. Retail load is billed at a single master meter. PEVs have a Wholesale Distribution Access Tariff (WDAT) interconnection behind a CAISO revenue grade meter to distinguish PEV demand and energy from the remainder of the Air Force Base, which remains on an otherwise applicable tariff (Southern California Edison, 2016).

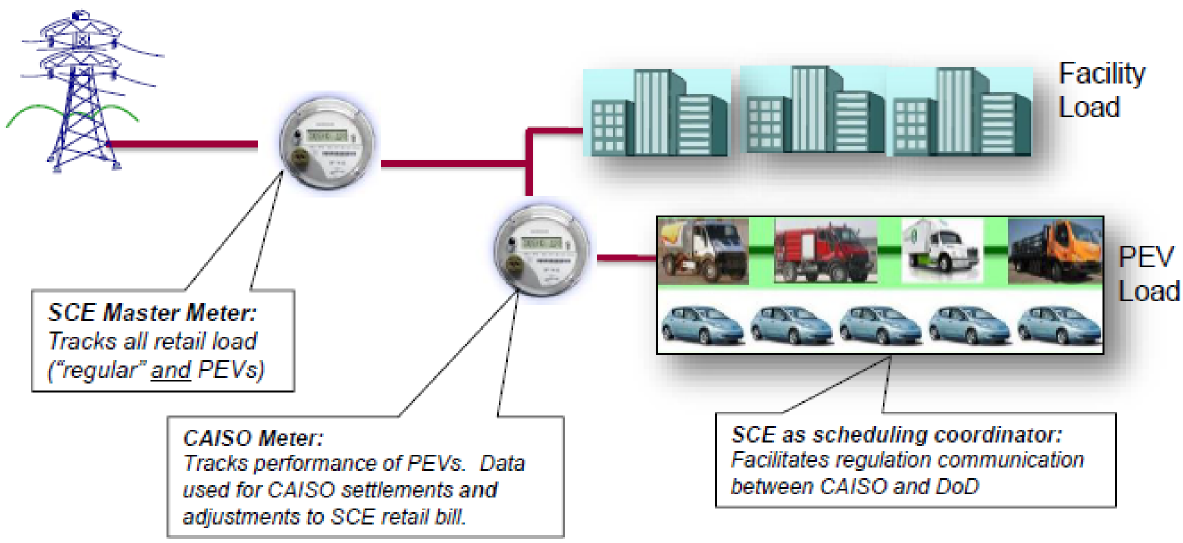


Figure 10-7: LAAFB Project layout (Southern California Edison, 2016)

III. BILLING AND SETTLEMENT PROCESS

CAISO-directed energy discharges are "backed out" of the retail bill through a manual process. During these periods, the PEV discharges are treated as if the device were an "in front of the meter" (IFOM) device.

IV. KEY CHALLENGES FACED

- How to isolate wholesale activity from retail activity?
- How to reconcile retail bill to wholesale activity and modify retail load to "back out" wholesale activity?
- Significant manual work required to identify wholesale hours and activities, determine energy to be added back to retail bill, and manually adjust retail bill.

- Key questions to be worked upon
- How to scale up the process?
- How can the process be automated?
- Is additional communication / reconciliation with the system operator necessary to ensure all settlements occur properly? (Southern California Edison, 2016)

V. CALIFORNIA PUBLIC UTILITIES COMMISSION (CPUC) FRAMEWORK FOR VEHICLE TO GRID INTEGRATION

The CPUC has defined four regulatory issues in EV integration as: 1) identifying the resource and determining at which point grid services are measured; 2) determining what entities may aggregate the resources and interact with the wholesale markets; 3) determining how to capture distribution system benefits, monetize those benefits, and distribute them to the various actors; and 4) determining the primacy among the potential VGI activities. The framework for policy creation developed by CPUC in various scenarios is given in following Table and Figure.

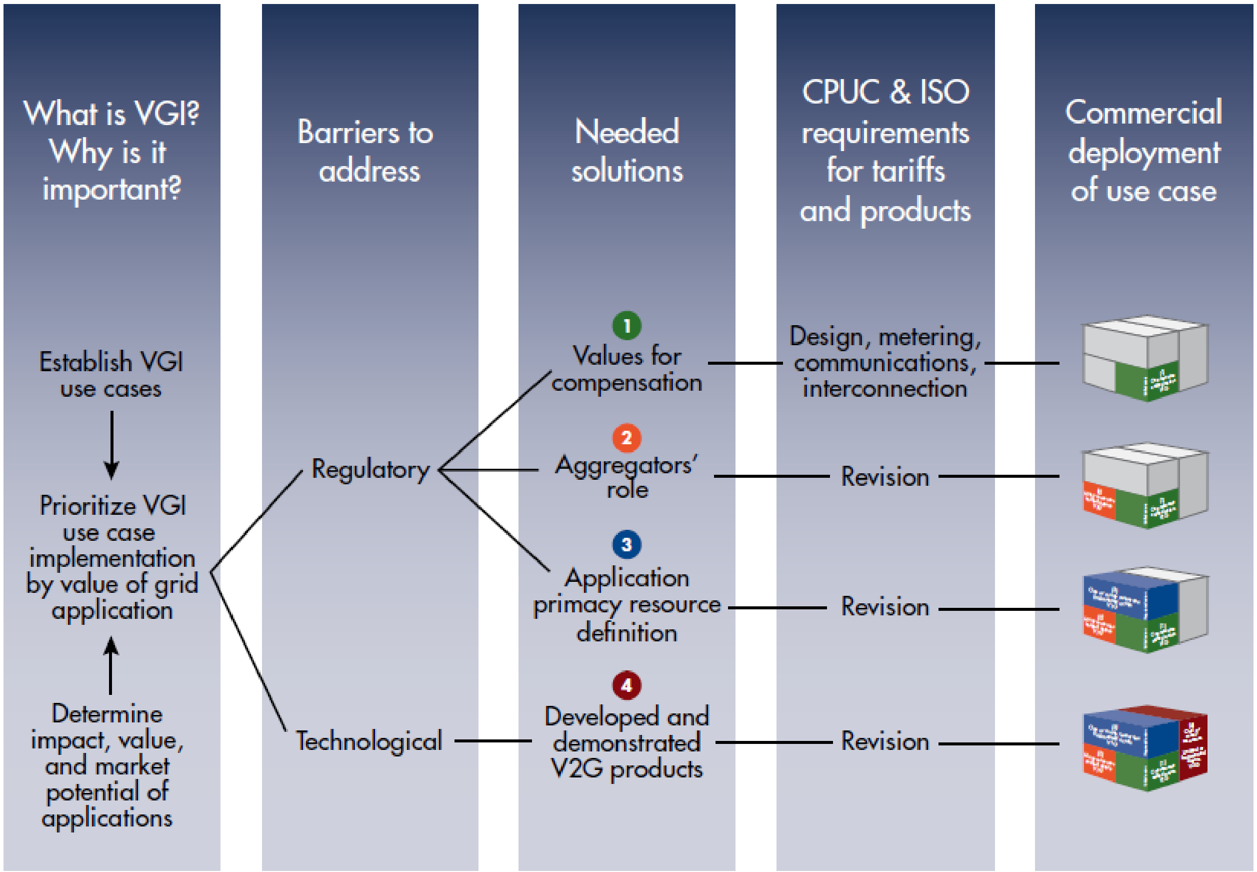


Figure 10-8: Proposed framework for developing VGI supportive regulations (California ISO, 2014)

Table 10-6: Policies for various scenarios (CPUC)

Scenarios and Needed Actions for Vehicle-Grid Integration	Customer Benefits	IOU/Distribution System Benefits			Wholesale Market Benefits		
		Tariff Design	Communication	Metering	Product Design	Communication	Metering
One Resource Unified Actors V1G	No action needed.	• Define DR Value and develop tariff • Measure benefits for renewable-following and neighbourhood scheduling through demonstration projects • Develop tariffs for DR and other distribution benefits	Select Communication Standard(s)	Choose to use facility meter or resource meter	Refine NGR and PDR products to account for the response time, size and flexibility of a vehicle resource	Select Communication Standard	Define metering location and accuracy requirements
(+) Aggregated Resources	Determine the marginal benefits of subscribing to an aggregation program.	Develop products to support aggregated resources	Determine communication requirements for an aggregated resource	Determine metering requirements for an aggregated resource			
(+) Fragmented Actors	Determine the marginal benefits of a regulatory solution to the agency issue.	Design tariffs based on the resource definition	Determine communication requirements based on resource definition	Determine metering requirements based on resource definition			
(+) V2G	Determine impacts to reliability, economics and customer mobility.	Wait to develop rules until automakers indicate when commercial technologies will be available. Determine incremental benefits, tariff, and interconnection requirements for bi-directional resources.					

10.2.2 AUSNET SERVICES V2G PILOT, AUSTRALIA

AusNet Services collaborated with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to examine the potential for electric vehicles to provide active support to the grid during high peak demand periods. It converted three Toyota Prius hybrid vehicles to plug-in hybrid electric vehicles by installing larger lithium-ion batteries and related control software. Each battery pack could hold 11.8 kWh of electricity equivalent to the daily consumption of a small family household. For the Vehicle to Grid trial, the CSIRO upgraded one of these vehicles to V2G capability, where it could be programmed to either charge from the grid, or discharge to the grid. Maximum discharge rate was 1.1. kW. The trail showed that a V2G capable electric vehicle successfully reduced the evening peak demand of the house to which it was connected by supplying the power to house during peak period.

Australian Energy Market Commission (AEMC) made number of recommendation and submission to Energy Council for integration of electric and natural gas vehicles with grid (Australian Energy Market Commission, 2012)

- Pricing signals (particularly network pricing signals) are a key means of facilitating efficient demand side participation (DSP), including encouraging efficient EV charging behaviour. These pricing signals should be developed in a manner that reflects the underlying cost of supplying electricity so that EV consumers can charge at times that lead to efficient market outcomes. As stated in our power of choice review, we propose that cost reflective network pricing be phased in through a banding approach, with medium to large consumers transitioned to efficient and flexible network prices to begin with (for large residential and small business consumers such network prices would be mandatory). This should be set to capture a high proportion of EV consumers.
- All EVs should have a metering installation with interval read capability. These metering arrangements would enable the application of time varying tariffs and allow consumers to manage their electricity consumption. These metering installations should be compliant with the SCER endorsed minimum functionality specification.
- Controlled EV charging, where an EV owner delegates the right to charge its EV to another party, is a form of load management and we recommend technical standards to encourage arrangements that balance the need to maintain network security while enabling different providers to offer controlled EV charging services.
- New metering arrangements that enable the separation of load (or generation) for the purposes of DSP. This should enable efficient EV charging and greater consumer choice. We have specified arrangements for embedded networks, parent/child metering, multi-element meters and situations where there is more than one Financially Responsible Market Participant (FRMP) at a connection point.
- The supply of electricity for EV charging is generally the legal sale of electricity for the purposes of the National Energy Retail Law (NERL) and in Western Australia. We note that there are divergent views and consider that the NERL should be amended to resolve this ambiguity.
- While our legal interpretation is that EV charging is covered by the NERL, we consider that as a matter of policy, EV charging in a commercial context should not be covered by the NERL by way of an exemption because of the contestable nature of these transactions. We therefore recommend that the Australian Energy Regulator (AER) review its retail exemption framework when applied to commercial EV charging.
- Certain aspects of Western Australia's electricity market arrangements could be reviewed at the appropriate time to enable the participation of DSP, including EVs.

10.2.3 MEREGIOMOBIL PROJECT, KIT GERMANY

The Energy Smart Home Lab was developed at Karlsruhe Institute of Technlogy (KIT) under the MeRegioMobil project and demonstrated possibilities of combining a smart home, transport (electric mobility), and energy (smart grid) such that best possible use of renewable energy sources is ensured and comfort of living is increased at the same time (Karlsruhe Institute of Technology, 2013).

This was the first Vehicle2Grid Scenario demonstration in Germany with participation from industry partners. Two of the industrial partners cooperating in the project MeRegioMobil are the OEMs Opel (German subsidiary of General Motors) and Daimler, each of them providing a BEV (Opel Meriva and A-Class E-CELL) capable of bi-directional charging (Marc Multin, 2011). The project was a successful attempt at making smart grid a sustainable experience.

The Energy Smart Home Lab consists of an apartment of 60 m² in area with two bedrooms. The apartment is equipped with latest technology. Via the energy management panels (EMP), the inhabitants can always view the current energy flows in the house as well as of the current electricity consumption. The energy management panels also are the user interfaces for interaction with the energy management system (EMS). For example, inhabitants can specify the next planned drive with their electric vehicle or the latest possible time at which the laundry is to be ready.

The electricity for the smart home is generated by a 4.8 kW photovoltaics system on the roof and a -cogeneration unit. An electric vehicle connected to the house is used as a storage system, via which the solar power produced at noon time can be stored and used in the evening (Karlsruhe Institute of Technology, 2013).

The Opel Meriva car used in the experiment has an electric motor of 60 kW (82 hp) in eco-mode and 80 kW in sports-mode rating with 215 Nm of torque. The Lithium-Ion battery pack has a capacity of 16 kWh and allows for a driving range of 64 km, reaching a top speed limited to 130 km/h. The car can be plugged into an outlet of 230 volts and 400 volts, allowing three-phase charging with a maximum power of 11 kVA. The added power inverter enables vehicle-to-grid (V2G) scenarios. The communication between the BEV and the charging point is realized via a homeplug 1.0 powerline network. The charging point is connected via a local area network to the smart home management device (SHMD), therefore the BEV's charging and feedback process can be observed and controlled by the SHMD (Marc Multin, 2011).

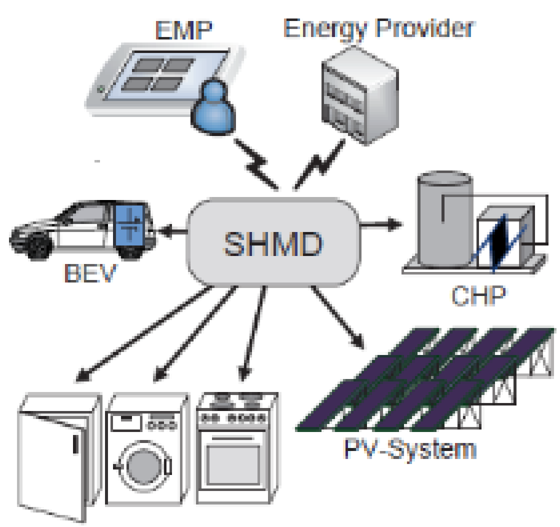


Figure 10-9: Smart Home Energy Management Set Up at KIT (Marc Multin, 2011).

The tests showed that a communication between the BEV (Opel Meriva) and the SHMD could be achieved and thus the charging and discharging could be controlled remotely according to the commands sent by the SHMD. The project also aimed to test the smart charge communication protocol allows for instructions for reactive power in order to facilitate the stabilization of the grid (Marc Multin, 2011).

10.2.4 ELECTRIC VEHICLES IN A DISTRIBUTED AND INTEGRATED MARKET USING SUSTAINABLE ENERGY AND OPEN NETWORKS (EDISON) PROJECT, DENMARK (GANTENBEIN & OSTERGAARD, 2009) (CHRISTENSEN, 2009)

The EDISON project was developed by IBM, DONG energy, the regional energy company of Oestkraft, Technical University of Denmark, Siemens, Eurisco and the Danish Energy Association. The project successfully demonstrated optimal system solutions for EV integration, including network issues, market solutions, and interaction between different energy technologies. The objectives for the project were:

- To develop system solutions and technologies for Electric vehicles (EVs) and Plug-in hybrid vehicles (PHEVs) which enable a sustainable, economic and reliable energy system where the properties of EVs are utilised in a power system with substantial fluctuating renewable energy.
- To prepare and provide a technical platform for Danish demonstrations of EVs with emphasis on the power system integration aspects.
- To develop standard system solutions for EVs, which are applicable globally, by utilising the Danish leading knowledge within distributed energy resources and operation of energy systems with high wind power penetration, and thereby, release the potential for Danish export of technology, system solutions, and knowledge.

The EVs were foreseen to act as buffers for the fluctuating wind power production with what we called “intelligent charging”. In 2008 this was a relatively ground-breaking concept, and it caused a lot of international interest in the project. The first meetings with EV manufacturers early in the project period showed that they were reluctant to involve their products in market set ups where EV batteries would be used for power system services. Their concerns were user acceptance and uncertainties about battery wear. The general view was that electricity is a commodity that always is available when connecting an appliance to the grid. The consortium developed a three-level conceptual EV system architecture, and five EV charging scenarios have been suggested which are listed below.

- Charging whenever needed (dumb charging)
- Charging with local control (timer based or price signal based charging)
- Charging with aggregated control (EVPP as a balance responsible party)
- Charging with aggregated control (EVPP under a balance responsible party)
- Advanced scenario (coexistence of decentralized and aggregated control concepts)

The project explored using an aggregator (fleet operator) to aggregate the consumption of a number of EVs and handle their interaction with the grid as one single unit which, gives the EVs an opportunity to participate in the electricity market. To demonstrate the possibility for EVs to participate in both power market and the market for regulating power an Edison EV Virtual Power Plant (EVPP) was developed. EVPP was the resulting server-side management system containing analytics technology and featuring standards based interfaces to DERs and grid stakeholders. These EVPPs took on the role of Fleet Operators (FO) for individual EVs (in Zurich, Copenhagen, Bornholm) in real-time coordinating their charging in private homes, company parking lots, and at charging stations. The EDISON project developed a reference model for a public charging spot which has been used during COP15 for concept development. This model ensured that the EVPP got the necessary information from the individual EVs during connection to the grid and during the charging.

Besides the development of “Intelligent charging” research was also conducted to gain more knowledge of battery technology and understanding various charging schemes that could influence on battery lifetime. Laboratory test on batteries were performed at SYSLAB and a mathematical model was developed to analyse the problem. Laboratory tests also showed that with adequate knowledge of the batteries and BMS, intelligent charging schemes can be performed without any negative influence on the battery lifetime.

The Project recommended development of Standardization for a fast deployment of EVs. The most important standardisation is required for having standardized plugs, a standardized infrastructure and a standardized connection. The IEC 61851-1 - mode 3 with PWM was recommended as first option. Along with IEC/ISO 15118 series as future solution for including intelligent charging not covered by former standard. IEC/ISO 15188 series was recommended for meeting the requirement of ensuring a stable and reliable power system. It also emphasised Interoperability between different grid areas is to ensure free mobility and integration of it in the ‘grid code’ (Foosnæs, et al., 2011)

10.2.5 INNOVATIVE EV SUPPORT PROGRAMS IN INDIAN PRIVATE SECTOR - SAP LABS GREEN CAR POLICY

SAP Labs India in Bangalore had announced a green car policy under which employees would be able own an electric car at a subsidized cost and get a monthly allowance to own and run it. SAP India in collaboration with Mahindra Reva offered upto Rs 6,000 per month as car allowance for employees who had completed six months of service. This was supported from subsidy of Rs 62,000 to Rs 82,000 offered by the Union ministry of new & renewable energy (MNRE) under its Alternate Fuels for Surface Transportation (AFST) Program. In addition, free car battery charging service on the campus, a dedicated parking slot in the campus, an extended battery warranty of 36 months instead of the standard 24 months, free routine maintenance, service on the campus and charging points at owners’ residences is also offered to the employees.

For SAP, the German enterprise software applications company, this scheme will help in achieving its global sustainability vision of reducing its carbon footprint to the level of 2000 by 2020. In 2007, SAP’s global carbon footprint (green gas emissions) was highest at 550 kilo tonnes (Tejaswi, 2011).

ANNEXURE: KEY POLICIES IMPLEMENTED FOR VEHICLE GRID INTEGRATION

Entity	Policy	Description & Relevance
FERC	Federal Energy Regulatory Commission Order No. 784 (Issued July 18, 2013)	• Expands FERC 755 pay-for-performance requirements to account for speed and accuracy • Potentially affects payment for VGI services, depending on VGI capabilities
FERC	Federal Energy Regulatory Commission Order No. 792 (Issued November 22, 2013)	• Adjusts the Small Generator Interconnection Procedures (SGIP) and Small Generator Interconnection Agreement (SGIA) for generating facilities no larger than 20 MW • Will shape interconnection associated with storage devices
ISO/IEC	Standard ISO/IEC 15118 (Stage 60.60: International Standard published as of April 16, 2013)	• Creates a global standardization of communication interface • Will likely shape VGI enabling technologies
SAE	Standard SAE J1772 (Most recent revision is October 15, 2012)	• Establishes a recommended practice for EVSE • Will likely shape VGI enabling technologies
CPUC	Assembly Bill (AB) 2514 and CPUC Storage Proceeding Docket No. R. 10-12-007	• Sets targets for the procurement of storage • States that EV capacity can contribute to the storage procurement targets • Potentially creates demand for VGI services, depending on how VGI compares to other options
CPUC	Resource Adequacy (RA) Proceeding	• Guides the resource procurement process and promotes infrastructure investment by requiring LSEs to provide capacity as needed by California ISO • Potentially influences demand for VGI services, depending on VGI capability to meet RA needs.

Entity	Policy	Description & Relevance
CPUC	Demand Response (DR) Proceedings Docket No. R.07-01-041	• Reviews and analyzes demand response to assess its potential role in meeting the state's energy needs • Potentially serves as a platform for clarifying rules about how EV may participate in DR
CPUC	Rule 24 DR Direct Participation	• Determines how customers might "directly participate" in, or bid services directly into, the wholesale market. • Potentially influences the process by which VGI services can offer wholesale market services.
CPUC	Rule 21 Interconnection and Net-metering (Docket No. R.11-09-011)	• Describes the interconnection, operating and metering requirements for generation facilities of various sizes to be connected to a utility's distribution system, over which the CPUC has jurisdiction. • May influence the interconnection requirements around VGI, where two-way power flows are possible
CPUC	Wholesale Distribution Access Tariff (Docket No. ER11-2977-000)	• Defines the tariffs architecture of energy transfer between California ISO and utilities or customers • Guides a portion of VGI payment processes
CPUC	EV Proceedings	• Addresses barriers to widespread EV adoption, on which the VGI market is dependent • Promotes communication among EV stakeholders, including those involved in VGI • Addresses EV sub-metering issues, which could influence VGI payment processes
CPUC	Smart Grid Proceeding (Docket No. R.08-12-009)	• Establishes standards, protocols, and policies which will affect Smart Grid • programs and strategies, such as VGI

MODULE 11

ENERGY EFFICIENCY AND DEMAND RESPONSE

Abstract

The supply and demand side of the generated power has evolved dramatically in the last decade and is laying more pressure on utilities than ever before. Utilities need well-run energy efficiency and demand response programs to procure a power mix that performs as per the expectations of the regulator and the customer at the best possible prices, which is essential for utility's continued health. This module discusses the concept and various programs related to energy efficiency and demand response.

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11 ENERGY EFFICIENCY AND DEMAND RESPONSE

11.0 INTRODUCTION

The simplest and apt definition of energy efficiency is ‘using less energy to provide the same service.’

The International Energy Agency (IEA) defines energy efficiency as “way of managing and restraining the growth in energy consumption, making something more energy efficient as it delivers more services for the same energy input or same services for less energy input”.

It can also be defined as an energy resource, yielding energy and demand savings that can displace electricity generation from coal, natural gas, nuclear power, wind power, solar power, and other supply-side resources. Investments made in energy efficiency measures and the resulting resource benefits are directly realized by the utility and this reduces the need for investment in new resources by allowing efficient operation of existing systems. The cost of energy savings achieved from consumer energy efficiency programs are one-third of the cost of new generation resources. Energy efficiency programs can also reduce the need to install, upgrade or replace transmission and distribution system. Many utilities across the world have utilized benefits of EE resources, few examples are given below:

- The Burlington Electric Department (BED), USA, started its energy conservation program in early 1990s; after bond measures to fund energy efficiency was approved in a city voting. In 1997, energy efficiency standards for rental housing were sanctioned and BED was named the program administrator. As a result of utility’s energy efficient programs, electricity consumption in 2007 was only 1 % above the 1989 level.
- In Ghana, the implementation of minimum energy performance standards for air conditioners is expected to reduce emissions by around 2.8 Megatons CO2 equivalent over 30 years and save consumers about US $64 million annually in energy bills.
- UN Climate Change Secretariat’s Momentum for Change initiative, enlighten, accelerating the transition to energy efficient lighting in developing countries where electrical demand is expected to grow rapidly.

11.1 HISTORY OF ENERGY EFFICIENCY IN INDIA

The earliest movements to promote "productivity culture" in the Indian electricity sector was seen when Government of India set up National Productivity Council (NPC) in 1958. The Third Five Year plan (1961-66) referred to increased efficiencies in large thermal boilers by using high temperatures and pressures. It also acknowledged the overall efficiency of thermal power station to be very low (≤20%) until 1960 with expected improvement in efficiency due to operation of larger units.

Integrated Energy Planning was recognized as an essential element in development of the country and thus in 1963, the Energy Survey of India Committee (ESIC) was established to study the demand and supply of energy on a national, regional and sectoral basis, so as to provide the government with a framework for energy development planning until 1981, specifically focusing rural energy requirements. To provide necessary technical support, the Energy Conservation Division was created in the Directorate General of Technical Development (DGTD) and in 1974-75, overall saving of around 15% was achieved in consumption of fuel oil.

An Inter-Ministerial Working Group on Energy Conservation (IMWG) was constituted in 1981 to develop policies to achieve energy saving targets, which in its report in 1984, stated the requirement of conducting 200 energy audits covering 12 industrial sectors. This required an investment of ₹36 billion in order to achieve savings worth ₹19.25 billion. In the Sixth Plan (1980-85), reduction of dependence on energy imports was emphasized. In 1989, Energy Management Centre (EMC) was also set up as an autonomous organization with assistance of the World Bank and United Nations Development program (UNDP), to promote energy conservation.

Despite all the activities carried out in the past, there was no legislation on the conservation of energy and thus no legal powers to enforce energy conservation and efficiency activities. In 1997, the Ministry of Power (MoP) decided to propose an enactment for energy conservation, which in turn, resulted in establishment of Bureau of Energy Efficiency (BEE).

11.2 ACTS AND REGULATIONS RELATED TO ENERGY EFFICIENCY

The Energy Conservation Act (The EC Act, 2001) was notified on 29th September 2001. The primary purpose of the EC Act, 2001 is to provide for efficient use of energy and conservation of energy. Bureau of Energy Efficiency (BEE) was established by the Central Government under the provision of the EC Act, 2001 to discharge various functions as envisaged under the Act. The Act also assigned specific responsibilities to the Central Government and State Governments to achieve the objectives of efficient use of energy and conservation of energy. The Act was amended on 12th March 2007 to specify the energy conversion values for various types of fuel in the industry.

The EC Act, 2001 is the primary legal framework and regulatory mechanism for the Central and State governments to facilitate the enforcement of efficient use of energy and its conservation. There are five main provisions within this Act, wiz., Designated Consumers, Standards and Labeling, Building Codes, Establishment of the Bureau of Energy Efficiency (BEE)[1] and Establishment of Energy Conservation Fund. The act was amended in 2010 and a new mechanism was introduced, called Perform Achieve and Trade (PAT) Scheme.

[1] *BEE provides leadership for energy efficiency to all sectors in the country and helps institutionalize energy efficiency services.*

Under the EC Act, 2001 energy intensive industries and other large consumers can be identified as designated consumers by the government, and specific regulations can be adopted for them on energy efficiency. Moreover, Energy Conservation Action Plan (ECAP) was formed to build institutional and human capacity, enabling the State Designated Agencies (SDAs)[2] to implement energy efficiency programs and undertake evaluation and monitoring of the energy conservation activities executed in the state. One of the key elements of the ECAP is the State Energy Conservation Fund (SECF) to financially support SDAs for carrying out energy efficiency and energy conservation activities.

Section 61 (c) of the Electricity Act of 2003 specially stresses that the Tariff Regulations are to be specified considering the factors which would encourage competition, economic uses of resources, efficiency, good practices and optimum investments. **Section 66 under The Electricity (Amendment) Bill, 2014** (still pending to be approved by the Parliament) states that, *"Appropriate Commission shall endeavor to promote the development of a market (including trading and forward and futures contract) in power and a market for encouraging energy efficiency in power in such manner as may be specified and shall be guided by National Electricity Policy, referred to section 3, and other directions issued by the Central Government in the public interest from time to time".*

Section 5.8.5 of the National Electricity policy (NEP) emphasizes on the need to improve efficiencies in the industry by way of incentives and disincentives to the consumers by prescribing suitable norms.

Section 5.9.5 of the NEP seeks agriculture sector to use energy efficient pump sets for water delivery systems, and the industrial sector to use energy efficient technologies and carry out energy audits for energy conservation.

In July, 2008, India released its first **National Action Plan on Climate Change (NAPCC)** outlining existing and future policies and programs addressing climate change mitigation and adaptation. The plan identified eight core "national missions" running through 2017. NAPCC's goal is to focus on measures that promote India's development objectives while also yielding co-benefits for addressing climate change. The plan includes a mission on energy efficiency and on solar energy, namely National Mission on Enhanced Energy Efficiency (NMEEE) and National Solar Mission (NSM)[3], respectively.

The **National Mission on Enhanced Energy Efficiency (NMEEE)** states four initiatives which includes market-based approaches to unlock energy efficiency opportunities, estimated to be about Rs. 74,000 crores. The four initiatives are as follows:

- Perform Achieve and trade (PAT): A market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through tradable certification of energy savings.
- Market transformation for Energy Efficiency (MTEE): Accelerating the shift to energy efficient measures to make the products more affordable through initiatives like
    - Super-Efficient Equipment Program (SEEP) for ceiling fans
    - Bachat Lamp Yojana (BLY) for CFLs and LEDs.
- Energy Efficiency Financing Platform (EEFP): Creation of mechanisms that would help finance demand side management programs in all sectors by capturing future savings.

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[2] *State Designated Agencies (SDAs) are nodal agency in the states to promote energy efficiency measures through institutional mechanism set up by Bureau of Energy Efficiency.*

[3] *NSM has been now renamed to JNNSM (Jawaharlal Nehru National Solar Mission)*

- Framework for Energy Efficient Economic Development (FEEED): Developing fiscal instruments to leverage financing for energy efficiency through risk mitigation by
  - Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE)
  - Venture Capital Fund for Energy Efficiency (VCFEE)

Achievements under the NMEEE by 2014-15 are as follows:

- Annual fuel savings more than 23 million toe.
- Cumulative avoided electricity capacity addition of 19,000 MW.
- CO2 emission mitigation of 98 million tons per year.

The Ministry of Power in its Advisory No. 14/05/2015 dated 05.01.2016 have given the mandate to CERC to discharge the functions of a Market Regulator in accordance with its Power Market Regulations, 2010. CERC in compliance to the Advisory Notice, issued a notification on 27th May of 2016, which defined a framework for dealing in Energy Saving certificates through Power Exchanges.

India is also a party to **the United Nations Framework Convention on Climate Change** and during the last Conference of Parties held at Paris in December, 2015 agreed upon **India's Intended Nationally Determined Contribution (INDC)**. INDCs include reduction in the emission intensity of its GDP by 33 to 35 % by 2030 from 2005 level and to create an additional carbon sink of 2.5 to 3 billion tonnes of CO2 equivalent through additional forest and tree cover by 2030. India is also anchoring a global solar alliance called International Agency for Solar Policy and Application (INSPA) for all countries located in between Tropic of Cancer and Tropic of Capricorn.

The Government of India (GoI) also launched a National Campaign on Awareness to make people aware about the need of energy conservation and benefits to the individual, society and nation as a whole. **Energy Efficiency Services Ltd. (EESL)**, a joint venture of four PSUs under Ministry of Power has also been established to provide market leadership and aid in financial services to several DSM programs in various sectors by capturing future energy savings.

11.3 REGULATORY APPROACH TO PROMOTE ENERGY EFFICIENCY (EE)/ DEMAND SIDE MANAGEMENT (DSM)

Improving energy efficiency in the electricity sector has been specifically emphasized in various sections of the Electricity Act, 2003 (EA, 2003). Demand Side Management approach to energy efficiency refers to energy efficiency measures taken at the consumer side of the meter, i.e. undertaking EE initiatives in the consumer premises. Reference to DSM can be found in various sections of the EA, 2003 (Figure 11-1).

Preamble to the Electricity Act, 2003	•An Act to consolidate the laws relating to generation, transmission, distribution, trading and use of electricity and generally for taking measures conducive to development of electricity industry, promoting competition therein, protecting interest of consumers and supply of electricity to all areas, rationalization of electricity tariff, ensuring transparent policies regarding subsidies, ***promotion of efficient and environmentally benign policies*** constitution of Central Electricity Authority, Regulatory Commissions and establishment of Appellate Tribunal and for matters connected therewith or incidental thereto.
Section 23 of Electricity Act	•WHEREAS section 23 of the Electricity Act 2003 provides that: "If the Appropriate commission is of the opinion that it is necessary or expedient so to do for maintaining the ***efficient supply***, securing the equitable distribution of electricity and promoting competition, it may, by order, provide for regulating supply, distribution, consumption or use thereof";
Section 42(1) of Electricity Act	•AND WHEREAS Section 42 (1) of the Electricity Act 2003 provides that: "it shall be the duty of a distribution licensee to develop and maintain *an* ***efficient, coordinated and economical distribution system*** in his area of supply and to supply electricity in accordance with the provisions contained in this Act"
Section 62 of Electricity Act	•AND WHEREAS Section 61 of the Electricity Act 2003 provides that: "The Appropriate commission shall, subject to the provisions of this Act, specify the terms and conditions for the determination of tariff, and in doing so, shall be guided by the following, namely:-"Clause (c) "the factors which would encourage competition, ***efficiency***, economical use of resources, good performance and optimum investment"
Section 86(2) of Electricity Act	•AND WHEREAS Section 86(2) of the Electricity Act 2003 provides that:: "State Commission shall advise the State Government on all or any of the following matters, namely:- "Clause (i) "promotion, competition, ***efficiency and economy in activities of the electricity industry***,"

Figure 11-1: Use the Home tab to apply 0 to the text that you want to appear here.
Reference to DSM in Electricity Act, 2003

Around 16 State Electricity Regulatory Commissions in India have promulgated their DSM regulations. These regulations demonstrate policy & regulatory framework for energy efficiency interventions through the management of consumer load and demand.

Figure 11-2: Status of DSM Regulations in Various States in India

The Regulations list the activities & sub-activities for planning, selection, approval and implementation of DSM measures and mandate the Licensee(s) to undertake the benchmarked measures to promote energy efficiency.

Figure 11-3: Activities to implement DSM measures

The following section will discuss about the various initiatives taken for EE measures under various programs.

11.4 ENERGY EFFICIENCY INITIATIVES UNDERTAKEN

11.4.1 DEMAND SIDE MANAGEMENT (DSM)

DSM is the selection, planning, and implementation of measures intended to have an influence on the demand or customer-side of the electric meter. DSM program can reduce utility's energy costs, and in the long run can limit the requirement for further augmentation of generation capacity and strengthening of transmission and distribution system. Under the 12th Five Year Plan, BEE was mandated to supplement the technical assistance to set up DSM cells and capacity building of personnel of DSM cells in the DISCOMs for enabling them to undertake following strategies and schemes:

- **Load Survey**

  Mostly, questionnaire based surveys are adopted to study the consumption pattern of consumers by utility.

- **Load Strategies**

  For electric utilities to modify the consumer load profiles and thereby reduce their peak demands, following load management techniques may be adopted by the Utility/DISCOMs:

- **Demand Response-**

  it is an effort for creating additional capacity during peak hours, by involving voluntary load curtailment by power consumers during peak load demand or whenever requested by the distribution companies. Load curtailment can be achieved by implementing load reduction by Energy Efficiency or by load shifting measures.

- **Load Management Programs-**
  - Dynamic/Real Time pricing: Based on the monitoring of real-time system of supply and demand.
  - Time-of-Use Rates: Customers are offered different rates for usage of electricity at different times of day.
  - Automated/Smart Metering: Implementing Dynamic/Real Time Pricing or Time-of-Use structure and billing accordingly.
  - Web-based/Communication System: Used by customers for information on prevailing demand, supply, prices on real time basis and the incentives and options for them, used to manage the demand.

- **Demonstration Studies**

  Direct installation programs, providing complete services to design, finance, and install a package of efficiency measures.

- **Advanced Metering**

  The capability of online communication, accurate measurements, local intelligence, load connect-disconnect facility and consumer friendly display unit sets Advanced meters in a new era for DSM initiatives. The technology will help DISCOMs, especially in implementing Demand Response Activities.

- **DSM Financing**

  The strategic value of DSM initiatives and energy efficiency rests in their ability to improve the financial cash flow of Indian utilities.

Some Examples of DSM Implementation in Indian Utilities

- **Public Sector**

  Maharashtra State Electricity Distribution Company Limited (MSEDCL) carried out energy efficiency and demand side management projects in different areas such as HVAC Systems and Agricultural DSM undertaking equipment such as Ceiling Fans, Chillers (HVAC), and Agricultural pump sets (Agri-DSM) and has achieved savings up to 23%.

- **Agricultural Sector**

  The Chamundeshwari Electricity Supply Corporation LIMITED, Mandya District, Karnataka replaced 1337 number of pump sets achieving total 56.68 lakh units of energy per annum (37 %) with an investment of 5.03 Crore. The project was completed on 18 March, 2015.

- **Commercial Sector**

  Aranya Bhawan, office building of the Rajasthan Forest Department in Jaipur was selected for The Indo-Swiss Building Energy Efficiency Project's (BEEP) Integrated Design Charrette and was implemented by the Rajasthan State Road Development and Construction Corporation limited (RSRDC), inaugurated on 23 March 2015.

The building occupies an area of 14,000 m2 and has 6 floors (including one in the basement for parking), which is used by approximately 250 users every day. Insulation of walls and roof was carried out along with replacement of single-glazed windows with double-glazed windows. A centralized high-efficiency water cooled-chiller was installed for air-conditioning the building. Waste water from the building is being treated for reuse in the centralized HVAC system. A 45 kWp roof-top solar photovoltaic (PV) system is also being implemented. Annual electricity savings of 2,40,000 kWh per year were measured with payback period of 3 years.

- **Industrial Sector**

  Use of energy efficient equipment and other low cost innovative strategies implemented by ITC Limited in its ITC Manufacturing plant in Bangalore accrued ₹ 548 lakhs in a period on 10 years with total investment of ₹ 145 lakhs for this initiative.

  Important works done during the implementation period were replacement of Air Cooled Chiller to Recycled Water Cooler Chiller, as the company is located in a water scarce area of Bangalore. Additionally, waste heat recovery from process exhaust was achieved for boiling water in the boiler, generating more steam.

- **Residential Sector**

  Resource Energy Efficiency Retrofit of the Godrej Bhavan building was conducted by Godrej and Boyce which included replacement of HVAC system, installation of energy–metering system and water flow meters, energy audit, replacement of lights with energy-efficient tube lights. The total cost incurred by the company was ₹ 53,84,000.

In the first year after the upgrade (FY 2010-11), Godrej Bavan's electricity use dropped to 5,27,856 kWh for an 11.4 % savings in electricity use and to 5,21,856 kWh for a 12.3 % savings in electricity in the next fiscal year (FY 2011-12).

The various DSM programs undertaken by Indian Utilities are given Annexure I.

There are four schemes under the National Mission for Enhanced Energy Efficiency (NMEEE) under the National Action Plan on Climate Change (NAPCC) described as under.

11.4.2 PERFORM, ACHIEVE AND TRADE (PAT) SCHEME

(PAT) is a market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy intensive large industries and facilities, through certification on energy savings that could be traded.

Under PAT scheme, quantified energy savings are converted into Energy Saving Certificates (ESCerts). When a designated consumer achieves and surpasses its target, it is permitted to sell its excess savings in the form of ESCerts. Moreover, if a designated consumer fails to achieve its targets, it necessarily needs to purchase the appropriate number of ESCerts to meet its energy savings targets. Monitoring and Verification of the energy savings will be conducted by Accredited Energy Auditors through a transparent system as prescribed under PAT Rules, 2102

The first compliance period of PAT started in 2012 and ended in 2015 under which 8 energy intensive sectors were identified as designated consumers namely, Power (thermal), Iron & Steel, Cement, Aluminum, Fertilizer, Pulp & Paper, Textile and Chlor-Alkali industries.

Table 11-1: PAT Cycle I- Notified Sectors and Achievements

S. No.	Sectors	No. of Identified DCs	Annual Energy Consumption (Million toe)	Share Consumption (%)	Apportioned Energy Reduction for PAT Cycle-1 (Million toe)	Savings (Million toe)
1	Power (Thermal)	144	104.56	63.38	3.211	3.06
2	Iron & Steel	67	25.32	15.35	1.486	2.10
3	Cement	85	15.01	9.10	0.815	1.44
4	Aluminium	10	7.71	4.67	0.456	0.73
5	Fertilizer	29	8.20	4.97	0.478	0.83
6	Paper & Pulp	31	2.09	1.27	0.119	0.26
7	Textile	90	1.20	0.73	0.066	0.12
8	Chlor-Alkali	22	0.88	0.53	0.054	0.13
	Total	**478**	**164.97**	**100**	**6.686**	**8.67**

The Cycle 2 of PAT scheme started in April, 2016 and will end in March, 2019, under which 11 sectors have been covered with new entrants like Refinery, Railways, Electricity DISCOMs, summing up to a total of 621 DCs with the share of 50 % of total energy consumption in India. Many amendment have been done to EC Act in order to make the PAT scheme more robust. Some of major amendments are:

- Definition of Accredited Energy Auditor, who carries out verification (Rule 2, after clause (a)).
- Definition of compliance period to define validity of ESCerts (Rule 2, after clause (a)).
- Definition of Normalization (Rule 2, after clause (a)).
- Definition of CERC, which regulates Exchanges for ESCerts trading (Rule 2, after clause (d)).
- Clarification of Grid Connection, which is necessary to differentiate between Grid Connection and Grid Synchronization (Rule 4, clause (b(iii)) of Sub Rule (1)).
- Inspection of Check Verification- Supervision, SDAs are declared as inspecting agencies. This has been explicitly provided for consistency and clarity (Rule 8, Sub-rule (2)).
- Function of CERC as market regulator for ESCerts trading, role of CERC as regulator of Exchange for ESCerts is explicitly provided for (Rule 12, Sub-rule (7)).
- The value of per metric ton of oil equivalent of energy for the year 2014-2015, (Rule 16, Sub-rule (3).
- Name of the Empaneled Accredited Energy Auditor Firm, to provide clarity (Form B and Form C)
- Insertion of Schedule II for incorporation of Normalization Factors, the schedule provides formulae for Normalization, as condition during baseline and target years may be very different (Schedule, After Schedule I).

Table 11-2: PAT Cycle II- Notified Sectors

Sr. No.	Sector	No. of DCs in PAT Cycle-I	Additional DC in PAT Cycle-II	Total no. of DCs in PAT Cycle-II
1	Aluminium	10	2	12
2	Chlor-Alkali	22	3	24
3	Textile	90	14	99
4	Pulp and Paper	31	4	29
5	Iron and Steel	67	9	71
6	Fertilizer	29	8	37
7	Cement	85	27	111
8	Thermal Power Plants	144	22	154
9	Refinery	NA	18	18
10	DISCOMs	NA	44	44
11	Railway	NA	22	22
	Total			**621**

PAT Cycle II
Baseline Year: 2014-15
PAT Cycle: 2016-19
AY: 2018-19

Total Energy Consumption from 11 sectors: 227 Mtoe

National Target: 8.869 Mtoe at the end of 2nd PAT Cycle.

The scheme has abundant potential of implementation in the existing as well as the added designated consumers. Many new units from existing sectors have been added as energy intensive units under operation. Addition of new sectors such as Railways, Refinery and Electricity DISCOMs has paved way for higher penetration of the scheme in the market.

Salient Features of PAT Scheme:

- Regulatory Instrument linked with market mechanism (Certification of energy saving- ESCerts).
- Consultative Approach (Ministries/DCs/Associations/FIs/Research Organizations).
- Outreach/ Capacity Development (Workshops/Seminars/Visits).
- Self-Competing (Unit specific targets).
- Relative responsibility (Less target for more efficient and more for less efficient).
- Supports improvement in energy management system (Measurement, recording and reporting).

All the DISCOMs having Aggregate Technical and Commercial (AT&C) losses of 1000 Million units (MU) and above have been identified as Designated Consumers and have been notified under the Notification issued on 29th December of 2015. Individual targets for reduction in T&D losses are issued for 44 DISCOMs on 31st March of 2016 through notification. The Committee chaired by Joint Secretariat (Distribution), Member of Parliament (MoP) involving members from CEA, BEE, PGCIL, REC and selected DISCOMs recommended that Transmission and Distribution (T&D) loss may be adopted as a proxy indicator/parameter for performance assessment of DCs under the PAT scheme. The Committee also recommended fixing the target for Electricity Distribution Company sector based on an overall reduction of 5.97 % for the sector as a whole over a period of 3 years.

11.4.3 MARKET TRANSFORMATION FOR ENERGY EFFICIENCY (MTEE)

Two programs have been developed under MTEE namely, Bachat Lamp Yojana (BLY) and Super Efficient Equipment Program (SEEP).

I. BACHAT LAMP YOJANA (BLY)

A Public-Private Partnership (PPP) between BEE, DISCOMs and private investors to escalate market transformation in energy efficient lighting. Over 29 million incandescent bulbs have been replaced by CFLs under this program. In the next phase of BLY, BEE is promoting use of LED lighting through the institutional structure of BLY program along with supporting Rural Electrification Corporation (REC) to distribute LED bulbs in villages based on technical specification, monitoring and verification of the energy savings from the LED bulbs, distributed under the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) [13].

II. SUPER-EFFICIENT EQUIPMENT PROGRAM (SEEP)

Under the SEEP program, financial stimulus is provided innovatively at critical point/s of intervention to accelerate market transformation for super-efficient appliances. Ceiling Fans have been identified as the first appliance to be adopted under the scheme. It supports introduction and deployment of super-efficient 35 W ceiling fans, replacing the existing 70 W rated fans, in order to achieve efficiency level of about 50 % more efficient than the market average by providing time bound incentive to fan manufacturers to manufacture super-efficient (SE) fans and sell the same at discounted price [13].

11.4.4 ENERGY EFFICIENCY FINANCING PLATFORM (EEFP)

Memorandums of Understanding (MoUs) have been signed between financial institutions and BEE to work towards the development of energy efficiency market and to identify issues related to it.

11.4.5 FRAMEWORK FOR ENERGY EFFICIENT ECONOMIC DEVELOPMENT (FEEED)

Two funds have been created under the program, wiz, Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE) and Venture Capital Fund for Energy Efficiency (VCFEE).

I. PARTIAL RISK GUARANTEE FUND FOR ENERGY EFFICIENCY (PRGFEE)

It is a risk sharing mechanism which provides commercial banks with a partial coverage against insecurities involved in extending loans for energy efficiency projects. The amount provided by the government will only cover equal to the agreed-upon percentage of the outstanding principal amount excluding interest or other fees owed to the bank. The guarantee doesn’t exceed ₹3 Crores per project or 50 % of loan amount, whichever is less.

II. VENTURE CAPITAL FUND FOR ENERGY EFFICIENCY (VCFEE)

The fund imparts equity capital for energy efficiency projects, not exceeding ₹ 2 Crores in a single investment. Specific energy efficiency projects shall receive last mile equity support, limited to a maximum of 15 % of total equity required, through Special Purpose Vehicle (SPV) or ₹2 Crores, whichever is less. A Board of Trustees has been constituted which is responsible for operationalization of VCFEE through VCFEE Trust, limited to Government Buildings and municipalities.

Apart from the above mentioned programs, in order to motivate industries and other establishments to adopt energy efficiency measures, National Energy Conservation Awards are given annually, recognizing innovation and achievements in energy conservation by the industries, buildings, zonal railways, state designated agencies, manufacturers of BEE star labeled appliances, DISCOMs, municipalities and raise awareness that energy conservation plays a big part in India's response to reducing global warming through energy savings.

Energy efficiency is identified as a key resource to meet the energy needs. India under its commitment to NAPCC has been taking number of initiatives to improve awareness and drive behavioral change in energy use. Consumers as well as the distribution utilities under their DSM and energy efficiency programs have potential to implement and bring about large scale energy savings.

11.5 DEMAND RESPONSE (DR)

The current electric grids are designed to meet the peak load requirements with high reliability and accuracy. Energy Efficiency programs can act as a problem solver for the grids to make the system more reliable. This has given rise to research in modern methods of DSM like demand response.

The Federal Energy Regulatory Commission has defined Demand Response as **"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized"**.

Demand Response (DR) differs from the broad-based DSM (Demand Side Management) as DR is primarily event-based with the objective of altering customer load pattern to reduce the peak electricity requirements. Demand Response was started as a fairly straightforward method of adding capacity by triggering customer response towards curtailment of load when requested. However further it became a strategy to extend existing energy sources as capacity in energy markets. Lately, it has gained consideration as spinning reserves and frequency regulation resources. DR programs are designed to move the focus of power management practices away from the utility companies, and directly towards the customers. By doing so, it is hoped that customers will be encouraged to be actively involved in reducing their electricity bills, and customize their usage as per the system requirement.

11.5.1 TYPES OF DEMAND RESPONSE PROGRAMS

A DR program can be classified into Price responsive or non-dispatchable DR and Incentive based or dispatchable DR.

Under non-dispatchable DR, consumers shift their consumption from periods of high prices to periods of lower prices. It has three main sub-categories: Time of use or Time of day; Real time Pricing and; Critical peak power pricing.

The second type of DR program is incentive based or dispatchable DR, in which end-use customers change their electric usage in response to incentive payments designed to induce lower electricity use at times of high wholesale market prices; or when system reliability is jeopardized. It is organized further into five types (Figure 11-4)

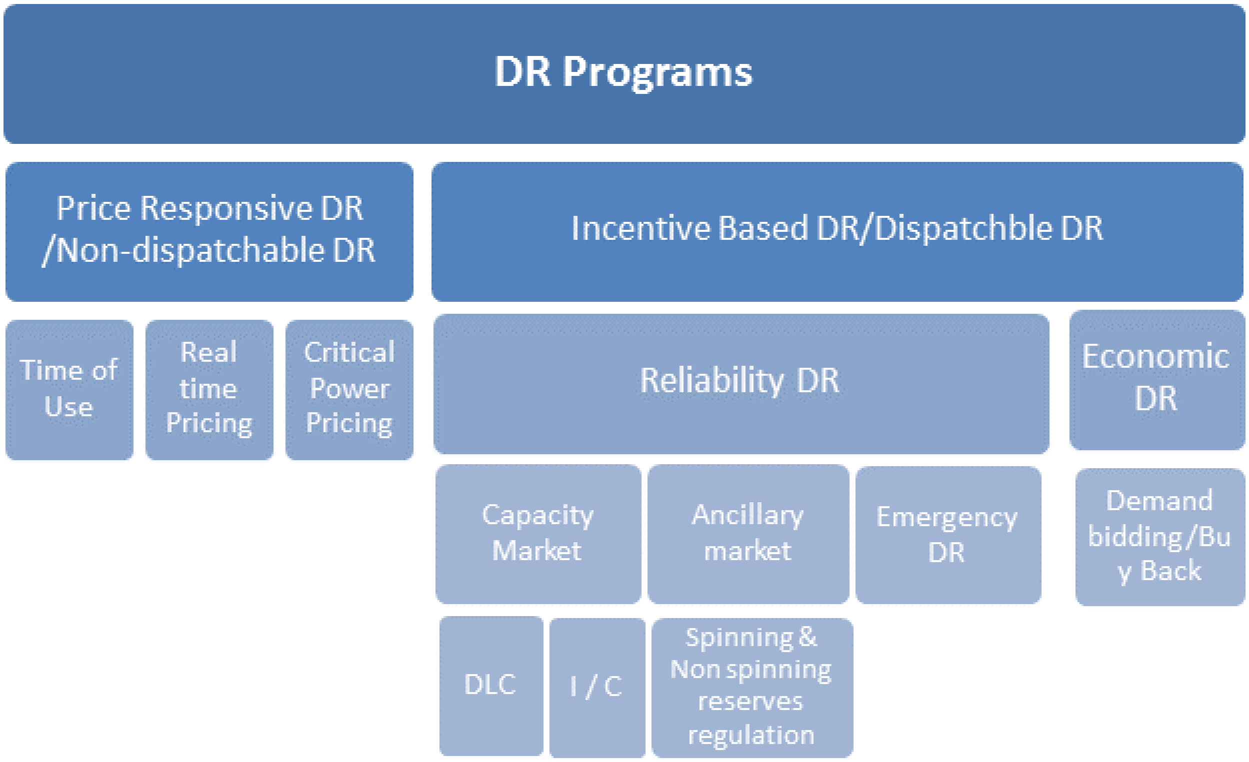

Figure 11-4: Classification of Demand Response Programs {IIT-B report]

Demand response programs require a certain degree of technological readiness from the perspective of each of the stakeholders. The technological requirement identified can be categorized as hardware component, software component and the communication technology that enables exchange of information across various entities involved.

11.5.2 DR BASED ON THE TECHNOLOGICAL COMPONENTS: MANUAL, AUTOMATIC AND BEHAVIOURAL

Manual Demand Response is when operators at various locations are monitoring the system constantly and processing the load flow according to the demand in peak and base load.

Automatic Demand Response or Auto-DR is an automated, voluntary reaction to a DR event called by Utilities and Independent System operators requiring energy consumption/reduction during anticipated period of imbalance in the grid.

Behavioural Demand Response is based upon the monitoring of change in users behavior and reduce peak period consumption from information on their power consumption and costs.

11.5.3 SNAPSHOT OF A DR PROCESS

The DR Implementation process can be characterised in four steps:

Planning, during the planning process, enrolment of consumers happens. This can be done through aggregators in case of smaller retail consumers. The infrastructure is also set in place for both metering and communication, the baseline is calculated, the settlement mechanism is created and, stakeholders are trained to participate in the event.

Pre-DR event, during which, DR participants are scheduled and system reliability and protocols are tested **DR event**, in which, the utility sends the communication signal to reduce the load and the event is monitored.

Post DR event, in which, the settlement is done. Billing and incentives to be given to the consumers are estimated, auditing and reporting of the event happens and, any conflicts are resolved. Based on estimated and reported values, incentives are given to consumers or aggregators if applicable.

11.5.4 DR AS AN APPLICATION OF SMART GRID INFRASTRUCTURE

Demand Response provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives. For most parts, these were one-way systems based on signals sent via energy management system to the controlling devices to temporarily turn off or cycle the desired appliance during peak conditions. The customer gets benefitted from the financial incentives for program participation and the utility gets benefitted from a better ability to manage demand and supply. The active consumer participation in DR is a key characteristic of Smart Grid. Advanced Metering infrastructure (AMI) systems are being deployed as part of growing Smart grid initiatives, providing significant foundational platforms for engaging consumer response to extraordinary DR events. By supplementing this technology with internet usage, energy consumers are enabled by the utility to actively manage system capacity. The AMI vendors have been preparing their systems to support the functionality of Smart Meters through industry initiatives such as ZigBee Alliance, promoting the integration of low-power wireless sensor and control network technology into a meter (Smart meter) to act as a bi-directional communication gateway to devices at home. These devices are used to both inform the consumer of current energy usage and to control the significant discretionary loads persisting at home. Together, the two-way AMI networks and Smart Meters enable the measurement and verification capabilities that allow the utility to verify the controlling devices taking part in a DR event and how much load was regulated.

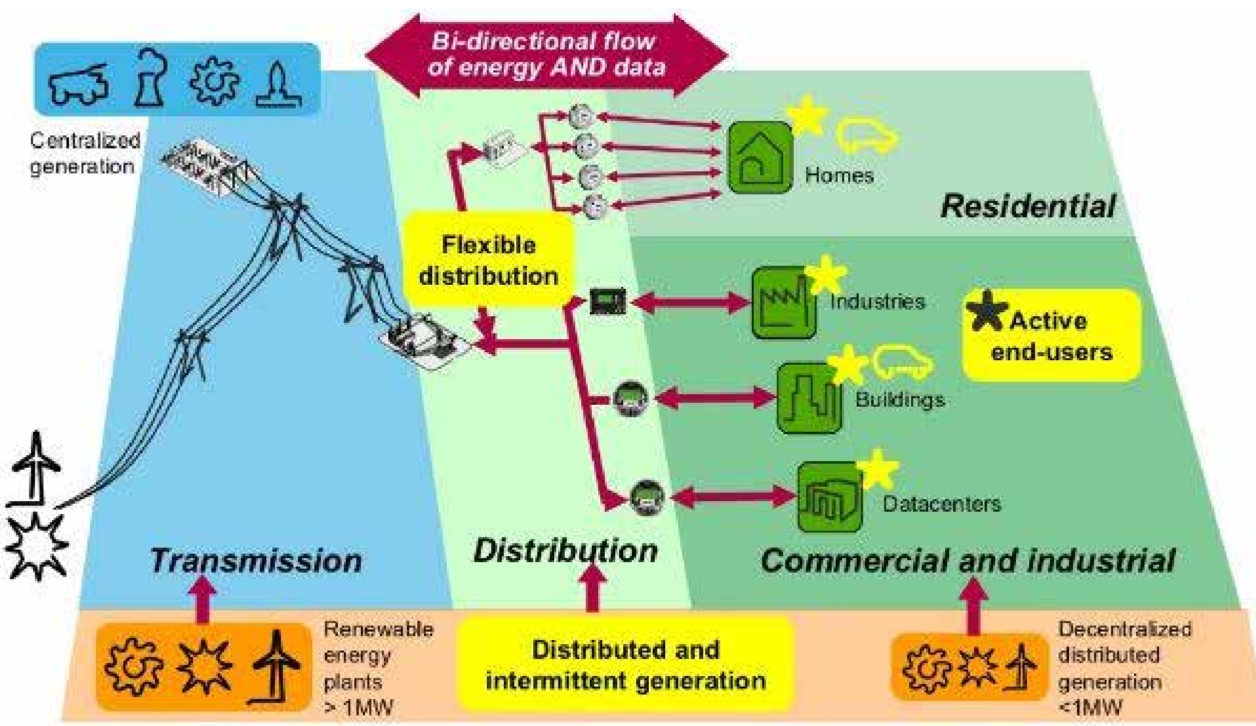

Figure 11-5: Demand Response as a part of Smart grid

11.5.5 DR PRICING AND ANCILLARY SERVICES

DR can result in savings for both the utility and the customer, so it should be valued from both perspectives. From the Utility's perspective, the savings through DR program implementation need to be greater than its loss of revenue due to reduced energy sales, its share of investment for setting up and implementing the DR program, and the DR incentives it has to pay the participants.

DR incentives ≤ (Utility Savings- Utility Loss of Revenue- Utility DR program costs)

The benefits of DR program for a participating customer include financial incentives for taking part in the DR program, and also the savings that result due to reduced energy consumption during peak hours. Customers, in a Time of Day (ToD) rate structure, are likely to have savings in their electricity bill by shifting their consumption from peak hours to non-peak hours, assuming they do not experience any significant rebound[4].

DR incentives ≥ (Customer opportunity Costs + Customer DR program costs – Customer Savings)

Ancillary Services provided by DR plays a vital role in negating the demand-supply mismatch, which primarily constitutes the genesis of Ancillary Services. The interest in fostering DR participation in ancillary services markets requires a clear financial incentive and market structures to capture it. The products of Ancillary services DR are Regulation of Unscheduled Deviations, Flexibility through additional load following reserve for large un-forecasted wind/solar ramps, Contingency for rapid and immediate response to a loss in supply and Capacity to serve as an alternative to generation.

The Indian electricity market did not have a regulatory framework for ancillary services until recently, when CERC introduced the Ancillary Services Operation Regulations in 2015 which defines the guidelines for participation in Reserves Regulation Ancillary Services (RRAS)[5].

11.5.6 RENEWABLE ENERGY STABILITY THROUGH DEMAND RESPONSE

Renewable energy sources like solar and wind energy have intermittent power generation due to the very nature of unpredictability in the availability of Solar and wind energy resource. This intermittent power generation when synchronized with the main grid can cause instability and load imbalancing in the grid. DR along with integration of energy storage system to such power generating facilities can mitigate such problems to a large extent and ease the interconnection of renewable resources to the Utility grid.

DR can help Renewable Energy integration in two main ways; **Load Shifting** and **Load Balancing**.

Load Shifting: DR can be employed to shift a part of the load to off-peak periods in order to absorb excess renewable energy generation (particularly for wind power, as it often exhibits inverse-peaking characteristics[6]). Energy efficiency and cost-benefits for consumers are additional features of shifting load to off-peak periods.

Demand-side Load Balancing: Swift demand response techniques can be deployed to mitigate imbalance between generation and load in real time. Loads can be clustered and directed to respond very quickly and thus be made capable of following the fast ramps of renewable energy generation, lowering the need

[4] Rebound: Increase in energy consumption during non-peak hours becomes greater than the reduction in consumption during peak hours.

[5] RRAS is the first of the ancillary services which calls on participants to increase/decrease generation under operational limits to maintain stable frequency.

[6] Generating more power during off-peak period and less power during peak load demand.

for ramping capability from conventional power generation. More research is needed to identify true aggregate value and DR capability in the area of RE integration as different types of load have different response capabilities with different costs of response associated.

ENERGY EFFICIENCY, DEMAND SIDE MANAGEMENT, DEMAND RESPONSE, GOI'S DELP PROGRAM

When Electricity Demand is more than the Availability, in order to avoid Load Shedding; a "three legged stool" approach is followed:

- Energy Conservation: Save Energy or Use Less Energy
- Improve Energy Efficiency : Use Technology to reduce energy consumption (by using Energy Efficient Equipments) & "do more with Less Energy"
- Invest in Renewable Resources at consumer level (Local non-conventional Generation Source, e.g. Roof-top Solar Roof Top Photo Voltaic Panels at Consumer ends)

Demand Side Management (DSM) is the cooperative activity between utility & its customers to implement options for increasing efficiency of energy utilisation, with resulting benefits to customers, utility and society as a whole. In fact, Energy Conservation Act 2001 is the first major policy initiative to coordinate various activities associated with efficient use of Energy & its Conservation. The Preamble of the Electricity Act 2003 also clearly specifies 'efficiency' & 'promotion of environmentally benign policies' as one of the key objectives of EA2003.

Basically, the DSM is an umbrella term which addresses two issues viz.

- Load reduction via Energy Efficiency & Energy Conservation
- Load shifting via Tariff Signal (Time of Use Tariff) and Demand Response.

11.5.7 DEMAND RESPONSE FOR CONGESTION IN TRANSMISSION NETWORKS

DR can limit congestion in the transmission network by adapting the demand in a region where incoming or outgoing electrical power is limited by congestion. There are three types of congestion patterns which can be alleviated using Demand Response.

The first type is **peak hour congestion**, where the importing region switch to a more expensive marginal power generation technology. Regions dominated by thermal power generation primarily experience such congestions. Demand Response can result in lower system Congestion during peak hours by shifting the load away to off-peak hours thereby allowing optimized utilization of transmission network.

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[7] *This can happen in (example) case of one region dominated by nuclear power and the other by natural gas.*
[8] *The load curtailment measures include lowering air conditioning load, using thermal storage, shifting of process load, etc.*

The second type is **low load hour congestion**, where one region has high share of intermittent generation with respect to its load and the other region has a load that is larger than the transmission network's capacity. During long loads and high intermittent power generation, congestion arises between two such regions. Implementation of Demand Response has a low impact on congestion in such a situation as the controllable load is small in comparison to the generated power. Using energy storage systems in such a case is advisable so as to implement demand response through power reserves.

The third type is the **all hour congestion**, where during both peak and low load hours, congestion persists. This occurs when the marginal cost of generation is always lower than in the other region causing constant flow of electricity from low cost to high cost regions[7]. Implementing DR, in such cases, can reduce marginal costs in both regions individually, and shifting away the load for some hours can decrease the difference between marginal costs of the two regions.

11.5.8 DEMAND RESPONSE PROGRAM IN INDIA

TATA Power Company for the first time in India rolled out Demand Response Program as part of their DSM initiative. Customized Energy Solutions (CES), selected in a competitive bidding process based on its technical strength and wide experience in such program's operation, acted as an aggregator and service provider for this Voluntary Pilot Demand Response Program. As an aggregator, CES along with TATA Power reached out to customers to explain the concept and its potential. The consumers could decide on their load curtailment strategy[8], analyze performance and pay customer based on performance on behalf of TATA Power. This helped utility have power during peak demands and customers earn revenue by reduction in energy bills, thus improving reliability along-with reduction in emission by lowering generation requirement.

When the demand is over stripping the availability, normally there are two options:

- Increase Capacity or
- Carry out more Load Shedding.

Demand Response is the method of exercising greater control over the electrical grid system; by using individual facilities' ability to reduce energy usage. When the grid is overly stressed & facing failure, instead of increasing supply; grid operators call for a reduction in demand by consumers to balance the grid. (Reduce peak loads). UDAY envisages improving efficiency in the State utilities by implementing both DSM & DR Schemes.

Performance of UJALA Scheme:

- The Program was launched in May 2015 & up to 26th April 2016, over Ten Crores LED Bulbs have been distributed (under UJALA by EESL & Institutional distribution Schemes), which led to the estimated energy savings of 35.6 GWH/day. The total savings in a year have been estimated as Rs 5194 CR, with a reduction in CO2 emission of about 10.5 Million Tonne.
- The Target set up for UJALA scheme is installing 77 CRs LEDs lamps, by replacing incandescent bulbs with an estimated saving of Rs, 40,000 CR.
- As on 26th April 2016, Andhra Pradesh is leading the country with 1.90 Crores of LED lamps distributed in the State. Maharashtra, UP & Rajasthan are following AP with 1.61 Crores, 1.01 Crores and 1.00 Crores LED lamps distributed in respective State.
- EESL, a joint venture of state-run power companies, is implementing the project and has achieved over 75% reduction in the price of LED lamps through a combination of aggressive and transparent procurement process and passing on this benefit to consumers. The Price of LED lamp which was Rs. 310 in Nov 2013 has come down to Rs.73 in July 2015.

11.5.9 GOI'S DOMESTIC ELECTRIC LIGHTING PROGRAM (DELP)

The "Domestic Efficient Lighting Programme (DELP)" scheme was announced by the Govt of India on the 5 January 2015, urging the Electricity Consumers to use LED bulbs in place of incandescent bulbs, tube lights and CFL bulbs as they are more efficient, long lasting and economical in their life cycle duration.

The Unnat Jyoti by Affordable LEDs for All (UJALA) was launched by Prime Minister of India Narendra Modi on 1 May 2015, replacing the "Bachat Lamp Yojana, which envisages the extensive use of LED lamps.

The scheme is being implemented by the Energy Efficiency Services Limited (EESL) (under the Ministry of Power).The Govt's target is to replace 77 crore incandescent bulbs in India with LED lamps by FY 2019, leading to an expected reduction in Connected Load of 20,000 MW with an annual estimated savings of over 100 MU and an annual reduction of 400 billion (US$5.9 billion) in electricity bills.

11.6 DEMAND RESPONSE PROGRAMS IN USA

The Electric Reliability Council of Texas (ERCOT) opened retail markets to competition in 2002, which enabled several types of DR. First, the Load Resources provide approximately 1,400 MW of Responsive Reserves to be deployed if frequency falls below threshold levels. Second, ERCOT has recently allowed qualifying Load Resources to submit bids to buy in its energy market dispatch. Third, a capacity resource, called Emergency Response Service (ERS), that is paid an availability payment to be deployable in system shortages having approximately 400 MW of participation. Large customers also adjust their consumption during peak demand periods in order to manage their transmission charges which have led to an estimated 700 MW of load reduction during high-priced period.

DR incentivizes electricity consumers for changing their usage of electricity, flatten load profile to mitigate the need of highly expensive peak power plants and avoid grid extensions, and facilitate the integration of intermittent renewables. To employ DR potential, the demand side needs to be amalgamated into a communication network so that DR can evolve along with smart grids.

11.7 RECOMMENDATIONS

Energy Efficiency and Demand Response can play a key role for utilities in India. Effective regulatory framework is necessary to deploy DR in the Indian Electricity Network in the coming years. The plausible appropriate regulatory approach is explained in Figure 11-5.

Performance of UJALA Scheme:

- The Program was launched in May 2015 & up to 26th April 2016, over Ten Crores LED Bulbs have been distributed (under UJALA by EESL & Institutional distribution Schemes), which led to the estimated energy savings of 35.6 GWH/day. The total savings in a year have been estimated as Rs 5194 CR, with a reduction in CO2 emission of about 10.5 Million Tonne.
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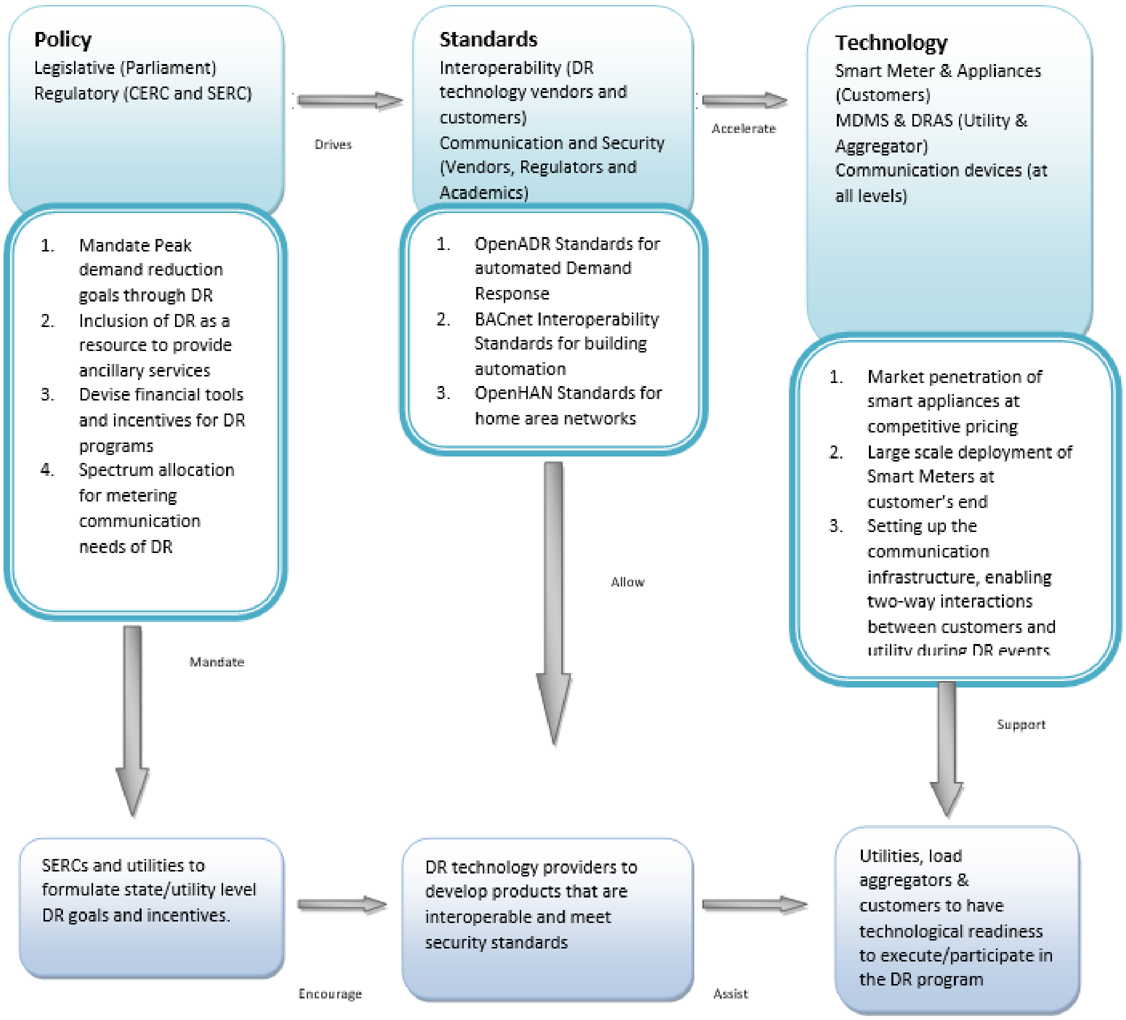

Figure 11-6: Regulatory framework for DR

ANNEXURE

Table 11-3: DSM Initiatives Undertaken by Utilities in India[9]

State	Distribution Company	Type	Appliance	Target Consumers R	C	I	A	P	Number of units replaced[10]	Status of the project	Comments
MAHARASHTRA	Tata Power Company – Distribution	Manual Demand Response	-		x				-	Completed	Savings achieved: 15MW
		HVAC	Thermal Storage		x					Completed	Incentive: Rs 1/kWh shifted. A total of 17,000 TRH enrolled Savings: 740 kVA, 4MU
		HVAC	Ceiling Fans	x	x				16000+	Under-Implementation	Incentive: Rs 600 / fan Savings achieved: 24 W / fan
		HVAC	Air Conditioners	x	x				700+	Under-Implementation	Incentive: Rs 5000 / AC
		Refrigeration	Refrigerator	x					1500+	Under-Implementation	Incentive: Rs 4500 / fridge
		Lighting	T-5	x	x	x			3300+	Completed	Incentive: Rs 150 / tube light
		Lighting	LEDs		x	x			1000	Under-Implementation	Incentive: Rs. 300 / LED
		Other	Walk Through Energy Audit	x	x	x			100+	Under-Implementation	Offered for Residential housing societies and Industrial and Commercial Consumers with loads < 50 kW; Incentive: Free for the consumers.
		Other	Energy Audit		x	x			120	Under-Implementation	Incentive: 25% cost borne by customers and 75% by utility.
		Other	Standard Offer		x	x				Under-Implementation	Any kind of Energy Efficiency Program. Incentive of Rs 1 / kWh offered.
		Lighting	CFL	x	x	x			6,00,000	Completed	Savings: 38 MU

[9] *MP Ensystems compilation, Sources include: www.bee-dsm.in, www.dsm-india.org, discussions with utilities, media reports.*
[10] *Where applicable*

State	Distribution Company	Type	Appliance	Target Consumers R	C	I	A	P	Number of units replaced[10]	Status of the project	Comments
	Reliance Infra – Distribution	Lighting	T-5 FTLs	x		x			4,000	Completed	Savings: 0.15 MU
		HVAC	Ceiling Fans	x		x			12,127	Under-Implementation	Savings: 1.01 MU
		HVAC	Air Conditioners		x				50	Under-Implementation	Savings: 0.19 MU
		Refrigeration	Refrigerator	x					3700	Under-Implementation	Savings: 0.57 MU
	Brihan-Mumbai Electric Supply and Undertaking (BEST)	Lighting	T-5 FTLs	x	x				25,000	Completed	Incentive: Rs. 200 Savings: 11-12 W / tube light
		HVAC	Air Conditioners		x				200	Under planning	-
		HVAC	Ceiling Fans	x	x				5,000	Under-Implementation	Incentive: Rs. 700 / fan offered
	Maharashtra State Electricity Distribution Company Limited (MSEDCL)	HVAC	Ceiling Fans					x	5,000	Under-Implementation	Undertaken for own buildings
		Agriculture DSM	Agriculture Pump sets				x		2,200	Under-Implementation	
		HVAC	Ceiling fans					x	20,000	Under-Implementation	
		HVAC	Chillers					x	30	Under-Implementation	15 chiller replacements and 15 chiller retro-commissioning
RAJASTHAN	Jaipur Vidyut Vitran Nigam Limited (JVVNL)	Demand Response	-	x					17	Completed	Savings: 88 MW
TAMIL NADU	Tamil Nadu Generation and Distribution Corporation (TANGEDCO)	Lighting	CFL	x						Completed	Subsidy to consumers: Rs. 85
		Agriculture DSM	Agriculture Pump sets				x			Under-Implementation	
ANDHRA PRADESH	APEPDCL	Lighting	CFL	x					3,80,000	Completed	
		Agriculture DSM	Agriculture Pump sets				x			Under-Implementation	
	APCPDCL	Lighting	CFL	x					16,50,000	Completed	
	All utilities	Lighting	LEDs	x						Under-Implementation	EESL as implementation partner
DELHI	BSES Yamuna Power Limited (BYPL)	Lighting	CFL	x					6,00,000	Completed	Savings: 35 MW

State	Distribution Company	Type	Appliance	Target Consumers R	C	I	A	P	Number of units replaced[10]	Status of the project	Comments
	Tata Power Delhi Distribution Limited (TPDDL)	Lighting	LED	x						Under-Implementation	80 lakh bulbs across Delhi
		HVAC	Air Conditioners	x						Under-Implementation	
		HVAC	Refrigerator	x						Under-Implementation	
		Demand Response	-		x	x		x		Under-Implementation	Savings: 34 MW
	BSES Rajdhani	Lighting	LEDs	x						Under-Implementation	
GUJARAT	Uttar Gujarat Vij Company Limited (UGVCL)	Lighting	CFL					x	6,100	Completed	Implemented in UGVCL's own offices
		Pumping	Agriculture Pump sets				x		12,929	Under-Implementation	
		HVAC	Ceiling fans					x	75000	Under-Implementation	Savings: 1.5 MW; Target consumers: educational and medical establishments
	Madhya Gujarat Vij Company Limited (MGVCL)	HVAC	Ceiling fans					x	75000	Under-Implementation	Savings: 1.5 MW; Target consumers: educational and medical establishments
	Paschim Gujarat Vij Company Limited (PGVCL)	HVAC	Ceiling fans					x	95,000	Under-Implementation	Savings: 1.9 MW; Target consumers: educational and medical establishments
	Dakshin Gujarat Vij Company Limited (DGVCL)	HVAC	Ceiling fans					x	75000	Under-Implementation	Savings: 1.5 MW; Target consumers: educational and medical establishments
HARYANA	Uttar Haryana Bijli Vitran Nigam Limited (UHBVNL)	Lighting	CFL	x					3,50,000	Completed	Subsidy to consumers: Rs. 80 per CFL
		Agriculture DSM	Agriculture Pump sets				x		210		

State	Distribution Company	Type	Appliance	Target Consumers R	C	I	A	P	Number of units replaced[10]	Status of the project	Comments
		Lighting	CFL	x					20,00,000	Completed	
KARNATAKA	Bangalore Electricity Supply Company Limited (BESCOM)	Street Lights	Timer Switch					x	10,000		
		Lighting	CFL	x					37,00,000	Completed	Maximum of 4 CFLs/ household. CFL exchanged with incandescent bulb at Rs. 15.
		Agriculture DSM	Agriculture Pump sets				x		277	Completed	29.23 MU saved from Apr, 2011 to Jun, 2013
		Agriculture DSM	Agriculture Pump sets				x		1,00,000	Under Planning	Contract signed with EESL for program implementation
		Lighting	Efficient Ballast	x					5,298	Completed	Total cost of program: Rs. 66.90 Lakh. Estimated savings: 0.35 MU/ annum
	Hubli Electricity Supply Company Limited (HESCOM).	Street Lights	Timer Switch					x	970		
	Gulbarga Electricity Supply Company Limited (GESCOM)	Street Lights	Timer Switch					x	110		
PUDUCHERRY	Electricity Department, Puducherry	Lighting	CFL	x					7,35,000	Completed	Subsidy to consumers: Rs. 310, Savings: 50MU

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MODULE 12

USE CASES, LESSONS LEARNED – PILOT PROJECT EXPERIENCES

Abstract

This module describes select smart grid projects and lessons learned from these projects. The discussion on smart grid projects covers 17 projects in various countries including the first smart microgrid village in Odisha, India – location, functionality, time period, brief description, background, implementation and outcomes of each project are described. Next section discusses exclusively projects in India – 10 of them with similar details as in the previous section. Some of the cancelled smart grid projects are also mentioned in this module. The module concludes with a brief information about four smart grid projects under National Smart Grid Mission (NSGM).

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12 USE CASES, LESSONS LEARNED - PILOT PROJECT EXPERIENCES

12.0 INTRODUCTION

This module presents the latest analyses and insights of 17 smart grid projects across the globe. Smart grid projects from North America, European Union and Asia Pacific at transmission and distribution level are covered. Projects aimed at making the grid smarter through new technologies (e.g. storage devices, electric vehicles, distributed renewable generators) and new ICT capabilities are covered in this module.

12.1 SMART GRIDS PROJECTS

12.1.1 PROSUMER: REMOTE PLATFORM FOR MANAGING DISTRIBUTED ENERGY RESOURCES FLEXIBILITY

Location: Grenoble, France
Functionality: DER flexibility Management
Time period of project: 2012-2016

Brief Project Description

More and more Distributed Energy Resources (DER: loads, producer, energy storage) are being installed in distribution networks, on both supply and demand sides. Key driver happens on demand-side: end-use consumers are becoming more and more proactive in consumption, storage or producing energy, leveraging various utility programs such as feed-in tariffs and demand response. In short, consumers are becoming Prosumers, proactive energy producers and consumers. There is a need for a solution that brings together end customers and utilities for making the most of Distributed Energy Resources (DER).

StruxureWare Demand Side Operation (SW DSO) is a cloud-based platform which manages the flexibility of DER. The platform uses predictive algorithms (forecast, optimizers) to provide end-user with the optimal schedule for use of energy generation, storage or controllable loads. Utilities, by having access to this platform, can then influence the way customers consume, produce, and store energy, in order to maximize the grid reliability, environmental footprint, and economical optimization. Each Distributed Energy Resource is connected to a DER box on the customer site. A secured connection is then established between the customer site and the cloud-based StruxureWare Demand Side Operation platform. The DER behaviour is then forecasted and optimized by Demand Side Operation, taking in account utility requests (Demand Response, frequency regulation etc.), weather forecast information, customers' constraints and electricity tariff rate. It make the link between demand side and supply side through an OpenADR 2.0b communication mean. Demand Side Operation takes the best in term of cyber security, internet of things, and analytics.

Project Background and Implementation

StruxureWare Demand Side Operation has been developed under the frame of a collaborative project named GreenLys. It is now deployed in different countries by Schneider Electric. It is available in Europe and North America, and more than 20 customer sites are now under operation, managing different types of DER (energy storage, electrical vehicle charging station, solar panel, HVAC loads, genset) across different use cases (Demand Response, tariff management, self-consumption).

One of the most famous examples is Oncor Microgrid in Texas, which is one of the most advanced Microgrid in the USA, leveraging the power of Demand Side Operation. The aim of Oncor is to experiment the solution on his own facilities before deploying it with their customers to provide benefits to both parties.

All those projects are done in conjunction with a Utility who takes benefit of this flexibility through tariff or demand-management scheme. It's also a way to think and test new mechanisms, such as advanced tariffs or new Demand/Response mechanisms.

Project Outcome

Potential impact

SW DSO provides a cheap mean to complete the grid balancing possibilities. It enable the access to a huge amount of flexibility at the end user side. This flexibility will allow to avoid launching polluting Power Plant during peak period or unexpected events on the grid.

Economic rationale

The worldwide market of flexibility management at the end user side is estimated at 2B$ in 2020. This is a win/win approach for both end-user and utility: The return of Investment for the end user is below 5 years (depending on the local accessible mechanisms), while potential benefits for both the Utility and the Society are significant.

Potential for replication or adaptation

This platform is a base for a global energy management offer. It's highly scalable thanks to its cloud base architecture and can serve the needs of different geography market through adaptation to local context (language, time zone, units, local tariff, mechanism, etc.). Furthermore, it is open and can share data and exchange information with upstream actors (aggregators and grid operators) or with downstream system (such building management system).

Innovation

SW DSO is a cloud based platform which provide services to both the end user and the Utility in a Software as a Service mode, paving the way to a transactional smart grid. It has direct access to dynamic information like weather forecast information, changing electricity tariffs, etc. in order to help the end user to manage its site energy consumption and benchmark versus other facilities. The service model make it easy and inexpensive to maintain for the end user.

Other benefits

For the end user: maximizing reliability, energy bill savings and environmental footprint.

For the utility: having access to increased DER flexibility located on the demand side and more reliability, savings, and easier integration of DER

12.1.2 CENTERPOINT ENERGY SMART GRID (CNP)

Location: Houston, USA
Functionality: AMS, IG, IGSDs, ADMS
Time period of project: February 2009 – March 2015

Brief Project Description

CNP's Smart Grid Composed of the company's Advanced Metering Systems (AMS), Intelligent Grid (IG), Advanced Distribution Management System (ADMS) and private telecommunications network. Since 2009, CNP has deployed fully operational advanced meters to virtually all 2.3 million metered customers, automated 31 substations, installed 859 Intelligent Gris Switching Devices (IGSDs) on more than 200 circuits, built a wireless radio frequency mesh telecommunication network across the company's 5000 mile electric footprint, and enabled real-time grid monitoring and control, leveraging information from smart meters and field sensors to manage system events through the ADMS, the brain of the company's Smart Grid.

Over 134 million customer outage minutes saved- a 20% reliability improvement on IG circuits, restoration of over 1.5 million outage cases without a single customer phone call, scores of millions of dollars in savings to consumers, and avoidance of nearly 12.8 thousand tons of CO2 emissions.

Project Background and Implementation

A Public Utility of Texas report states that "a critical component of the evolving Texas Electric Market are smart meters." After Hurricane IKE, It was found out that smart grid offers the best returns-on-investment for improving grid resilience and enabling storm recovery" and that finding the means to accelerate CenterPoint Energy's deployment of intelligent grid technology in the Houston area is the Task Force's strong recommendation. The US Department of energy agreed, awarding CNP one of only six $200 million smart grid investment grants.

CNP started installing smart meters in 2009, deploying 2.3 million customers. Till now CNP's AMI has executed over 14 million service orders which has saved 1.4 million gallons of fuel and avoided 12,792 tons of CO2 emissions.

Project Outcomes

The utility has saved approximately $100 million since 2009 from reduced meter reading, reduced billing expectations and recovered revenue/prevented loss from electricity theft. Also cost benefit analysis estimated $1.6 billion in net consumer benefit. CNP's SAIFI on automated circuits improved by over 26% in 2015 avoiding sustained outages for 284000 customers. AMS meters Power –OFF Notification (PONs) help CNP localize outages 50-70% faster while restoring notification allow over 506000 customers enrolled in CNP's Power Alert Service (PAS) to be notified by text, email, and/or phone when their power goes out, received an estimated time of restoration and status updates. PAS has resulted in 90% customer satisfaction and call deflection up to 95%.

CNP's data analytics team developed situational Awareness displays showing case details and available restoration resources in tabular and geospatial formats so controllers can more quickly and effectively trouble spots and route the right crew to the right place at the right time to improve response time and customer satisfaction.

Consumers save $20-25 million per year in eliminated fees from service automation, and some have used the SMT web portal, In-Home Displays or automated usage reports to save up to $100 per month. Millions of reduced truck rolls are not only good for the environment but also help reduced Houston's notorious traffic.

12.1.3 AUTOMATED IMPEDANCE FAULT MAP PREDICTION FOR SMART GRID SYSTEMS

Location: Florida, USA
Functionality: Fault mapping by impedance calculation on the conductor
Time Period: 2010-2015

Brief Project Description

"The Automated Impedance Fault Map Prediction for Smart Grid Systems" project is part of an overarching effort by Florida Power & Light Company (FPL) to build a stronger and smarter grid and deliver the most reliable electric service in the United States. The Automated Impedance Fault Map Prediction project is focused on lowering the risk of a momentary event or outage by utilizing a state-of-the-art diagnostic centre and fault mapping system for smart grid devices and systems. In deploying the smart grid project, FPL focused on using grid data to intelligently monitor its network in real time. The project is claimed to have reduced power outages and improved the utility's service delivery by 25% over the last five years.

Commenting on the benefits of the project, Eric Silagy, CEO of FPL, said: "Leveraging advanced solutions such as the Automated Fault Mapping Prediction System, gives us unprecedented visibility across the grid so we can more quickly detect and prevent many issues before they become problems for our customers."

Project Background and Implementation

Momentary power outages or flickers are brief power outages lasting less than one minute that can occur at any time of the day. Flickers are caused by a number of factors, including lightning strikes, damaged electrical equipment, vegetation and animals. The flickers occur when the electric system detects interference on the power line and then shuts off momentarily to allow the system to determine if there is a break in the line. This process helps isolate the problem area and prevent damage to the grid and can prevent longer outages that effect more customers. Because the State of Florida experiences some of the highest rates of lightning strikes in the U.S., these flickers are one of the leading causes of customer dissatisfaction.

FPL has long used an impedance fault map process based on industry standards to identify the most probable locations and causes of momentary outages. This conventional fault mapping process takes more than three days to generate a fault map and this inefficient process resulted in 42 percent failure rate in detecting and predicting problem areas. In 2015, FPL deployed a number of different smart grid technologies, including automated feeder and lateral switches and fault current indicators to reduce customer interruptions. The automated switches automatically detect, clear, and isolate faults, while the indicators provide information on the faults, line disturbances and event wave form. This automated impedance fault map enables quicker and better momentary investigations providing FPL with the opportunity to proactively mitigate disturbances before they can affect customers and improves the reliability of the grid.

Project Outcomes

This project has had a significant impact on grid reliability, with a location detection accuracy rate of 85 percent, and automated response that follows the detection. FPL experienced a 35 percent reduction in "flicker" complaints as a result of these improvements. This project, in combination with other smart grid technologies and systems, has increased FPL's reliability by more than 25 percent over the past five years. This equates to over $46 million in savings in 2015 due to the avoidance of multiple restoration trips, costs to dispatch trucks and other related costs. More than 680,000 customer interruptions have been avoided, and restoration times and customer minutes interrupted each have been reduced by 8 percent. The FPL service territory and has maintained a reliability rating of more than 99.98 percent.

12.1.4 ESS FOR FREQUENCY REGULATION BY KEPCO

Location: Jeollanam-do, Korea
Functionality: Energy storage Systems (ESS), Frequency regulation
Time Period: 2011 onwards 2017

Brief Project Description

The "ESS for Frequency Regulation of KEPCO" project is focused on using energy storage systems (ESS) to assist in frequency regulation to improve the reliability of the power grid. The ESS utilized as part of this project allows electricity storage at large capacities and can provide rated power to the system 20 times faster than thermal power generators. The project initially began with a pilot project where KEPCO installed ESS in the form of a 4 MW power conversation system and 8 MWh batteries in the Jocheon substation on Jeju Island in 2011 to demonstrate the system capabilities in the form of frequency regulation, peak management and higher stability of renewable energy. After completing this successful pilot, KEPCO then used the information to build a larger scale ESS (52 MW) in Seo-Ansung and Sin-Yongin substations. KEPCO now has plans to integrate ESS for frequency regulation with a total capacity of 500 MW by 2017 and has already completed the construction of 236 MW of ESS. An evaluation of the 2014 ESS installation estimated a cost savings of $3.6 million from July to December 2015.

Project Background and Implementation

Because the Republic of Korea is located on a peninsula with water surrounding three sides, the Korean power grid system is independently operated with the rated frequency being maintained for stable operation. To prepare for grid events, such as a loss of power from a large generators shutting down, a power reserve of 1500 MW is maintained and Korea limits the output of thermal plants to 95 percent to help maintain this reserve. Korea has one of the highest levels of power quality and stability in the world; however, to compensate for this reserve, some higher cost generators need to operate at higher than optimal levels. When ESS can be utilized to reduce these reserve needs, KEPCO better optimizes the economic and environmental dispatch of power generation while ensuring reliability to customers.

The installation to date by South Korean battery storage provider Kokam Co. Ltd comprises 56MW with a 24MW/9MWh lithium nickel manganese cobalt (NMC) system – claimed to be the world's largest of its type – and a 16MW / 6MWh lithium NMC system alongside a 16MW / 5MWh lithium titanate oxide (LTO) system that was deployed in August 2015. The two lithium NMC systems became operational in January 2016.

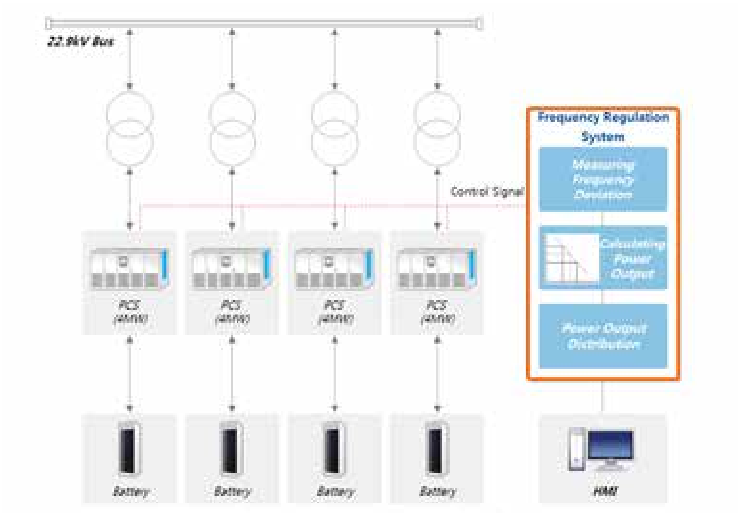

Figure 12-1: System Architecture of Energy Storage System

Project Outcomes

KEPCO's ESS for Frequency Regulation project has provided an opportunity to facilitate a new energy industry and smart grid market in Korea. The increase in performance and decrease in cost for energy management systems, power conversation systems, and batteries, which are essential for smart grids, gave opportunities for companies to participate in this business and allowed early commercialization of smart grids. The full implementation of ESS will enable broader adoption of renewable energy sources while maintaining the reliability of the grid. In addition, KEPCO has established purchase specifications to ensure the quality of ESS installations and has created maintenance procedures and test procedures for stable operation, which could easily be adopted in other locations throughout the world. Apart from the cost savings and clean energy environmental benefits, the ESS for Frequency Regulation project stimulated the growth of new energy businesses in Korea.

Building from a 2011 pilot on Jeju Island and the later addition of much larger ESS at two substations, KEPCO plans to continue its installations of ESS for frequency regulation to a total capacity of 500 MW by 2017, of which 236 MW has already been constructed (in 2015). The ESS will help KEPCO better optimize economic dispatch of the power generated, enabling broader integration of renewable energy sources, while ensuring one of the highest levels of power quality and stability in the world.

12.1.5 UNLOCKING RELIABLE DEMAND-SIDE CAPACITY IN COLOMBIA WITHOUT ADDING GENERATION

Location: Valle, Colombia
Functionality: Peak Load Management, Intelligent Energy Platform (IEP)

Brief Project Description

EMCALI is one of the five largest electric distribution companies in Columbia. This project focuses on the development and integration of an Interactive Energy Platform (IEP) that was used in a pilot program to optimize the integration of 1 MW in demand-side resources to help address peak load issues and stabilize the grid. The IEP involves installing a number of automated controls and management systems in commercial and industrial buildings, which then connect building system technologies within the building and can respond to signals from the grid. The platform works by engaging with customers and providing automated demand-side management response to reduce peak demand.

Project Background and Implementation

Columbia is a dominated by hydroelectric power, but in recent years has faced some of the worst droughts in its history, which has stressed the electricity system and worsened issues with reliability. The country has also faced natural gas shortages, wholesale generation volatility, and growing peak electricity demand. The EMCALI service territory experiences two peaks daily, year-round which adds approximately 800 peak hours a year.

This project focuses on the development and integration of Innovari's Interactive Energy Platform (IEP) that was piloted by one of the largest electric distribution companies in Colombia, EMCALI, to optimize the integration of demand-side resources to help address peak load issues and stabilize the grid. The platform works by engaging with commercial and industrial customers and providing automated demand side management to reduce peak demand through installation of a number of automated controls and management systems that connect building system technologies and make them responsive to signals from the grid.

During the feasibility study, the IEP enabled EMCALI to automatically manage load through automated demand side management in nine commercial and industrial buildings and integrate one distributed generator for a total capacity of 1MW at half the cost of a conventional peak-load generation plant. In 2016, EMCALI aims to expand the 1 MW pilot to 25 MW and eventually leverage the IEP to offset the top 876 hours of peak demand (10 percent), which would offset 70 MW of generation and provide reliable demand-side capacity that is not subject to outside variables and forces like drought conditions.

This project was partially funded by the U.S. Trade and Development Agency (USTDA)

Project Outcomes

As part of the pilot testing, the IEP provided utilities with an affordable capacity at half the cost of a peak-load generation plants. The IEP demonstrated that demand side resources offered the lowest-cost capacity alternative to generation and effective peak shaving capabilities. The platform also effectively engaged with customers such that participation in the program was sustained throughout the pilot. Customers realized a 6 percent reduction in energy expenses during the pilot.

12.1.6 CHPCOM - COMBINED HEAT AND POWER COMMUNICATIONS

Location: Copenhagen, Denmark
Functionality: Communication
Time Period: 2014 onward – till now

Brief Project Description

CHPCOM – Combined Heat and Power Communications, is a Danish research, development and demonstration project that demonstrated a standards-based secure communication system for monitoring and controlling decentral power plants. CHPCOM was a unique project because it brought together a broad coalition of actors in the Danish power system: the electric power distribution industry, the district heating industry, the national transmission system operator, software suppliers, and system integrators.

Decentral CHP plants are essential for the balancing fluctuating wind power in Denmark. The project sought to demonstrate a new generation of data communication system for decentral CHP plants, based on the international standard IEC 61850 that improves on the current situation by:

- Allowing the CHP plants' data to be accessed directly by all relevant external actors
- Improving data security
- Being easy to configure when a CHP plant changes balance responsible party (BRP)
- Requiring nothing more than regular "best-effort" internet service
- Being supported by multiple commercial suppliers. These goals were all achieved in the project

The results from this project have been used to revise and improve the IEC standards, and the results will be used in the future to shape grid codes for new CHP plants in Denmark. The project has resulted in improvements to existing commercial products, and the launch of new products targeted to distributed energy resources.

Project Background and Implementation

The local DSO monitors the electric output of CHP plants using the DSO's own equipment. Often, the DSO forwards these measurements to the TSO. Furthermore, the CHPs are obligated to report historical information about their operation to the TSO and other public authorities (i.e. tax authorities, environmental monitoring authorities). This reporting is typically done manually (via paper, or a web portal), and the same data is often collected by different authorities. With the system demonstrated in CHPCOM, all data delivered directly from the CHP plant, using the same communications infrastructure.

The project demonstrated data communication between CHP plants and their BRP, their DSO, and the system operator using the protocols defined in IEC 61850, with security provided by the protocols defined in IEC 62351. The demonstration took place at 6 CHP plants, involving 2 BRPs, 2 DSOs and one TSO. When preparing the demonstration, the partners tried various commercially available products, but found them all lacking in some way. The nature of IEC 61850, with its many optional features, made it unclear what parts of the standard a "IEC 61850 compliant" device actually supported. The project also implemented, for the first time, newly proposed extensions to IEC 61850. The CHPCOM project found that a rigorous test procedure was required to insure interoperability. During the project, tools were developed to facilitate the specification and execution of conformance tests. A high level of security was required when placing the CHP plants' IEC 61850 server on the internet. A Public Key Infrastructure (PKI) was created for the project using well-established international standards (X.500). This PKI had several adaptations for the needs of the energy system; such as fully automated the creation and renewal of security credentials. Role Based Access Control (RBAC) was demonstrated, which ensured that CHP plant owners could easily who had access to what data. A standalone security appliance was developed by the project partners to act as a bridge between the public internet, and the CHP plants' private network. This appliance handled the authentication of users and encryption of data. The demonstration showed that standard security protocols could be used to secure IEC 61850 communication over the internet.

Project Outcomes

The project demonstrated newly proposed IEC standards, and through participation in standardisation committees, the project partners have disseminated the results from this demonstration to revise and improve the standards. Furthermore, project partners are currently involved in revising the grid codes for new CHP plants in Denmark, and the outcome of the project demonstration will shape the future requirements for CHP plants. The project has resulted in improvements to existing commercial products, and the launch of new products targeted to distributed energy resources.

The project analysed the business case for adopting standardized communication. The business case was based on the unique advantages of the CHPCOM system, which were:

- The removal of redundant communication equipment within the CHP plant
- A reduction in the one-time cost to the plant when changing BRP
- The automation of reporting of production data to public authorities, and the exchange of production plans with the BRP, DSO and TSO

There were large uncertainties in estimating values of these advantages, and the costs of the demonstration project were not necessarily indicative of the cost of implementing IEC 61850 in future plants. Nevertheless, it was concluded that for new CHP plants, there is a solid economic argument for adoption of secure, shared data communication. The Danish District Heating Association disseminated the project results to their members, so that CHP plants all over Denmark are familiar with the advantages of standardized secure communication. Because the primary target audience for this effort was Danish businesses, the majority of the project documents are in Danish.

12.1.7 IVECS - INTELLIGENT ELECTRIC VEHICLE CHARGING STATION

Location: Toronto, Ontorio, Canada
Functionalities: Electric Vehicle Infrastructure
Time Period of Project: January 2015 - September 2017

Brief Project Description

IEVCS (Intelligent Electric Vehicle Charging System) solution is co-funded by the Ministry of Energy, Ontario under smart Grid fund. IEVCS has been conceived by utilities, industry and government together to ensure the “Excellence in Smart Grids”. Tech Mahindra, Center of excellence Ryerson University, SDG&E, Niagara on the Lake Hydro (Local distribution Company & project demonstration site) has come forward and build state of the art smart grid solution for catering the growing need of Electric Vehicle infrastructure and its impact on Electricity grid.

IEVCS is comprehensive solution to address the challenges and harness the opportunities coming up on the last mile of distribution grid (such as rooftop solar, home energy storage, community energy storage, electric vehicles and other loads). Key features of IEVCS are an integrated control, monitoring & optimization system to ensure that Electric Vehicle adoption is not going to impact the grid in an adverse way but is an opportunity to use the dynamic capacity in the grid based on the available solar, storage and grid supply, capacity in the wires. IEVCS is smart grid solution covering the electric charging efficiency and cost, distribution assets monitoring & control, driver experience and enablement, enhancing the life of car batteries apart from other benefits.

Project Background and Implementation

Ontario is building one of the most advanced electricity grids in the world. The Smart Grid Fund has been supporting these innovative projects and the development of a modern, intelligent electricity system since 2011. Tech Mahindra a leader in Utilities and Smart grid solutions space partnered with leading utilities of the world (SDG&E), leading research institutes (Ryerson University) and a forward looking local distribution company (NOTL Hydro), and multiple vendors of smart Grid technologies to implement the demonstration project solving most of the challenges of future grid. Ontario government has shown its commitment towards smart Grid and co-funded the project.

Purpose of the Project was to build the integrated & interoperable solution for smart grids addressing most of the challenges at the last mile of electricity grid.

IEVCS will ensure that none of the distribution assets should fail because of change in loading conditions of the grid because of new loads and generation, primarily the electric vehicles as each of the electric vehicle is equal to the load of a house hold.

Customers can use the time of use billing, demand response, and others market mechanism to reduce the cost of charging the electric cars. Have a interoperable platform supporting all of the leading chargers, sensors, meters and storage devices, forecasting of the demand and supply to balance the grid in spite of additional load of charging, queuing algorithm to queue the loads so as to ensure the charging is being given to vehicles based on the priority set by the drivers and the grid operators.

Tech Mahindra has proven that integrated platform will substantially improve the reliability, asset utilization and cost of the operation of existing distribution grid even with a new loads and generation.

Since the project is supported by the government of Ontario, it is being promoted as platform of choice to further strengthen the Electric Vehicle infrastructure in Ontario and other geographies considering the fact that this is one of the first demonstration in the world. Tech Mahindra has demonstrated with its solution that "Range Anxiety" and capacity of electrical network can be solved using the smart grid technologies, and this project is a big leap in this direction.

Project Outcomes

Solution is having three distinct areas of influence which are matches with the objectives of smart grids.

Distribution Grid

- Reduce the asset failure by 10- 30%
- Reduction in maintenance cost of network 8-22%
- Reduction in theft – zero theft
- Reduction in nontechnical losses – (2-3%)
- Enhancing the asset life – (10 – 20 %)

Electric Car infrastructure

- Reutilizing the existing electrical infrastructure for additional car load (25-35%)
- Cost of charging – optimization by 15-30%
- Adoption rate increase – 25-30%

Human factor (Car drivers, Utility crew, Utilities Operation team)

- Ease of use for drivers
- Reduction in range anxiety
- Reduction in time of fault identification, repairs
- Real time information about the outages to the utilities

As number of EV vehicle sores up, electrical utilities are facing the uncertainty of its effect on the grid. It is not the number of electrical vehicles on the road but there population density within a sub division. This leads to the challenge of designing and maintaining distribution infrastructure as it may result in the overloading of the grid due to more number of vehicles being charged at the same time. It requires efficient and precise approach for solving the issue of regulations compliance as far as the grid is concerned.

For reducing the load on the grid, distribution level monitoring can be used to ensure that any overloading because of EV charging could be controlled at distribution level by having an intelligent communication between EV charging station, distribution Network and utilities operations center.

Since the adoption of electric vehicle is one of the most important clean technology initiative by the governments and other stake holder. It also offers the big opportunity for utilities to have additional demand, which is reducing because of increase of distributed generation.

12.1.8 VTWAC (VERMONT WEATHER ANALYTICS CENTRE): DELIVERING A POWERFUL RETURN ON SMART GRID INVESTMENT

Location: Rutland Vermont USA
Time Period of Project: February 2014-February 2016
Functionalities: load forecast

Brief Project Description

Driven by significant increases in the frequency, strength and cost of punishing weather events and the astonishing expansion of distributed generation, VELCO joined with IBM Research to develop the Vermont Weather Analytics Center (VTWAC). VTWAC is a powerful energy data and analytics tool that utilizes linked data, coupled models and leading-edge analytics to deliver actionable information that enables lower weather-event related operational costs, optimized integration of renewable generation resources with overall increased grid reliability. VTWAC delivers 72-hour advance weather forecasts, precise to 1 km^2, linked to customer demand data and the most accurate solar and wind generation models in the world.

The VTWAC project comprises four elements

- Deep Thunder — a Vermont-specific version of this IBM predictive weather model that produces high-resolution forecasts;
- Demand Model — an advanced electric demand forecast utilizing smart meter data, Deep Thunder and other resources in order to produce detailed demand forecasts;
- Renewable Generation Model — generation forecasts for solar, wind, which uses Deep Thunder and other data, and separately correlated hydro to improve power supply planning ; and
- Renewable Integration Stochastic Engine — a coupled model with a probabilistic framework that links the other models' output to produce actionable information to better balance generation and demand.

Figure 12-2 shows the components of VTWAC. VTWAC is a collaborative replicable, scalable accomplishment that delivers value to utilities, customers, and state agencies

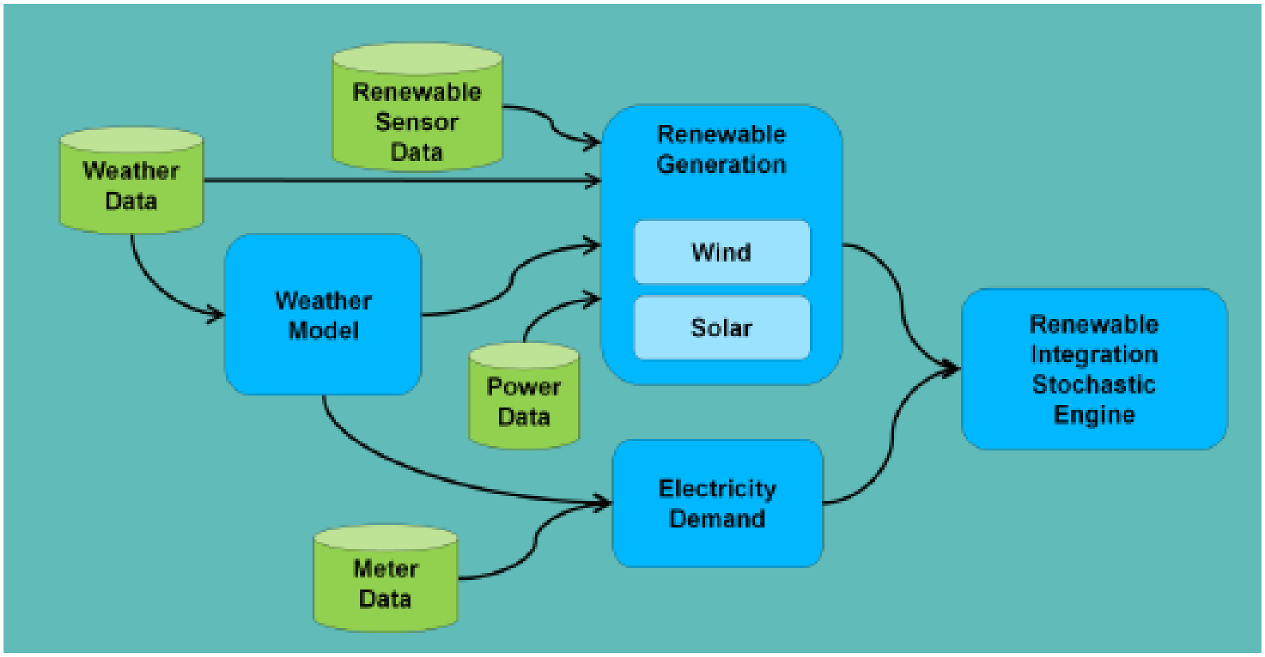

Figure 12-2: VTWAC System

Project Background and Implementation

Vermont is a small state with roughly 1000 MW of total electrical, less than four percent of New England peak demand. Today, roughly 200 MW of wind and solar resources feed power to Vermont's grid, with 25 to 30 additional megawatts, driven by state policy and tax incentives, expected to come on line annually in the next several years. Operators and planners need visibility into installed capacity, location, and real-time production information, as well as the ability to accurately predict future output of weather dependent resources. VTWAC meets those needs.

VTWAC link is analytics built upon high-resolution physics-based weather forecasts. Data gleaned from Vermont's smart Grid helps to drive the models especially when looking at demand at the distribution substation level as well as renewable generation production from smaller scale systems. This globally unique platform integrates information from data sources traditionally available but not linked: high-resolution weather forecasts, real-time power measurements from network telemetry, smart meter data from hundreds of thousands of individual customers, and detailed information about the Vermont grid's physical properties. These data streams are complemented with best-in-class energy analytics capabilities. Major advancements include energy forecasts for individual distribution substations that explicitly account for distributed renewable energy sources including behind-the-meter resources, such as residential rooftop solar systems. Specialized models for particular types of electrical loads, e.g., snowmaking in Vermont ski resorts, were also developed. Such information is essential to predict and mitigate anomalous network conditions due to a high percentage of renewables. This effort accelerates smart grid advances by transforming grid operations through the use of linked analytics.

Vermont's DOE-sponsored Energy Project provided the foundational infrastructure required for VTWAC, i.e. a smart grid provides data that drives the analytics deployed with VTWAC.

Project outcomes

- Forecasting inaccuracy has been reduced to 5% for individual solar farms.
- Wind direction is predicted with a bias of only 0.17 degrees, and wind speed bias is less than one mph.
- Energy demand forecasting achieves an accuracy of 97.6% at the state-wide level and 97.3% at the Distribution Utility level. Traditional forecasts provide information to a 12 km² resolution. These new techniques provide 72-hour forecasts to the 1 km² level including wind speed and direction, solar irradiance and precipitation for every 10 minute-increment. As Figure 4 shows, these 2015 developments led to the VTWAC forecast validation results shown for a recent storm event.
- Increased effectiveness and lower-cost weather event assessment, preparation, response and customer service restoration from increasingly severe and frequent weather events.
- VEC/GMP combined storm costs for 2013 alone were $22 million, $33million 2104.
- Bolstered advocacy at ISO-NE for non-transmission alternatives through provision of accurate, real-time data on renewable generation sources.
- The total project cost equals $400 million worth of transmission project deferrals secured out of a possible $4.8 billion in currently anticipated regional transmission costs.
- Predictive modeling of wind/solar generation resources helps renewables integration and load balancing to maintain system reliability.
- Improved forecasting of intermittent wind and solar renewable resources could potentially be worth $1 million to $4 million annually to New England and several hundred thousand dollars to Vermont.

12.1.9 FACTORY MICROGRID (LIFE13ENV/ES/000700)

Location: Peralta, Navarra
Time Period: 2014-2017
Functionality: Microgrid

Brief Project Description

Factory Microgrid (LIFE13 ENV / ES / 000700) is a demonstrative project whose main objective is to implement a full-scale industrial smart microgrid. Microgrids can become one of the most suitable solutions for energy generation and management in factories. Project partners are the Jofemar Corporation and the National Renewable Energy Centre, CENER.

In order to do that, both partners will design and implement a microgrid at Jofemar's industrial facilities in Peralta (Navarra). The Factory Microgrid smart grid will meet the specific energy needs of the Jofemar plant, so it can demonstrate the feasibility and suitability, both technical and economic, of these solutions in industrial environments. The smart grid features a 120 kW wind turbine and 40 kW of PV on deck, as power generation, and Zn-Br flow batteries capable of storing up to 500 kWh, as storage systems. The microgrid will also integrate six V2G bidirectional charging points for electric vehicles and one 50 kW fast charge point, which will supply the 6 electric vehicles from Jofemar Electro mobility, the division of Jofemar Corporation specializing in electric mobility, integrated in the project.

Project Background and implementation

This project aims at being the basis for developing a new environmentally friendly business model which will offer a comprehensive solution to meet energy and sustainable mobility needs. The architecture for Factory Microgrid is hybrid which poses several advantages in terms of controllability, stability and efficiency. Two buses or grids coexist -one of them uses direct current whereas the other uses alternating current. Both buses are connected through power electronics and the connection of the DC bus with the grid is made using a bidirectional converter.

The following data are being monitored and they will be analyzed once the microgrid have been running for 6 months:

- Electricity purchased from the grid
- Self-consumption
- Reduced electricity purchased from the grid
- Infrastructures investment deferral
- Reduced peak demanded from the grid
- Contribution to distribution grid stability
- Provision of ancillary services
- Loss reduction potential: calculation of kWh that would be lost in distribution grid in absence of microgrid;
- Increased grid reliability

Project outcomes

OBJECTIVE 1

- To generate 56,215 kWh/year free of CO2 because of the installation of 40 kWp of photovoltaic panels
- To generate 103,323 kWh/year free of CO2 because of the installation of 100 kWp of wind turbine
- To store energy and to manage energy flows in order to allow consuming all the renewable energy generated, saving (56,215+103,323) kWh/year * 222 g CO2/kWh = 35.4 Tm of CO2 en emissions
- To avoid 38 Tm of CO2 emissions because of integration and use of EVs as part of the microgrid
- In total, to avoid 73.4 Tm of CO2 emissions per year

OBJECTIVE 2

- To reduce energy consumption due to energy management of 100 kW of dispatchable loads, allowing a reduction of 23 Tm of CO2 emissions per year
- To allow offering ancillary services (voltage and frequency control) to the distribution grid and contributing to grid stability

OBJECTIVE 3

As a consequence of the success and dissemination of the project results, the uptake of microgrids will allow to:

- An increase of the generation of electricity using CO2 free sources
- More grid stability, allowing to rise renewable energy generation to more than 40 percent by 2020

12.1.10 AL-LINK

Location: Mariehamn, Aland, Finland
Time Period of Project: 2013-2015
Functionalities: HVDC

Brief Project Description

Before the project, Aland received 70% of its power via a subsea AC cable from Sweden, in addition to locally produced renewable generation. Significant part of existing aging fossil fuel back-up systems, were to be retired but lack of backup power for the dominating AC cable left serious reliability concerns.

The VSC HVDC system gave reliability in combination with existing generation and incorporated special features such as active AC voltage support providing greater network stability. It also provided the unique Black-start capability, which gave fast grid restoration in the event of a blackout.

The Al-link is also grid enabled, i.e. prepared for a multi-terminal configuration, which allows for additional in-fed from stations, such as future wind power plants.

Project Background and Implementation

The driving Forces for the project were mainly reliability in combination with facilitation of RE introduction:

-Reliability in areas like

- Fast grid restoration with strong Black Start Capabilities
- Back up to existing power production, with full back up of the AC cable to Sweden
- Provide interruption free power

- Today Aland has 25% of energy consumption covered by renewables. With the link, planning is to cover >70% by local RE and remaining part will be covered by low CO2 power from mainland Finland and Sweden.

-Expandable Grid for major RE introduction: Providing a grid with the possibility to expand the VSC HVDC link to a three terminal system and connection of future 100 MW windfarm by providing reliable power from mainland Finland, the closure of old diesels on Aland was possible.

Project outcomes

- Aland today have reliable, stable and a grid fully enabled for co2 free power
- Black start capability has been done in full scale with the complex Aland grid and with successful result.
- In case of very rare occasions of black outs, the restoration of the entire will be in seconds instead of minutes or hours.

12.1.11 SMART CONSUMER - SMART CUSTOMER - SMART CITIZEN (S3C)

Location: European Union Countries
Time Period of Project: Nov. 2012 – Oct. 2015
Functionalities: Active Demand Side Management, Load Management, AMI, Smart Metering

Brief Project Description

The S3C project aims at developing ready-to-use tools for long-term end-user engagement by addressing the end-user in his three roles as smart consumer, customer and citizen. An interactive toolkit website will be developed throughout the project. The first S3C deliverable describes a variety of insights on end-user engagement in smart grid projects from a theoretical and from an empirical perspective. From the theoretical perspective, it is found that various theories exist that can be used to frame and analyse consumer behaviour.

The current generation of smart grid demonstration projects is very much focused on technology and the functioning of electricity grids. There is little insight in the behaviour of consumers in a connected living environment. Nevertheless, the success of active load and demand-side management strongly depends on appropriate technologies, incentives and consumer acceptance.

Gathering 7 project partners from 7 different EU Member States, the project "Smart Consumer – Smart Customer – Smart Citizen" (S3C) addresses these shortcomings by giving centre stage to the energy end users in households and small commercial/industrial entities. From this perspective, smart grid technologies are seen as opportunities for end users to modify and adapt their energy-related behaviour.

Project Background and Implementation

In this project the end users can take on different positions with respective responsibilities and opportunities, beyond acting as a passive consumer of energy supplied by active providers,

As a smart consumer, an end user can be challenged and enticed to change his lifestyle routines (e.g. heating, showering, using appliances, etc.) in order to make energy savings.

As a smart customer, an end user can be challenged and enticed to enforce his market position with respect to the energy providers, offering load flexibility, or even becoming a commercial partner as 'co-producer' of energy or provider of energy services (e.g. generation, storage facilities, controllable loads).

As a smart citizen, an end user can be challenged and enticed to become part of 'smart energy communities' – i.e. a group of smart consumers or customers who interact continuously and (mostly) automatically to optimize the 'smartness' of the entire energy system in a city or region. As smart citizens, end users have to bother with issues such as power quality, environment preservation and data privacy concerns with respect to energy consumption.

Project Outcomes

S3C's final output will be validated recommendations and guidelines that facilitate the implementation of the selected technical user-interaction schemes in future smart-grid projects and roll-outs. Active involvement of a large group of stakeholders will ensure that S3C results are widely publicised and will find their way into an ever growing Smart Grid Family in Europe. The guidelines as such and an easy-to-use toolkit will be available from a project website as soon as they will have been tested.

12.1.12 GRID4EU - LARGE-SCALE DEMONSTRATION OF EUROPEAN SMART DISTRIBUTION NETWORKS

Location: Europe
Time Period of Project: November 2011 – January 2016
Functionalities: Renewable Energy Integration to the grid, AMI, Demand Side Management, EV, Microgrid

Brief Project Description

Designed in response to a call for projects from the European Commission, GRID4EU is a Large-Scale Demonstration of Advanced Smart Grid Solutions with wide Replication and Scalability Potential for Europe. The project was led by six electricity Distribution System Operators (DSOs) from Germany, Sweden, Spain, Italy, Czech Republic and France, in close partnership with a set of major electricity retailers, manufacturers and research organizations. As a whole, the consortium gathers 27 partners. GRID4EU consisted of six Demonstrators, which were tested over a period of 51 months in six different European countries. The project strived at fostering complementarities between these Demonstrators, promoting transversal research and sharing results between the different partners as well as with the wider Smart Grids community. A brief description of the six GRID4EU Demonstrators is provided in the figure 12-3.

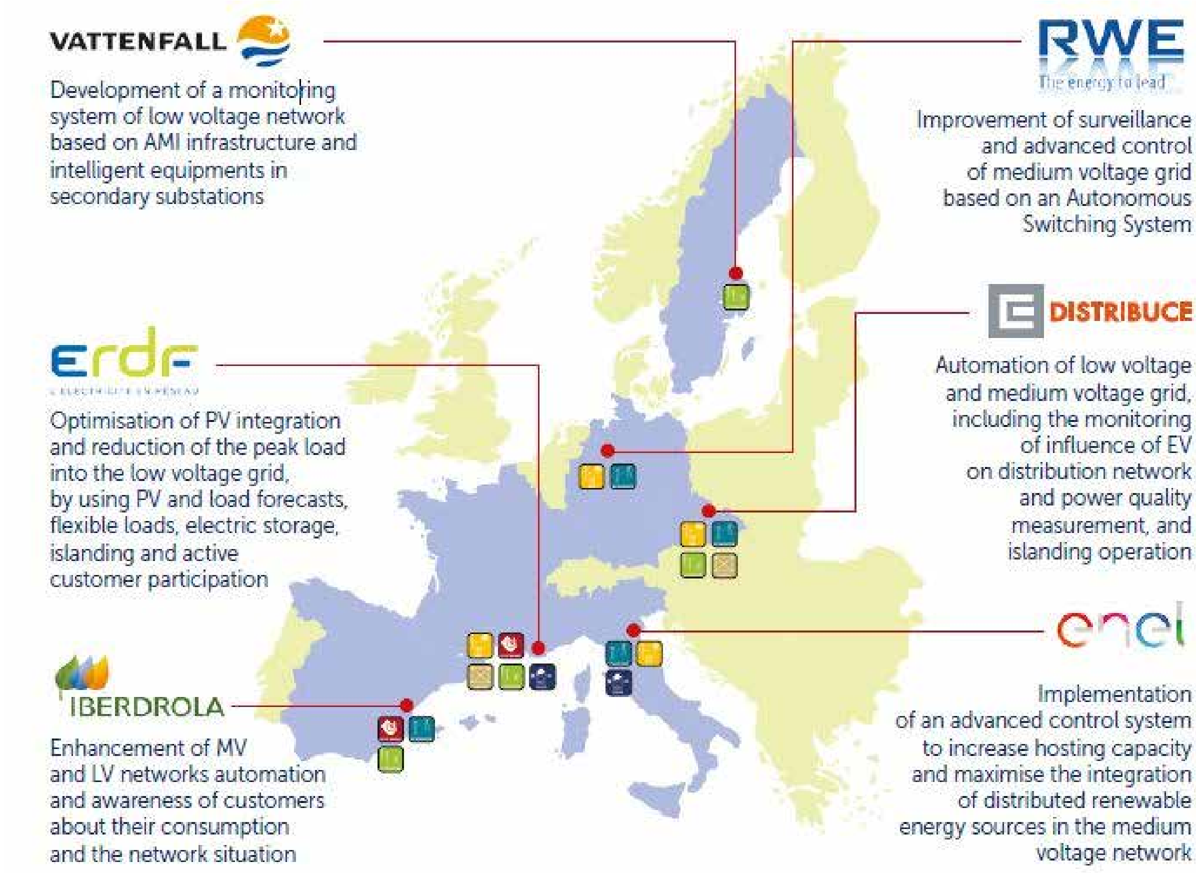

Figure 12-3: Six GRID4EU Demonstrators

Grid4EU is the biggest smart grid project to be funded by the European Union. The project is led by six European DSOs covering more than 50% of the electricity supply in Europe: CEZ Distribuce (Czech Republic), Enel Distribuzione (Italy), ERDF (France), Iberdrola Distribucion (Spain), RWE (Germany) and Vattenfall Eldistribution (Sweden). Altogether 27 partners from several countries (including manufacturers, system integrators, research centres and universities) are collaborating in the project.

The main objectives of Grid4EU are:

- To develop and test innovative technologies,
- To define standards through the set-up of large-scale demonstration,
- To guarantee the scalability of these new technologies,
- To guarantee the replicability over Europe,
- To analyse Smart Grid Cost-benefits (market mechanisms for DER, business models for storage, demand response market mechanisms, etc.).

Project Background and Implementation

Grid4EU consists of six demonstrators (one per DSO leading the project), which will be tested over a period of four years. The emphasis will be on fostering complementarity between these projects, and on promoting transversal research and sharing results between the different DSOs involved.

- **GridEU Demo 1 (Germany, led by RWE):** Demonstrator in Reken focused on the improvement of MV network monitoring and control based on autonomous acting Multi-Agent-System (MAS).
- **Grid4EU Demo 2 (Sweden, led by Vattenfall):** Demonstrator in Uppsala focused on the development of LV network monitoring and control system based on AMI infrastructure and smart substation equipment.
- **GridEU Demo 3 (Spain, led by Iberdrola):** Demonstrator in Castellon focused on the enhancement of the MV and LV grid automation, the awareness of the Customers about their consumption and network situation and the participation of customers in demand response.
- **GridEU Demo 4 (Italy, led by Enel Distribuzione):** Demonstrator in the Forli-Cesena area (Emilia Romagna region) focused on load-flow optimization with the implementation of an advanced Power Flow Control (PFC) system to increase the hosting capacity of the MV network and maximize renewable energy integration.
- **GridEU Demo 5 (Czech Republic, led by CEZ Distribuce):** Demonstrator in Vrchlabi focused on LV and MV grid automation including EV charging technologies and islanding.
- **Grid4EU Demo 6 (France, led by ERDF):** Demonstrator in Carros focused on the optimization of PV integration into the LV grids by using PV forecasts and demand forecasts, load flexibility, electric storage and islanding. It will also encourage stimulate demand response of end-customers and assess the social impacts of smart grid technologies.

Project Outcomes

Five General Work Packages support the six Demonstrators to facilitate dynamic knowledge sharing, technical assistance and coordination. In particular, a way to analyse cost and benefits and validate technical solutions for all components, while participating to standards definition, has been implemented. Additionally, the project studied how to deploy the model at DSO scale (scalability) and then to spread it to other DSOs (replicability). As the DSOs involved in the project cover more than 50% of the metered customers in the European Union, the scaling-up and replication of the results obtained help contribute efficiently to reaching the EU 2030 energy targets.

The project aimed at testing innovative concepts and technologies in real-size environments, in order to highlight and help remove barriers to the deployment of Smart Grids in Europe. It focused on how DSOs can dynamically manage electricity supply and demand.

12.1.13 VENTEEA

Location: Champagne-Ardenne region, France
Time Period of Project: December 2012 – June 2016
Functionalities: Renewable Energy Integration, Energy Storage, Grid Automation

Brief Project Description

Venteea is a project focused on the integration of large wind generation in Medium Voltage (MV) distribution networks. The demonstrator Venteea aims to improve grid efficiency and the integration of large wind generation in MV distribution networks, while optimizing connection costs. Indeed, the electric grids were not intended for renewable energy production, so they have to adapt to their fast development. The challenge is to develop new products in order to increase grid observability and controllability nearby renewable energy production. Products and solutions experimented by Venteea should enable to limit disturbances on the electric grid and to smoothen electric production fluctuations.

Project Background and Implementation

The objective of this project is to create the best conditions to ensure an economically and technically efficient integration of renewable energy, particularly wind power plants, in MV distribution networks of the future. The scope of testing will be directed towards issues related to production facilities of significant power connected to the distribution network HTA (20kV) in a rural area where the rate of wind energy development is particularly high. These tools will enable to adapt voltage plans and to detect and locate faster potential incidents on the grid. Besides, the scope of testing also includes means of storing energy that could be installed next to decentralized production means. These solutions could contribute to stabilizing the grid and to enable installation of new energy production means. Additionally, the project aims to remove the main barriers which may hamper the massive integration of renewable energy production on the networks and to implement innovative solutions for energy-efficient network operations of existing and future distribution networks.

From a technological point of view, this demo will:

- Improve network reliability in presence of production
- Adapt network management and automation and also the controllability of production facilities in order to optimize the operation of the system
- Reduce technical losses networks through the use of devices for voltage regulation and reactive power
- Validate the use of an energy storage solution for operation of distribution networks services
- Establish the system information’s needed evolutions to allow the development of smart grid and a more evolved system in order to facilitate the integration of renewable energies

VENTEEA will test different automation and communication solutions to optimize the integration of wind generation in MV network.

Project Outcomes

- Voltage and power sensors for network real time diagnosis
- MV network state estimator
- Voltage regulation function
- Command and control system (PS) to manage the voltage on MV network in real time
- Devices to exchange data with DER to facilitate their integration in the network
- Devices to transfer field measurements
- Multifunctional/multi-stakeholder storage of 2 MVA
- Use of production forecast and voltage regulation thanks to cooperation and data exchange with wind power generator
- Improving automation of the MV/LV power grid and develop new products
- Studying the impact of renewable energies on quality and reliability of energy supply
- Use of storage for several actors and several system services

12.1.14 INOVGRID

Location: Portugal
Time Period of Project: 2011 – 2014
Functionalities: Smart Metering, Renewable Energy Integration, Energy Storage, Grid Automation, EV
Inovgrid is EDP's umbrella project for smart grids

Brief Project Description

InovGrid is a distinctive project in the European landscape because it combines a reasonable size, in terms of the number of customers reached, with a strong focus on the Smart Grid vision. After compiling a catalogue of all European Smart Grid projects, the Joint Research Center (JRC) of the European Commission has recognized the unique positioning of project InovGrid by choosing it as the single case study on which to base the development of its *"Guidelines for Conducting a Cost-Benefit Analysis of Smart Grid Projects"*. Additionally, InovGrid was the first national project receiving the Core Label by the European Electricity Grid Initiative (EEGI).

Project Background and Implementation

Active Demand response is stimulated by providing user-friendly interfaces for consumers with information on energy consumption, generated energy and management tools to react to external signals (e.g. price). Additionally, the project investigates the use of a real-time gateway for stakeholders to control the local consumption of electricity using demand-side management of large energy consuming devices such as heat pumps, electric vehicles (EVs), etc.

Integration with Smart Homes is achieved by providing energy management functions of home automation devices and smart appliances that stimulate energy efficiency. Smart Metering Infrastructure includes the EDP Box to substitute the conventional meters at the consumer/producer premises and the DTC at the

MV/LV substations. This equipment enables grid monitoring through data gathering at the consumer and substations level, data analysis functions and interface with commercial and technical central systems, enhancing grid automation and new market solutions.

Smart Metering Data Processing is the functionality of the Smart Grid Asset Data Management System. It includes all features related to the execution of commands and data gathering of the InovGrid infrastructure with the possibility to be integrated with commercial systems, management of communications and network settings.

Integration of DER is achieved using advanced control and automation functionalities distributed over different levels of a hierarchical control structure that matches the physical structure of the electrical distribution grid. This hierarchical control architecture enables the coordinated and synergistic management of (Distributed Energy Resources) DER, including distributed generation (DG), responsive loads and distributed small-scale storage.

Integration of EV By anticipating an important future development, the project exploits the potential flexibility of actively managing electric vehicles battery charging at home premises. Additionally, the already existing Portuguese EV charging infrastructure energy flow is monitored and controlled by the InovGrid platform.

Monitoring and control of LV networks: The EDP boxes and DTCs provide real-time information on the grid. That information will also be used to evaluate the impact of micro-generation on system voltages, currents, reliability and, of course, losses.

Automation and Control of MV networks includes the use of the control intelligence integrated in the DTC and automation mechanism. The possibility of remote control of MV devices reduces the need of intervention of work field teams and ensures short time failures. Besides, electric remote controls and monitoring at the substation level are essential to anticipate problems.

Integrated Communications Solution: The DLMS-COSEM is used in InovGrid to enable a structured way of transmission of data currently from the Smart Meter EDP Box to the Systems. A SCADA application is used to collect data from the DTC and support remote control on the medium voltage. For communications, Prime PLC technology is being applied.

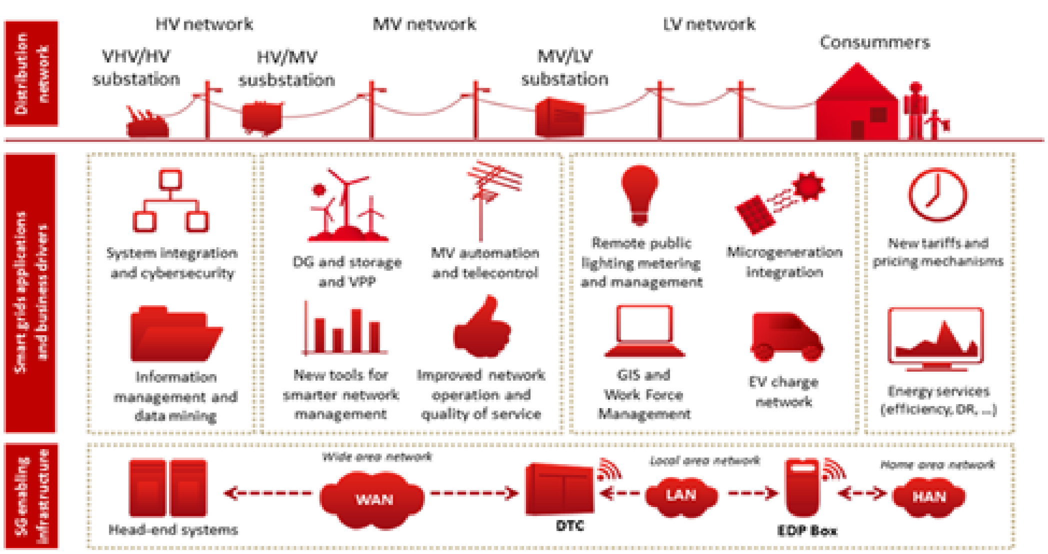

Figure 12-4: Integrated Communications Solution

Project Outcomes

Currently, the project is expanding to other portuguese cities, including Guimarães, Lamego, Batalha/ Marinha Grande, Alcochete, Algarve and São João Madeira; reaching more than 150 thousand consumers at the end of 2014. Additionally, starting in the 2015, all the new installations will use EDP boxes, making it the standard technology in Portugal.

From a societal point of view, the business case for InovGrid is based on a set of benefits of the project accruing to several stakeholders, including: the DSO itself, regulators, electricity users, energy services companies, electricity retailers, distributed generation promoters and vendors, electric vehicle owners and vendors and, considering the economic and ecological impact, society in general.

EDP believes that InovGrid project is of utter importance to align the EDP Group strategy with the European 2020 Energy objectives, because it has an holistic approach to the different involved aspects and plays a central role acting as an integrated platform, which can leverage the development of new business models, that will allow to reduce the CO2 emissions, inject more renewables in the grid and promote energy efficiency, thus giving a major contribution to meet the European Energy targets.

12.1.15 SMART GRID STATION OF KEPCO

Location: Korea
Time Period of Project: 2009 – 2013
Functionalities: AMI, Renewable Energy Integration, Energy Storage, EV

Brief Project Description

"Smart Grid Station" of Korea Electric Power Corporation (KEPCO) is an integrated regional-based control center for best-managing independent energy systems converged with information and communication technologies. The project widely embraced diverse areas of smart grids and renewable energy encompassing heating/cooling, photovoltaic, wind turbine, energy storage system, advanced meter infrastructure, and electric vehicle charger, while implementing technologies developed from the Je-ju smart grid pilot project (2009-2013).

Project Background and Implementation

The project developed a hybrid power conversion system (PCS) and energy management system (EMS) in order to efficiently integrate systems and manage energy consumption in buildings. In the "Smart Grid Station," each building is installed with an EMS that integrates various independent systems, such as renewable energy resources, energy storage, smart devices, heating and cooling devices, etc. The hybrid PCS successfully integrates the inverter that controls renewable energy sources and the power conversion system, which controls charging/discharging status of batteries while the EMS monitors and controls the Smart Grid Station system components. In addition, a charging/discharging algorithm of energy storage optimizes energy usage, peak load, and cooling/heating status automatically.

Project Outcomes

The Smart Grid Station of KEPCO reduced indoor energy consumption by 10% of and reduced peak demand by 5%. By better enabling effective demand side management, peak demand reductions, and load shedding, the project reduces transmission and distribution costs, while stabilizing energy supply and demand. The Smart Grid Station project involved 39 different small and medium enterprises participating in the 2014 project and there are plans to expand the application of the Smart Grid Station to 75 KEPCO buildings in 2015.

12.1.16 DS3 - DELIVERING A SECURE, SUSTAINABLE ELECTRICITY SYSTEM

Location: Ireland
Time Period of Project: August 2011 – 2020
Functionalities: Smart Metering, Renewable Energy Integration, Energy Storage, Grid Automation, EV

Brief Project Description

EirGrid's "DS3 - Delivering a Secure, Sustainable Electricity System" project is focused on identifying and overcoming the challenges associated with integrating variable renewable generation into a synchronous power grid at unprecedented levels (40% renewable electricity target). The project is centered on the electricity system supporting the Island of Ireland and Northern Ireland.

Project Background and Implementation

The DS3 project is divided into three pillars - System Performance, Policies and Tools, under which a number of new innovative smart grid tools, policies and methodologies have been developed, including a metric to examine the maximum possible variable renewable generation capacity while operating the system in a secured and safe manner. By integrating planning and development between the three pillars, EirGrid Group has securely managed real-time penetration levels of up to 50% of system demand on a continual basis, and has created a framework to increase this to 75% by 2020.

Project Outcomes

In order to ensure the system performance required to meet the renewable integration goals, DS3 has focused on

- "Grid Code" modifications, rate of change of frequency (RoCoF) modifications, and the provision of system services with demand side management to meet renewable integration goals
- Increasing participation from demand connected loads and enhanced performance monitoring
- EirGrid has been collecting system statistics and developing key system indices to identify trends and inform policy changes.
- Major outcomes of DS3 include enhanced controllability of Wind Farms, a cutting-edge wind dispatch tool, best-in-class wind forecasting tools and DS3's Wind Security Assessment Tool and Dynamic Studies tools

12.1.17 SMART MICROGRID IN A REMOTE VILLAGE IN ODISHA, INDIA

Location: Chotkei, Odisha
Functionalities: Microgrid

Brief description

It is the first such smart-microgrid village implemented in India. The Chhotkei Smart Nanogrid™ consists of 30kWp solar-power plant to meet the energy demands of 140 households, 20 streetlights, a temple, and three community centres consuming about 20kWp. The rest 10kWp has been set aside for day-time use by irrigation pumps and microenterprises to improve agricultural output, enable value-addition to agriculture, and generate employment. This brings energy-sufficiency to the village, and eliminates grid-dependency.

Project background and implementation

Chhotkei is a small remote village inside the hilly and scenic terrain of Satkosia Tiger Reserve, about 160km from the state capital, Bhubaneswar. While Angul is one of the most developed districts of Odisha, and the Power House of the state lighting the country, it unfortunately, fails to expel the darkness underneath.

The scenario is changing since SunMoksha implemented it Smart Village Nanogrid™ at Chhotkei under the CSR program of Wartsila India Pvt. Ltd. Power is supplied through the distribution boxes, spread throughout the village, over underground electrical cables to minimize losses and and set-up long-lasting infrastructure. It is distributed to the consumers through metering & control system of the Smart NanogridTM. A local area network has been set-up over underground optical fibre cables (OFC) and Wi-Fi hot spots for complete operations of the Nanogrid™ managed by NanoSoft RemoteTM. As the village does not have any means of voice or data communication, a VSAT have been installed for communication between the village and the cloud server for remote monitoring and maintenance.

NanoSoftTM manages metering, billing, payment, differential tariff, and alerts/cut-off if unpaid. The system switches off power supply, if a consumer exceeds maximum energy or power allocated. It schedules demands of microenterprises, irrigation pumps, street lights, etc. to match the power generation constraints. Smart sensors help ensure safe operations of the power plant equipment. The IoT/IT-enabled Smart Nanogrid™ ensures reliable and predictable power supply through demand and supply management and citizen-centric power services. Citizens not only get quality, reliable power but can also schedule their power requirement accordingly to their convenience, view their electricity consumption and bill in real time, pay their bills and register their complaints – all through a Mobile App. An Energy Card with QR Code is provided to each consumer to effortlessly login to the Mobile App.

Project outcomes

Smart NanogridTM at Chhotkei not only ensures operational efficiency, but also scalability, by remotely monitoring and technically supporting the village projects in a cost-efficient and timely manner. It makes data available to experts in real time for a timely intervention, in case of failures or malfunctions; thus bringing long-term sustaianbility. The cloud data is available to all remote stakeholders such as sponsors, government agencies, implementers, O&M providers, and domain experts to remotely monitor the performance of the project and intervene, if needed, bringing complete transparency and scalability. A special portal has been created at www.smartnanogrid.net to network all such Nanogrids for not only real time monitoring of the projects, but also for information exchange and cross-learning.

12.2 SMART GRID PILOT PROJECTS IN INDIA

In order to kick-start smart grid technologies demonstration projects in the country, the Ministry of Power (MoP), Govt of India (GoI), allotted 14 pilot projects to different distribution companies in various states. The combined cost of these projects is about $68 million and they are likely to help technology section guides and business case developments for larger projects in the next phase. These projects are partly funded by the MoP (50 per cent of the project cost as a grant from GoI). Brief description of 10 pilot projects which are in various stages of execution and 4 projects which were cancelled are presented in this section.

12.2.1 ASSAM POWER DISTRIBUTION COMPANY LIMITED (APDCL) SMART GRID PILOT PROJECT

Location: Guwahati Distribution Region, Assam
Functionalities: AMI, Renewable Energy Integration, Peak Load Management, Outage Management, Power Quality

Brief description

The pilot project covers 15,000 consumers involving 90 Million Units (MU) of input energy. APDCL is in the process IT Implementation under R-APDRP and SCADA/DMS implementation is also to be taken up shortly. APDCL has proposed the functionality of Peak Load Management using Industrial and Residential AMI, Integration of Distributed Generation (Solar and available back-up DG Set) and Outage Management system. The utility has envisaged that Power Quality Monitoring will be a by-product of the deployment. The project is a smart grid pilot in the Power Distribution Sector. The funding programme for the project is under the RAPDRP, Part-C scheme.

Project background and implementation

The Project was awarded to M/s Fluentgrid Limited (formerly known as Phoenix IT Solutions) on 02.03.2015 at a cost of Rs.29.86 Crs inclusive of FMS and training charges of 1.47Crs and Medhaj Techno concept was engaged as the consultant for the pilot project. As suggested by Government of India, after exclusion of IHD (In Home Display) and cost of FMS and Training, final cost of Smart Grid Pilot Project is revised as Rs 20.92 Crores. KPI data submitted by the Utility. The Utility has achieved first milestone for payment and the corresponding claims of Rs 2.61 Crs have been forwarded to MoP. The project Functional Design Document of the functionalities was approved by APDCL and the Detailed Design Document of the functionalities was approved in 2016. M/s Ericsson has been engaged by M/s Fluentgrid for the Smart Metering part of the project. The Single Phase and Three Phase meters of M/s Sinhal Udyog make was tested and approved by APDCL.

Project Status (November 2017)

14000 smart meters has been installed. Installation of Control Centre hardware equipment is in progress. Integration of smart grid with RAPDRP systems being initiated with M/s TCS. LoA was issued to M/s Vodafone for providing MPLS backhaul. Draft regulations notified by AERC. DCU's have been deployed in Narengi Area. Project Completion Date: March 2018

Expected Project outcomes

The following are the outcomes and benefits of the APDCL smart grid pilot project.

- Increased available energy during peak time
- Revenue increase through Power Quality measurements and power factor penalty
- Reduction in AT&C Losses
- Reduction in interest payments due to deferred Capital Investment in sub-transmission networks
- Improvement of availability (reduction of Customer Minutes Lost)
- Improved management of power procurement options
- Unscheduled Interchange using Short Term Load Forecasts

12.2.2 CHAMUNDESHWARI ELECTRICITY SUPPLY COMPANY (CESC), MYSORE

Location: Additional City Area Division, Mysore, Karnataka
Functionalities: AMI, Outage Management System, Peak Load Management, Renewable Energy Integration

Brief description

The CESC, Mysore Smart grid pilot Project involves 21,824 consumers with a good mix of residential, commercial, industrial and agricultural consumers including 512 irrigation pump sets covering over 14 feeders and 473 distribution transformers and accounting for input energy of 151.89 MU. Additional functionality like Agriculture DSM with community portal, consumer portal to support DSM/DR, employee portal for knowledge sharing and benefit realization, KPI based MIS and data analytics for decision support are also proposed.

Project background and implementation

The Approved Project Cost for the project was Rs.32.59 Crs with the Government of India Support of Rs.16.30 Crs. The Letter of Intent was issued to M/s Enzen Global Solutions on 04.03.2014 at a cost of Rs.32.56 Crs excl. FMS of whom the First instalment of Rs.4.07 Crores has been released to the utility from MoP. Powergrid has been engaged as the consultant for the pilot project. The AMI part of the project is being executed by M/s Cyan Technologies, UK, an ISGF Member. The Three Phase meters being procured from L&T and Single Phase Meters from El Swedy Electrometers.

Project Status (November 2017)

19600 Single Phase meters, 548 three phase smart metrs, 453 DCUs, 318 DTMU, 5 FPIs and 130 HT modems installed. 16000 meters and 80 modems are communicating with Head End System. 500 RF pre-payment meters delivered. 494 installed and 300 of them commissioned. 200 RF Net meters delivered, 1 meter installed. 53 LT-CT meters installed.

Applications integration under progress. 5 RTUs / data loggers for SCADA installed in substations. Consumer awareness and survey programs started. Remote disconnect/connect started for defaulting customers.

Expected Project outcomes

The following are the outcomes and benefits of the CESC, Mysore smart grid pilot project.

- Reduction in AT&C losses
- Shifting of load in industrial and domestic consumer during peak hours
- Reduction in number of transformer failure
- Reduction in Meter Reading cost
- Reduction in unforeseen outages and also recovery time for unforeseen outages

12.2.3 ELECTRICITY DEPARTMENT, GOVERNMENT OF PUDUCHERRY (PED)

Location: Division 1 of Puducherry
Functionalities: AMI

Brief description

The Project proposes covering 87031 no. of consumers with dominant being domestic consumers (79%). The area has around 367 MU input energy consumption. The proposed project area is also covered under RAPDRP Scheme for IT implementation and system strengthening which is likely to be completed in 2013. The module of Automated Metering Infrastructure (AMI) for Residential Consumers and Industrial Consumers are proposed to be implemented to assist with consumer issues like event management & prioritizing, billing cycle review and revenue collection efficiency for Energy auditing and AT&C loss reduction. Common Meter Data Management Systems is proposed to be developed that shall take data from MDMS of Different meter manufacturer/solution provider and integrate the information for use with Time of Use and Net Metering tariffs.

Project background and implementation

The Approved Project Cost for the pilot was Rs.46.11 Crs with the Government of India Support of Rs.23.06 Crs. Powergrid has been engaged as the consultant for the pilot project. The pilot project is implemented for 34,000 consumers, which includes 1643 high end LT CT operated consumers and 110 Nos. of Distribution Transformer meters. The project has been awarded to M/s Dongfang, China on 3rd March 2016 but the contract would be formally signed after getting approval of the Regulatory Commission. The site survey work has being started and the Initial consumer survey and awareness has been completed. An Investment of 50% of the SG Pilot cost will be done by Dongfang China which will be repaid in 60 equal monthly instalments by the State Government after the successful commissioning of the project.

Project Status

Site survey has been completed and baseline data submitted to Ministry of Power. Civil and Electrical works at Control Centre building has been completed. Type test of meters has been completed successfully. DRS has been approved and FAT of meters at Dongfang Electric's China facility is completed. BIS Certification received for single phase and three phase smart meters. Control centre software and application documents are under review. First lot of meters is under shipment.

Expected Project Outcomes

The following are the outcomes and benefits of the PED, Puducherry smart grid pilot project.

- Reduction in Distribution Losses
- Reducing cost of billing
- Increasing revenue collection efficiency

12.2.4 UTTAR GUJRAT VIJ COMPANY LIMITED (UGVCL), GUJRAT

Location: Naroda of Sabarmati Circle, Gujrat
Functionalities: AMI, Outage Management System, Peak Load Management, Power Quality

Brief description

Project proposes covering 20,524 consumers in Naroda and 18,898 agricultural

Unmetered consumers in Deesa-II division and accounting for input energy of around 1700 MU (Naroda : 374.52 MU & Deesa : 1321.27 MU for 2010-11). The functionalities of Peak load management, Outage Management, Power Quality Management are proposed by implementing Automated Metering Infrastructure (AMI) for Industrial, Commercial and Residential Consumers. Some additional functionalities like Load forecasting and Asset Management are also proposed and functionalities of load forecasting, peak power management and outage management are also considered at utility level which will impact all consumers of utility (i.e. 27 lac consumers) indirectly. Renewable energy integration has also been proposed to be carried out at Patan Solar Park and few roof top installations at some of the universities. The funding scheme for the programme is RAPDRP, Part-C.

Project background and implementation

The Approved Project Cost for the project was Rs.82.70 Crs with the Government of India Support of Rs.41.35 Crs. Powergrid has been engaged as a consultant for this pilot project. A tender with Naroda of Sabarmati circle and Deesa-II of Palanpur circle was floated in the initial stages of the project but was subsequently scrapped because of some internal reasons. The project with revised scope was awarded to M/s Genus in March 2017.

Project Status (November 2017)

Detailed work order has been released and survey work hasbeen started by Genus Power. Single Line Diagram (SLD) for data center has been submitted for approval. Delivery schedule of smart meters: November 2017- 1000 Nos; December 2017- 5000 Nos, Jan 2018- 10,000 Nos and remaining in Febuary 2018. 50 meters installed for field performance testing. First installment of MoP share amounting Rs 2.89 Cr has been released to utility. Control Centre Hardware FAT schedule for 15 December 2017.

Expected Project Outcomes

The following are the outcomes and benefits of the UGVCL, Gujrat smart grid pilot project.

- Reduction in AT&C losses
- Savings in Peak Power Purchase cost by reduction of peak load
- Reduction in Transformer failure rate
- Reduction in number of outages
- Reduction in Meter Reading cost, Cost of payment collection etc.

12.2.5 PUNJAB STATE POWER COMPANY LIMITED (PSPCL), PUNJAB

Location: Tech-II Sub-division, SAS Nagar, Amritsar, Punjab
Functionalities: AMI, Peak Load Management

Brief description

The functionality of Outage Management (OM) is proposed to be implemented in the project area for 2,737 no. of consumers predominantly domestic consumers with an overall consumption of 112.8 Mus per annum. Unrestricted Peak demand is about 30 MW. The proposed project area is covered under RAPDRP Scheme for SCADA Implementation and GIS Mapping.

Project background and implementation

The Approved Project Cost for the project is Rs.10.11 Crs with a Government of India support of Rs.5.06 Crs. Powergrid has been engaged as the consultant for the pilot project. The Project was awarded to M/s Kalkitech on 31.03.2015 at a cost of Rs.8.17 Crs inclusive of training and the AMC charges of 1.32 Crs.

The project has been cancelled as the meters could not pass the type test.

12.2.6 UTTAR HARYANA BIJLI VITRAN NIGAM LIMITED (UHBVN), HARYANA

Location: Panipat City Subdivision, Haryana
Functionalities: AMI, Peak Load Management, SCADA, Outage Management System

Brief description

The pilot project covers 30,544 consumers and distribution system of 531 DTs. The area has around 131.8 MU input energy consumption. The proposed project area is covered under RAPDRP Scheme for IT implementation and system strengthening. The functionality of Peak load management is proposed by implementing Automated Metering Infrastructure (AMI) for Residential Consumers and Industrial Consumers.

Project background and implementation

This project is being implemented through a Japanese grant of Rs 93 Crores from NEDO, Japan. NEDO has appointed a consortium of Japanese companies lead by M/s Fuji Electric, an ISGF Member. The GIS survey data is taken from R-APDRP. The Tendering for a local control centre building by UHBVN is under progress in Panipat. The Training Centre and DR will be made operational at Panchkula by July 2016.

Project Status (November 2017)

Operation control room in Panipat is commissioned. 5100 Smart meters (RF-Mesh &TWACS) installed. Integration of smart meters with RAPDRP systems being taken up with M/s HCL Technologies. SCADA and OMS testing is completed. Project is expected to be completed by December 2017

Project Outcomes

The following are the outcomes and benefits of the UHBVN, Haryana smart grid pilot project.

- Reduced Distribution Losses
- Reduced Peak Load Consumption
- Reduced Cost of Billing

12.2.7 TELANGANA STATE SOUTHERN POWER DISTRIBUTION COMPANY LIMITED (TSSPDCL), TELANGANA

Location: Jeedimetla Industrial Area, Telangana
Functionalities: AMI, Peak Load Management, Outage Management System, Power Quality

Brief description

The Project proposes covering 11,904 consumers. The proposed project area is covered under RAPDRP Scheme; DAS, IT and SCADA shall be implemented. The functionalities of Peak load management, Power Quality and Outage Management are proposed by implementing Automated Metering Infrastructure (AMI) for Residential Consumers and Industrial Consumers.

Project background and implementation

The approved Project Cost is Rs.41.82 Crs with Government of India support: 20.91 Crs. The Consultant for this project is Central Power Research Institute (CPRI). The Letter of Intent was issued to M/s ECIL, Hyderabad on 28.10.2015 for a contract price of Rs.35.86 Crs. An agreement was concluded with M/s ECIL and Notice to Proceed with work was issued on 17-03-2016.

Project Status (November 2017)

Since this project has not made any significant progress, Ministry issued letter to ECIL, to assess the project and communicate the possibility of completing the project in entirely or partly by March'2018 or abandoning the entire Project. TSSPDCL, CPRI & NSGM visited ECIL on 13-10-2017 and the minutes of meeting was mailed to the Director (NPMU) for approval of extension of project up to March 2018.

Project Outcomes

The following are the outcomes and benefits of the TSSPDCL, Telangana smart grid pilot project.

- Reduced Distribution Losses
- Reduced Peak Load Consumption
- Reduced Cost of Billing

12.2.8 TRIPURA STATE ELECTRICITY CORPORATION LIMITED (TSECL), TRIPURA

Location: Electrical Division No.1 of Agartala town
Functionalities: AMI, Peak Load Management

Brief description

The pilot project covers 46,071 no. of consumers. The proposed project area is covered under RAPDRP Scheme for IT implementation and system strengthening. The functionality of Peak load management is proposed by implementing Automated Metering Infrastructure (AMI) for Residential Consumers and Industrial Consumers.

Project background and implementation

The approved Project Cost was Rs.63.43 Crs with Government of India support of Rs 31.72 Crs and the Consultant engaged for this pilot project is Powergrid. The Project was awarded to M/s Wipro on 22.09.2015 at a cost of Rs 80.08 Crs inclusive of training and maintenance charges of 16.98 Crs against the

MoP approved cost of Rs.63.43 Crs with utility bearing the additional cost. The First instalment of Rs 7.93 Crs was released to the Utility from MoP.

Project Status (November 2017)

Total 16000 meters are installed and are communicating with the server and balance 26000 meters will be supplied by the end of December 2017 and installation will be completed by February 2018. 97 DCUs have been installed and commissioned successfully. Control Centre (hardware and software) installed. Rooftop solar net metering and billing is being integrated with AMI system. MDM to billing system integration is in progress. Acceptance testing of applications under progress. Expected project completion: March 2018.

Project Outcomes

The following are the outcomes and benefits of the TSECL, Tripura smart grid pilot project.

Benefits

- Reduced Distribution Losses
- Reduced Peak load consumption
- Reduced cost of billing

12.2.9 HIMACHAL PRADESH STATE ELECTRICITY BOARD (HPSEB), HIMACHAL PRADESH

Location: Industrial town of Kalamb, Himachal Pradesh
Functionalities: AMI, Peak Load Management, Power Quality

Brief description

The pilot project covers 1251 consumers and having annual input energy of 533 MUs. The functionality of peak load management and outage management is proposed by implementing Automated Metering Infrastructure (AMI) for Industrial Consumers, Distribution Automation and Substation Automation and power quality management by deploying Power Quality meters at HT consumers.

Project background and implementation

The approved Project Cost is Rs.19.45 Crs with Government of India support of Rs.9.73 Crs at Kalamb Industrial area with 1,251 consumers. The Project was awarded to M/S Alstom T&D on 28.02.2015 at a total cost of Rs.24.99 Crs which was inclusive of a maintenance charges of Rs.6.42 Crs. The First instalment of Rs 2.43 Crores released to the utility from MoP.

Project Status (November 2017)

All Sectionaliser, RTU, FPI and DTMUS are installed and commissioned. 1065 Smart meters installed (885 single phase and 180 three phase). MPLS link established. Johron substation and Kalamb substation RTUs reporting on MPLS link. GSM/GPSR SIM Connectivity tested, one of each type of devices Autoreclouser, Sectionalizer and Distribution Transformer Monitoring Units reporting to Control Centre. Smart meters data stated receiving at control centre and automatic bill generation started with smart meter data. FAT has been completed and getting ready for System Availability Test (SAT). Project is expected to complete in December 2017.

Project Outcomes

The following are the outcomes and benefits of the HPSEB, Himachal Pradesh smart grid pilot project.

Benefits

- Shifting peak load
- Reduction in penalties
- Reduction in outages

12.2.10 WEST BENGAL STATE ELECTRICITY DISTRIBUTION COMPANY LIMITED (WBSEDCL), WEST BENGAL

Location: Siliguri town in Darjeeling district, West Bengal
Functionalities: AMI, Peak Load Management

Brief description

The pilot project proposes to take up 4 nos. of 11 KV feeders for implementation of Smart Grid covering 5275 consumers. The area has 42 MU input energy consumption. The utility has proposed the functionality of AT&C loss reduction and Peak Load Management using Automated Metering Infrastructure (AMI) for Residential and Industrial Consumers. The project is funded under the RAPDRP Part-C scheme.

Project background and implementation: The approved Project Cost is Rs.7.03 Crs with Government of India Support of Rs.3.52 Crs. The Consultant engaged for the project is Powergrid. The Project is awarded to M/s Chemtrols on 06.06.2015 at a cost of Rs.8.10 Crs inclusive of training and FMS charges of Rs.0.34 Crs. The MoP issued sanction order for release of Rs.87.87 Lakhs against MoP share.

Project Status (November 2017)

FAT for 1000 smart meters completed successfully and 50 meters sent for type test. 5300 single phase smart meters ready for dispatch. Make change of 3-phase whole current meter was approved by WBSEDCL which will be procured from IDMI. DRS for Smart Meters and

DCUs approved. All documents for hardware installation have been approved. CMS to deploy temporary data centre at Siliguri for testing purpose.

Project outcomes

The following are the outcomes and benefits of the WBSEDCL, West Bengal smart grid pilot project.

Benefits

- Reduced AT&C Losses
- Reduced Peak Load Consumption

12.3 CANCELLED PROJECTS

12.3.1 KSEB, KERALA

Approved Project Cost: Rs.27.58 Crs, GoI Support: Rs.13.79 Crs

Order for cancellation of the project has been issued on 22 April 2016 as the lowest bid received in successive tenders were much higher than the approved project cost.

12.3.2 JVVNL, RAJASTHAN

Approved Project Cost: Rs.33.38 Crs, GoI Support: 16.69 Crs

The project was dropped because the state regulator didn't allow for the ToD tariff to be implemented in the state.

12.3.3 CSPDCL, CHHATTISGARH

Approved Project Cost: Rs.5.55 Crs, GoI Support: Rs.2.78 Crs

Project has been cancelled as the lowest bid received in successive tenders were much higher than the approved project cost.

12.3.4 MSEDCL, MAHARASHTRA

Approved Project Cost: Rs.28.21 Crs, GoI Support: Rs.14.11 Crs

Project has been cancelled as the lowest bid received in successive tenders were much higher than the approved project cost.

12.4 SMART GRID PROJECTS UNDER NATIONAL SMART GRID MISSION

12.4.1 CHANDIGARH ELECTRICITY DEPARTMENT, CHANDIGARH

Location: Smart Grid Project at Sub Division 5 of Chandigarh (29,433 Consumers)
Functionalities: AMI, DT monitoring, S/S Automation, Rooftop Solar PV, IT infra
Approved Project Cost: Rs.28.58 Crs, GoI Support: Rs.8.6 Crs (@30%)

- REC Power Distribution Company Limited (RECPDCL) appointed as Project Management Agency on 30 Aug 2016
- Smart Grid Cell and SLPMU formed by CED
- RECPDCL issued tenders for AMI, DTMU and SCADA on 10 Mar 2017, and 5 bids received in June 2017
- RECPDCL to withdraw tenders floated in March 2017 due to high price bids. Fresh Tender to be floated

12.4.2 MAHARASHTRA STATE ELECTRICITY DISTRIBUTION COMPANY, MAHARASHTRA

Location: Amravati, MSEDCL, Maharashtra (1.48 Lakh Consumers)
Functionalities: AMI, OMS, DR
Approved Project Cost: Rs.90.05 Crs, GoI Support: Rs.27.02 Crs (@30%)

- Sanction letter to MSEDCL was issued on 22.04.2016
- Tender floated on 22.12.2016

12.4.3 MAHARASHTRA STATE ELECTRICITY DISTRIBUTION COMPANY, MAHARASHTRA

Location: Congress Nagar Division of Nagpur (1.25 Lakh Consumers).
Functionalities: AMI, SCADA, OMS, DR
Approved Project Cost: Rs.139.15 Crs, GoI Support: Rs.41.74 Crs (@30%).

- Project was approved by Empowered Committee of NSGM on 29 Mar 2016 for a cost of Rs.90.05 Crs against the estimated DPR cost of Rs.133.57 Crs. Sanction letter to MSEDCL issued on 22 Apr 2016
- Tender floated on 22 Dec 2016. Pre-bid meeting held on 03 Jan 2017.Corrigendum is issued
- Tripartite agreement signed between Maharashtra Government, MSEDCL and NSGM on 28-3-2017
- Technical bid opening reschedules for 4th December 2017

12.4.4 KANPUR ELECTRICITY SUPPLY COMPANY, KANPUR

Location: Kanpur City (5.39 Lakh Consumers)
Functionalities: AMI, PLM, DT Monitoring, DG
Approved Project Cost: Rs.319.57 Crs, GoI Support: Rs.95.87 Crs (@30%).

- Project was approved by Empowered Committee of NSGM on 27 Oct 2016 for a cost of Rs.319.57 Crs. Sanction letter to KESCO issued on 17 Nov 2016 with recommendations of Empowered Committee.
- Utility is expected to communicate decision regarding reallocation/ continuing of Smart Grid Project"

India Smart Grid Forum

MODULE 13

UJWAL DISCOM ASSURENCE YOJANA (UDAY) ELECTRICITY ACT 2003, ELECTRICITY (AMENDMENT) BILL 2014 AND UJWAL DISCOM ASSURENCE YOJANA (UDAY)

Abstract

The development of a dynamic regulatory environment is a pre-requisite to stimulate the market towards Smart Grids in India. Providing clear signals to different stakeholders such as utilities, investors and technology providers of the direction of the market and thus providing some certainty and confidence for the necessary investments. Through incentives and performance guarantees, consumers can be motivated to also take an active role and demonstrable cost benefits will convince regulators of the necessary investment requirements. This module covers electricity act starting from 1910 to the latest amendment bill. This module also covers UDAY scheme launched by Ministry of Power in 2015.

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13.1 ACTS IN INDIAN ELECTRICITY SECTOR

On the November 10, 1897, the first hydro power station in India, and reportedly in Asia too, was commissioned at Sidrapong near Darjeeling town. This can be regarded as the first power utility run on commercial basis for use of general public, heralding the electrical-energy-era in the Indian sub-continent, and ushering in a revolutionary change in the socio-cultural and economic life of Indian society.

13.1.1 INDIAN ELECTRICITY ACT 1910

This Act provided basic framework for electric supply industry in India. It was envisaged in this Act that the growth of the power sector in the country will be through the private sector. Hence, the Act mandated issuing of licenses, for supply of electricity in a specified area. The licenses were issued by the State Governments. The Act also provided for the legal framework for laying down of wires and carrying out other allied electrical works for erection and commissioning of the generation plants, transmission lines and distribution network. The Act defines the steps for relationship between licensee and consumer.

13.1.2 THE ELECTRICITY (SUPPLY) ACT 1948

The Electricity (Supply) Act 1948 was enacted after independence. Though the Indian Electricity Act 1910, envisaged that the power supply to Indian citizen will be provided by the private sector, it was noticed that licensees were interested in urban areas only (Mumbai, Calcutta, Surat, Ahmedabad etc.). Hence the Electricity (Supply) Act 1948, mandated creation of State Electricity Boards (SEB). Need was felt for the State to step in (through SEBs) to extend electrification (so far limited to cities) across the entire State (including Rural areas). The SEB's through the successive five year plans, undertook rapid growth expansion by utilizing plan funds. The Industrialization and Green Revolutions were possible due to the untiring efforts by SEBs.

However, due to inability of the SEB's to take the decision on tariff in a professional and independent manner, the retail tariff determination was done by the State Governments. Since there were no fixed tariff regulations, the cross subsidies had reached unsustainable level and almost all SEBs were facing serious financial crunch.

13.1.3 ELECTRICITY REGULATORY COMMISSIONS' (ERC) ACT 1998

Since majority of SEBs were in severe financial crunch and the cross subsidies had reached unsustainable levels, the Electricity Regulatory Commission's Act 1998 was enacted. The ERC Act 1998, had a pr ovision for setting up of Central / State Electricity Regulatory Commissions with powers to determine tariffs.

The basic aim of ERC Act 1998 was distancing of the Government from the tariff determination process. State like Orissa, undertook reforms through their own Reform Act and thus involved unbundling of the SEBs.

13.1.4 THE ELECTRICITY ACT (EA) 2003

The Electricity Act 2003 was notified on the 10th June 2003. The main Objectives of the Electricity Act 2003 are Competition, Protection of Consumers interests and Power for all Areas. After enactment of EA 2003, all earlier Acts in Electricity Sector were repealed (after one year), as EA 2003 is a consolidation of all essential provisions of Law in the Electricity Sector.

There are 185 Sections described in 18 Parts in the EA 2003. The first Amendment to the EA 2003 was issued as "The Electricity (Amendment) Act 2007, with effect from 15th June 2007.

The Electricity Act 2003 has the basic mandate of "Reforming the Electricity Sector in the country.

I. SALIENT FEATURES OF EA 2003

The major salient features of EA 2003 are:

- Creation of liberal framework for power development
- State to restructure the SEBs in Generation Company (Genco), Transmission Company (Transco) and Distribution Companies (Discoms)
- Need for creation of competitive environment, which facilitates Private sector investment, Renewable Energy generation and cogeneration
- Delicensing of generation Sector except for hydro
- Captive Generation freed from controls of the Government.
- Transmission is licensed activity: Private Players are allowed in Transmission
- Trading is not allowed for Transmission Licensees
- Transmission Licensees has to provide Non-discriminatory Open access for using the network.
- CERC to regulate Inter-State Transmission and SERCs to regulate Intra-State Transmission
- Distribution: Licensed activity: SERCs to regulate
- No license required for stand-alone generation and distribution in rural areas
- OA in Dist to be allowed in phases: mandatory to allow OA to >1 MW customers

- Multi-Year Tariff framework to be followed by Regulators
- Parallel Licensing to be allowed only where the incumbent is inefficient, inadequate or expensive
- Under EA 2003, no person can undertake trading in electricity (purchase of electricity for resale thereof) without obtaining a specific license from Regulatory Commission.
- ERC to specify technical requirement, capital adequacy requirement and creditworthiness for an electricity trader
- Trading margin: Inter-state trading to be fixed by CERC. For Intra-State trading: SERC to fix trading margin.

There is a clear demarcation of roles and responsibilities in EA 2003:

- Govt.: Policy making Function
- Independent Regulatory Commissions: Powers of framing Regulations
- Central Electricity Authority: expert body on technical matters

The Preamble of Electricity Act 2003 (36 of 2003)

An Act to consolidate the laws relating to generation, transmission, distribution and trading of electricity and generally for taking measures conducive to development of Electricity Industry, promoting competition therein, protecting interest of consumers and supply of electricity to all areas, rationalization of electricity tariff, ensuring transparent policies regarding subsidies, promotion of efficient and environmentally benign policies, constitution of Central Electricity Authority, Regulatory Commissions and establishment of Appellate Tribunal and matters connected therein or incidental therein.

II. VARIOUS AUTHORITIES UNDER E.A. 2003

- Regulatory Authorities:
    - Central Electricity Regulatory Commission (For regulating Central Sector Generators, Inter State Lines)
    - State Electricity Regulatory Commissions (for Intra- State Transmission and Distribution, Trading licenses)
    - Joint Commission (for UTs) / Appellate Tribunal for Electricity (Sections 76-79/86/109/111: Part-X)
- Authorities Governing operational aspects of Electricity System:
    - Central Electricity Authority : Advisory Functions (Section 73)
    - National Load Dispatch Centre/ Regional Load Dispatch Centers/ State Load Dispatch Centers : Ensuring Stability of Grid Operation (S26-32)
    - Central Transmission Utility (PGCIL) and State Transmission Utility (Govt. owned Transco): for Inter-State and Intra-State Trans Network (respectively) Planning and Development (S38/39)
- Monitoring Agencies: For investigation, monitoring and enforcement of the legal provisions: Assessing officer/ Chief Electrical Inspector/ Electrical Inspector (safety and Appellate Authority Theft matters under S135)

III. DEREGULATION AGENDA IN EA 2003: OPEN ACCESS, PARALLEL DISTRIBUTION SYSTEM

Open Access:

- The basic aim of Open Access is to usher Competition. In Open Access the Customer can pick and choose their supplier and any supplier can use the existing lines to reach any customer; on payment of wheeling charges, surcharge and any additional surcharge, wherever applicable. (Sec 42(2), (4)). Open access means enabling Sale/ purchase of energy between two parties utilizing the system of an (in-between) third party and not blocking it on any unreasonable grounds
- Discom Perspective: Due to OA, demand from Revenue intensive Industrial and Commercial consumers is reducing (Loss of built in Cross-subsidy in Retail tariff), leading to under recovery of revenue by a Discom.
- Charges to paid by Open access Consumer in addition to the Energy Charges:
    - Cross Subsidy Surcharge (CSS): To compensate partial revenue loss of existing DL, as Cross subsidy is built in retail tariff. Tariff Policy mandates that CSS should not be Onerous that it eliminates competition. CSS to have Revenue neutrality for DL. The Regulatory Commission decides the Cross Subsidy Surcharge, during tariff determination.
    - Additional surcharge: to meet out the fixed cost of such Distribution Licensees , arising out of its obligation to supply (LTPP Commitments of Stranded capacity of DL) (Section 42(4)), as due to Open Access Consumers the Utility Demand will reduce. Under such circumstances, the power tied up in Long Term Power Purchase (LTPP) agreements, may not be required and hence only Fixed charges of under LTPP stranded Generators will have to be compensated, by OA consumers.
    - Standby Support charges: In case consumer meets part of his demand through OA and if the supplier defaults to supply power (In case of failure by OA supplier) and the consumer is meeting all his requirement from DL, Energy settlement would be at Temporary tariff as permitted in NTP.
    - Scheduling and System Operation Charges: payable to SLDC

Parallel Distribution Licensee:

- The Appropriate Commission can grant Distribution Licences to more than one persons for Distribution through their own networks in the same area (6thproviso S14)
- Section 62(1) proviso 1(d): “In case of distribution of electricity in the same area by two or more Distribution Licensees (DL), the SERC may, for the purpose of promoting competition, among DLs, fix only maximum ceiling of tariff for retail sale of electricity”.

Difficulties in Parallel Distribution licensing

- The new Distribution Licensees will have to lay their own Distribution Network, (Wires) which will need for High capital expenditure for Dist. Infrastructure
- For laying new Distribution network within the same licensee area, Right of Way (ROW) may be difficult and uneconomical, especially in congested Municipal Corporation cities. Moreover, High Road Reinstatement Charges (RI Charges) levied by Municipal Corporations further pushes up the CAPEX and finally the retail tariff of the Parallel Licensee.

- If new Licensee lays parallel Under Ground cables or Over Head lines, then utilization of each Distribution network would be less and existing Distribution assets may get stranded. Distribution Licensees would have no means to recover these costs.
- Hence there is a need for Wire and Supply Separation, so that there will not be any necessity to lay additional parallel lines and all licensees can share the existing Distribution infra structure.

IV. PROVISIONS FOR THEFT AND PILFERAGES

Section 126: UNTHORISED USE OF ELECTRICITY:

- "Unauthorized Use': usage of electricity by means not authorized by concerned Licensee" may be through a Sub-Meter or through a tampered meter; for the purpose other than, for which usage of electricity was authorized (Residential consumer à using it for Commercial or Industrial purpose) or for premises or area other than those; for which supply of electricity was authorized.
- If on inspection, it is found that Equipment, gadgets, machines, devices or Records maintained by any person shows that the person is indulging in Unauthorized use of electricity, the Assessing Officer (Authorized Utility Officer), shall raise a provisional bill, after assessing to the best of his judgment, the Electricity Charges payable by such person.
- The basic purpose of Sec 126 is to achieve and ensure stoppage of unauthorized use of electricity and to ensure prevention of revenue Loss of the Utility.
- The Consumer has seven days for raising objections before Assessing Officer or deposit assessed amount with Distribution Licensee. Assessing Officer has to give an opportunity of Hearing the Consumer's say. The final order shall be passed, within 30 days from the date of service of provisional assessment.
- After hearing, if the Assessing Officer comes to conclusion that unauthorized use of Electricity has taken place, he shall assess charges, at the rate, twice the Consumer tariff for entire period of unauthorized use or If period of such unauthorized use cannot be ascertained, assessment shall be for a period of 12 months; immediately preceding date of inspection.

SEC 127: APPEAL TO THE APPELLATE AUTHORITY:

An appeal (within 30 days) against an order under Sec 126 shall lie to the Electrical Inspector (prescribed Authority). The Appeal shall only be entertained, after half of the assessed amount is first deposited by the consumer; with the Distribution Licensee. After hearing, Appellate Authority shall pass an appropriate order.

If No payment is made within 30 days of the Bill for unauthorized use; thereafter the Appellant shall be liable to also pay interest @ 16 % per year, compounded; every 6 months. The Order of the Appellate Authority shall be a final and no Civil Court shall entertain any suit or proceedings in respect of any matter assessed, under Sec 126 or Sec 127. (Sec 145)

SEC 135: THEFT OF ELECTRICITY (AFTER AMENDMENT ON 15TH JUNE 2007)

On detection of theft, supply of electricity may be immediately disconnected by the authorized Utility officer. Such officer shall lodge a complaint in writing of the theft, in a Police Station having jurisdiction, within 24 hours, of such disconnection.

If the person pays the assessed amount, the licensee shall restore the supply within 48 hours of such deposit or payment. In the event of a second or subsequent conviction, for such abstraction/consumption or use, of a load exceeding 10 KW; such a person shall be debarred from getting any electric supply for a period which shall not be less than 3 months but may extend up to 2 years. He shall also be debarred from getting supply for that period from any other source or Generating station.

No commonality between Sec 126/ Sec 127 and Sec 135 of the EA 2003

Sec 126 and 127 deal with orders of assessment for unauthorized use by the consumer (Use for different Purpose or unauthorized extension). Sec 126 primarily deals with an action and remedy under Civil Law.

Sec 135, deals with offences and penalties for theft of electricity, with offences of theft of electricity, which squarely falls within the dimension of Criminal Jurisprudence where Mens-Rea (intent to engage in a Criminal Activity) is one of the relevant factors

V. CONSUMER GRIEVANCE REDRESSAL

Sec 42: Duties of Distribution Licensee: Consumer Grievance Redressal Forum (CGRF) and Electricity Ombudsman (EO):

- Sec 42(5): Every Distribution Licensee shall establish CGRF: Forum for redressal of grievances of consumers
- Sec 42 (6): Any consumer, who is aggrieved by non-redressal of his grievances by CGRF, may make a representation for redressal of his grievance to EO appointed or by SERC.
- The decision on Consumer Grievance by the Electricity Ombudsman is treated as final and there is no appeal provided for EO's Order in the SERC. However, the consumers can approach the SERC for non-compliance of CGRF/EO's directives by the Distribution Licensees and request the Commission for an appropriate action under Section 142, 146,149 of the Electricity Act 2003.
- Sec 142: Punishment for non-compliance of directions: Any person who has contravened any of the provisions of this Act or the rules or Regulations made there-under, or any direction issued by the Commission, the Commission may, direct that such person shall pay, by way of penalty, which shall not exceed one Lakh Rupees for each contravention.
- Almost all Distribution Utilities have established the Consumer Grievance Redressal Forums and the SERCs have appointed the Electricity Ombudsmen.

13.2 NECESSITY FOR AMENDING THE ELECTRICITY ACT 2003:

13.2.1 DRAFT ELECTRICITY (AMENDMENT) BILL 2013

The Electricity Act, 2003 was enacted to:

- Consolidate laws relating to Generation/ Transmission /Distribution / Trading and use of electricity
- Taking measures conducive to development of electricity Industry and Promotion of competition therein
- Protecting interest of consumers/Utility and supply of Electricity to all areas,

- Rationalization of Electricity tariff
- Ensuring transparent policies, regarding subsidies
- Promotion of efficient and environmentally benign policies
- Better Consumer Services: CGRF/EO for Consumer Grievance Redressal

However, not much of success was obtained in:

- Promotion of competition in Distribution; as Parallel Licensees could not be developed (main issue: development of their own Network)
- Rationalization of Electricity tariff: Cross subsidy in retail tariff has not come down (due to high initial skewing)
- Open Access (Choice to Consumers): Cross Subsidy Surcharge for Open Access Consumers, which has been introduced to compensate for Discom's losses is substantially high.

Hence, the Electricity (Amendment) Bill 2013 was formulated and presented to the Parliament on 19th Dec 2014. The Review and Amendment in Electricity Act 2003 sought for:

- Market Development and bringing in Competition in Sector
- Carriage and Content Separation (Wire and Supply Separation)
- Increasing Efficiency in Distribution system, by giving choice to consumers
- Promotion of Renewable Energy
- Better maintenance of Grid Security
- Rationalization of retail tariff
- Improving the function of Electricity Regulatory Commissions

13.2.2 MAJOR CHANGES/MODIFICATIONS ENVISAGED ON DRAFT ELECTRICITY (AMENDMENT) BILL 2013

The following modifications in the Electricity Act 2003 have been envisaged in Electricity (Amendment) Bill 2003:

- Separation of Carriage (Distribution Wire Network) and Content (Supply of Electricity): Separate licenses for Network and supply business to be issued by SERC.
- Each area of Distribution will have one Distribution Licensee (DL) responsible for Wires and metering and multiple Supply Licensees (SL) for supply and billing. At least one Supply Licensee will be Govt. owned Company.
- SERC to set category wise Ceiling tariff for Supply Licensees (SL). The SL is free to sale power at lower rates: however, if SL incurs any losses due to selling of power at lesser rates, these losses cannot be recovered from other consumers of the Supply Licensee by rasing their tariff
- Choice of Open Access for 1 MW (+) consumers, making them "Deemed OA consumers". SERC to determine Wheeling Charges and Cross Subsidy Surcharge (CSS) for OA consumers
- New Renewable Energy (RE) Policy for dynamic growth of the RE Sector and National policy for harnessing Solar Power to be formulated by Govt. of India (Already formulated)

- No Cross Subsidy Surcharge (CSS) for Open Access based on Renewable Energy Sources
- Section 127: Any person aggrieved by the Final Order made under Section 126 (for unauthorized use of Electricity) by the Utility's Assessing Officer, can prefer an Appeal to Electricity Ombudsman, who shall be Appellate Authority (Presently Electrical Inspector is the Appellate Authority)
- Indian Railways, Delhi Metro Rail Corporation, DVC, SEZs or such other transport entities as deemed Licensees
- Smart meters to be provided for measurement of consumption and metering of electricity for proper Energy Accounting from Generation to consumer end
- "Ancillary Services: Services necessary to support Power System or Grid Operation for maintaining Power Quality, Reliability and Security
- Commission to promote Smart Grid, Net Metering, Ancillary Services

Bill proposes to modify/amend 62 sections out of 185 Sections under EA 2003 (Amendment: 43, Substitution: 11, Insertions: 6, Omission: 1, New: 1)

13.2.3 REPORT SUBMITTED BY "STANDING COMMITTEE ON ENERGY" MAY 2015

The Electricity (Amendment) Bill, 2014 was referred to the "Standing Committee on Energy" for examination on 22nd Dec 2014. The Committee had discussions with various stakeholders all over the country. The Electricity (Amendment) Bill, 2014, Fourth Report was prepared by the Standing Committee on Energy and was presented to the Lok Sabha and also laid in the Rajja Sabha on 7th May 2015.

The Committee in the Fourth Report indicated that it is an imperative need that the 3rd generation reforms in Energy sector are initiated with concentration on:

- Separation of COM losses i.e. theft/ leakages: all stakeholders including State Govts, GOI, and Regulators have to take serious note of high Commercial losses
- More transparency and accountability in Regulatory system is needed. There is a need for evaluation of Performance of Regulatory system
- The Separation of Carriage and Content is an important provision of the Amendment Bill and this provision needs carried out in phases, (considering the amount of modifications to be carried out in existing system). Choice for customers to select the Electricity supplier should be provided, in phases.
- The Progress of Energy Efficiency Programs and Clean and Green Power needs to be accelerated.
- We need to formulate Healthy Tariff Policy, keeping view the interest of all stakeholders.
- It is important that while moving forward towards improvement or reforms, there is a need to include flexibility clauses in the Legislation, so that the transition can be smooth.
- As electricity is a concurrent subject, views and suggestions of the States need be given equal weightage and consideration

Since the Report has been submitted by the "Standing Committee of Energy", the Bill is now pending for approval.

13.3 ISSUES INVOLVED IN CARRIAGE AND CONTENT SEPARATION IN ELECTRICITY SECTOR

The separation of the Carriage (Distribution Network) and the Content (Electricity Supply) is an Important Provision included in Amendment Bill to usher competition and private sector participation in Distribution wing. This means that Distribution network Utility will be separated from the work of supply of electricity. Hitherto, this is being performed by single entity (i.e., majorly by State Discoms).

The Bill proposes multiple Supply Licensees for supply business along with the mandatory provisions of one Govt. Supply company.

However, the activity of development and maintenance of Distribution Network will remain with the State Government owned Distribution Company. The main Intent is to segregate the entire network business from the supply business.

This will help in clearly identifying the Technical and Commercial losses. Hitherto Technical losses are usually accounted to network business while commercial losses to supply business.

The Distribution Licensee will be responsible for wire Business i.e. Metering, Balancing and Settlement. Hence, there will be a need of elaborate, accurate, reliable metering infra structure.

The Transfer Scheme to be carried out by the State Govt (for dividing the existing Discom into a Distribution Company, in charge of Distribution Network and a Govt. Owned Supply Company) is a time consuming process.

The Universal Supply Obligation (USO) will be the responsibility of incumbent Supply Licensee and subsequent Supply Licensees will have obligation to supply progressively based on Load factor, prescribed by GOI. The compulsion of USO only by incumbent Supply Licensee will be result the Govt Supply Licensee, as the default supplier for Agricultural and subsidized LT Consumers. (This issue needs further analysis before the decision is taken).

As requested by various stakeholders, the choice for selecting the area should not be left entirely to the private Supply Licensees. Instead, areas in which subsequent Supply Licenses are to be allowed should be progressively notified, in consultation with all concerned stakeholders.

This Concept would need lot of clarity before SERCs draft enabling procedures and Regulations to facilitate the same. There is a need to frame broad and flexible guidelines, giving States due scope to align these guidelines as per the conditions in their States.

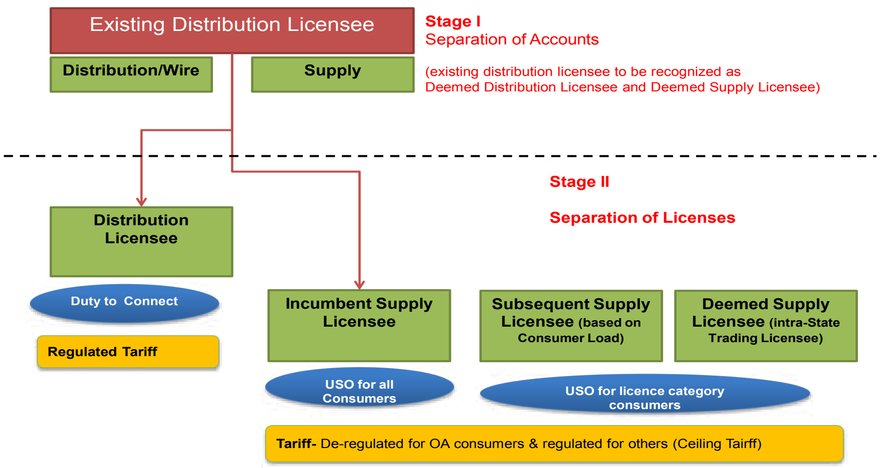

Figure 13-1: Separation of Wire and Supply: Way Forward

The first step towards Wire and Supply Separation is Separation of Accounts. Every Distribution Licensee will have to maintain separate Accounts for wires business and supply business and make separate application for determination of tariff for Distribution Wire business and Retail supply business.

The Annual Revenue Requirement (ARR) for Wire Business includes Return On Equity, Interest on Loans, Depreciation, OandM Expenses, Interest on Working Capital etc. (for the assets pertaining to Wire (distribution) Business)

The ARR for Supply Business includes all the above items for Supply Business (for the assets pertaining to Supply business), Power Purchase Expenses and Transmission Charges.

Incidentally, MERC in its MYT Regulations have mandated all Distribution Licensees to separate the Accounts for Wire and Supply business and also directed the licensees to separately submit ARR for Wire and Supply business. The Wheeling Charges are being computed for LT and HT consumers separately, for all Distribution Licensees in Maharashtra.

13.3.1 CASE STUDY ON CARRIAGE AND CONTENT SEPARATION IN GREAT BRITAIN

The Electricity Act 1989, laid the legislative foundations for the restructuring and privatization of the electricity industry in Great Britain. The Act made provision for a change in ownership from the State to private investors, the introduction of competitive markets, restructuring and a system of independent Regulations.

The area Boards were replaced with twelve Regional Electricity Companies (RECs). The local Distribution systems were transferred to the RECs and each REC was obliged to supply, on request all reasonable demands for electricity in its authorized area.

It established the electricity pool as the wholesale market mechanism through which electricity was traded in England and Wales.

While the key reform in the privatization of the electricity industry was the breaking of vertical linkages to allow the introduction of competition into some parts of the industry, some vertical integration remained.

The RECs were established as integrated distributors and suppliers and were also allowed limited involvement in generation of up to 15% of their sales volume.From 1990 to 1995, privatization of the entities took place by public floatation.

The supply market was opened up to competition in three phases, culminating in May 1999, when all consumers became eligible to choose their suppliers, as follows:

- From April 1990, customers with peak loads of more than 1 MW (about 45% of the non-domestic market) were able to choose their supplier;
- From 1 April 1994, customers with peak loads of more than 100 kW were able to choose their supplier;
- Between September 1998 and May 1999, the remaining part of the electricity market (that is, below the 100 kW peak load) was opened up to competition.

Since the opening up of the industrial and commercial market (that is, the above 100 kW market) to competition, there has been a substantial development in competitive activity.

The process started in 1990-91, when about 43% of above 1MW customers changed their suppers and by 1999-2000, 80% of above 1 MW Customers, 67% of 100KW-1MW Customers and 38% of <100KW Customers had shifted from the original supplier to the new suppliers.

It is very important to note that even though there was an initial increase in the numbers of licensed electricity suppliers operating in the electricity supply market at the outset of privatization, the recent increase in merger and acquisition activity suggests a trend toward consolidation of the electricity supply market.

There are now only seven supplier groups created from the former PESs (Public Electricity Suppliers) through takeovers and mergers, compared to 14 in the initial stage.

The Electricity Association (2002) point to falling prices and relentless competition as spurring on companies to seek opportunities for consolidation to become more competitive. There has also been a trend towards integration of generation and supply in recent years.

13.4 OTHER MODIFICATIONS SUGGESTED IN DRAFT BILL

13.4.1 SPINNING RESERVE AND RENEWABLE GENERATION OBLIGATION (RGO):

Section 7 of Draft Amendment Bill proposes that every GENCO to build and maintain Spinning reserve (Back up capacity of Gen, which shall be made available on directions of System operators, within specified time limit).

Renewable Generation Obligation (RGO): GENCO to establish Renewable Energy Generation capacity up to 5% of Thermal power installed capacity. It is mandatory 5% Installed Capacity of all new Thermal Generation. Old Thermal plants will be allowed to set up Renewable capacity, but only with concurrence of Power Procurers.

The Amendment envisages Sec 142 penalties for non-compliance of Renewable Power Obligation / Renewable Generation Obligation

13.4.2 PROVISIONS RELATED TO OPEN ACCESS:

Sec 49: All 1MW (+) consumers will be "Deemed OA Consumers" They will have a choice to select their supplier.

Implications: Due to shifting of High Revenue consumers from incumbent Supply Licensee to other generation sources on OA, there will be a financial burden on incumbent Licensee. Revenue from Cross Subsidy Surcharge (CSS) may not compensate for the loss for Incumbent Supply Licensee, as CSS is proposed to be determined for the area and not Supply Licensee wise.

13.4.3 PROVISIONS RELATING TO REGULATORY COMMISSIONS AND APPELLATE TRIBUNAL FOR ELECTRICITY

Section 64 (3): Tariff Orders to be issued within 90 days from Receipt of application (Existing Provision 120 days)

Section 92: additional Clause: Other Orders from Commission, to be issued within 120 days and for delay, reasons to be recorded.

The Committee, recommended that Electricity Regulatory Commissions (ERC) should be mandated in such a way that they act in a transparent manner for the purpose of implementing the various provisions of the Electricity Act and they should be made accountable for the functions, which they are assigned to do.

The Amendment seeks to make specific provisions for institutionalizing performance review of Regulators through a Committee constituted by GOI to review the performance of ERC as and when required.

13.4.4 TARIFF DETERMINATION: PROVISIONS OF TARIFF POLICY AMENDMENTS, 2016 (ISSUED ON 20TH JAN. 2016)

The Govt of India amended the Tariff Policy for Electricity on 20 January, 2016, which is focussed on Renewable Energy and sourcing of power through competitive bidding. The amendments also aimed at achieving the objectives of Ujawal Discom Assurance Yojana (UDAY) scheme.

The Salient features of the Tariff Policy Amendments, 2016 are:

- The Policy envisages 24*7 power supply to all consumers by 2022. State Governments and Regulators will devise a power supply trajectory to achieve this.
- The policy allows production of power from coal washery rejects {these are generated during coal washing} to provide affordable power to people living near the coal mines.
- Procurement of power from waste-to-energy plants has been made compulsory. This will help the Swachh Bharat Mission
- To increase efficiency through optimal utilisation of land and other resources, power plants will be allowed to increase power production on the same project site to the extent of 100% capacity. This will remove the hassles of land acquisition, forest and environment clearance, etc. This will also promote private investment.
- To promote Renewable Energy, it is proposed to increase solar Renewable Power Obligation (RPO) to 8% by 2022. Currently, the solar RPO is below 1% in most states.(RPO is an obligation imposed by law on Obligated entities (Distribution Licensees, Open access Consumers, Captive Generation) to either buy electricity generated by specified ‘green’ sources, or buy, in lieu of that, ‘Renewable Energy Certificates (RECs)’ from the market.)
- Renewable Generation Obligation (RGO) is introduced for new coal/lignite based thermal plants that will need to establish or procure a five percentage of Renewable Energy to meet their RPO. The modalities of both the RPO and RGO will be determined by the State Electricity Regulators.
- Inter-State transmission charges and losses for Renewable Power (wind/solar) have been exempted. This will encourage inter-state power transmission but the exemption is applicable only to wind and solar power, and not for other renewables like small hydro and biomass.
- For the growth of hydropower generation capacity, hydro power projects will be awarded under cost-plus basis and they are exempted from competitive bidding till 2022. A cost-plus model promises assured returns over the investment made. For existing hydro power projects, the power purchase agreement will extended by 15 years, beyond the existing 35 years.
- Power plants are allowed to sell the surplus power generated in spot market through power exchanges. This is applicable when State Electricity Distribution utilities are not buying the contracted capacity as per the power purchase agreements. This would improve the PLFs of generating station which have to reduce the capacity when states don’t buy the contracted power.

- CERC will decide tariff for composite schemes where more than 10% power is sold outside State. This will give clarity on tariff setting Authority for multi-State sales.
- To ensure faster completion at lower cost, transmission projects will be developed through Competitive Bidding process. This will allow greater flow of private capital into the lagging transmission sector.
- The policy removed market uncertainty by allowing pass through for impact of any change in domestic duties, levies, cess and taxes in Competitive Bid project
- Smart meters are to be installed for consumers consuming 500 units by 2017 and 200 units by 2019.

The Govt has made 30 amendments in the existing tariff policy. The policy aims in promotion of renewable generation sources and creation of more competition, efficiency in operations and improvement in quality of power supply.

As per the new Policy, CERC and SERCs shall necessarily be guided by the tariff policy in discharging their functions including framing the regulations under section 61 of the Electricity Act 2003.

Overall, the new tariff policy 2016, would have a great impact on Renewable Energy sector and also ensure provision of electricity to all consumers at reasonable and competitive rates and to attract more investors.

13.5 UJWAL DISCOM ASSURANCE YOJANA: UDAY SCHEME, 2015

13.5.1 NEED FOR UDAY SCHEME: OUTCOME OF EARLIER FINANCIAL RESTRUCTURING SCHEMES. WHY UDAY IS NEEDED NOW?

Ujwal DISCOM Assurance Yojana (UDAY) is the financial turnaround and revival package for the electricity distribution companies (DISCOMs) initiated by the Government of India, with the intent to find a permanent solution to the ever-increasing financial loss in Distribution Sector.

The scheme comprises four initiatives

- Improving operational efficiencies of Discoms,
- Reduction of cost of power,
- Reduction in interest cost of Discoms and
- Enforcing financial discipline on Discoms through alignment with State finances.

UDAY Scheme allows the State Govt, which own the Discoms, to take over 75% of Discom's debt as of September 30, 2015, and pay back lenders by selling bonds. Discoms are expected to issue bonds for the remaining 25% of their debt.

Thus, Power sector distribution companies are being bailed out by the Govt for the third time in 13 years. The earlier two bailouts have failed. The failure of the previous two bailout packages was more on account of political reasons than operational inefficiencies of the Discoms.

The losses of various distribution companies (Discoms) are amounting to Rs 3.8 Lakh Crore and the Reserve Bank of India pointing out in its Financial Stability Report of June 2015 those Rs 53,000/- Crore exposures of banks to seven SEBs had a "very high probability" of turning into non-performing assets by the quarter ending September.

The State Govt are being asked to take over 75% of the debt of the Discoms over two years: 50% in 2015-16 and 25% in 2016-17.

Collectively Discoms owe banks Rs 5.5 Lakh crore. This is a sum equivalent to two-and-a-half times the defense budget; roughly six times the amount that will be spent this financial year on building roads; and enough to wipe out India's fiscal deficit. Rajasthan alone having a debt of Rs 85,000 crore, followed by Tamil Nadu at Rs 70,000 crore and UP at Rs 32,000 crore.

The UDAY scheme identifies certain steps to be taken by Discoms within specified timelines to cut TandD and ATandC losses and improve operational and functioning efficiency. Some steps, for example, quarterly tariff revisions (due to fuel cost adjustments), will require political will on the part of the State to implement, as tariff hikes have typically assumed political hues. Other steps, for example, checking power theft, are in the nature of information, education and communication campaigns.

The UDAY scheme also rightly identifies reduction of the cost of power as a measure to achieve operational and financial efficiency of Discoms, though the scheme focuses more on improving domestic coal supply and rationalizing coal prices by Coal India Limited ("CIL)". Reducing the cost of power" is a constant refrain in all verticals of the power sector: be it Generation, Transmission or Distribution. Reducing the cost of power would therefore need a coordinated effort of all parties involved in the power sector including the Regulators.

The focus on improving coal supply and rationalizing coal prices is important as coal is the primary fuel for electricity generation in India. Also, the cost of washing or scrubbing domestic coal has to be assessed against cost benefits arising from consequent reduction in coal usage due to increases in calorific value of washed coal.

On the whole, the UDAY scheme goes a step beyond previous restructuring schemes for Discoms, and its success will, to a large extent, depend on the support it receives from the participating States in carrying out the spirit and intent of the scheme, as well as assumptions on which the scheme is premised, holding true. So far, the UDAY scheme has been well received with some fifteen States already signing up for it.

13.5.2 GOI'S OFFICE MEMORANDUM DATED 20TH NOV 2015 AND NEED FOR FINANCIAL RESTRUCTURING OF DISCOMS:

Features of UDAY scheme:

The Ujwal Discom Assurance Yojana (UDAY) was announced by the Govt of India in November 2015. UDAY Scheme is optional for the States to join. However fifteen states have joined the scheme. Jharkhand was the first state to join. Other states that have given their in-principle approval are: Gujarat, Chhattisgarh, Andhra Pradesh, Rajasthan, Punjab, Haryana, Jammu and Kashmir, Himachal Pradesh, Madhya Pradesh and Uttarakhand, Uttar Pradesh, Bihar, Odisha and Maharashtra.

UDAY is more comprehensive than any other SEB restructuring schemes planned till date. It talks about cost-side efficiency such as immediate reduction of interest service burden, reduction in fuel cost through coal swapping, time-bound loss reduction, etc. On the revenue side, it talks about a strict discipline of quarterly fuel cost adjustment, annual tariff increase, taking Regulators on board and finally including Discom losses in the FRBM limits for the States.

UDAY is a Discom revival plan rather than a simple debt restructuring package. It has all the three elements: clear up the legacy issues of past losses and debt/ provide a financial road map to bring tariffs in line with costs by FY19/ provide enough deterrents for the State Govt to not allow the State Discoms to become loss ridden post FY18: as losses start to impact their Fiscal Responsibility and Budget (FRBM) limits.

States shall take over 75% of DISCOM's debt as on 30 September 2015 over two years: 50% of DISCOM debt shall be taken over in 2015-16 and 25% in 2016-17. State DISCOMs will comply with the Renewable Power Obligation (RPO) outstanding since 1 April 2012, within a period to be decided in consultation with Ministry of Power.

States accepting UDAY and performing as per operational milestones will be given additional / priority funding through Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY),Integrated Power Development Scheme (IPDS), Power Sector Development Fund (PSDF) or other such schemes of Ministry of Power and Ministry of New and Renewable Energy. States not meeting operational milestones will be liable to forfeit their claim on IPDS and DDUGJY grants.

Such States shall also be supported with additional coal at notified prices and, in case of availability through higher capacity utilization, low cost power from NTPC and other Central Public Sector Undertakings (CPSUs).

The Ujwal DISCOM Assurance Yojana (UDAY) focuses on four major initiatives: improving operational efficiencies of Discoms; reduction of cost of power; reduction in interest cost of Discoms and enforcing financial discipline on Discoms through alignment with State finances.

Thus, UDAY a step in right direction which has potential to unclog the entire power chain (if implemented, as intended) as operational efficiency improvements to reduce the distribution losses from around 22% to 15% and eliminate the gap between average revenue and average cost of supply by FY19.

13.5.3 IMPROVING OPERATIONAL EFFICIENCY:

The basic objective of Ujwal Discom Assurance Yojana is financial turnaround of Discoms, with the main aim to improve Operational and Financial efficiency of the State Discoms. As envisaged in the UDAY Office Memorandum issued by the Govt of India, dated 20th Nov 2015, the participating States and utilities would follow the specified time for the following targeted activities for improving operational efficiencies:

Table 13-1

Sl. No.	Sectors
Compulsory feeder and Distribution Transformer (DT) Metering by States	Ability to track losses at Feeder level and DT Level for Corrective action
Consumer Indexing and GIS Mapping of losses	Identification of loss making area for corrective action
Upgrade, change Transformers and Meters	Reduce Technical Losses and minimize outages
Smart metering of all Consumers, consuming more than 200 Units	Smart Meters will be tamper proof and allow remote reading thus helping reduce theft, Implementation of DSM activities and Consumer engagement
DSM which includes Energy Efficient LED Bulbs, AG Pumps, Fans, Air-conditioners and efficient Industrial equipments through PAT (Perform, Achieve, Trade)	Reduce Peak Load and Energy Consumption, Annual estimated Savings of Rs. 40,000 Crores, for consumers from LED Lighting program alone

Sl. No.	Sectors
Quarterly Tariff Revision, particularly to offset Fuel Price Increase to be permitted.	Such Periodic Tariff Revision will be easier to implement and can be absorbed by consumers.
Comprehensive IEC Campaign to check power theft	Enhance Public participation to reduce theft
Assure increased Power supply to areas where ATandC losses improve	Engage Local participation to reduce theft

The above activities need to be completed with their target dates from 30th June 2016 to 31st Dec. 2019 (about 42 months for executing the Scheme). In addition the participating States need to develop State Specific Targeted Program for other activities to improve, Discom efficiency, as envisaged in "24x7 Power for All" Program.

The Outcome of Operational Improvements will be measured through following indicators:

- Reduction of ATandC loss to 15% in 2018-19 as per Loss Reduction Trajectory finalized by Ministry of Power (MOP) and States
- Reduction in Gap between Average Cost of Supply (ACOS) and Average Revenue Realized (ARR) to Zero by 2018-19 as finalized by MOP and States

13.5.4 REDUCTION OF COST OF GENERATION OF POWER:

As per Para 5.0 of the Office Memorandum, both Govt of India and States will take all steps (efforts) to reduce Cost of Power. The steps to be taken, for reduction of costs of Power Generation by GOI are:

- Increased Supply of Coal
- Coal Linkage rationalization
- Liberally allowing Coal Swaps from Inefficient Plants to efficient Plants and from Plants situated away from mines to pit-head to minimize cost of coal transportation
- Coal price rationalization based on Gross Calorific value (CGV)
- Correction in Coal Grade Slippage through reassessment of each mine.
- Coal India to supply 100% Washed coal, for G10 Grade and above by 1st Oct 2018
- Supply of 100% crushed coal from Coal India by 1st April 2016
- Faster completion of Transmission lines and adequate transmission by 31st March 2019, mostly through Competitive Bidding
- Allocation of Coal Linkage to States at notified price, based on which the State will go for Tariff Based Bidding

To reduce the cost of Power the States shall take following steps for:

- Prospective Power Purchase through transparent competitive Bidding by Discoms
- Improving Efficiency of State Generating Units, for which NTPC will handhold with the State Gencos.

13.5.5 STRUCTURE OF THE SCHEME FOR FINANCIAL TURN ROUND:

In UDAY Program it is envisaged that the States shall take over 75% of Discom's debt as on 30th Sept 2015, over two years 50%in 2015-16 and 25% in 2016-17. The Govt of India will not include the debt taken over by the States as per the above scheme in the calculation of fiscal deficit of respective States in the financial years 2015-16 and 2016-17.

States will issue non-SLR (non-Statutory Liquidity Ratio) bond including SDL (State Development Loan) bonds in the market or directly to the respective banks / Financial Institutions (FIs) holding the DISCOM debt to the appropriate extent

Non-SLR Portfolio

Government will subscribe to the rights issue through non-SLR bonds, which may get Statutory Liquidity Ratio (SLR) bond status later. SLR is the percentage of total deposits that banks have to invest in government securities. At present, the minimum SLR is 25 per cent.

In layman terms if bank invest in bonds issued by Govt then it is categorized as SLR investment and non-SLR investment for other bonds.

SDL Bonds

State Government borrowings are managed by the RBI. Fortnightly auctions of State Development Loans (SDL) are held by the RBI. SDL issues are primarily of ten year maturity though a few States issue four and seven year maturity loans. SDLs are priced off the Government bond yield curve.

DISCOM's debt which is not taken over by the State Govt; shall be converted by the Banks (Financial Institutes) into loans or bonds, with interest rate not more than the bank's base rate plus 0.1%.

Alternately, the debt, which is not taken over by the State Govt; may be fully or partly issued by the DISCOM as State Guaranteed DISCOM bonds at the prevailing market rates which shall be equal to or less than bank base rate plus 0.1%.

States shall take over the future losses of DISCOMs, in a graded manner. Henceforth the Banks/FIs shall not advance short term debt to Discoms to finance losses.

For Working Capital Banks/FIs shall lend to Discoms only up to 25% of the Discom's previous year's revenue or as per prudent norms.

Ministry of Power, Govt of India, will device a suitable review mechanism with representation from the Ministry of Finance (MoF) to ensure close monitoring of performance on monthly basis to prevent any slippage.

13.6 UDAY REFORM PROGRAM: STEPS TO BE FOLLOWED BY DISCOMS

Basically, UDAY (Ujwal DISCOM Assurance Yojana) aims at permanent resolution of DISCOM issues. The past debt (75%) will be taken over by the State. For the present, it enables the quarterly tariff increase/ Improving operational Efficiency and availability of Low cost power to Discom. This should result in budgetary discipline in Discom, making it financially more stable.

The main advantage of UDAY is the reduction in Interest cost. The quarterly revision of tariff (may be through Fuel and Other Cots adjustments) will mitigate the cost increase burden, which will be easy to absorb by the consumers.

13.6.1 NECESSITY OF POWER DISTRIBUTION SECTOR REFORMS, VARIOUS CENTRAL GOVT. SCHEMES

Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY): The main aim of the scheme is to electrify all unelectrified villages and also access of electricity to remaining 5 Crore unelectrified households.

- System strengthening Scheme under DDUGJY includes installation of Power transformers (33/11KV), Distribution transformers, new HT/LT Lines, Energy Meters for consumers (11 Million), Metering of Distribution transformers and 11KV feeders. Total Outlay approved for DDUGJY including Renewable Energy Component is Rs. 75,893 Crores.

Integrated Power Development Scheme (IPDS): It is an integrated scheme for urban areas covering Infrastructure upgrdation, IT implementation for better customer services, installation of Smart and tamper proof meters for residential consumers, The estimated savings through ATandC Loss Reduction is about Rs. 5000 CR. IPDS also includes solar installations (Rooftop solar panels). The total outlay for IPDS is Rs. 65,424 Crores.

13.6.2 ATANDC LOSS REDUCTION

Aggregate Technical and Commercial (ATandC) Loss is the clearest measure of overall efficiency of the distribution business as it measures Technical as well as Commercial losses. ATandC Loss provides a realistic picture of energy and revenue loss situation. The impact of ATandC Loss reduction is; lesser Burden on consumer due to efficiency improvement

- Billing Efficiency (BC) = Total units sold / Total Input
- Collection Efficiency (CE) = Revenue Collected/ Revenue Billed
- % ATandC Loss = (1-(BE X CE)) x 100
- ATandC Loss have two components: Technical Loss and Commercial Loss

Tech Loss is inevitable, and is due to flow of power in TandD Network.

Low voltage operation in Dist is a major reason of higher Tech losses due to inherent properties of the network. (Low Voltage à High Current à High Losses)

Commercial Loss is due to deficiencies in metering, Theft of Energy by tampering Energy Meter or hooking the Electrical wires/cables and misuse of category on realization of Revenue

- As per MoP data, the All India system Billing Efficiency for FY 2013-14 is 71% and Collection Efficiency is 97 % Hence, AI ATandC Losses for FY 2013-14 were computed as 32 %.

The Proposed Action Plan for improving Billing Efficiency and Collection Efficiency, as envisaged in UDAY Program, along with the target dates for completion of the activity, is as follows:

- Action Plan for Billing efficiency Improvement:
  - Feeder and Distribution Transfomer (DT) metering : For tracking losses at feeder and DT level and planning Distribution System Improvement for Loss Reduction à to be completed by June 2017
  - Consumer Indexing and GIS Mapping: For Identification of loss making areas and taking corrective action à to be completed by Sept 2018

- Upgrdation or changing Distribution Transformers, Energy meters etc. à To reduce technical losses and minimize outages à by Dec 2017
- Conducting Regular (Monthly/ Quarterly/ Yearly) Energy Accounting for the Circle/ Division/ Sub-division/ 11KV Feeders/ Distribution Transformers
- Smart metering of all consumers having consumption >200 Units/Month) consumers à Tamper proof meters and possibility of remote reading, so that theft can be controlled à Dec 2019

Action Plan for Collection efficiency Improvement:

- Awareness campaign to ensure that Honest consumers do not pay for dishonest consumers, who are stealing energy and or not paying electricity charges regularly à Conducting regular Theft detection drives Enhancing public participation to reduce Power theft à Awareness program up to Dec 2016
- Increasing the % of normal meter reading (Reading 100% Energy Meters and billing the consumers only on correct meter readings) and reducing % Average billed consumers (due to not reading the meters, Faulty Energy Meter status, Door Locked status etc.)
- Assuring increased power supply in areas where the ATandC losses have reduced: By encouraging Local participation for theft curtailment à March 2018

Table 13-2: AI AT&C Losses in FY 2013-14

State	Billing Efficiency	Collection Efficiency	% AT&C Losses
Goa	88%	101%	11%
Delhi	85%	101%	14%
Maharashtra	86%	100%	14%
Andhra Pradesh	89%	95%	15%
Gujrat	95%	99%	16%
Chattisghar	76%	102%	23%
MP	75%	96%	28%
J&K	49%	104%	49%
Zarkhand	66%	87%	42%
Bihar	56%	96%	46%
Manipur	73%	77%	44%
Arunachal Pradesh	41%	78%	68%
Sikkim	68%	42%	71%
All India	71%	97%	32%

13.6.3 TRAINING NEEDS FOR IMPLEMENTATION OF UDAY

Since UDAY is a time bound Program for financial turnaround of Discoms, achievements as envisaged in targets are necessary for the success of UDAY scheme. In order to reach the targets set by MOP for successful implantation of UDAY Program, within the specified time, there is a need to put in serious efforts, by all Officials, staff in Discoms.

UDAY envisages many technical schemes to be started and completed in time, in the field. The officials at corporate level need to monitor the targets of various activities in UDAY, scrupulously.

The Reforms as proposed in UDAY will be able to be achieved, if and only if the reform in the mindset of Electricity Utility Personnel is achieved.

Hence it is felt utmost necessary that the Utilities conduct extensive training Programs (for continuous improvement) to the Personnel in Utility (Technical/ Finance/ Administration staff and officers). The following two separate programs are suggested:

- Training program for Corporate Office Staff and Corporate level management Officials for monitoring the targets
- Training for Field staff for implementing various scheme within the time span indicated in UDAY Scheme

These Programs may include the information about technical advancement in the Power sector, along with various management techniques for fulfilment of the scheduled targets.

Innovative methods for Distribution Loss Reduction and improvement in Collection efficiency (which will lead to financial stability of the Utility) needs to be the central theme for the training Program along with the new construction practices and Information about technology advancements (developments) in Energy meters (and meter reading) and Distribution Transformers. The training needs to cover methods for better Energy Accounting and Energy audit.

Suggested UDAY Training Program for Middle level Management of Distribution Utility

The UDAY Training Program needs to cover following basic topics:

- Importance of UDAY: Necessity of Power Distribution sector Reforms. Why Financial Turn-round is essential?
- Results achieved from earlier schemes of financial restructuring for Discoms,
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India Smart Grid Forum

MODULE 14

SMART GRID REGULATIONS

Abstract

Smart Grid Regulations were issued by Forum of Regulators in September 2015. The objectives of these regulations are to enable integration of various smart grid technologies and measures to bring about economy, efficiency improvement in generation, transmission and distribution licensee operations, manage the transmission and distribution networks effectively, enhance network security, integrate renewable and clean energy into the grid and micro grids. This module covers all the aspects of these regulations.

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14 SMART GRID REGULATIONS

14.1 NEED FOR SMART GRID REGULATIONS IN INDIAN CONTEXT

Synchronous operation of an integrated Electricity Grid was the greatest engineering achievement of 20th Century. In this integrated Power Grid, there used to be limited nodes of generations (points of power injection) and millions of points of consumption (consumers connected on the grid).

However, in 21st Century, there has been a rapid development of distributed and renewable energy (RE) generation sources. In India about 50 GW, (17% of the total installed generation capacity) is from RE. Further, the National Mission on Electric Mobility has a target of 6-7 million Electric Vehicles by 2020. The National target for renewable energy is set at 175 GW to be achieved by 2022.

With such increasing number of intermittent energy sources and Electric Vehicles, the use of smart automation and IT systems in the power systems are imperative.

The preamble of Electricity Act 2003 explicitly mentions that it is "An Act for taking measures conducive to development of electricity industry, promoting competition therein, protecting the interests of consumers and promotion of efficient and environmentally benign policies". Further, as per Sec 61 of EA 2003 "Regulatory Commission shall be guided by the factors which would encourage competition, efficiency, economical use of resources, good performance and optimum investments".

The development of Smart Grid, as per EA 2003 is with reference to "Promotion of efficient and environmentally benign policies."

I. SMART GRID IN DRAFT ELECTRICITY (AMENDMENT) BILL 2014: NEW TERMINOLOGIES: CONCEPT AND DEFINITIONS

The term "Smart Grid" has been explicitly defined in the Draft Electricity (Amendment) Bill 2014 (Sec 2 61(A)) *as: Smart Grid is the Electricity Network that uses Information and Communication Technologies to gather information and act intelligently in automated fashion to improve the efficiency, reliability, economics and sustainability of generation, transmission and distribution of electricity, and such other information as may be specified by the authority".*

The Draft Electricity (Amendment) Bill 2014 seeks to promote provision of electricity through Smart Grid. In Section 55 of the Draft Bill, the Proviso has been included for smart meters for proper energy accounting from generation to consumption.

Further, under Section 79 "to regulate the Inter State Transmission System (ISTS), including promotion and development of Smart Grid, Ancillary Services and Decentralized Distributed Generation has been included as additional function of CERC."

In addition, under Section 177 i.e. "Powers of Authority to make Regulations" of the Draft Bill, the Central Electricity Authority (CEA) has been empowered to frame Regulations generally to carry out Provisions of this Act for the grid standards as per Section 34 and also measures for Smart Grid and Ancillary Services.

II. WHY SMART GRID REGULATIONS?

The development of Smart Grid is a capital intensive activity. The existing grid which is having unidirectional communication needs to be revamped for bi-directional communication with the insertion of some intelligent devices. Electricity distribution utilities (Discom) is a regulated entity. As CAPEX has an impact on retail tariff, all major capital investments by a Discom need to be approved by the respective Electricity Regulatory Commission (in certain ERCs for investment above Rs. 100 million).

Discoms normally like to recover their investments through tariff. Huge capital investment will result in higher tariff shocks. Hence, the Regulators need to find out a balance, so that the capital investment in Smart Grid does not have a severe impact of retail tariff. As the consumers get improved quality of supply due to Smart Grid, the proactive and flexible Smart Grid Regulations are needed. While framing the Smart Grid Regulations due considerations need to be given on the following issues:

- Smart Grid is an integrated system involving Discom, the Consumers, Prosumers (consumers, who also generate electricity through Distributed Renewable Energy sources); Aggregators (an interface between Discom and consumers for implementing Demand Response Schemes) and Energy Storage systems. Regulations need to bind all these elements for proper integrated functioning.
- New Technologies: Advanced Metering Infrastructure (AMI), Electric Vehicles and their Charging Stations, Cyber Security, Microgrids, Wide Area Measurement Systems (WAMS) need to be clearly defined in the Regulations.
- Smart Grid Regulations need to interface with existing and evolving standards for Smart Grid applications. Moreover, these Regulations should also take into considerations the existing Regulations particularly for the Energy Efficiency and Demand Side Management and Demand Response.
- Since the Smart Grid Technologies are new and evolving and as it is not proven for years, there is a risk in this investment. Normally, the Regulators are risk averse. Hence the Smart Grid Project investment report needs to be scrupulously checked, before "in principle investment approval".
- As for many items in smart grid projects, the investment needs to be done upfront and benefits are realized much later (e.g. communication backbone) or some benefits may not be quantified (improving quality of supply), the cost-benefit analysis of smart grid projects need to be looked at differently.

Thus, proactive Smart Grid Regulations, taking into consideration the above important issues are necessary. The Regulations need to provide for enabling framework for the development of Smart Grid Projects.

14.2 GLOBAL REVIEW OF REGULATORY PRACTICES IN APPROVAL OF SMART GRID PROJECTS BY REGULATORS

Since Smart Grid Projects are capital intensive, its Regulatory approval for capital investment, forms an important step in the project development. Smart grid technologies are still developing and hence many smart grid projects were taken up as pilot demonstration projects by various utilities in the world. In many cases, the funding has been provided centrally through some efficiency related initiatives or through funds available for Renewable Energy development (Green Energy funds).

While approving the investment for smart grid projects, the Regulators all over the world have basically given importance to the impact of investments on consumer tariffs, improvement in quality and reliability of consumer supply/services due to smart grid projects and cost benefit analysis, to ensure that alternative better ways of investments are not available to render the similar benefits.

In India, the Discoms submit their Capital Expenditure (CAPEX) plan along with the Annual Revenue Requirements (ARR) and tariff revision proposal to the Regulatory Commissions. In some States (e.g. Maharashtra) the Discom has to submit every CAPEX proposal (for investment more than Rs 100 million) in the form of Detailed Project Report (DPR) to the Commission for in principal approval for financial investment.

The investment on non-DPR (having CAPEX less than Rs. 100 million) is allowed up to 20% of the total CAPEX in the year. The Commission carries out prudency check and then issues in-principle approval for the CAPEX for individual DPRs for various schemes. During ARR and tariff determination process, the impact of only the approved capital investment is taken into consideration.

Impact of Capital Investment on Retail Tariff

Example:

Consider that capitalization of a CAPEX scheme in a year for a utility is Rs 1000 Crores. The debt equity ratio is 80:20. So, (Rs. 800 Crores: debt and Rs. 200 Crores equity).

Impact of capitalization on retail tariff is computed as:

- Interest rate on debt at 12% per year. Total Interest: Rs. 96 Crores
- The return on equity at 16% per year is Rs. 32 Crores
- Assume that salaries of staff / repairs and maintenance charges and administration and general expenditure for maintaining these assets is Rs. 30 Crores/ year
- Depreciation at 5% per year = Rs. 50 Crores
- Assume Tax (MAT) = Rs. 10 Crores
- Total impact on ARR : Rs. 218 Crores

If the Utility ARR is Rs. 10,000 Crores (without considering the impact of Rs 1000 Crores CAPEX) and Average Cost of Supply (ACS) is Rs. 5 per Unit. (I.e. in this example we have considered the annual sale of 20,000 MU)

The per unit impact of Rs. 1000 Crores CAPEX: Rs 218 Crores/20000 MU = Rs. 0.109 (i.e. ACS: Rs.5.109 per unit i.e. rise by 10.9 Ps/unit which is about 2.2 % tariff hike, in this example)

Note: this example only takes into consideration the cost side of the project. Due to accrual of benefits, the rise in sale of energy (due to overall efficiency improvements) have not been considered, which will reduce the final tariff impact.

As excessive capital investment results in exorbitant Tariff rise, to the consumers, prudency check for Capital Investment by Regulators is essential

14.2.1 STUDY OF SMART GRID SYSTEM INVESTMENTS IN US

US Department of Energy published a report "2014 Smart Grid System Report" in Augsut2014, which provides an update on the status of smart grid deployment nationwide, technological developments, and barriers that may affect the continued adoption of the technology.

U.S. electric grid is undergoing significant transformation. The application of digital technologies, policies encouraging the growth of renewable and distributed energy resources, and increasing involvement of electricity customers in both managing and producing energy is changing the scenario.

The electricity industry spent an estimated total $18 billion for Smart Grid technology deployed in the US during 2010- 2013. Smart grid investments under the ARRA (American Recovery and Reinvestment Act 2009) accounted for nearly half; approximately $8 billion, during the same time frame.

The rate of Smart Grid technology adoption varies across the US and depends largely on State policies, Regulatory incentives, and technology experience levels within utilities. It will take time to adequately assess and validate the costs and benefits of the technology for utilities, their customers, and society. The integration of these technologies and practices will require a faster-acting, more flexible grid and new business and Regulatory approaches.

In US, investment in Smart Grid Project is being carried out in four key technology application areas: Advanced Metering Interface (AMI), Customer-based Systems, Distribution, and Transmission.

About 46 million smart meters were installed in the US by Dec 2013. Cost benefit case study: Central Maine Power Company has deployed smart meters to its 625,000 customers and has reduced its meter operations costs by more than 80% with annualized savings of about $6.7 million: due to fewer service calls, resulting in about 1.4 million fewer annual vehicle miles traveled.

Oklahoma Gas and Electric (OG&E) decided to offer Critical Peak Pricing (CPP) rate to all its customers based on pilot results that reduced peak demand by at least 70 MW in one year. With a current goal of achieving 20% participation, OG&E hopes to reduce peak power requirements by 170 MW and thereby defer the construction of a peaking power plant planned for 2020.

More than half of the ARRA projects are deploying distribution automation technologies ARRA projects have invested about $2 billion as of March 2013 in distribution automation to deploy field devices, such as automated feeder switches and capacitors, and to integrate them with utility systems that manage data and control operations.

RRA projects include a total public-private investment of about $330 million that will increase U.S. Synchro phasor coverage from 166 networked Phasor Measurement Units (PMUs) in 2009 to more than 1,000 networked PMUs deployed by the 2015. As PMUs are deployed, transmission owners and reliability coordinators are working to develop suitable applications, build out high-speed data networks, improve data quality, and share synchrophasor data between transmission owners and operators across large regions.

Utilities and Regulators are considering new benefit streams for valuing the technology and making investment decisions:

Some utilities are now providing estimates of avoided customer costs of outages, rather than applying the traditional reliability indices (that merely provide the duration and frequency of outages); when submitting cost/benefit analysis of smart grid technology to their Regulators.

These value-of-service (VOS) estimates help Utilities and Regulators to understand the customer-related and societal benefits of applying automated feeder switching and other system upgrades for improving reliability. This valuation approach will allow utilities and Regulators to understand the true costs of power interruptions and help prioritize investments that lead to improved reliability and resilience.

In Arizona the net metering laws spurred rooftop solar development by providing needed support for solar owners, but resulted in lost revenues for its utilities. As the number of rooftop solar customers increased, the Arizona Public Service Company (a distribution utility) asserted that non-solar customers now had to bear a higher amount of the costs for maintaining the grid, by as much as $1,000 per installed solar system. To ease this cross-subsidization issue, the Arizona Corporation Commission ruled in November 2013; to institute a fixed charge of $0.70 per kW per month for new customer, who signs a contract with a solar installer, in addition to their usage rate.

The report indicates that "With greater levels of customer generation and energy efficiency, the traditional utility business model may be threatened by reduced revenues, increased costs, and lower profitability potential for utilities. Regulators may need to consider new rate structures; that determine how to best recover the costs of smart grid implementation"

Smart grid technologies are being deployed across the US at varying rates depending largely on decision-making at utility, State, and local levels. Basically the ARRA funding provided a strong incentive for Smart Grid deployment, and noticeable impacts are now being observed with respect to gains in reliability, efficiency, and consumer involvement.

In US for Smart Grid Technology investments, while computing the depreciation rate the life of equipment's is being considered as 10 years (instead of 20 years). The accelerated depreciation allows utilities to take larger tax deductions on investments.

14.2.2 STUDY OF REGULATORY APPROACHES ADOPTED FOR APPROVAL OF SMART GRID PROJECTS ACROSS EUROPEAN COUNTRIES

I. GREAT BRITAIN: NATIONAL REGULATORY AUTHORITY (OFGEM)

The fundamental structure of the price control mechanisms is designed to keep Tariff within limits, without giving severe shock to the customers due to Smart Grid investments. New RIIO (Regulation, Innovation, Incentive leading to Outputs) mechanism is being employed.

Up to 90% of the cost of certain Smart Grid projects can be funded from network tariffs. However, the network company still has to consider the balance between costs, benefits and risks before initiating a project.

II. ITALY: NATIONAL REGULATORY AUTHORITY (NRA)

For transmission operator, an incentive was set by Regulatory Order 87/10, which refers to an indicator Benefits/Costs, thereby promoting higher benefits at lower costs. For distribution operators, the legislative decree of 3 March 2011 introduces an economic incentive for modernizing distribution networks "by the smart grid concept". The basic priority is for Control and Regulation for management of Generating Units and Demand Side, Electric Vehicles' recharge systems. The NRA is mandated to define the characteristics for the solutions.

III. FINLAND: NATIONAL REGULATORY AUTHORITY

All network investments, inclusive of Smart Grid investments are accepted in network valuation (regulated asset base) by using Standard Unit Prices. The network operators have an incentive to make investments in the most cost-effective way, within the Standard Unit Prices.

IV. AUSTRIA NATIONAL REGULATORY AUTHORITY

Austria National Regulatory Authority follows Incentive based Regulation Module. There is a Total Expenditure (TOTEX) benchmarking. The individual and general productivity offsets guarantee cost-efficient solutions, because of the incentives.

14.2.3 IMPORTANT OBSERVATIONS FROM THE CASE STUDIES AND ISSUES FOR CONSIDERATION IN INDIAN ENVIRONMENT

The following important issues need to taken into consideration by all stakeholders in Indian environment, while developing Smart Grid Projects:

Regulators: since Smart Grid is at an early stage of development, Smart Grid investment needs to be incentivized, by approving higher levels of returns, depreciation and Administrative and General expenses for tariff determination purposes etc.

Utility: there is a necessity to bring out clear cost benefit analysis in the Smart Grid DPR. The cost of training to Employees and consumers also needs to be included in DPR. The Smart Grid being a developing field using digital technology, has a shorter life span of less than ten years compared to normal Grid equipment life of 20-30 years.

Cost Recovery for Utility Investments in Smart Grid can be:

- Through Socialization: including Smart Grid CAPEX in ARR, so that impact of tariff rise is shared by all consumers
- Through only the consumers who are benefitted: Pricing for new Services, Design of Surcharge

14.3 TARIFF DESIGN FOR SMART GRID CONSUMERS

Regulators all over the World have introduced tariff based incentives to customers who save Energy, when the Utility is facing problems, for avoiding purchase of High cost Power and also to use more energy, at off peak periods, when the system more generation is available (high frequency period)

14.3.1 NEED FOR DYNAMIC PRICING MECHANISM IN INDIAN CONTEXT

Indian Utilities' load curve experiences the morning and evening peak hours, with increased load compared to the Average Load. Utilities need to purchase High Cost power, during Peak hours and have excess availability during off peak. The load curve flattening can be obtained through the Dynamic Pricing Programs.

14.3.2 ENABLING FRAMEWORK FOR DYNAMIC TARIFF IN ELECTRICITY ACT, 2003

The Electricity Act 2003 also supports Dynamic Pricing, as per Section 62. (Determination of tariff) (Sub-section (3))

"The Appropriate Commission shall not, while determining the tariff under this Act, show undue preference to any consumer of electricity but may differentiate according to the consumer's load factor, power factor, voltage, total consumption of electricity during any specified period or the time at which the supply is required or the geographical position of any area, the nature of supply and the purpose for which the supply is required".

Similar enabling provisions are also included in the Tariff Policy (8.4) and National Electricity Plan (5.4.9)

14.3.3 TIME OF DAY (TOD) / TIME OF USE TARIFF (TOU)

In this method, the electricity tariff to consumers varies with the Time of the day (and also Day of the week). The tariff is higher during Peak Periods and lower during Off Peak periods. The TOD/TOU tariff is decided by the Regulators along with the ARR and is known to the consumers, at least a year before; hence TOD/TOU is practically not the Dynamic rate Option. It offers consumers the least potential reward at the lowest risk. TOD/TOU tariff is very easy to implement and incentivizes the consumers to shift their non-essential load from peak period to off peak period, for efficient resource allocation.

MERC TIME OF THE DAY (TOD) TARIFF: A CASE STUDY

Maharashtra Regulators have introduced TOD tariff for consumers, in their first Tariff Order dated 5th May 2000.

During 2015-16, TOD tariff was available for all consumers with sanctioned load of 20KW and above.

- The basic energy charge for HT industrial consumers is 671 Ps/Unit.
- During 0900-1200 Hours the TOD consumer pays 80 Ps/unit more (+12%)
- During 1800-2200 Hours the extra charges to be paid are 110 Ps/Unit (+18%).
- But for consumption during, 2200-0600 Hours, the rebate of 150 Ps/Unit (-23%) is available to the Consumers.
- During 0600-0900 and 1200-1800 Hours, the basic HT Industrial tariff is being charged.

TOD tariff (Fy 2015-16) available to the HT Industrial consumers in UP:

- During 0600-1700: (0%: basic tariff),
- During 1700-2200 (+) 15% extra and

14.3.4 CRITICAL PEAK PRICING (CPP)

In Critical Peak pricing mechanism, the system operator captures the true cost of power generation during the Peak Demand period. It is in fact the crest of Load duration curve. This period normally ranges between 1-3% of the year (75-225 Hours in a year).

If the consumers are ready to pay for the actual cost of power during this period (i.e. CPP Period, which is much higher than TOD tariff), they are offered a discounted rate, for all remaining hours of the year.

CPP tariff is charged for the number of days on which the peak crosses a particular limit. The actual time block during which, the CPP will be in effect is identified on a day-ahead basis, depending on the demand–supply balance.

CASE STUDY:

PJM Interconnector (System operators) publishes Critical Peak Pricing (CPP) rates, (normally for a period of 2 weeks, related to summer cooling load) that encourage, downstream the consumers to reduce consumption during this time and get the benefit of incentives at off peak loads

14.3.5 EXTREME DAY PRICING

Extreme Day pricing is similar to the Critical Peak Pricing. The basic difference is that in CPP the peak pricing is for the limited peak period in the critical day. But in Extreme Peak pricing has the higher price in effect for all 24 hours of critical days

14.3.6 EXTREME DAY CRITICAL PEAK PRICING

In this method of pricing, the Critical peak price and lower off peak price applies to critical peak hours on extreme days. There is no Time of Day (TOD) tariff available for consumers on other days.

14.3.7 REAL TIME PRICING

In this method, the retail Energy Prices change on an hourly basis, for the entire year; to reflect the true cost of supply, in the wholesale market. The Energy rates are notified on day-ahead basis. As Real time Pricing is volatile, it can harm consumers (having fairly constant load demand) and may discourage their participation in the program although Real Time Pricing offers consumers potentially the highest reward compared to traditional flat-rate pricing.

Case Study of Real Time Pricing Programs Offered by Utility Ameren Illinois

The Ameren's Residential consumers are charged as per Hourly wholesale Real time market supply pricing, for the electricity they consume. The hourly prices for the next day are set at the night before and are communicated to the consumers, so they can determine the best time of day, to use their major electrical appliances (Washing machine, dryers, Dishwashers etc.)

14.3.8 RETURN OF SMART GRID INVESTMENT THROUGH SURCHARGES ON CONSUMERS WHO ARE BENEFITTED

The advantages of Smart Project implementation are improved service quality, lesser interruptions, increased safety, and AT&C Loss reduction, the beneficiary consumers, in some countries are being charged an additional System Improvement Surcharge (SIS) or Reliability Improvement Surcharge. The SIS normally appears as an additional Charge expressed in % and applied to the total billed amount in consumer bills. The SIS is innovative Regulatory policy, as it assures return on investments to the Investors, leading to accelerated investment in Smart Grid Projects.

Case Study: Pune Zero Load Shedding Model: Indian Experience in Charging for 'Reliability

MERC introduced reliability surcharge for withdrawal of load shedding.

During 2006-07, in order avoid Load shedding in Pune City, the stranded/ surplus Captive Power Plant Capacity in and around Pune (about 90 MW) was used to mitigate the Load shedding.

During the Load shedding hours, these Captive Plants (costly power) were put "ON" and load shedding in Pune city was avoided transforming Pune as the "Zero load Shedding" City.

The charges for Captive Power (Costly power), used to mitigate the Load shedding, were being charged to all consumers in Pune city. The Domestic Consumers with consumption less than 300 Units/ month were excluded from charging the Surcharge. All other Consumers in Pune City were levied Reliability Charge of Rs. 0.42 per Unit, which was in lieu of providing reliable supply to consumers (Zero Load shedding)

From the above case study following conclusions can be drawn:

- It is feasible to sell "reliability" as a service
- Pooling EXPENSIVE peaking power with base load power, helps in gaining acceptability for expensive services.

14.4 CONSUMER AWARENESS, PARTICIPATION AND GRIEVANCE REDRESSAL IN SMART GRID SYSTEMS

The Smart Grid enables bi-directional flow of information from the Grid Operators to the Consumer. The basic advantages of Smart Grid is Utility can plan better demand management programs, by bringing behavioral changes in consumers. In order to get maximum benefit from Smart Grid Programs; the consumer awareness (training) and his actual involvement in the Program is very much essential.

Smart Grid Consumer Engagement Report: Lessons from North American Utilities: A report for Natural Resource Canada by IndEco Strategic Consulting Inc, Toronto, Canada dated 18th Jan 2013

In past five years, dozens of North American Utilities have begun to deploy Smart Grid technologies, beginning with smart meters. These initiatives have encountered mixed successes; in some cases, consumer resistance and negative media attention have compromised the credibility of Smart Grid.

As a result of these experiences, utilities now recognize the importance of pairing Smart Grid Technology Developments, with effective consumer engagement initiatives: to promote awareness and support to minimize the complaints, and to drive active participation of consumers.

Utilities now have realized that customers will not automatically understand and accept Smart Grid Technology. Utilities can only gain customers' support and active participation, if they create positive customer experience at all stages of technology deployment. In light of these realities, utilities are moving towards a new approach, "Customer engagement".

After studying in detail, the issues in 9 major utilities in US, the Report has tabulated the summary lessons for improving customer experiences, which has been classified in four success factors:

1. Understand and respond to Customer needs:

- Conduct market research
- Provide Information to those, who need it and when they need it
- Develop Programs and services that value for customers,
- Invest time and money into marketing and customer education

2. Go further in providing Consumer-centric programs and Services:

- Develop range of Programs, use range of marketing tools
- Make it easy to participate
- Track your success
- Take small steps and learn from your experience

3. Take consumer Concerns seriously:

- Anticipate and prevent problems
- Train Customer Service representatives
- Work with individual customers to address their concerns

4. Use the Smart Grid to build relationships:

- Build relationships with your customers
- Partner with Other Organization on Education and Engagement

Utilities are expected to play a key role in consumer Education and engagement, with the help from expert organizations

14.4.1 DISPUTE RESOLUTION

The Model Smart Grid Regulations, issued by the Forum of Regulators, also provides for creation of adequate awareness, and hence promote consumer participation and involvement in Smart Grid initiatives/programs. In fact it is necessary that each Smart Grid DPR should have a clear strategy for Prosumer/ consumer involvement.

A prosumer generates electricity through Renewable Energy Source, which is intermittent, and also consuming electricity and feeding the excess energy to the Grid.

It is necessary to resolve the disputes between prosumers and utility in the matter of billing disputes, power quality, Interruptions etc. The Smart Grid Regulations need to provide for Grievance Redressal (dispute settlement) mechanism (between Prosumers and utility or Smart Grid customers and Utility).

Similarly the Aggregators in Demand Response Programs are the interface with Consumers on one side and Distribution utility on the other. The Grievances or disputes involving consumers and aggregators and Utility and aggregators, need to be solved though a Consumer grievance Redressal system.

"Grievance" is defined as any fault, imperfection, shortcoming or inadequacy in the quality, nature and manner of performance which has been undertaken to be performed by a Distribution Licensee in pursuance of a license, contract, and agreement or under the Electricity Supply Code. It inter alia includes (a) safety of distribution system having potential of endangering of life or property, and (b) grievances in respect of non-compliance of any order of the Commission or any action to be taken in pursuance thereof.

The existing consumer grievance redressal mechanism as envisaged in the Electricity Act 2003, Section 42(5-7) and SERC (CGRF and Electricity Ombudsman) Regulations is a three tier system.

Internal Grievance Redressal Cell (IGRC): First dispute settlement Authority at local Offices. In case the consumer grievance is not resolved at IGRC, the Consumer can approach CGRF

Consumer Grievance Redressal Forum: CGRF is formed as per provisions of Section 42(5) of EA 2003, at each Zonal Office, by the distribution utility. In case the consumer is still not satisfied by the Orders of CGRF, the consumer can approach Electricity Ombudsman (EO)

Electricity Ombudsman: EO is appointed by the SERC, as per provisions of Section 42(6) of EA 2003 in the State. In consumer grievance matters, the decision of EO is final and binding on utilities as well the consumers.

It is proposed that similar to the standard practice for redressal of consumer grievances, even the Grievances of Smart Grid Consumers, Prosumers, and Aggregators (third party) will be dealt with the same three tier system: IGRC, CGRF and EO. However, the staff in IGRC, CGRF, EO systems may need further strengthening (also training about new environment) for dealing with the Grievance in the matters related to Smart Grid.

14.4.2 SAFETY STANDARDS FOR SMART GRID PROJECTS

Since smart grids will involve the merger of power generation, distribution, metering and switching equipment with communication, information technology, and with new user applications, it would make sense to take a modular approach to safety. In India, the responsibility for development of product standards lies with the Bureau of Indian Standards (BIS).

The best way to approach is to break it down into its component technologies, then use new standards to evaluate safety issues, involving the component technologies. Instead of a single standard for, say for a smart meter, it would make sense to continue to use the base product safety standard for meters, but plug-in the additional telecommunications and information technology safety modules. In modular approach, IEC 62368-1 is well-suited for providing the plug-in modules for evaluating the safety of IT and communication circuitry portion of the Smart Grid equipment.

14.4.3 SYSTEM STANDARDS

The CEA is prescribing System standards on matters such as construction of electrical plants, electric lines and connectivity to the grid, installation and operation of meters and safety and grid standards in India. Some of the important Standards notified by the CEA are as follows:

Metering Regulations:

- CEA (Installation and Operation of meters) (Amendment) Regulations, 2013
- CEA (Installation and Operation of meters) (Amendment) Regulations, 2010
- CEA (Installation and Operation of meters) Regulations, 2006

Advanced Metering Infrastructure (AMI) Specifications:

- CEA (Installation and Operation of meters) Specification, 2016

Connectivity Standards:

- Technical standard for Connectivity to the Grid (Amendment) Regulation, 2013
- Technical Standards for Connectivity of the Distributed Generation Resources
- Technical standard for Connectivity to the Grid Regulation, 2007

Operation Standards:

- CEA (Grid Standards) Regulations, 2010

Further, CERC specifies the Indian Electricity Grid Code (IEGC), which lays down the rules, guidelines and standards to be followed by various system participants to plan, develop, maintain and operate the Power System, in the most secure, reliable, economic and efficient manner. SERCs are also mandated to notify the State Grid Code consistent with the provisions of IECG. Smart Grid Regulatory framework also needs to be interfaced with IEGC.

14.4.4 PRODUCT, NETWORK AND COMMUNICATION STANDARDS

BIS released "Standard for Smart Meter (IS 16444: Static Direct Connected Watt-hour Smart Meter Class 1 and 2 – Specification), 2015.

In view of several challenges in ensuring seamless communication and Information flow across multiple entities for integrating technologies and industries, harmonized set of Network and Communication standards is inevitable. BIS has released draft Guidelines on Standards for Interoperability in Power System Communications (LITD-10) 3299 on 3rd June 2013. The matter is being dealt with by the Power System Control and Associated Communications, Sectional Committee, LITD 10.

For matters relating to cyber security, the Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology, GOI has specified the National Cyber Security Policy (NCSP) on 9th July 2013. The main objective of the NCSP is to create secured Cyber-ecosystem in the country, generate adequate trust and confidence in IT systems and transactions in cyberspace and enhance adoption of IT in all sector of Economy.

14.4.5 CONSUMER DATA PROTECTION STANDARDS

The Smart Grid has an advanced metering infrastructure, two-way communication network and data management that enables active information exchange between the utilities and the consumer; hence it poses Data Privacy issues.

US Department of Energy (USDOE) has issued "Regulator's Privacy Guide to Third-Party Data Access for Energy Efficiency" which is an effective regulatory framework on consumer data protection. It necessitates a simplified choice for consumer to make decision about his data and also needs to obtain an affirmative consent about data usage.

In India, we need to formulate Regulations for "Data management and Data Protection". The following classification of consumer data can be done to set Regulations on data access by third parties:

- Personally Identifiable Information: This includes the sensitive personal information about Consumer (Consumer name, address, number, Phone/ Mobile numbers and other information that specifically identifies the person or entity to which it applies);
- Consumer-Specific Energy Usage Data: This includes detailed information about the utility service provided to the consumers.

Secure and safe IT communication:

Using public networks for Smart Grid data transfer will lower investment costs, but will significantly increase the vulnerability of power grids to cyber-attacks. Hence it is necessary to have Private Networks for Smart Grid data transfer. It is also necessary that various Regulations, Interoperability Standards, data Protection Standards for Utilities are framed before the actual implementation of Smart Grid Projects.

14.4.6 PERFORMANCE STANDARDS

As per Section 57 of EA 2003, SERC specifies the "Standards of Performance" (SOP) Regulations for the Licensee, specifying the minimum standards for various parameters ((e.g. Period of supply for new connection, shifting of meters/service lines, and change of names, change of tariff category., which reflect the overall performance of the utility). Section 57 (2) of the EA 2003, mandates that if a Licensee fails to meet SOP standards specified, there is a provision for levying Penalty on Licensee, which shall be paid to the person affected.

14.4.7 IMPORTANCE OF BETTER STANDARDS

Adherence to relevant standards is critical from multiple dimensions:

- To ensure an interoperable system that involves seamless communication across multiple entities involved
- To prevent vendor lock-in and proliferation of proprietary standards
- To ensure scalability of the systems installed

It is necessary to take modular approach for the safety evaluation of merged Technology (Energy, Communication and IT). Some system standards and product standards have been issued. BIS has released draft Guidelines on Standards for Interoperability in Power System Communications. The Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology, GOI has specified the National Cyber Security Policy (NCSP) relating to cyber security issues.

As data security is an important issue, it is necessary to have Private Communication networks for Smart Grid Communications. Smart Grid Data Analytics will enable accurate measurement of SOP parameters; and coupled with adequate analytics the Utility will be able to improve its performance and earn incentives as prescribed in the SOP.

14.5 MODEL SMART GRID REGULATIONS DEVELOPED BY FORUM OF REGULATORS FOR INDIA

In 2010, for advising appropriate Policies and Programs for Smart Grids, the Ministry of Power constituted

- India Smart Grid Task Force (ISGTF): Inter-ministerial body to provide policy direction to Smart Grid initiatives
- India Smart Grid Forum (ISGF): PPP initiative for helping stakeholders in deployment of Smart Grid technologies and undertaking research work for promotion of such technologies

National Smart Grid Road map was released on 10th Sept 2013 with "Access, Availability and Affordability of Power for all", as central theme (www.powemin.nic.in). It's a complete code; indicating the proposed development of Indian Power System in next 15 years. The basic aim has been "Quality Power on Demand for All by 2027" The Smart Grid Roadmap articulates goals and timelines for deployment with respect to the above objectives. The Roadmap provides key targets for 12th, 13th and 14th plan for Smart Grid development in India.

The National Smart Grid Mission statement is "Transform Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholder".

In order to achieve goals envisaged in Smart Grid Roadmap, a National SG Mission (NSGM) is launched by MOP, GOI on 27th March 2015. The NSGM Directorate is the institutional mechanism, to act as focal point for coordinating following basic activities being undertaken for development of Smart Grid Infrastructure in India.

The basic Smart Grid infra structure activities are as under:

- Deployment of Smart Meter and AMI
- Development of Micro grids (Commercial hubs, institutions etc.)
- Development of Distributed Generation (Roof Top PVs)
- Consumer engagements and training
- Real Time monitoring and Control of Distribution Transformer
- Creation of Electric Vehicle Charging Infrastructure
- Creation of Smart Grid Knowledge Centre

14.5.1 SMART GRID STAKEHOLDERS AND THEIR EXPECTATIONS

Smart Grid investment needs to be looked at from the perspective of its main stakeholders: Utility, Consumers and Service Providers.

Consumers' Expectations:

- Need for User friendly interface and Privacy protection
- Greater transparency and help to control over energy consumption
- Affordable supply, Improved Quality and reliability of supply (no power cuts, no more Stabilizers and Diesel Generators/ inverters)
- Need options to save and conserve energy

Utility Expectations

- Serve customers in sustainable manner
- Maintain quality and reliability of supply
- Maintain costs within approved Regulatory norms and Higher efficiency

Smart Grid Vendors' Expectations

- Opportunity to collaborate in value chain to gain market access
- Opportunity to create new products and services to take to market
- Clearly defined standards and interoperability requirements
- Supporting new business models for Financial viability

Regulator's have a key role to balance the interest of all stakeholders. Some of the Key issues before the Regulators, while framing the Smart Grid Regulations are:

- Smart Grid (being capital intensive) cannot evolve without dynamic, flexible "Enabling" Regulations. Investors will need return on investment. Regulators need to protect the interests of consumers
  - "Avoid Tariff Shocks as Smart is Capital Intensive investment"
  - "Data Privacy Protection: Consumer desires his data to be secured
- Regulator need to a facilitator to Smart Grid business ("Catalyst")
- Discoms need to demonstrate, clear positive benefits to consumers ("more benefits at optimum cost")
- Smart Grids should be delivering policy objectives and ensuring value and protection to consumers

14.5.2 FORUM OF REGULATORS' MODEL SMART GRID REGULATIONS

The Forum of Regulators (FOR), (constituted vide, Section 166 (2) of the Electricity Act 2003), issued the Model Smart Grid Regulations on 28th August 2015. It provides a framework for SERCs to adopt these Regulations in their respective States, according to their needs and priorities. After issue of FOR's Model Smart Grid Regulations SERCs of five States namely Assam, Haryana, Karnataka, Madhya Pradesh and Tripura have also issued Draft Smart Grid Regulations, by 31st March 2016.

WHY REGULTIONS ARE NEEDED?

Acts and Regulations are quite different and it can be confusing knowing which is required as they often have similar titles and obviously deal with the same subject.

An ACT is legislation passed by the Parliament. Acts, (not including Schedules to Acts) can only be amended by another Act of Parliament. Acts set out the broad legal/policy principles.

REGULATIONS, RULES, CODES etc. are commonly known as "subsidiary legislation" and require publishing in the Government Gazette to become legal. These are the guidelines that dictate, how the provisions of the Act are applied. They may also contain pro forma official forms that are required under the Act. Regulations and schedules to Acts can only be amended by a notice, published in the Government Gazette.

Generally, legal/statement of Law is mentioned in the Act. For the implementation detail, the Regulations are required.

Scope of FOR Model Smart Grid Regulations' framework includes:

- Setting Smart Grid objectives and guidelines
- Defining Smart Grid processes
- Formation of Smart Grid cell: Roles and Responsibilities
- Formulation and execution of Smart Grid projects and programs
- Mechanism for cost recovery
- Monitoring, Evaluation, Measurement and Verification (EMandV) of execution and performance of Smart Grid project

14.5.3 OBJECTIVES OF SMART GRID PROJECTS IN THE INDIAN CONTEXT

The basic advantages of Smart Grid are:

- Self Healing: Automatically detects and resolves/isolates problems in network
- Resilience: Resists attacks; faster restoration capabilities
- Asset utilization: Better asset monitoring/ visibility/ measurement and control system
- Integration: enables incorporation of multiple Generation and Storage options
- Inclusive: Promotes two way communication and enables consumer participation

The Regulations need to specify that the utilities should take into consideration, the Smart Grid Vision and Roadmap notified at the Central and the State level. Due to greater technology adoption across the value chain in Electricity sector, the model FOR Smart Grid Regulations specifies the following objectives of the Smart Grid project:

- Efficiency improvement in Generation, Transmission and Distribution licensee operations
- Manage T&D network effectively
- Enhance network security and Enhance network visibility and access
- Integration of Renewable Energy
- Improve consumer /prosumer service level
- Promoting optimal asset utilization

Considering the early stages of development, the model FOR Regulations provide flexibility to experiment with new technologies and applications, while duly protecting the legitimate interests of consumers. The Regulations should enabling and not overly Prescriptive, and should be in consonance with other existing Regulations.

14.5.4 DEFINITIONS IN MODEL REGULATIONS (REGULATION 2)

The following terms have been defined in the Model Regulations:

- **Aggregator:** Entity registered with Distribution licensee to provide aggregation of services like Demand Response, Distributed Generation, Energy Storage etc.

- **Interoperability:** Measure of ease of integration between two systems or software components, to achieve a functional goal.
- **Wide Area Measurement System:** Advanced measurement technology, information tools and operational infrastructure facilitating the management of Large Power System to enhance System Operator's "situational awareness" for safe and reliable grid operation;
- **Microgrid:** Intelligent Electricity Distribution system that interconnects multiple loads, distributed energy resources and storage within clearly defined electrical boundaries to act as a single controllable entity with respect to the main grid.

14.5.5 GUIDELINES ON SMART GRID PROCESS (REGULATION: 4)

SERC may from time to time issue the guidelines for Licensees, for execution of following activities:

- Formulation/ implementation and Cost Effectiveness Assessment of Smart Grid Programs
- Monitoring and Reporting of Smart Grid Plans/programs
- Essential requisites for Smart Grid programs
- Customer engagement and participation and Customer data protection
- Training and capacity building
- Methodology for setting Smart Grid plans and funding levels
- Database development framework and Information system requirements

However, the issuance of such guidelines shall not be a pre-requisite for preparation and submission of the SG plan by the Licensees

14.5.6 CONSTITUTION OF SMART GRID CELL AT THE UTILITY (REGULATIONS: 5)

As the Smart Grid Projects, deal with various functional Departments of the Utilities, for ensuring successful implementation of Smart Grid Project and further seamless operation and maintenance of the Project, the Model Regulations have suggested for creation of Smart Grid cell within the Utility, within 3 months of Notification of Regulations. The main responsibilities of the Smart Grid Cell may include:

- Baseline study and development of data
- Formulation of Smart Grid Plans, Programs, Projects,
- Design and development of Smart Grid projects: Cost Benefit analysis, plans for implementation, monitoring and reporting for Measurement and Verification
- Seeking necessary approvals to Smart Grid Plans, Programs, Projects
- Implementation of Smart Grid programs

Utility may have a common cell for activities related to Energy Efficiency, DSM and Smart Grid implementation. Further, it may be difficult to get the proper Personnel for Utility Smart Grid Cell from the existing officers/ managers, hence it is desirable that Utilities undertake capacity building Programs (for imparting training with basic knowledge of Smart Grid technologies and various aspects of planning and deployment for undertaking Smart Grid projects) for the interested staff and post them in Smart Grid Cell.

14.5.7 INITIATION OF BASE LINE STUDIES: (REGULATION:6)

Base-Line studies are important to establish the initial performance level of parameters (baseline KPI). On the basis of the results of base line studies, the utility shall develop the Smart Grid program. Baseline study is also important to identify targets and final outcomes for the Smart Grid projects and also to build the data base. The Utility Smart Grid Cell will study the cost-benefit analysis for various options, which can be tackled.

14.5.8 FORMULATION OF SMART GRID PLAN, PROGRAMS, PROJECTS (REGULATION 7)

The Model Regulations directs the utilities to submit an integrated Multi-Year Smart Grid Plan along-with Multi-Year Tariff Petition or ARR Petition for approval of the Commission.

All Smart Grid projects requiring investments of more than Rs. 10 Crores shall be submitted to SERC, for prior approval of investments. The Smart Grid project with Investments less than Rs 10 Crores shall not require prior approval of SERC, if it is part of approved Multiyear Smart Grid Plan.

The proposal for Smart Grid Projects should include:

- Detailed Project Report (DPR)
- Customer engagement and participation plan
- Training and capacity building plan

The DPR would include inter alia description of:

- Project objective
- Technical feasibility study,
- Projected financial implications,
- Target stakeholders,
- Detailed cost benefit (all costs qualitative and quantitative)
- Proposed mechanism for recovery of costs
- Delivery strategy
- Implementation Schedule and mechanism
- Monitoring and Verification plan
- Plan for Increasing awareness among the stakeholders

List of 14 Indicative Smart Grid Projects/Programs (Schedule: X)

1. Advanced Metering Infrastructure (AMI)
2. Demand Response
3. Micro-Grids
4. Distribution SCADA
5. Distribution Management
6. Distributed Generation

7. Peak Load Management
8. Outage Management/ Asset Management
9. Wide Area Measurement Systems
10. Energy Storage Projects
11. Grid Integration of Renewables
12. EV: Grid to Vehicle (G2V) and Vehicle to Grid (V2G) Interactions
13. SG Data collection and analysis
14. Tariff Mechanism including interruptible and dynamic tariffs

14.5.9 SMART GRID PROJECT APPROVAL PROCESS AT SERC (REGULATION 8)

The model regulation mentioned the following steps for project appraisal

- After checking the prudency of expenditure SERC approves Smart Grid Program, Projects if it is in line with the objectives of Smart Grids.
- SERC while approving the proposals, may identify costs, relating to program, project, and decide methodology, procedure, process for recovery of such costs.
- SERC may provide incentive / disincentive mechanism for licensees linked to the execution, implementation and performance during the life of project.
- SERC may specify financial incentives/ disincentives to participating consumers to encourage effective participation in Smart Grid programs.

14.5.10 EXECUTION OF SMART GRID PROJECTS (REGULATION: 9)

Smart grid project execution adheres to the following

- Licensees to execute projects in line with approval given by SERC
- Licensees to adopt System standards, as per CEA Regulations and Network, communication, products, interoperability and cyber security as per BIS standards or as per IEC/ IEEE/ANSI Standards
- Performance Standards as per SOP: Assessment of performance of projects shall be carried out for incentivizing/ penalizing the utilities
- Licensees shall ensure consumer data protection and also consumer privacy, as top priority.

14.5.11 MECHANISM FOR RECOVERY OF SMART GRID PROJECT COST FROM BENEFICIARY CONSUMERS (REGULATION: 10)

The below mentioned mechanism need to be followed for cost recovery

- Utilities need to Identify net incremental costs, associated with planning, design and implementation of programs
- Utilities to propose methodology for recovery of these costs through tariff rise to all consumers i.e. ARR (Socialization) or Pricing of new services: through Surcharges to only beneficiary consumers

- In order to qualify for cost recovery, each program must be approved, prior to implementation and implemented according to the approved Program Plan

14.5.12 SMART GRID PROGRAM, PROJECT COMPLETION REPORT (REGULATION: 11)

Utilities need to perform the following functions after project completion

- On completion of Smart Grid Project, Utilities need to submit a detailed Project Completion Report, within one month of completion covering Project expenses, physical achievements, constraints and difficulties faced and deviations, if any
- Utilities need to place the Smart Grid Project completion report in public domain through its website

14.5.13 MONITORING, EVALUATION, MEASUREMENT AND VERIFICATION (MANDV) OF EXECUTION AND PERFORMANCE OF SMART GRID PROGRAM/ PROJECT

Following steps to be followed for performance evaluation of smart grid project

- Smart Grid program shall be monitored and evaluated based on appropriate methodology including Key Performance Indicators (KPI).
- Utility shall also submit an evaluation report, which inter alia will include outcomes, benefits, lessons learnt and way forward
- SERC to frame detailed Regulations for EM&V for Smart Grid projects

14.6 IMPORTANT ISSUES IN FRAMING SMART GRID REGULATIONS

Five State Regulatory Commissions have issued Draft Smart Grid Regulations, taking FOR Model Regulations, as the base. Other States are in the process of issuing the Draft Smart Grid Regulations. Basically, the State Smart Grid Regulations need to provide for the following:

14.6.1 FOR PROMOTION OF INVESTMENT IN SMART GRID PROJECTS

Since Smart Grid is at early stages of development, the Regulations need to be proactive in providing incentives to promote Smart Grid investments. These may include approval for higher levels of Return on Equity (ROE), higher depreciation rate during tariff determination process.

In certain cases, the Smart Grid investment shall be required upfront and benefits may be realized over a longer period of time. The Regulations need to take note of such investments (e.g. WAMS, AMI, Communication backbone etc), and SERC need to approve such investments, subject to adequate prudence check.

14.6.2 SMART ANALYTICS FOR TRANSFORMING DATA INTO INFORMATION

With deployment of AMI and intelligent SCADA systems, huge amount of data will be generated and hence Smart Analytics is needed to analyze the raw data and derive meaningful information out of it. Smart Grid Regulations need to emphasize the requirement for State of the Art analytics to be part of all DPRs, being submitted by the utilities, to the Commission for approval.

14.6.3 TRAINING TO ALL STAKEHOLDERS

Smart Grid is an evolving subject. There is an immense need for imparting the extensive training to the employees of the Utility, Regulatory Staff, Consumers Prosumers and Aggregators. All project proposals should have a sufficient allocation for cost of training to ensure that all stakeholders are empowered with the right knowledge for the success of the Smart Grid Program.

14.6.4 ADDITIONAL ISSUES TO BE INCLUDED IN SMART GRID REGULATIONS BY SERCS

In addition to the above points, it is suggested that some additional issues may also be included in Smart Grid Regulations for bringing in more clarity in process, more involvement of Stakeholders and faster implementation of the Smart Grid projects.

I. SMART GRID CONSULTATIVE COMMITTEE (SGCC) AT SERC

There is an immense need for Institutional Regulatory framework for Smart Grid deployment. It is therefore, proposed that SERC constitutes "Smart Grid Consultative Committee" at their Head Quarters. The SGCC will act as a nodal Agency for implementation of Smart Grid Projects in the State.

The SGCC will provide assistance to SERC in evaluation of Smart Grid projects and recommending the Smart Grid Projects to the SERC, for in-principle approval of the financial investment. Only those projects recommended by SGCC shall be considered by SERC for approval.

The SGCC is proposed to be appointed by the Commission. The Chairperson of SGCC needs to have adequate experience in Regulatory Process and also be knowledgeable about the Smart Grid developments at National and International levels. The Secretary or Director of the Commission may be appointed as the Secretary of the SGCC. The other members of SGCC may be:

- Representatives of the Licensees (leaders of utility Smart Grid Cells)
- Representative from the State Load Dispatch Center,
- Faculties from reputed local Academic Engineering Institutions
- Consumer Representative (appointed by the SERC as per Section 94 (3) of the Electricity Act, to represent the interest of consumers) and
- Smart Grid sector Specialists (Representatives of manufactures of Smart Grid components, Communication and Information Technology Experts).

The SGCC meeting may be held once in two months for quick assessment and approval of the Smart Grid DPRs, submitted to SERC. The basic idea of formulating the SGCC is to have a Consultative approach, while dealing with Smart Grid which is relatively a new subject. This will also avoid the delay in approval of the CAPEX for Smart Grid.

The Basic Objectives of formation of SGCC are:

- To help to deploy Smart Grid Technology in an efficient, cost effective and scalable manner

- To bring together all stakeholders to design business cases
- To study technological advancement in Renewable Energy, Microgrids, Electric vehicles, Ancillary services and Energy Storage Systems
- Assisting the Commission in approving the Smart Grid projects, submitted by the Utilities
- To suggest proposals for modifying the Smart Grid Regulations as per the needs of system

II. FUNDING FOR SMART GRID PROJECTS AND RANDD ACTIVITIES IN SMART GRIDS

SGCC needs to function independently. In order that SGCC functioning should not be a financial burden on the Commission, a fund needs to be created for SGCC. SERC may create a fund under the aegis of the Commission to fund activities to be carried out by SGCC through: 1% of Annual Licensees fees or 1% of Annual Budget and/ or contribution from various Stakeholders.

Smart Grid is a new innovation of combination of use of advances in IT and Communication sector, for improving the performance of the Power sector. For developing a proper Smart Grid application, SERC may allow creation of fund as a provision for R&D activities in Smart Grid projects, in the ARR of Distribution Licensees equivalent to 1 Ps/U sales or 0.010 % of the ARR. This fund may be used for developing State Specific Smart Grid R&D activities, at a Govt. Owned R&D Institute in State.

14.7 CONCLUSIONS

Regulatory support for Smart Grid projects is required across following three key dimensions:

Financial Support:

- Fast Investment Approval Mechanism
- Optimal tariff design that promotes Smart Grid Applications

Safety and Standards:

- Interoperability Standards
- Standards for Cyber Security and Electric Vehicle Charging

Awareness and Capacity Building:

- Consumer Awareness
- Capacity Building for Utilities, Regulatory Commissions and Technology Providers

ISGF
India Smart Grid Forum

MODULE 15

SMART GRID BUSINESS MODELS

Abstract

Given the economic potential of the Smart Grid and the substantial investments required, there is a need for methodological approach to estimate the costs and benefits of smart grid projects. There are wide learnings from the smart grid projects across the globe to identify these methods and business models. This module describes the key parameters to identify the business models and cost benefit analysis for smart gird projects.

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15 SMART GRID BUSINESS MODELS

15.0 INTRODUCTION

The transition from the current electricity distribution networks towards a more sustainable and efficient one by means of the smart grid is expected to bring changes in the way utilities operate. A range of technological innovations are expected to make impactful changes in grid efficiency, facilitate automation to reduce cost and improve quality, enable the integrated and optimal use of distributed and renewable generation, and promote interaction between supply and demand resources and between the consumer and the utility that will provide benefits for both.

But this future comes at a cost and with immense challenges along the way. It requires capital investment. It means transforming the grid from an electromechanical system to a fully automated system. Its full potential requires much to happen on many different fronts. Utilities face tough dilemmas on the timing of investment, choice of technologies, implementation partners, and how to maximise the benefits.

Currently, power generation, transmission and distribution is one way flow of electricity. Power is generated at power station and then transmitted through high voltage transmission lines and distributed on low voltage lines to the end consumers. But this is going to change with the inception of rooftop solar PV by which a consumer will become a prosumer (consumer + producer) of electricity. Consumer will not only consumer electricity from the grid but could also sell the excess generation to the grid. Similarly, with Vehicle to Grid technologies, electric vehicles can send the electricity back to the grid during the peak hours. The Smart Grid will facilitate two way flow of electricity by allowing interaction and response to situations in real time. This will require huge infrastructure upgrades in terms of communication network, smart devices, field equipment, IT applications etc which are capital intensive.

A Smart Grid project entails capital expenditure and the benefits are realized over a period of time. Therefore, the regulatory framework should ensure that risk is minimum for investors and reasonable return on investment is ensured.

15.1 WHY NEW BUSINESS MODELS

Major technology changes, old infrastructure, low efficiency are leading to major policy level changes in the power sector. Advances in distributed generation (especially rooftop solar) and storage, electric vehicles, communication and automation are opening new avenues for investment and value creation. Third party providers and new investors are pitching in to provide energy access to un-electrified villages (even electrified in some cases) by implementing Microgrids which helps in managing the distributed resources at the local level. India is giving huge push to energy efficiency which has attracted various ESCOs (Energy Saving Companies) who invest on the benefit sharing models and various other business models. Solar sector has begun a different revolution all together with new investors ready to invest in rooftop solar in both industrial and residential sectors by providing innovate business models like leasing of roof for rooftop solar.

Together, these changes are creating new possibilities for multi-directional flow of electricity and information that will empower customers to play an important role in this whole value chain. Whereas, present business model of utilities are designed for technologies and needs of customers which are outdated or are going to be outdated pretty soon.

Along with utilities there will be other stakeholders who will play a vital role in this major change in the power sector in India. Regulators will create incentives and penalties to encourage and hold utilities accountable for achieving transparent goals and metrics to be outlined for measuring progress and success. Technology innovators and third party service providers will collaborate with customers and utilities to create products and services that support policy goals, engage customer interest and integrate efficiently with the grid. Utilities will partner with third-party providers and customers to provide reliable, affordable, clean energy in the most efficient way possible. Customers will be educated in opportunities to deploy new services to enhance the value of their electric service and achieve societal benefits, such as reducing their environmental footprint.

15.2 NEW BUSINESS MODELS FOR UTILITIES

15.2.1 BENEFIT SHARING MODEL

The Aggregate Technical and Commercial (AT&C) losses in the electricity network in India are very high. Presently the AT&C losses in the distribution network (33kV and below) are around 25%. In 2002, the AT&C losses were above 36%. During the past ten years we could reduce the AT&C losses by about 10% through programs such as APDRP, R-APDRP, RGGVY and IPDS funded by the Central Government; and several state level projects. The technology interventions in all these programs helped in identification of causes, locations of losses and helped distribution companies (Discoms) to take appropriate technical and managerial measures to reduce these losses. Considering that the total generation of electricity in 2015-16 was over about 1100 billion units, the reduction of 10% of AT&C losses amounts to saving of 110 billion units in 2015-16 alone, which is equivalent to INR 440 billion (US$ 6,7 billion) in cost (@INR 4.00 per kWh average cost of supply) for the Discoms. The investment made in APDRP, R-APDRP and other state level projects so far is approximately INR 700 billion (US$ 10.7 billion).

The Delhi example of Discoms reducing AT&C losses from >50% in 2002 to below 15% now through technology intervention is another live example to justify that investments in technology can lead to huge benefit for Discoms and in most cases the payback period is 2-3 years. The automation and IT systems for smart grid can be extended to other infrastructure services domains to build smarter cities at marginal cost.

Developing countries like India need to invest in both strengthening the electrical network as well as adding communications, IT and automation systems to build strong and smart grids. Several states in India report very high AT&C losses which are above 35% in several states.

The Ministry of Power, Govt of India issued Smart Grid Vision and Roadmap for India in 2013 which envisages transformation of the entire Indian power system to smarter grids by 2027. Ministry of Power has also launched 14 smart grid pilot projects which are now in implementation phase, large states like UP, Bihar, MP, Tamil Nadu, Odisha etc. having high AT&C losses could not take part in these smart grid pilot projects. Preliminary studies by India Smart Grid Forum (ISGF) indicate that in towns with AT&C losses above 30%, smart grid projects can bring it down to 15% and the payback period is 36-48 months. Some of the benefits that can be realised by implementation of smart grid projects are:

I. REDUCTION IN AT&C LOSSES

Smart grid systems will increase visibility of power flows in real time which will help the utility to take appropriate measures to arrest the losses – both technical and commercial. For example, consider a typical town with 250,000 consumers, 10 substations (33kV/11kV); 100 feeders, 1000 distribution transformers and annual energy consumption of 500 million units (including industrial and commercial consumption) where AT&C losses are >30%. If the losses can be reduced to 15%, the resultant savings will be 75 million units per year which at an average cost of INR 4.00/kWh is equivalent to INR 300 million/year in savings.

II. REDUCTION IN EQUIPMENT FAILURE RATE

Owing to overloading of the electrical network, thousands of distribution transformers (DT) burn out every year in most distribution utilities in India. Smart grid technologies will help reduce/balance the load on DTs by correcting phase-imbalances. Besides DTs, large quantities of several other electrical assets (cables, meters, connecters, breakers etc) damage owing to over loading every year.

III. REDUCTION IN POWER PURCHASE COST

Smart grid functionalities like Demand Response and Smart Microgrids can reduce the peak demand. This will help in reduction of the expensive peak power purchase cost for the Discoms.

IV. REDUCED INVESTMENT FOR NETWORK UPGRADATION DUE TO PEAK LOAD

With un-controlled growth in peak demand, a Discom need to import power at higher tariff and also need to strengthen the network/equipment capacity frequently. Smart grid technologies that can curtail/shift demand during peak hours would help defer such system upgrade. This will help save capital investment for the utility.

Investments required for a typical Smart Grid Project

Following are some of the typical systems that need to be implemented to upgrade the existing electricity distribution system to smart grids:

- Electrical network strengthening at 33kV/11kV/0.415kV levels*
- SCADA/ DMS and Distribution Automation**
- Moving overhead lines to underground cables at select locations
- Conversion of Air Insulated Substations to Gas Insulated Substations***

- Communication systems connecting all substations and DTs on fibre optic network
- Smart Metering or Advanced Metering Infrastructure (AMI)
- Billing, CRM and Consumer Portal*
- Mapping electrical assets and consumers on GIS maps*
- IT Network, Data Centre, Asset Management and other Enterprise IT Systems*
- ERP
- OMS (Outage Management System) and Mobile Crew Management Systems
- Enterprise Applications Integration and Analytics

(*being implemented in 1401 towns under R-APDRP program;

** being implemented in 78 towns under R-APDRP program;

***Gas Insulated Substations can be housed in the basement of a building and the land of the existing substation can be commercialized to bring in huge revenues for the Discoms)

For a typical town with 250,000 consumers (20 substations, 100 feeders and 1000 DTs), the indicative cost for the above systems could vary from INR 2.5 billion to INR 3.5 billion depending upon the condition of the electrical network. Assuming: INR 3 billion (US$ 50 million), the annual benefits can be in the range of INR 0.5 billion to 0.7 billion from place to place. This could far exceed if the Discom's smart grid assets are leveraged by other infrastructure domains as described in the next sections.

Model Framework for Smart Grid Project Implementation on Benefit Sharing

Following steps may be adopted to implement a Smart Grid project under benefit sharing model:

- Implementing Agency (IA) submit a Letter of Interest to the state government/Discom
- State government/Discom identify a suitable town and give concurrence to the IA
- IA conduct a preliminary site survey to assess the feasibility
- All parties enter in to an MoU
- IA (along with project partners) undertakes detailed feasibility studies, cost estimation, establish KPIs, develop financial models and prepare a Detailed Project Report (DPR)
- Appraisal of the DPR by the state government/utility or a reputed third party and execute contract agreement with IA along with payment guarantees
- Project execution and operation; training and capacity building for Discom to take over and maintain the new systems
- Measurement and monitoring of improvements in KPIs and payments to IA from benefits realized

Building business cases for smart cities is complex and justifying return on investments even more difficult. But as explained in this paper, business case for smart grids on benefit sharing model is a viable option; and once smart grid infrastructure is in place, extending it to cover other domains and services to build smarter cities can be achieved at marginal cost.

15.2.2 ROLLOUT STRATEGY FOR AMI

Considering huge capital investment required for the rollout of millions of smart meters and the present financial health of the Discoms, it is proposed to undertake the AMI rollout on 'Leasing' and 'Service Model' as explained below:

I. METER PROCUREMENT ON LEASING MODEL

It is proposed to engage a nodal agency who will issue tender for procurement of smart meters as per BIS Standards (IS 16444 and IS 15959 – Part 1 and 2). The rates will be finalised on annual basis. Manufacturers with BIS-certified smart meters may be empanelled with rates of meter and different communication devices which the Discoms can choose based on their unique requirements. The cost of the smart meters and cost of the communication devices/Network Interface Cards (NIC) to be specified separately.

Once manufacturers are empanelled, capacities declared and rates finalized (valid for a specified duration), each Discom can buy from these empanelled organisations provided they have the capacity to supply according to the rollout schedule of the Discom.

Since the quantity of the meters to be installed is in tens of millions and the capital expense will be large, neither the meter manufacturer nor the Discom will be able to fund the program. Hence in the interest of faster roll out, it is proposed to have a financial intermediary (a bank, PFC or other financial institutions) who will buy meters and communication devices from the manufacturers and lease it to the Discoms against a monthly rent for a period of ten years.

II. AMI IMPLEMENTATION AND MAINTENANCE ON SERVICES MODEL

AMI involves expertise in three distinct domains, namely metering, telecommunication and information technology (including both software and hardware). Experience from around the world shows that no one agency could master these distinct components of AMI. Early-mover utilities tried to invest and own all these systems and have seen mixed results. All successful AMI projects have a strong system integrator playing the major role either as a prime contractor or as a utility's consultant (like a Master Systems Integrator) who tests and approves each sub-components of the AMI system and ensures its interoperability and integration with other utility applications.

It is proposed to appoint a Metering Services Agency (MSA) who will be responsible (along with their sub-contractors and associates) for a variety of functions related to implementation of AMI and its maintenance. Typical scope of services of a MSA would include:

- Testing and certification of the meter and communication devices to be procured by the Discom for the defined scope of AMI in a given area/town with chosen communication technology/technologies
- Taking delivery of meters and communication devices from the Discom and installing them at customer premise; and return of old meter to the Discom
- Establishing and maintaining the last mile communication connectivity for smart meters for a period of at least 10 years
- Selecting the appropriate communication technology for providing a Wide Area Network (WAN)/ backhaul network
- Leasing of bandwidth (wherever required) and maintaining for 10 years

- Sizing of software and hardware of HES, MDMS and associated IT systems, and providing O&M services for at least 10 years. The MDMS, HES and associated IT systems to be housed at Discom premises or hosted in a sovereign public cloud
- Integrating, testing and commissioning of the entire AMI system
- Creation of middleware (if required) and integration of MDMS with middleware
- Integration of MDMS with other systems such as billing, collection, customer care, connection/ disconnection, OMS etc.
- Ensuring availability of complete AMI system at mutually agreed Service Level Agreements (SLAs)

The proposed AMI Rollout framework is described below:

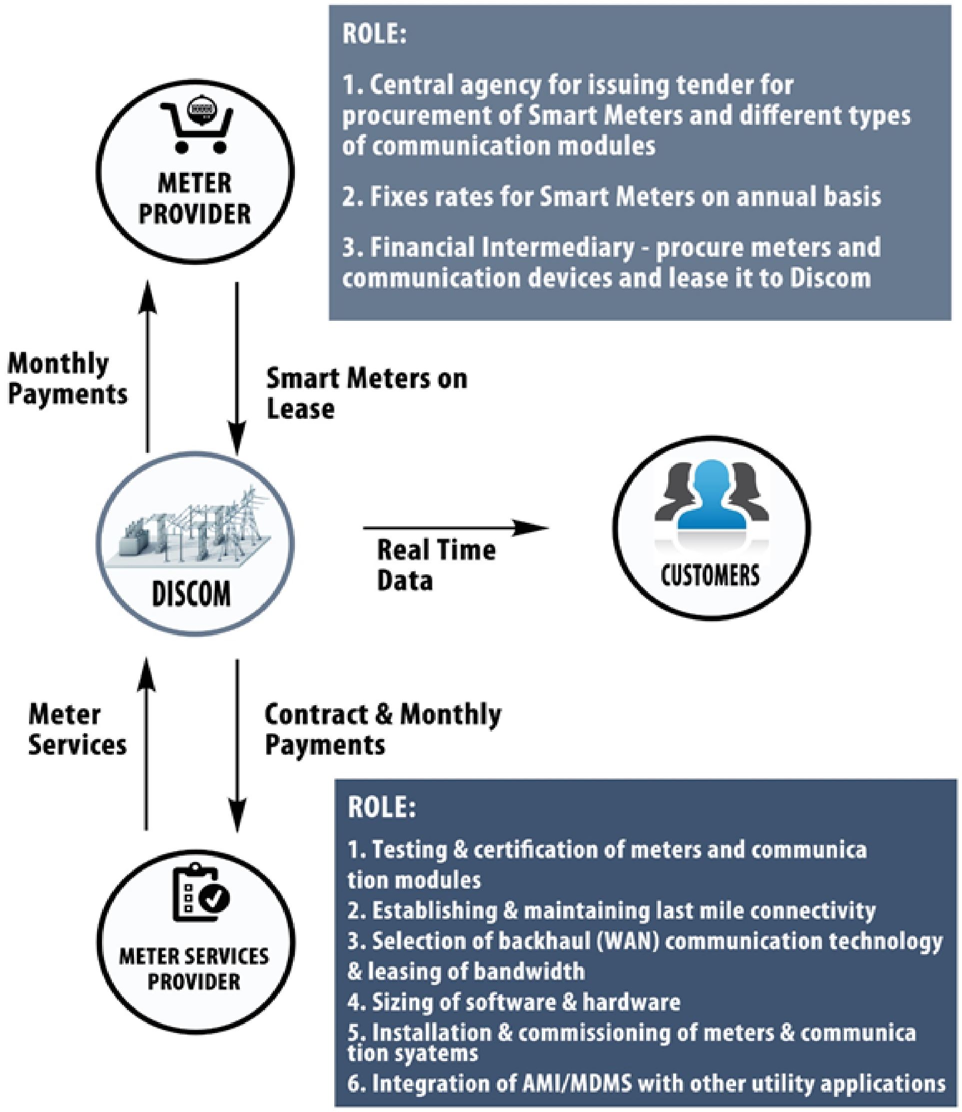

Figure 15-1: Proposed AMI Rollout Framework

III. ROLL-OUT PHILOSOPHY

The new Meter Standards (IS 16444: AC Static Direct Connected Watthour Smart Meter – Class 1 and 2 Specification and IS 15959 - Data Exchange for Electricity Meter Reading, Tariff and Load Control — Companion Specifications pertaining to smart metering have been issued by BIS. All new meters purchased by Discoms should conform to these standards.

In order to facilitate large scale deployment of smart meters,

- All feasible communication technologies may be allowed to operate in order to encourage innovation in view of the fact that the communication technologies advance much faster compared to other electrical technologies
- IPv6 shall be made mandatory as this is in line with the IPv6 roadmap of the Ministry of Communications and IT, which states that:
  - All new service provider-owned Consumer Premises Equipment (CPE) deployed after June 30, 2014 to be IPv6 ready
  - Replacement/upgradation of 25% of CPEs by December 2014
  - Replacement/upgradation of 50% of CPEs by December 2015
  - Replacement/upgradation of 75% of CPEs by December 2016
  - Replacement/upgradation of 100% of CPEs by December 2017
- MoP may advise all Discoms to strictly abide by the new BIS meter standards. Hence, all meters procured by Discoms may be IS 16444 and IS 15959 compliant
- A neutral agency may be appointed to assess the efficacy of the various communication technologies deployed in successful AMI projects around the world and in pilot projects in India and prepare a technology selection guide and roadmap for smart meter deployments in the country
- Neutral agencies may be engaged for customer awareness and engagement programs related to smart metering and smart grids
- Discoms to deploy smart meter on such feeders that have a large number of customers with monthly consumption greater than 500 kWh. Subsequently, customers with monthly consumption lesser than 500 kWh may be brought under AMI. Deployment to be done on feeder-wise and NOT customer-wise so that the last mile communication network can be established and maintained at reasonable cost
- As per IS 16444, the communication module has to be a part of the smart meter (either in-built or pluggable units). Hence retrofitting will not be possible. This was a decision taken by the technical committee at BIS as the stakeholders cited the following concerns if the communication module is retrofitted on existing meters:
  - Theft of communication module
  - Increased points of failure
  - The unsuccessful use case of AMR in R-APDRP (where meter manufacturers were blaming the MODEM makers who in turn blamed the telecom network operators for poor bandwidth and vice versa)

Sending engineers and technicians to customer premises again and again to check and rectify the meter-modem-bandwidth issues is several times more expensive than the cost of new meter and communication device. Hence retrofitting communication modules on already-installed meters should not be practiced.

15.3 NEW ROLES FOR UTILITIES

15.3.1 ELECTRIC VEHICLES AS VALUABLE ASSETS

As utilities struggle with shortage of supply, high AT&C losses, not so good financial health, they should take any kind of good news they can get. One of the best things that could happen to the utility business might be Electric Vehicles (EVs). Yet, few utilities talk about it as a growth driver. EVs are one of the best opportunities utilities have for growth in the next decade, and if utilities are smart, they'll find a way to make EVs a money maker. But in the present scenario, the idea of innovation in utilities may be as novel as the electric car itself.

As per the National Mission on Electric Mobility, by 2020, Government of India plans to rollout 6-7 million electric vehicles, with an average battery pack size of 15 kWh (4 W) and 2,5 kWh (3 W) and 0.5 to 1kWh (2W), this would amount to over 50 GWh of mobile electric storage capacity. The addition of such a large and potentially unpredictable load could present problems for grid management if electric vehicle charging is not handled effectively and hence utilities needs to act more intelligently and consider EVs as network assets that needs to be smartly managed.

I. BENEFIT OF EVS TO UTILITIES

Utilities are looking for ways to balance supply and demand, especially when rooftop solar becomes more common among consumers, it will be difficult for utilities to predict the demand as consumer is generating and consuming as well and it becomes difficult for a utility to predict a consumer's demand. With Vehicle to Grid technology pitching in, EVs can play a role in making grid reliable and can also act as a backup power for the consumer during the power cuts or during peak times when rates are higher and hence reducing the reliance of a consumer on diesel generators and inverters.

EVs could play a big role in making the grid more reliable and cost-efficient. Southern California Edison, a distribution utility in US, has a pilot program that's testing the idea of curtailing charging EVs when grid demand is high. Customers will have the option to charge normally regardless of price, allow curtailment if grid demand is high, or draw a lower level of energy that has less demand on the grid, taking longer to charge.

Programs like Demand Response where price incentives is given to the customer will result in significant peak shifting; off-peak EV charging will be critical to enabling utilities to shift peak demand and defer capacity upgrades in their distribution network. In future, creating an active load through EV charging can help utilities integrate renewable energy sources and avoid having to build new peak generating capacity, EV batteries acting like energy storage without actually investing in utility level energy storage systems. At the end of the day, if utilities can find a way to participate in the EV charging business, it could be a boon for them long term. EVs will drive a big increase in consumption of electricity and that would be big business. Plus, they may make the grid more stable in the era of distributed intermittent generation resources connected on the low voltage network.

Whether it's demand response, energy storage, or EV charging station ownership, utilities are going to have to find a way to adapt their businesses to compete in the future of energy markets.

15.3.2 TAKING ADVANTAGE OF ANALYTICS

To get a complete view of the customer, utilities need to gain a better understanding of who their customers actually are beyond their customer number, rate or tariff program. For years, organizations have recognized that a better understanding of customers can translate to more sales, increased customer satisfaction and reduced customer churn. In other industries, initiatives that have focused on gaining a 360-degree view of the customer have synthesized customer profiles, sales history and other structured data from multiple sources across the enterprise. Now organizations are discovering that there is more opportunity for growth when they enhance that complete view with information from more sources, both within and beyond the enterprise. Information in email messages, unstructured documents and social media sentiments that previously were beyond reach now can be used to extend their understanding of the customer. Organizations that take full advantage of these data sources can glean new insights and gain a competitive edge by making the customer's experience more personalized, encouraging loyalty and accelerating sales. By taking this wide range of data and applying analytics, utilities can obtain a comprehensive view of the customer and use this view to engage the customer as an individual.

These geographical data or other relevant data may be shared with other utilities in the same area like gas or water and cost sharing can be done.

15.3.3 EXPLORING NEW OPPORTUNITIES

When you target a personalized message to the correct person, you can increase the success rate for cross-sell and up-sell opportunities. Some energy retailers are targeting specific customers with new loyalty programs. For example, those customers who sign up for a two or three year rate-lock contract might receive gift cards, loyalty points or other offers.

With better segmentation and a deeper understanding of each customer, utilities can proactively provide information to them about outages, weather warnings or high bill alerts. Utilities also can tailor offers and tips based on a customer's consumption. For example, utilities can consider incorporating new payment options such as time of use, tiered and personalized rates. These are just a few of the creative programs being incorporated by utilities now: Fixed-rate plans for 12, 24 or 36 months; Themed rewards programs, such as family rewards, travel rewards or shopper's rewards where customers receive gift certificates for paying their bills on time; Get more, save more plans with a competitive energy charge for the first 1000kwh and a lower charge for additional usage. Renewable energy plans where the power comes from sources such as wind or solar; Cash-back offers or plans where customers can exchange reward points for goods and services; Connected home mobile applications so customers can manage their accounts on the go or control their cooling, home security and door locks.

Last Mile Communication Sharing is also an option for the utilities to do cost sharing with other utilities like water, gas and municipal corporations (for street lights etc). Once the last mile communication backbone is set up by the distribution utilities for the implementation of AMI, then this communication infrastructure can be used by the other utilities as well for their own use and will save the cost of laying down of additional last mile communication infrastructure.

15.4 COST BENEFIT ANALYSIS

Smart grid policies and missions are transforming the distribution utilities and optimising their operations in day-to-day business activities. Smart grid technologies have proven that electric utilities can contribute to low carbon future in a big way. Huge investment is getting into the smart gird projects for utilities and cost-benefits analysis has become crucial for short term and long term goals to achieve out of that investment. As per the functionality of smart girds, every project has different stakeholders and benefit monetization criteria.

Table 15-1: Functionality and Exptected Benefits of Smart Grid Components

Sr. No.	Smart Grid Functionality	Expected Benefits (Description)
1.	Advanced Metering Infrastructure (AMI)	- Reduction in meter reading cost - Reduced human errors and time consumption - Streamlining the billing process/ automated billing - Detecting Energy Theft/Pilferage on Near Real-Time Basis/Temper detection - Enabling Faster Restoration of Electricity Service After Fault - Power Quality Enhancement - Peak Load Management/Demand Response - Detection of faulty meters and replacement ***More detailed explanations given in Module-3 on AMI***
2.	SCADA/DMS	- Remotely control power flows in real time - Remote monitoring of current, voltage, active and reactive power, power factor etc.
3.	Substation Automation	- Remote operation (No human resources needed to operate substations) - Reduced equipment failure rates and maintenance costs - Enhanced power quality (no financial penalties to utility) - Reduction in the faults
4.	Distribution Automation	- Fast fault detection and restoration of supply - Reduced outage time - Enhanced power quality (no financial penalties to utilities) - Reduced failure rate of equipment and reduced maintenance cost - Higher revenue owing to lower outages

Sr. No.	Smart Grid Functionality	Expected Benefits (Description)
5.	Gas Insulated Substations	- Saving in O&M expense - Reduction in the space required for the substation - Increased reliability - Land saved can be commercialized
6.	Cyber Security	- Secure electric grid operations - Prevention from malpractices
7.	EV Charging Infrastructure	- Reduction in Green House Gas Emission - Saving in the cost of running of vehicle - Electric Vehicles can be participate in Demand Response programs using Vehicle to Grid technologies - New means to increased revenue - Support RE integration in low voltage grid
8.	Solar Rooftop PV	- Saving in the peak demand - Utilization of the available renewable energy resources - Reduction in the energy bill
9.	LED Street lighting	- Saving in the cost of electricity to Utility - Leverage the Street Light Pole with communication facility for other applications such as pollution (air and noise) monitoring, security cameras etc

MODULE 16

NEW TARIFF STRUCTURES

Abstract

This module discusses the process and history of tariff setting in India. It gives an overview of the time of day or time of use tariffs and other innovative, dynamic pricing structures. It also discusses various types of tariffs applied currently for charging of electric vehicles and gives broad recommendations on tariff structures and decision making processes.

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16 NEW TARIFF STRUCTURES

16.0 INTRODUCTION

Tariff determination is the process of deciding the price of electricity to be paid by the consumers. Electricity tariff is determined based on the provisions contained in (a) Electricity Act 2003 and (b) Tariff Policy notified by the Government of India. Determination of electricity tariff is an important function of the Regulatory Commissions. Tariff is determined through a transparent process with the involvement of all stakeholders, including consumers. The regulator follows a set procedure and hears the views of the public and the utilities before the tariff is determined.

Tariff determination process can be used as a tool to

- Affect the financial viability of the system
- Improve quality of service
- Make electricity affordable to consumers
- Raise social and environmental concerns

History of electricity tariff in India

Indian Electricity Act, 1910

- Does not attempt to regulate the tariffs
- Allows reasonable return to the licensee (Power Utilities)

Electricity Supply Act, 1948

- Attempts to regulate the monopolistic power of utilities by defining the basis of tariff
- Creation of State electricity board (SEB) to supplement the efforts of private licencees

State of SEBs till 1990

- SEBs were not able to earn minimum specified surplus (3%)
- No tariff defining principals for individual generating stations
- POWERGRID was established in 1989

K. P. Rao Committee Suggestions, 1990

- Deemed generation to compensate generators for available idle capacity
- Two-part tariff with fixed and variable cost
- Reduction in incentives and disincentives for recovery of fixed cost
- Operational norms for station heat rate, auxiliary power consumption and specific oil consumption

History of electricity tariff in India

Electricity Supply Act Amendments, 1991 (adoption of suggestions)

- Generation fixed cost to be linked to PLF and capacity
- Return on equity for IPP to be capped

Electricity Regulatory Commissions Act, 1998

- Establishment of Central and State Electricity Regulatory Commissions with the intent of rationalizing electricity tariffs, transparent policies regarding subsidy, promotion of efficiency and environment friendly policies

Electricity Act, 2003 (replacing the above acts)

- Regulatory commission to determine tariff for generation company and distribution licensee
- Enhance competition by enhancing participation from private sector
- Introduction of multi-year tariff principles and tariff orders

Electricity Tariff Policy, 2006

- Ensures availability of electricity to consumers at reasonable and competitive rates
- Ensure financial viability and attract investments
- Multi-year tariff framework to be adopted from 2006 to give stakeholders an element of certainty.
- Availability based tariff to be introduced
- Power purchase agreements
- Cross-subsidies to be brought down between different consumers

16.0.1 TARIFF SETTING PROCESS

Different countries follow different procedures for tariff setting depending on the state of the electricity market. Figure 1 below shows the two possible market scenarios. The electricity prices in monopolistic scenario needs to be regulated[1] whereas in deregulated market the price of electricity is set by competition.

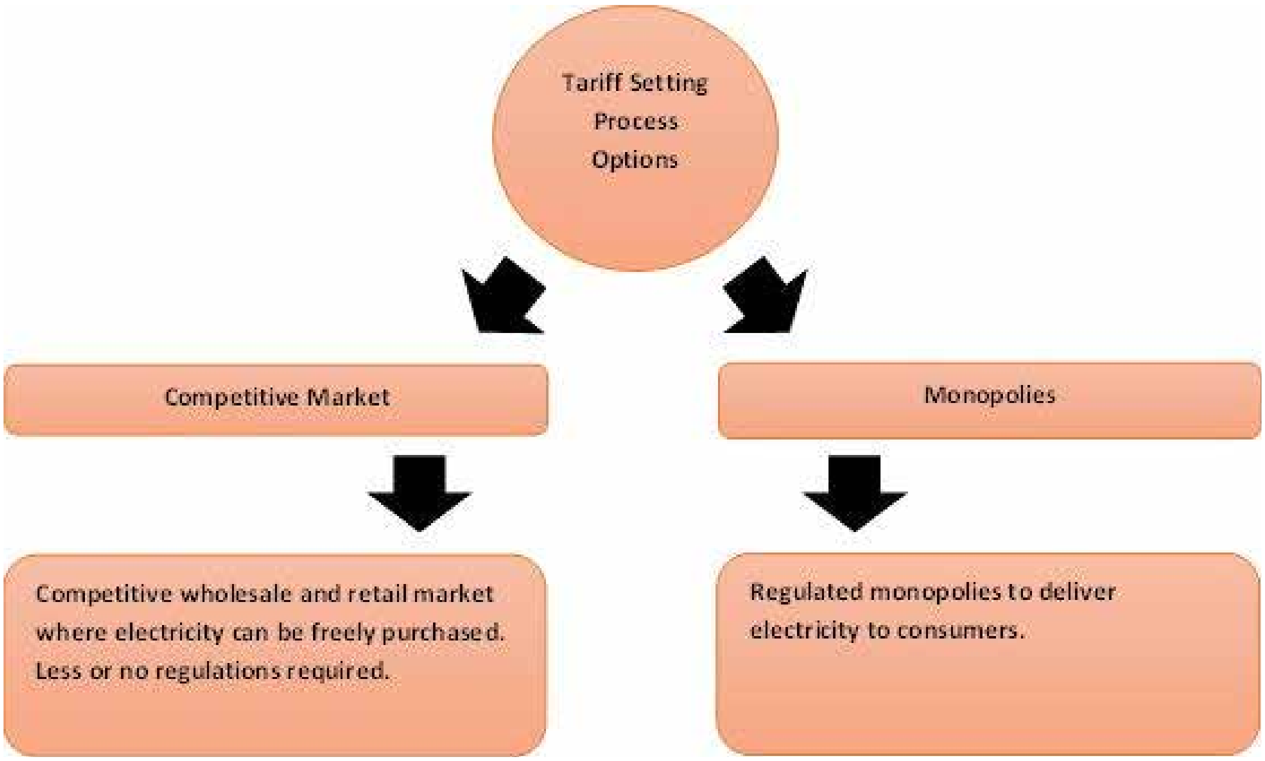

Figure 16-1: Different types of electricity markets

India has a regulated electricity market where as Latin America, UK, Nordic Pool countries (Norway, Sweden, Germany), Canada, and a few US states etc have deregulated markets.

In India, the tariff setting process requires utilities to file their petition on Annual Revenue Requirement (ARR) including the costs and revenue, to the respective State Electricity Regulatory Commission (SERCs). The SERC is responsible for the decision-making process and follows a methodological process to scrutinize the ARR to accept or modify it. The SERC internally analyses the application through various process and then shares this application to public for public comments followed by public hearings. Subsequently, the tariff is approved and is applied to the consumers of the utility.

16.0.2 TARIFF OBJECTIVE

Tariff determination is the primary tool available with the SERCs for creating an enabling environment to full fill its mandate under the Electricity Regulatory Commission Act. The SERCs use tariff as a measure to achieve multiple objectives, which are listed below:

[1] Regulation means that the government has set down laws and rules that put limits on and define how a particular industry or company can operate. [29]

i) To balance the interest of the consumers and the utilities in the sector

ii) To promote competition, efficiency and economy in the activities of the industry

iii) To provide incentives for optimum investments

iv) To provide incentives for good performance and for improving the quality of supply and service to the consumers

v) To ensure that electricity generation, transmission and distribution are conducted on commercial principles

vi) To ensure planning, evaluation and implementation of a programme for reduction of Transmission & Distribution (T&D) losses

vii) To facilitate utilization of environmentally sound options

viii)To provide incentives for efficient utilization and conservation of electricity

A tariff structure should be attractive enough to encourage capital investment, should not allow any misuse of service and should be fair to the consumers. Effective tariff structures often follow the Bonbright's Principles related to revenue, cost and practicality

- Revenue related Attributes
  1. Effectiveness of yielding total revenue
  2. Stability and predictability of revenue
  3. Stability and predictability of rates
- Cost-related Attributes
  4. Discouraging wasteful use of services
  5. Understanding of present and future private and social costs and benefits of service provided
  6. Fairness of rates in the apportionment of total costs of service among different consumers
  7. Avoidance of discrimination in rates
  8. Promotion of innovation and cost-effectiveness in the face of changing demand and supply patterns
- Practical-related Attributes
  9. Simplicity, understandability, public acceptability, and feasibility
  10. Freedom from controversies as to proper interpretation

16.0.3 TARIFF METHODOLOGY

Different methodologies used by regulators for tariff determination can be categorised as:

i) **Rate of Return:** The tariff is determined in a way that reviews the utilities' rate of return compared with its cost of capital

ii) **Price cap:** The tariff is set to account for any inflation in the economy and efficiencies effecting the productivity

iii) **Cost of Service method:** The cost of service method balances future estimated revenue with the cost incurred for the utility. A few disadvantages of cost of service method are that it does not provide any incentives for utility to reduce the costs on its own and it is difficult to accurately estimating cost and preventing excess estimates by utilities

iv) **Performance-based approach:** The performance-based approach provides incentives to utilities for improved efficiency and reducing costs

16.1 TIME OF DAY TARIFF

Power demand in an electricity distribution network varies with the seasons of the year and with time of day within a day. During the summer months, the demand for power is maximum in afternoon because of the cooling requirements of the various industrial, commercial and residential users; where as in winter months it could be maximum during the nights owing to heating loads. This peak demand is satisfied through building extra generation, transmission and distribution capacities which remain idle rest of the time. Reducing this peak demand can drastically decrease the investment required and greatly improve the grid stability. One of the most innovative and economical Demand Side Management (DSM) tool of countering climate change is the implementation of Time of Day (ToD) tariff. Time of Day tariff is a scheme where individual consumptions during three (or more) time blocks, namely “Off Peak”, “Normal” and “Peak” are separately metered and charged at different rates. It is a measure which is used to send price signals to consumers to shift their loads from peak to off-peak time.

Other dynamic tariff structure designs are also available to regulators to bring down peak load. The below figure tries to explain the risk of utility and consumers by different dynamic tariff structures.

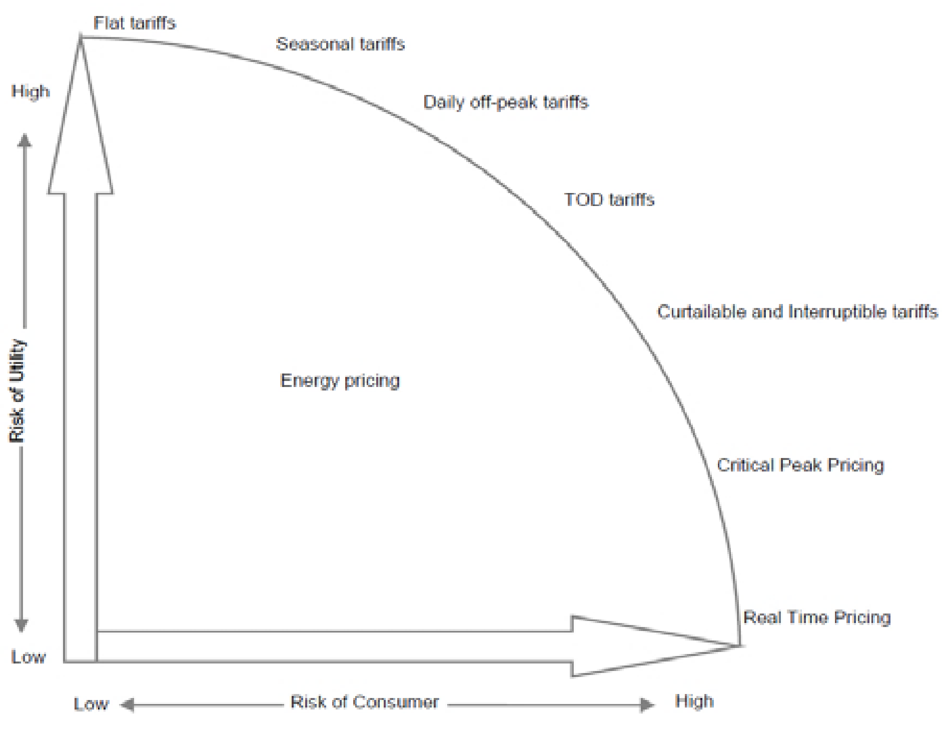

Figure 16-2: Risk of the utility vs. dynamic tariff structures

In Critical peak pricing a higher critical peak tariff is imposed at critical peaks in addition to the normal ToD tariff. In real time pricing the tariff rates vary at specific time interval throughout the year depending on the actual electricity generation/power procurement cost.

General objectives of the ToD tariff are

- Send price signals to consumers that reflect the underlying cost of supplying electricity
- Incentivize consumers to shift their consumption to off peak periods and/or reduce the peak loads
- Transfer the tariff burden to consumers who consume during peak hours

16.1.1 HISTORY AND STATUS OF TOD TARIFF IN INDIA

Over 15 SERCs[2] have implemented ToD tariffs for industrial and commercial sectors. Some states have mandatory ToD structures such as Maharashtra and Gujarat while others have optional ToD tariff structure like West Bengal. In some states, the ToD tariffs specified for different consumer categories vary as per seasons (West Bengal, New Delhi).

ToD was first introduced in the country by the Kerala State Electricity Board for the Extra High Tension (EHT) consumers in the year 1998, followed by the Maharashtra Electricity Regulatory Commission (MERC) in the year 2000 for the High Tension (HT) industrial consumers. In the next decade, the SERCs of other states have also comprehended the benefits of ToD and adopted ToD tariffs.

Legislative and legal frameworks such as Electricity Act (2003), National Tariff Policy (2006), National Electricity Policy (2005), Forum of Regulators (FOR) Recommendations (2009) and Central Electricity Authority (CEA) Regulations promote the implementation of ToD tariffs as an important tool for Demand Side Management (DSM).

Section 62(3) of the Electricity Act 2003, which guides the SERCs to incorporate ToD tariff is:

"The Appropriate Commission shall not, while determining the tariff under this Act, show undue preference to any consumer of electricity but may differentiate according to the consumer's load factor, power factor, voltage, total consumption of electricity during any specified period or the time at which the supply is required or the geographical position of any area, the nature of supply and the purpose for which the supply is required."

The provision no 5.4.9 of the National Electricity Policy also advocates the ToD tariff which says that:

"The Act requires all consumers to be metered within two years. The SERCs may obtain from the Distribution Licensees their metering plans, approve these, and monitor the same. The SERCs should encourage use of pre-paid meters. In the first instance, ToD meters for large consumers with a minimum load of one MVA are also to be encouraged. The SERCs should also put in place independent third-party meter testing arrangements."

The National Tariff Policy also mentions in section 8.4 Definition of tariff components and their applicability:

"Two-part tariffs featuring separate fixed and variable charges and Time differentiated tariff shall be introduced on priority for large consumers (say, consumers with demand exceeding 1 MW) within one year. This would also help in flattening the peak and implementing various energy conservation measures."

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[1] *States with ToD tariff: Assam, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab (Pilot), Tamil Nadu, Telangana, Tripura, Uttarakhand, Uttar Pradesh.*

16.1.2 BARRIERS TO TOD TARIFF

Despite the evident benefits, implementation and successful working of ToD in India has large number of barriers:

- Different ToD tariffs are needed for different consumes and utilities throughout the country, as it increases complication since these parameters cannot be standardised
- Requirement of fresh investment, as most of the existing metering infrastructure does not allow to measure consumption during different time slots. The existing meters with ToD capabilities do not allow remote reconfiguration which restricts the ability of utilities and regulatory commissions to change the ToD structures without additional investments.
- Unavailability of any proper research and studies on the capabilities of different consumers to respond to different ToD tariffs during different times in a day, different days in a week and in different seasons

16.1.3 FROM TOD TO TOU

Although, TOD based tariff rates offer more flexibility over flat tariff rates and is a strong proponent for DSM; it doesn't support real time pricing. Generally, TOD tariffs are issued well in advance, so that consumers can shift their consumption load appropriately. The electric grid is a sensitive technical infrastructure, wherein certain parameters (frequency, voltage) need to be maintained for effective functioning of the system. Given their unpredictability, it is difficult to ascertain, conditions of supply for a given time period in advance. It would be appropriate to have a tariff structure that reflects real time cost.

TOU or Time of Use is similar to TOD in structure, but is reflective of the associated real time costs. Each day is split into different zones similar to TOD but do not have a pre-estimated tariff prescribed to them. Instead, each time zone would have a variable tariff that would be dependent on the seasonal changes, unexpected circumstances such as congestion in transmission or sudden increase in demand and system imbalances to name a few. Although, it would be at a higher slab rate; this would have nearly negligible cost variations between supply and demand and it would be more dynamic than other tariff structures.

16.1.4 SMART GRID AS AN ENABLER TO IMPLEMENT TOD AND TOU STRUCTURES

Smart Grid can be help India scale up ToD and TOU tariff implementations. Smart Grid is the electrical grid that uses technology to gather information on the usage and pricing in consumption, generation, distribution. Studies have demonstrated that time of day tariff motivates behavioural changes resulting in overall energy saving of about 3% to 4% with around 30% impact at critical peak periods. Smart grid technologies enable and allow the electricity consumers to know their power consumption and give an ability to make informed decisions.

Innovative dynamic tariff structures can also help unlock benefits of smart grid to a wide range of stakeholders all along the electricity value chain, including the revenue generation end to consumers, distribution companies and local and national government. It can assist Indian utilities to better perform by reducing the peak power demand thereby reducing power cuts due to peak power shortage.

16.1.5 TOD TARIFF SETTING PROCESS

Following steps are considered for designing ToD tariffs:

Define objectives for the program	Identify the Target Population	Create the time schedule	Define revenue neutral baseline	Design the rate
• To shift the load? • To assigning the costs? • Mandatory or optional?	• Based on ability and willingness to shift/respond	• Based on load curve of the utility	• Based on actual power procurement cost of the utility • Should not jeopardise consumer's interests	• Define the rates for various hours of the day

16.2 SPECIAL TARIFF FOR ELECTRIC VEHICLES (EVS)

16.2.1 RATIONALE

Across the world, the recognition for EVs and their role in sustainable future transport and potential grid services is growing. Utilities and regulators need to respond to the growing market with a wide variety of policies and programs meant to promote the sales of EVs while ensuring that their additional electricity consumption benefits the electric system. Development of the charging infrastructure for EVs is essential to support adoption of EVs at a wider scale. In order to boost the number of charging stations and thereby encouraging EV owners' confidence in driving range of EVs, utilities shall have to offer rebates and incentives for residential and commercial charging stations. A number of utilities in the US and Europe are installing and operating their own charging stations and ensuring that enough charging stations are publicly available to support significant growth in EV ownership.

However, the challenge faced by utilities would be to ensure that the additional electricity consumption must not coincide with peak periods of electricity demand. For the EV load to have a positive effect on the grid, the charging time during a day becomes crucial. For example, in San Diego solar is a major contributor to grid power, hence charging infrastructure is created at the workplace, so that vehicles can charge during the midday peak of solar output. In other cases, the demand in late night hours might be less, which then becomes the optimal time to charge at a concessional tariff.

16.2.2 POSSIBLE FRAMEWORK AND STRUCTURES

As mentioned in the previous section, special tariff rates need to be considered for EVs, in order to ensure that growing EVs do not add to the already stressed electricity grid. Various pricing structures have been considered in other countries, which are discussed in the following paragraphs:

- Time-of-use (TOU) rate, where in the electricity rate varies with the hours of the day; charges a lower price for energy during certain hours of the day and higher during other hours. It could provide EV owners with an incentive to delay EV charging from the day-time peak hours, to overnight off-peak hours. For example, NV Energy, Nevada offers ToU rates having wide differentials for on- and off-peak power. Its summertime rate for northern Nevada varies from 40.7 cents/kWh for on-peak power (from 1 pm to 6 pm) and to 5.53 cents/kWh for off-peak power (from 10 pm to 6 am). In Europe, EDF in France offers off-peak discount; a special EV TOU rate is offered by RWE in Germany;

and a day/night tariff is offered by EON in Germany. The effect of TOU rates in shifting the EV charging times to off-peak hours was supported by a study done by the California Public Utilities Commission.

- Real-time pricing (RTP) tariff dynamically sets prices based on the real-time marginal cost of energy. Although electricity tariffs provide indirect control of EV charging, detailed analyses of such schemes are scant.

  However, experience with such dynamic pricing arrangements for electric vehicle charging is still limited, and ongoing changes in technology, including the systems used to control charging, contribute to uncertainties about how dynamic pricing will affect charging behaviour.

- Day-ahead hourly rate provides dynamic hourly rates for EV charging on a day-ahead basis. It allows the user to know optimum hours for charging his vehicle and gives the flexibility to minimize the charging cost predictably and reliably. This structure is being tested by San Diego Gas and Electric (SDG&E). However, one disadvantage of this structure would be that the customers may not be comfortable with the complexity of dynamic pricing, in which case aggregators will needed to aggregate the load and obtain the benefits of dynamic pricing.

- Managing the load through direct control: In this approach charging loads could be controlled directly by grid operators or utilities or aggregators of charging infrastructure within the defined parameters set by the user. This would give the flexibility to avoid overloading the distribution network and optimize all assets on the grid under a dynamic pricing regime. However, it would be infrastructure intensive and require Advanced Metering Infrastructure (AMI) to measure hourly or sub-hourly demand and to enable billing for dynamic pricing. It would also require high degree of communication between the network operators, aggregators, distribution utility and the EV user.

16.2.3 CREATING ENABLING FRAMEWORK

I. ROLE OF REGULATORS AND UTILITIES

State Electricity Regulatory Commissions have a major role to play in promoting EVs and providing optimum tariff structure for EV charging without jeopardising the interest of both utility and users.

For example, California Public Utility Commission in EV proceedings stated, "rate structures can convey the costs and environmental impacts of the supply and demand of electricity to consumers, providing incentives for individuals to make choices consistent with the collective good. Because electricity for electric vehicles can displace fossil fuel consumption, it is appropriate for utilities to structure rates so that off-peak charging is encouraged."

On the other hand, if a utility does not recognize incentive to expand electricity sales to recharge EVs it can supress the commercialization of EVs. Utility should also benefit directly from the new EV demand (from its grid supporting services), so that the fixed cost of the new electricity-generation and infrastructure assets are not applied over a shrinking rate base. This can cause utility rates to increase across the board, which would be problematic for EV owners and other utility customers.

Further research and study is required to understand the potential benefits of decoupling domestic electricity use from EV recharging or creating a separate tariff category altogether. This may allow utilities dual benefit of separately structuring domestic electricity tariff to encourage conservation and structuring EV rates to encourage beneficial charging behaviour. However, this will require additional investment in metering infrastructure for EVs. Hence, further in-depth studies are needed to understand how best to manage future EV recharging demand.

SERCs can play a leadership role by reassessing their regulatory frameworks to harmonize technical standards, provide guidelines on streamlining the installation of household and commercial charging stations, and create innovative tariff structures to promote charging at off-peak hours.

SERCs can also assess opening up the recharging infrastructure market to utility participation, strategic partnerships, and the inclusion of third-party vendors.

Oregon's Public Utility Commission, in early 2012, allowed utilities to build and maintain EV charging infrastructure and recover capital costs through the utility rate base, although after crossing a high bar set by the commission, which required utility to demonstrate that its ownership and operation of recharging equipment is particularly beneficial to EV drivers, not just the public.

California Public Utility Commission on the other hand, opted to exclude Californian utilities from the recharging infrastructure market, owing to a $100 million settlement of a dispute between the California Public Utility Commission and Texas-based utility NRG Energy. As a result, NRG will get exclusive rights to build at least 200 fast-charge stations along major state highway corridors, as well as 10,000 individual charging stations at apartment complexes, office parks, schools, and hospitals in California. NRG will get exclusive access to these locations for eighteen months.

II. ROLE OF PRIVATE SECTOR

EV charging infrastructure needs to be developed on a large scale for utilities to realise the benefits of the grid-support services from EVs. However, the ownership models are still being debated; whether utilities should provide the public charging network at subsidised cost or should private sector be allowed to establish the infrastructure. As a part of the EV project by United States Department of Energy (US DoE) which started in 2009, public charging stations were established across various states and service was initially provided free of cost. However, it proved to be ineffective in encouraging EV rollout. Subsidised infrastructure can initially be provided to stimulate growth but in the long-run private participation with cost recovery would be essential.

16.3 INNOVATIVE TARIFF STRUCTURES IN OTHER COUNTRIES

TEMPO ELECTRICITY TARIFF – ÉLECTRICITÉ DE FRANCE (EDF), FRANCE

In France, electricity bills for residential and small business customers include a standing charge determined by the level of maximum demand (in kVA) nominated by the customer (puissance souscrite), and an energy usage charge based on the type of tariff chosen by the customer (type d'abonnement). In 1993, EDF introduced a new rate design, TEMPO tariff to its 120,000 residential customers. Thus, a residential and small business customer could choose from three types of electricity contract.

Table 16-1: Tariff Design

Option Base	Option Heures Creuses (Option HC)	Option Tempo
For lower usage, smaller homes with only occasional usage.	For the majority of houses occupied full-time with non-electric heating	***For high use households with electric heating and full-time occupation, and for small business customers.***
Simplest, with the lowest standing charge and a flat rate for electricity usage all the time throughout the day and year.	• Two-part time-of-use tariff with normal (heures pleines) and off-peak (10 pm until 6 am each night) (heures creuses) rates. • Usually used in conjunction with a water heater operated by ripple control so that the heating element is switched on only during off-peak periods.	• Complicated tariff system with six rates of electricity pricing based upon the actual weather on particular days and on hours of use. • Each day of the year is colour coded. o Blue (jours bleus): low prices o White (jours blancs): medium prices o Red (jours rouges): high electricity prices. • The colour of each day is determined mostly by the electricity provider Électricité de France (EDF) based on the forecast of electricity demand for that day. • The French transmission network operator also has the ability to determine the day colour if there is significant congestion on the electricity network.

Tempo tariff has been successful but less than 20% of electricity customers in France have chosen Option Tempo. The Tempo tariff was designed specifically for the situation where EDF is a monopolistic generator and retailer of electricity. In July 2009, EDF discontinued the Tempo tariff for new customers and for customers who are on the tariff at their current residence and then move house. [23]

GULF POWER'S GOODCENTS SELECT

The Florida based Gulf Power Company employs Critical Peak Power Pricing mechanism, which is similar to a time-of-use rate most of the time, with the exception that on declared "critical-peak" days, a pre-specified higher price is charged for a specific time period [24].

GoodCents® SELECT is a residential advanced energy management system that allows consumers to program their central heating and cooling system, electric water heater and their pool pump to automatically respond to varying prices. There are three TOU prices for non-critical hours, and a CPP that can be invoked no more than one percent of the hours in a year [25]. The Program showed Significant Real-Time demand reduction and Customers could save up to 15% on electricity bill annually.

REAL TIME PRICING

Several utilities in US and Europe offer real time electricity tariffs for their consumers. Real-time pricing means that the electricity prices vary hour-to-hour and are determined from wholesale market prices using an approved methodology. Real-time pricing allows consumers to adjust their electricity usage by scheduling usage during periods of low demand with cheaper electricity price. Utilities of Illinois i.e. ComEd and Ameren offer real-time pricing programs in Illinois [26]. For RTP, enabling technologies (e.g., smart meters) are usually involved to support the accuracy of measurements. The reason RTP highly relies on enabling technologies is that it has to be closely connected with wholesale market prices, as well as with consumer feedbacks (two-way communication required) [27].

Nova Scotia Power, Canada offers one part Real Time Pricing (RTP) to customers who have loads of 2,000 KVA or 1,800 KW and over. The consumers are charged based on the company's actual hourly marginal energy costs, plus the fixed cost for on-peak and off-peak usage [28].

PEAK TIME REBATE

PTR refers to the payment that consumers can receive for reducing demand during peak periods on event days. It is inverse of CPP, where customers will be reimbursed for the amount of reduced power consumption during the critical peak period [27]. Utilities such as San Diego Gas and Electric (SDG&E) ComEd offer PTR to their consumers.

16.4 RECOMMENDATIONS FOR REGULATORS

Based on the international experience and demonstration pilots on various tariff structures to optimise electricity use, following recommendations are submitted to the regulators in India for consideration:

- Further study and research should be done to devise and apply tariff structure suitable for Indian consumers. More research should be done to analyse consumer behaviour
- Effective evaluation, measurement and verification methodologies should be developed to monitor and assess the impact of new policy changes and proposed tariff regimes
- Consumer engagement and awareness is a key to success in inducing optimal and judicious use of energy. It should not merely rely on providing enabling technologies but should be undertaken through public engagement and education
- Innovative pricing mechanisms such as linking retail prices with wholesale market prices can be implemented on certain pilot projects
- It is important for the regulators to consider the policy context and the policy's implications on all involved entities and stakeholders

ISGF
India Smart Grid Forum

MODULE 17

SMART GRID FOR SMART CITIES

Abstract

The Smart Cities Mission has triggered the planning and designing of 100 Smart Cities in India and it is expected that by 2030 more that 40% of India's population will live in urban areas. Using Smart Grids as anchor infrastructure to build Smart Cities in India makes sense given the need for modernizing the electricity distribution system to provide 24x7 supply of quality power to all citizen. Compelling business cases are available for investment in smart grid technologies to improve operational efficiency and reduce system losses. This module describes how Smart Grid assets can be leveraged to build Smarter Cities at marginal cost by extending the automation, IT and communication infrastructure of the Smart Grids to other infrastructure and domains in a city.

Note: ISGF first published the White Paper "Leveraging Smart Grid Assets to Build Smart Cities at Marginal Cost" in September 2014 which ignited a series of debates on the subject globally and in IEEE PES launched a series of conferences titled "Smart Grids 4 Smart Cities" in 2016.

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17 SMART GRID FOR SMART CITIES

17.0 INTRODUCTION

The Smart Cities Mission in India has triggered the planning and designing of 100 Smart Cities in India. It is expected that by 2030 more that 40% of India's population4 will live in urban areas. This is an additional 315 million people – almost the population of the United States today – are expected to live in India's cities by 2040. This is important from a global context too. Half of humanity now lives in cities, and, within the next two decades, 60% of the world population will reside in urban areas, where nearly 90% of future economic growth will take place.

Using Smart Grids as anchor infrastructure to build Smart Cities in India is imperative given the need for modernizing the electricity distribution system to provide 24x7 sustainable, reliable, and affordable supply of quality power to all citizen. Compelling business cases are available for investment in smart grid technologies to improve operational efficiency and reduce system losses. A Smart Grid is essential to integrate renewable energy resources on to the grid and decarbonized clean energy and its efficient use is a key element for Smart Cities and their sustainable future. Following sections describe how Smart Grid assets can be leveraged to build Smarter Cities at marginal costs by extending and integrating the automation, information technology (IT) and communication infrastructure of the Smart Grids to other infrastructure and services domains in a city.

17.1 URBANIZATION IN INDIA

The rise of cities has grown over millennia, and have evolved over time as places where the entirety of human activities and services concentrate, spanning multiple modes of transportation, water supply, electricity, telecommunication and internet, schools and colleges, hospitals, markets and businesses, other resources and services across people with varied skills. As cities evolved with more and more facilities and services, they became more and more attractive to people from rural areas leading to even faster urbanization. Rapid growth of cities has led to the creation of metropolitan regions - clusters of cities in a region.

Urbanization accompanies economic development. Rapid urbanization followed as India transformed from an agrarian economy to industrial cum services economy during the past three decades. While the urban population is currently around 31% of the total population, it contributes to over 60% of India's GDP. It is projected that urban India will contribute nearly 75% of the national GDP in the next 15 years. It is for this reason that cities are referred to as the "engines of economic growth" and ensuring that they function as efficient engines is critical to our economic development. This trend of urbanization that is seen in India over the last few decades is expected to continue for few more decades. Hence, we need to plan our growing urban areas as sustainable cities. The relatively low technology penetration in cities allows us to plan our urbanization strategy in the right direction by taking advantage of the latest developments in technology.

Comprehensive planning and development of physical, institutional, social and economic infrastructure is the right approach to develop smart cities. Government of India is accelerating the development of cities in India with the Smart Cities Mission. The 100 Smart Cities are to make their infrastructure ready to take on the population growth, provide 24x7 reliable electricity, secure every citizen's life with good health, education and employment facilities and make the city more liveable, workable and sustainable.

Increasing energy demand makes all these targets challenging as energy consumption from fossil fuel will lead to more carbon emission and environmental issues. Energy is the key driver for cities and non-polluting energy is essential in smart cities. To ensure 24x7 sustainable supply of electricity and energy security, the efficient management of the electricity distribution network in real time through use of intelligent devices and applications has become necessary.

17.2 SMART GRID: A PARADIGM SHIFT

The 21st Century electric grid is witnessing several disruptive changes. After 100 years of centralized power generation and creation of massive electric grids, the shift is now towards de-centralized generation. For the past five years we are witnessing an increasing share of new generation resources being added at the low voltage or distribution segment of the grid which is a major transformational change to the electric grid. The traditional model of electricity being generated at large power plants and transported to millions of consumers through long transmission and distribution lines is changing. The traditional boundaries between Generation, Transmission and Distribution are fast disappearing and the grid is evolving as an integrated grid. This change is primarily driven by distributed generation from renewables which have already achieved grid price parity to most customer classes in many geographies. Electric Vehicles are going to make the electric grid even more complex to manage as there will be less predictability of the loads!

Smart Grids have emerged as the critical enabling infrastructure for all flagship programs for Government of India (GoI) such as 24x7 Power for All, 100 Smart Cities, 175 GW of Renewable Energy by 2022, National Mission on Electric Mobility with a target of 6-7 million Electric Vehicles by 2020 etc. In order to bring efficiency and sustainability in the electricity distribution sector in India, introduction of Smart Grid technologies started with Restructured-Accelerated Power Development and Reforms Program (R-APDRP) and is continued with Integrated Power Development Scheme (IPDS). To take this on fast track a National Smart Grid Mission (NSGM) has been launched by GoI. NSGM is expected to launch projects in conjunction with other ongoing programs of GoI and State Governments to build smart grids in the country in a phased manner starting with urban areas and regions with huge transmission and distribution losses.

17.3 SMART GRIDS FOR SMART CITIES

Smart grid is an electricity grid with communication, automation and IT systems that enable real time monitoring and control of power flows from points of generation to points of consumption at the appliances level. It is an evolving grid system that manages electricity demand in a sustainable, reliable and economic manner built on advanced digital infrastructure and tuned to facilitate the integration of both demand and supply. Automation, communication and IT systems of Smart Grid can be shared by other utilities like water, sewerage, piped gas, streetlights, transport, security etc., at marginal cost and create a holistic eco-system with common command and control centre in a smart city. Preliminary studies by India Smart Grid Forum (ISGF), indicate that in towns with above 25% Aggregate Technical and Commercial (AT&C) losses in the electricity distribution network, Smart Grid projects can bring it down to 10% with the payback period of 3-4 years. There are compelling business cases for Smart Grids which makes it an anchor infrastructure for Smart Cities and once Smart Grid infrastructure is in place, extending it to other domains and services to build Smart Cities can be achieved at marginal cost.

In the Indian context, where cities do not have a single owner for all its services, it would be a herculean task to integrate all infrastructure and services on a common platform. However, a beginning can be made by extending the available digital platform of one domain (say power) to offer services in other domains (say water, gas, internet, transport, security, etc.). The smart cities may be two categories – existing cities that will be made smarter by integrating all services on digital platforms; and green field or new cities that will be designed and built as smart cities with integrated communication, IT and automation systems.

The typical systems in a smart city would cover the following:

- Building GIS data of all infrastructure and services in an integrated fashion by one designated agency (with rules for sharing, security, etc.)
- Smart electricity grids that ensure 24x7 stable electricity to all citizens
- High levels of renewable energy mix that is integrated with the electric grid
- EV charging infrastructure and ability to operate large fleets of grid-connected EVs as virtual power plants (VPPs)
- Efficient water distribution network and safe gas distribution networks with leakage detection systems and automated controls
- Integrated billing systems for a variety of services (electricity, water, gas, internet, house tax etc.); common customer care centers and user friendly payment platforms
- Intelligent transportation systems - coordinated operation of traffic lights, alerts on congested routes in advance, common cards for toll payments etc. which also extends to improved public transportation
- Digital security systems integrated with emergency services (police, fire, ambulance, municipality etc.)
- Intelligent and grid-interactive buildings with rooftop PV and EV charging facilities integrated with automation systems of the electric utility participating in the electricity markets to leverage price arbitrage to buy-store-sell electricity in real-time
- Demand Response that would strengthen "negawatt" market and IT infrastructure permit its aggregation for meaningful dispatch and to address intermittency of RE generation resources

- . Energy independence and significantly lower greenhouse gas emissions in long term and "intelligent energy harvesting" that would recycle incoming energy flows
- Sharing of data between various domains and building smart analytical tools
- Seamless payment system for all services in a city
- Systems integration, cyber-security, privacy, and interoperability
- Data access and visibility for analytics (e.g., smart metring, IoT etc)

While building new cities and new neighbourhoods, it is possible to build all these in an integrated fashion, it is a tougher task to integrate the same in existing cities with different owners for different domains. The silver lining is that there are hardly any IT and Automation systems in most infrastructure domains in Indian cities which eliminates the risk of legacy systems with proprietary databases and protocols that cannot readily be integrated with one another.

17.4 LEVERAGING THE SMART GRID ASSETS FOR SMART CITIES

All state owned electricity distribution companies (Discoms) in India have implemented a set of basic IT and Automation solutions under the R-APDRP scheme of the Ministry of Power. Some of the digital assets created under this program in 1411 towns can be leveraged to build smarter cities at marginal cost. The IT and Automation Systems of the Discoms that can be leveraged by other infrastructure services providers is briefly explained below:

- GIS Map of the Towns: All electrical assets (33kV, 11kV and Low Voltage lines and substations) and consumers are mapped on a digital map and the Discoms are updating this system on a regular basis to capture changes/addition to the electrical network as well as new consumers/buildings. This digital map can be effectively used by other infrastructure services providers for planning as well as operation and maintenance of their systems. This will be very useful for planning the laying of water supply and sewerage lines, telecom cables, gas pipe lines etc. It can also be used for planning of road network. As the simplest example of how a good GIS system can help beyond a single domain – if one knows the routing of underground power cables, then the same can be synergized to other utilities that would need to dig up roads (like water, sewage, telecom, etc. – thus one should, in the future, never interrupt other services for adding new connections/lines/pipes).
- Billing and Customer Relationship Management (CRM) Systems: State of the art Billing and CRM systems have been implemented in all these 1411 towns and the electricity customers have multiple options to make their payments. There are also Customer Care Centers at strategic locations and interactive Customer Portals. Discoms have regular interactions with their customers on – meter reading, bill distribution, payment collection, attending to complaints, information on planned outages etc. Large number of customers are already using the Customer Portals. All water and gas customers are electricity customers also. The Billing and CRM systems of the electricity Discoms can be used for collection of water and gas bills, house taxes and other municipal dues, and can even be extended to private utilities such as cable TV, internet, telephone, etc. This not only reduces the overall collection cost, but also facilitates higher compliance in timely payment. One integrated bill for all services is much easier for the customers to make payment on time rather than paying multiple utility bills in different locations/platforms. In this scenario a customer cannot default or delay payment of any one service because all his/her services would be disconnected if the combined bill is not paid on time which will drastically improve the cash flow of all utilities.

- SCADA/DMS System: For larger towns with population of 400,000 people and above (about 78 towns), Discoms are implementing SCADA/DMS systems for monitoring and controlling the real-time power flows. The field infrastructure and dedicated communication bandwidth for SCADA/ DMS can be leveraged to automate the water and gas supply networks as well at marginal cost. The dedicated communication network of SCADA/DMS of electricity network can be shared with traffic and security cameras as well.
- Common Command and Control Center: Under R-APDRP, Customer Care Centers (CCC) have been setup in all the 1411 towns. These CCCs can be upgraded as Common Command and Control Center (CCCC) of a smart city that can handle the complaints from customers for all their grievances related to electricity, water, gas, internet etc. The incoming calls (on single number) can be diverted to the respective teams responsible for each domain and their crew through IVR. The IT and communication infrastructure and cost can be hugely optimized. It will boost customer satisfaction to a great extent as they do not have to knock at different doors for each service.
- Outage Management Systems (OMS) and Mobile Workforce Management (MWFM): OMS and MWFM of the electric utility can be shared with water, gas and internet/ other services providers in a city.
- Application Integration: All the applications of all interconnected domains can be integrated and the data can be shared and dashboards can be made available to operators, managers and policy makers to effectively plan and manage the city.

17.5 STANDARD FRAMEWORK FOR SMART CITIES

ISGF has studied various domains and sub domains of Smart Cities and designed an exhaustive matrix depicting the interdependency of each of these domains on other domains. Each domain can achieve its described features with the help of technology enablers relevant to all the domains. Four main Smart Cities Pillars are:

- Physical Infrastructure
- Institutional Infrastructure
- Social Infrastructure
- Economical Infrastructure

Each pillar can be divided into domains and sub-domains.

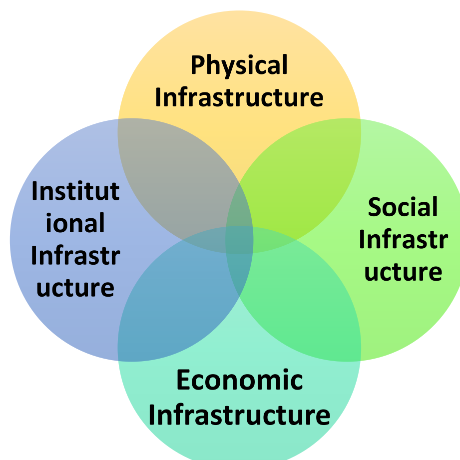

Figure 17-1: Smart City Infrastructure Pillars

Key technology enablers for the infrastructure are:

- GIS (Digital Map)
- Instrumentation and Control
- ICT
- Interoperability
- Cyber-Physical Security

- Data Management
- Analytics
- Planning and Modelling Tools
- Environment Friendliness
- Citizen Engagement and Participation
- Governance

Sample of the Interdependency Matrix is as follow:

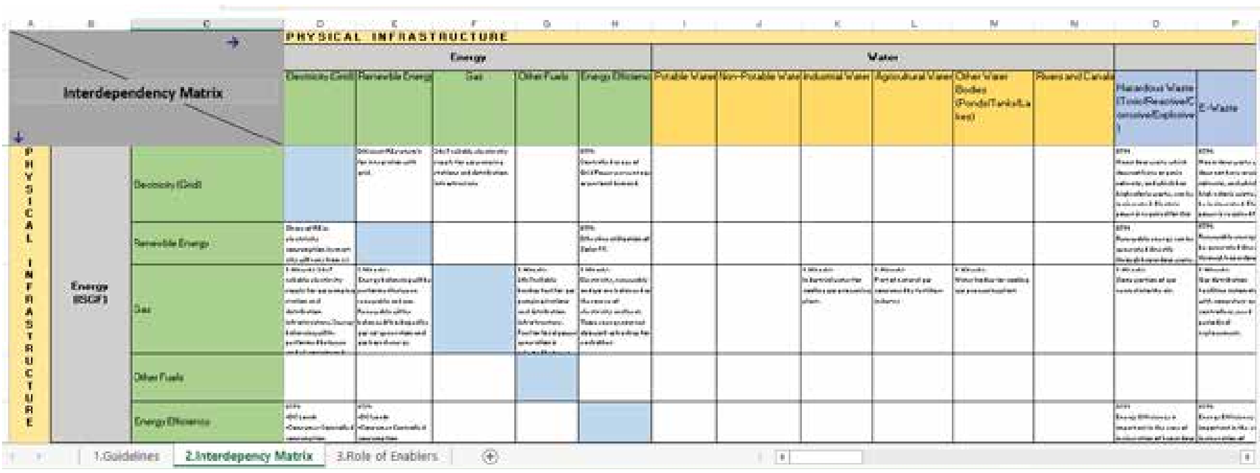

Figure 17-2: Smart Cities Domain Interdependency Matrix

Each cell of the matrix describes “what is the interdependency of respective domain with other domains”. For example a smart city with 24x7 water supply would require reliable electricity supply; and what the electricity grid should do to achieve reliable supply to all water pumping stations can be described. Certain technology enablers can be common to multiple domains.

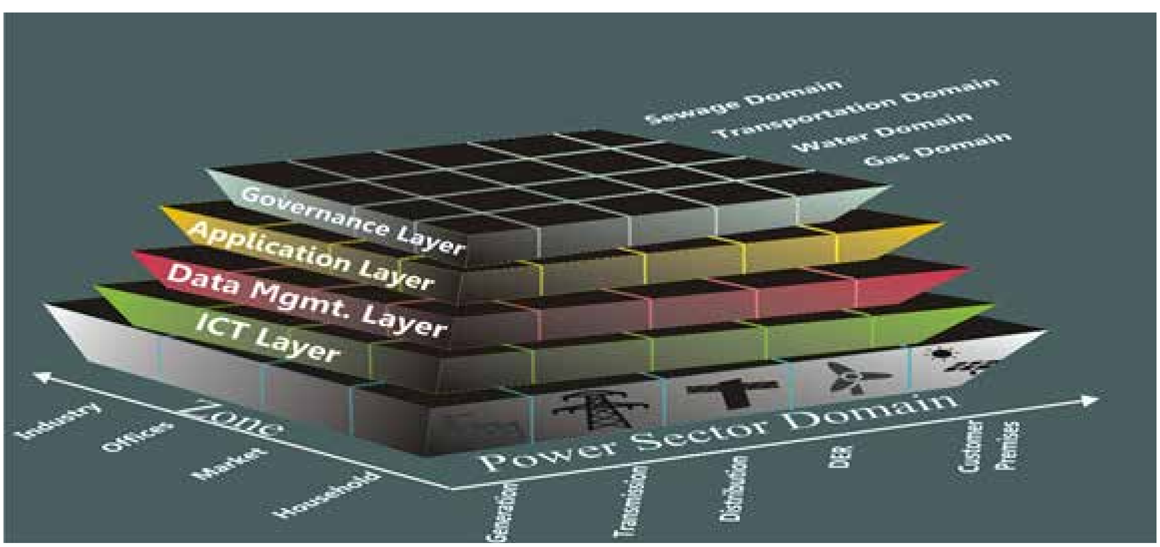

Figure 17-3: Interdependency of Domains

Table 17-1: Detailed list of Infrastructure Pillars/Domains/Sub-domains

Sr. No.	Pillar	Domain Name	Sub-domain Name
A.	Physical Infrastructure	Energy	1. Electricity 2. Renewable Energy 3. Gas 4. Other Fuels (cooking, heating, manufacturing) 5. Energy Efficiency
		Water	6. Potable Water 7. Non-Potable Water 8. Industrial Water 9. Agricultural Water 10. Other Water Bodies (Ponds/Tanks/Lakes) 11. Rivers and Canals
		Waste	12. Hazardous Waste (Toxic/Reactive/Corrosive/Explosive) 13. E-Waste 14. Medical/Bio-medical Waste 15. Sanitation & Sewage 16. Radioactive Waste 17. Rain Water/Storm Water/Drainage 18. Municipal Solid Waste (Incl. Religious Waste)
		Transportation	19. Road/Rail/Metro/Tram/Multimodal 20. Water 21. Air 22. Electric Vehicles
		Buildings and Markets	23. Residential 24. Commercial 25. Industrial 26. Shopping Malls 27. Market Places/Mandis 28. E-Commerce Infrastructure 29. EV charging stations 30. Parking Lots

Sr. No.	Pillar	Domain Name	Sub-domain Name
		Communication	31. Voice 32. Data (Incl. M2M & IoT) 33. Video 34. Post & Courier
		City Command and Control Centre	35. Common Command and Control Room 36. Weather & Events Forecasting
B.	Institutional Infrastructure	Governance Transparency & Accountability	37. E-Governance 38. Service Delivery
		Security	39. Physical Security 40. Cyber Security 41. Policing 42. Surveillance
		Emergency Services	43. Fire 44. Ambulance 45. Disaster Management
		Enforcement	46. Policing
		Planning	47. GIS 48. Modelling Tools 49. Data Collection and Analytics
		Legal	50. Court 51. Legal Cells 52. Prison/Juvenile Centres
		Environment	53. Environmental Sustainability
C.	Social Infrastructure	Education	54. Primary Education 55. Higher Education 56. UGs/PGs/PHDs 57. Research Institution 58. E-learning 59. Adult Literacy Centres 60. Vocational Training

Sr. No.	Pillar	Domain Name	Sub-domain Name
		Health	61. Primary Healthcare Centers 62. Super Specialty hospitals 63. Mobile Health care services 64. Emergency Health care services 65. Preventive Vaccination 66. Child Mortality rate 67. E-Healthcare
		Religious And Culture	68. Public Parks 69. Recreation Clubs 70. Theatre and Auditoriums 71. Places of Worship
		Sports Recreation & Entertainment	72. Playgrounds/Gardens 73. Sports Academies/Training Centres 74. Training Centres
		Innovation	75. Culture inspiring Innovation, Development of Clusters
		Peoples participation in decision making	76. RWAs 77. Complaint/Suggestion Review 78. Feedback Collection
		Citizen Advisory Committees	79. Women/Children Welfare Bodies
D.	Economic Infrastructure	Economy	80. GDP 81. Job Creation 82. Incubation Centers 83. Government Institutions 84. Livelihood Activities 85. Market Growth
		Finance	86. Banking 87. Micro Finance 88. FDI & FII Investors

17.6 SMART CITY MATURITY MODEL (SCMM)

ISGF studied the ISO 37120 standard which specifies the benchmarking points for various themes/domains and is working to design a Standard Benchmarking Framework for Smart Cities called the Smart City Maturity Model (SCMM). In the SCMM, the levels of maturity of a city in each of the above city domains/ sub-domains will be defined with clearly measurable characteristics. This can be an effective tool for assessing the "AS-IS" state of a city in each of the domains. Once the "AS-IS" state is surveyed/evaluated, the stakeholders can decide where the city should focus on improving its infrastructure and services based on the long term vision for the city. Once the "TO-BE" state is defined for the city in each of the infrastructure domains and services, it will be possible to prepare a transformation roadmap for the city and plan projects in each domain in a phased manner and also undertake cost-benefit analysis for each of those projects. SCMM is being developed on the basis of Smart Grid Maturity Model (SGMM) maintained by the Software Engineering Institute at Carnegie Melon University. This tool would help in order to prioritize and plan activities and develop a roadmap for building smarter cities and it would bring the competitiveness, sustainability and better quality of life in these Smart Cities.

17.7 CONCLUSION

The concept of a Smart City is gaining popularity, but the main challenge becomes how to start the process, and coordinate it. Instead of treating this as an IT project, it makes sense to anchor this around Energy and Power, for the following reasons:

- Information Technology (IT) is an enabler, a means to an end. The services and outcomes are really the end-goal
- Power is a critical human need, and spans the entire multitude of operational, logistical, and philosophical needs for public utilities and services. It is neither as profitable as telecom, nor as loss-making as water/sewerage. It is neither entirely a public good (basic human right) like water, nor a purely commercial commodity
- The scale and scope of both power and underlying efforts (from R-APDRP to Smart Grids) make this utility a logical anchor for all other functionalities

Smart Grid can become the anchor of Smart Cities to accelerate the development of liveable, workable and sustainable eco system in cities. Renewable energy is the key to build sustainable future which will enable green energy consumption in Smart Cities. Standard Framework for Smart Cities would help in understanding the interdependencies of various domains and better planning. Smart City Maturity Model would map and benchmark various domains in the City and offer a framework to develop the roadmap for transformation from AS-IS state to TO-BE state in a phased manner.

APPENDIX

BASICS OF ELECTRIC POWER SYSTEM

The generation of Electricity, its transmission and distribution, is such a complex process that most people don't have much idea on what goes on behind the scenes to bring electricity to our homes, factories or offices, wherever required. This appendix serves to provide the foundations of the electrical power systems to those with little or even no background in the area. We will first focus on the technical points involved and then subsequently provide a brief overview of system planning. We would like to keep the discussion as general as possible and covering the most fundamental aspects, not focussing on a particular region or country as there are minor differences in the structure, operation and planning of power systems across the globe.

THE BASICS OF ELECTRICAL POWER

To understand electric power systems we need to have a basic understanding of the various terminologies. Electrical power has some basic terms like voltage, current, impedance, power factor, reactance, power, energy etc.

VOLTAGE

Voltage is measured between 2 points and is the difference in the electric potential between those points. It is analogous to water flowing in a closed pipe driven by a pump. If there is a pressure difference between 2 points the water will flow from high pressure to low pressure. Now this flowing water can perform useful work such as drive a mini turbine etc. Same is the case with the phenomenon of voltage. Current flows from high to low potential which can then drive electrical loads such as fans, lights, compressors etc. Voltage is measured in Volts (V). For larger values, kilovolts (kV) and Megavolts (MV) are used.

CURRENT

The electric current is the flow of electric charge. It is the rate of flow of charge through a conductor. The unit of current is Ampere (A). Current flows when there is a voltage difference between 2 points.

Current can be of 2 types: AC (Alternating Current) and DC (Direct Current)

DC is unidirectional. It flows in only a single direction and 1 point is always at a higher potential than the other point.

On the other hand, in AC the current flows bi-directionally and the higher and lower potential points keep on switching amongst themselves. Hence we can say that the voltage keeps reversing polarity continuously. Alternating currents and voltages in power systems are generally sinusoidal in nature.

Mathematically, voltage and current are characterised by primarily 3 parameters namely, amplitude, frequency and phase. The maximum value of the waveform is called as the amplitude. Since AC is variable, hence it is more useful to express the AC waveform in to its equivalent DC which is done by using the RMS (Root Mean Square) value. It is the equivalent DC voltage with the capacity to perform the same amount of work.

Frequency is the rate of polarity reversal in an AC waveform. The unit of frequency is hertz (Hz) – number of periods in one sec, where period is defined in the figure below. DC has a frequency equal to zero since no polarity reversal is involved in DC. AC can take any frequency depending on the speed of its pulsations. Nevertheless, power systems in India employ 50 Hz as the grid frequency. On the other hand US, parts of South America and Japan use 60 Hz frequency.

The AC waveform takes a specific amount of time to switch from 1 polarity to the other and back again. This time duration is called as the 'period'. It is the inverse of frequency. The phase of the waveform is the measure of when the waveform crosses the zero point relative to some reference waveform. It is expressed in degrees or radians and it ranges from -180 to +180.

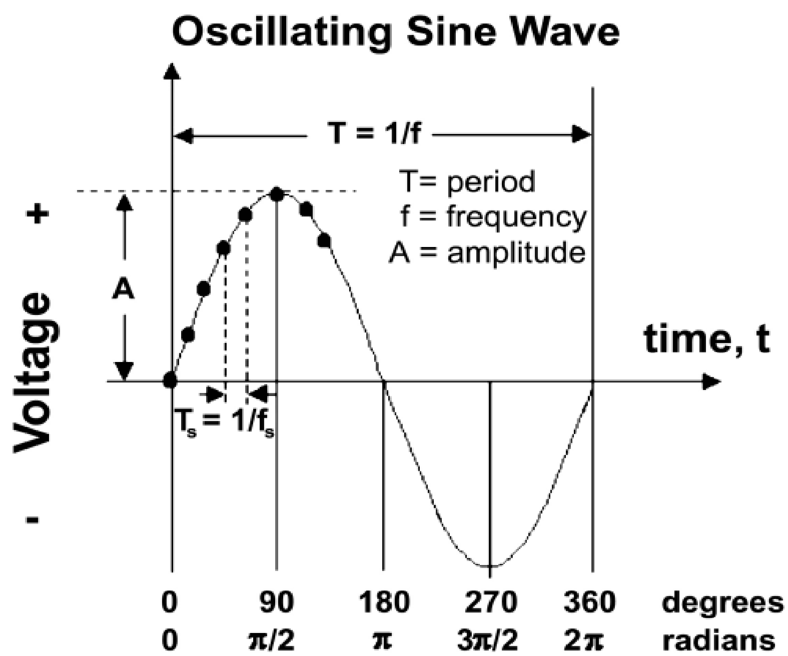

Figure 1: Amplitude, Frequency and Phase of an Alternating Current and Voltage[1]

Electric power systems are normally AC apart from a few sections of the line. The main advantage with AC is that its voltage levels can be varied using transformers. Changing voltage levels of DC is difficult as it involves expensive and complicated power electronics equipment. However, DC systems in the form of HVDC (High Voltage Direct Current) transmission are employed if the electricity is to be transmitted to very long distances.

RESISTANCE

Resistance is the property of the conductor to resist the flow of electrons or the current through it. The wires engaged in the power system have a resistance associated with them. The resistance varies directly with the line length and varies inversely with the cross sectional area of the conductor. Moving charges with the conductor collide with the conductor atoms producing heat loss in the line. The rate of energy loss is equal to square of RMS current times the value of resistance. Unit of resistance is ohm - higher units are kilo Ohms or Mega Ohms.

REACTANCE

Reactance is the measure of obstruction caused by the magnetic and electric fields formed due to the voltages and currents. Reactance doesn't cause power loss but the energy is stored in the fields. This energy keeps sloshing back and forth between the source and the line and thus no useful work is done by this energy. Reactance is a function of frequency. In case of Energy in the form of magnetic fields, the element is said to have "inductive reactance" while in energy in the form of electric fields causes "capacitive reactance". Inductive reactance causes the current to lag the voltage but capacitive reactance causes the current to lead the voltage. The impedance of the line is basically inductive, which causes the current to lag the voltage. To avoid this undesirable behaviour the capacitors are connected to the line to nullify the effect of inductance in distribution systems. This is known as "line compensation". The reactance of the line poses a limit on the power transfer capability of the line in addition to reducing its power factor. DC has zero reactance hence making it a viable alternative in case of very long distance transmission.

Long high voltage transmission line has significant amount of capacitance between the phases, and the phases and ground which requires shunt compensation in the form of reactances (known as reactors) at the end of the line.   Unit of reactance is Ohms - higher units are kilo Ohms or Mega Ohms.

IMPEDANCE

Impedance has 2 components – resistance and reactance. The unit of impedance is ohms. Impedance is the resistance offered by the conducting device or the line (in case of ac power systems) to the flow of current. High impedance means more resistance and low impedance means less resistance to the current flow. Unit of impedance is Ohms - higher units are kilo Ohms or Mega Ohms.

POWER

Power is the rate of doing work or the rate of flow of energy. The product of voltage and current gives us the power or accurately the instantaneous power. High voltage is used in modern power systems to reduce the resistance losses as less current is to be transmitted for same amount of power. The voltages and currents in ac systems are variable i.e. their values keep changing constantly. So we have to average the power over numerous cycles to get an idea of how much power is flowing in the system. These measures are called real power, reactive power and apparent power. Apparent power is the resultant of both the real and reactive power.

REAL POWER

Real power or active power is the power that does some useful work and produces a tangible result. In real power the phase difference between voltage and current is zero hence the power flows in only one direction. Unit of real power is Watt (W). Higher units are Killowatts (kW) or Megawatts (MW).

REACTIVE POWER

If the phase difference between voltage and current is non zero then there is a reactive power component associated with it. Pure reactive power is when the phase difference between voltage and current is 90 degrees. This phase difference is induced due to the reactance of the line and the power flow is bidirectional i.e. the energy keeps sloshing back and forth between the source and fields. The sign of the reactive power indicates the relative phase difference between the current and voltage. By convention, reactive power is positive when the current lags the voltage and is negative when the current leads the voltage. Reactive power compensation is done in power systems because it is undesirable for the power system as it puts unnecessary burden on the line and reduces its power transfer capability. Unit of reactive power is Var -Higher units are KiloWatts (kW) or MegaWatts (MW).

APPARENT POWER

Apparent power is the combination of active and reactive power. Most of the equipment are rated on apparent power because it is the total power they have to handle. Apparent power is measured in VA (Volt Ampere). Higher units are Kilo Volt Ampere (kVA) or Mega Volt Ampere (MVA)

POWER FACTOR

Power factor gives a quantitative idea of how much real and reactive power is present in the system. The ratio of real and apparent power gives us the power factor. It is desirable to keep the power factor close to one (unity) as it signifies more real and less reactive power in the system. Note that power factor is a ratio and hence a dimensionless quantity.

ENERGY

Energy is defined as the capacity for doing work. Energy can't be created or destroyed and can only be transformed from one form to the other eg. Sunlight is converted into electricity by solar photovoltaic panels which in turn can be converted into a usable form such as heat, light, sound etc. The unit of energy is Joule but in electrical power systems and for more practical purposes KWh is the most widely used unit. 1 KWh is equivalent to 3.6 × 106 Joules. 1 KWh is said to be dissipated when 1 KW of power is consumed for a 1 hour duration. For larger values Mega, Giga and Tera watt hour are also used. Smaller unit of energy is Watt hour (Wh) – one watt of power is consumed for 1 hour duration.

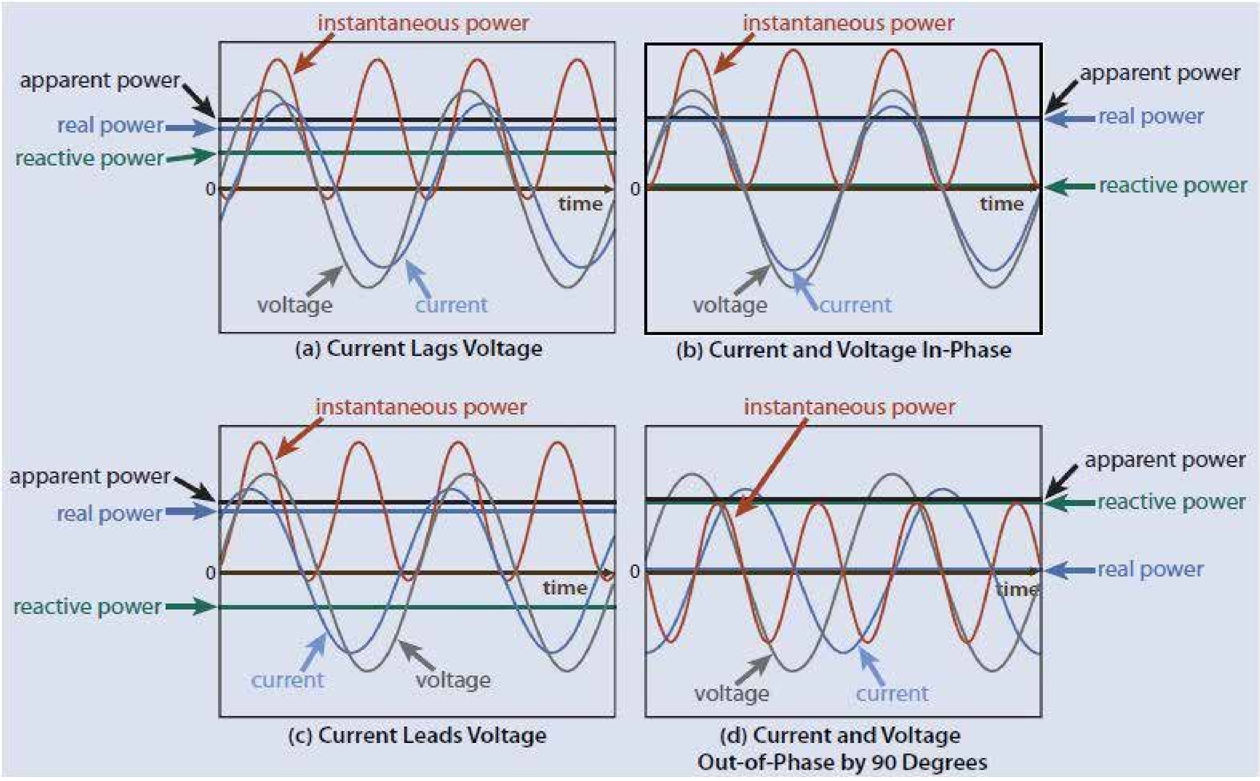

Figure2: Current, Voltage and Power in AC System [2]

STRUCTURE OF THE ELECTRIC POWER SYSTEM

Modern electric power systems consists of large or centralised generating unit which generate electricity in scales of megawatts. These generating stations are normally located in isolated areas which are far from load centres hence there arises a need to transport the generated power to the load centres which actually utilise this power for various purposes. Modern power systems have evolved as a highly interconnected and complex systems which cover large areas. These allow economies of scale, better utilisation of economical generators and improve the reliability of the overall systems. Although, such interconnections are not all advantageous because a slight variation in one part of the system affects the system as a whole. We now discuss each of the subsystem separately which form part of the power system.

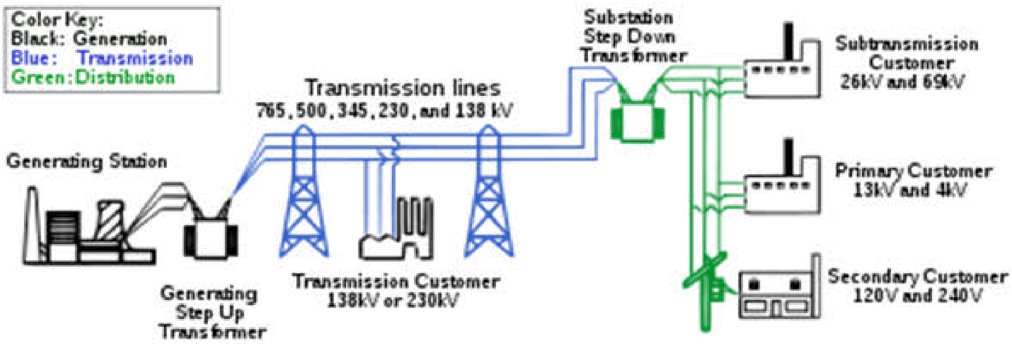

Figure 3: Structure of Power Systems [3]

GENERATION

Electric power is produced by various generating stations which convert primary energy to electrical energy. Primary energy comes from a number of sources like fossil fuels, nuclear, solar, wind, hydro etc. In thermal power generating units fuel is used to convert the chemical energy stored in the fuel to heat energy and then use the heat to drive a turbine using the high pressure heat. The generators used are 3 phase generators producing 3 phase electricity. The 3 phases employed are 120 degrees apart from each other.

3 phase power has many advantages over single phase power. It requires less conducting material, and has the advantage of uniform power i.e. the power is not pulsating like in case of single phase power but is a constant value.

Hydro energy and wind energy convert the kinetic energy of water and wind into electrical energy using a turbine which is connected to a generator. Nuclear power units are just like thermal power units the difference being in just the fuel i.e. in nuclear energy units the fuel used is uranium or plutonium. Solar thermal and geothermal units directly convert the energy of sun into heat. The heat produced is used to heat a working fluid and subsequently run a turbine connected to an alternator which convert the energy of sun directly into electricity. Solar PV modules or arrays are another source of energy which directly convert the energy of sun into electricity. Gas based units are the units which produce heat by cracking of gases such as natural gas etc. and then follow processes similar to thermal power plants. Combined cycle gas turbine plants are an extension of gas turbine power plants in which the waste heat from gas turbine is also used for heating or power generation applications.

From the operation viewpoint, the generating units are classified into 3 categories: baseload, intermediate and peaking units. Baseload units supply base power or the average demand which is required by the system. They are more economical to operate because they run continuously except in cases of emergency or operation and maintenance purposes. However they are slow in varying their output power and involve high capital expenditure during their building phase.

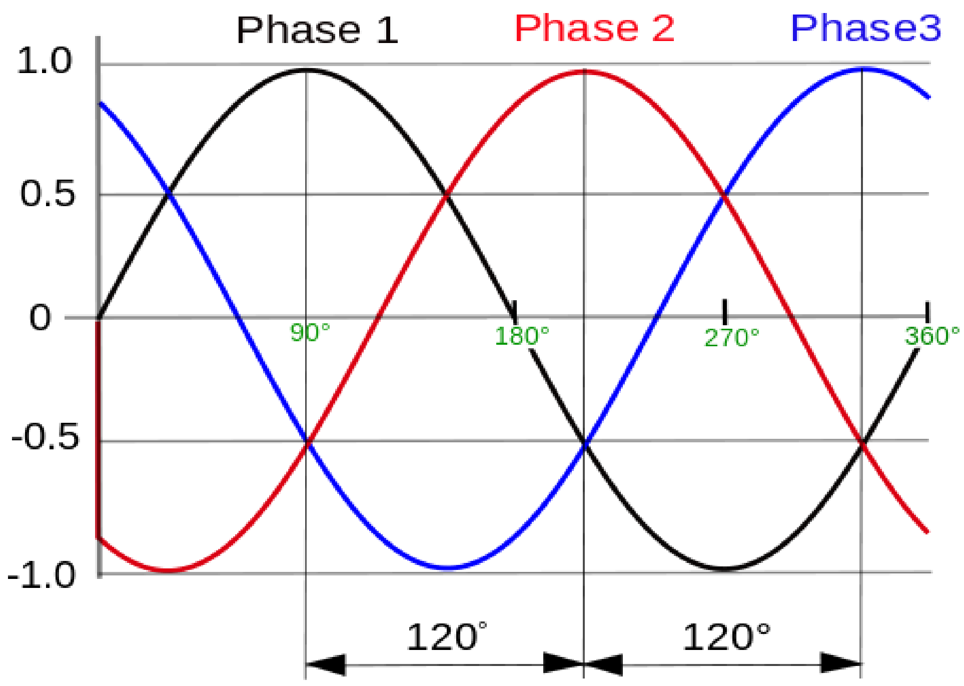

Figure 4: Three Phase System Waveforms[4]

Intermediate units are generally smaller power generating units which operate on lengthy periods of time. In such installations the power output can be varied more quickly than the baseload plants. They are generally the old thermal power plants and combined cycle power plants which operate as intermediate units.

Peak load units are the units which operate in cases when the peak demand is to be met. The power demand is generally not constant and varies constantly. Sometimes the power demand escalates much above the average demand and then peak load power units come into play. They can be switched on or switched off within minutes in order to supply the balance power. But they are expensive to operate as they have high running costs. Gas turbine power plants and hydroelectric plants with reservoir are usually used as peak load plants.

The three phase power produced by various generation technologies has to be transported to the load centres which are far away with as little losses as possible. This is done by stepping up the voltage to a few hundred volts by using three phase transformers. In addition to these centralized generation sources, there are distributed generation sources also which generate power at low voltages. They are normally single phase and are connected at the distribution system level. The most popular example of such sources include solar photovoltaic systems.

TRANSMISSION [2]

The purpose of the transmission system is to transport the power produced from the points of generation to the points of actual use. A typical transmission system primarily consists of long transmission lines and substations. The substation houses transformers, switchgears, measuring instruments and communication equipment. Transmission lines are generally installed on high towers but in very congested places underground cables can also be laid. Transformers are used to change the voltage levels while switchgears consists of circuit breakers and other protection equipment to isolate the system in case of faults. Measurement instruments record the various data like the phase and line voltages, currents, power for monitoring and control purposes. Additionally, the communication equipment are also present for transmission of data to control centres and for remote controlling purposes.

Since transmission system is simply a power transport system hence it is desired that the efficiency of the system has to be very high. Hence to minimise losses in the line the transmission voltage is kept as high as possible. But higher transmission voltage means better insulation and larger clearances from various structures and earth in order to maintain safety. Transmission systems are 3 phase systems - transmission voltages are of the order of 110 KV and above. Lower voltages like 33 KV and 66 KV are used at sub-transmission levels. Voltages lesser than 33 KV are used for distribution. Very high DC voltages are also employed for transmission purposes when the distance at which power has to be transmitted is very large. They are called HVDC (High Voltage Direct Current) systems. They are Direct Current systems and hence require only 2 conductors instead of 3 in case of three phase systems. They have lower losses as the reactance is zero in DC. Also, no reactive compensation is required in DC systems because of the zero reactance. But HVDC requires high capital expenditure as complex power electronic circuitry and converter-inverter systems are employed to covert AC to Dc and then back into AC. Another application of HVDC systems is that they are also used in places where 2 systems with different frequencies have to be interconnected together.

Transformers connect the high voltage transmission system to the medium voltage sub-transmission system and also the sub-transmission system to the low voltage distribution system. Transmission system carry power over very long distances from the power plants to the sub transmission system. Sub transmission systems are the connecting link between the transmission and distribution systems. Transmission systems and sub transmission systems are mesh networks (multiple paths between any 2 points) and not radial in nature. Hence power can flow from any point to any point because of the multiple routes. This increased redundancy in the network is desirable because it improves the reliability of the system as the power can flow to the desired point even if a line connecting to that point is out. But on the other hand the system as a whole becomes complicated and it becomes very difficult to precisely track of each and every power flow on each line in the network. The presence of multiple paths also leads to undesirable flows which are called as “loop flows”.

The power that can be transmitted over the line is influenced by 3 important factors, viz. thermal, voltage and transient stability constraints. The Thermal voltage constraint means that the power flow across the line is limited by heat losses i.e. the heat losses must not exceed a certain limit. Voltage stability constraint is that the voltage at the receiving end must not sag or decrease below a certain voltage if the power flow increases above a level. The transient stability constraint is the capability of the line to cater to fast changes in power flows and its ability to resist the loss of synchronism of the generators attached to it. Normally the power flow on short transmission lines is limited by thermal limits and on transmission and sub-transmission lines by voltage and transient stability limits. Due to these limits, sometimes power can’t be transmitted to loads because of the congestion in line.

This situation generally occurs in peak hour periods and it is easy to observe that the installation of more peak load plants wouldn't help in such a case. Therefore the development of power infrastructure should be in line with the increase in installation of power plants in order to serve the consumers in an effective way.

DISTRIBUTION [2]

Distribution systems are the ones that carry the power to our homes or to the places where we need the power. They are characterised by their low voltage levels and their radial topology. The voltage from sub transmission systems is stepped down to the distribution system voltage levels by distribution transformers. Distribution substations also isolate the faults in the transmission and sub-transmission systems. Distribution substations also regulate the voltage and compensate the voltage drop across the line. In order to connect the consumer/load ends with the substations we have Feeders. Feeders start from the distribution substations and connect the consumer area with the substations. Distribution substation. They carry 3 phase voltages but the consumers are connected at single phase as the power from individual phases is distributed in the area.

Distribution networks can have different topologies, such as either radial or ring topology. In a radial system each node or consumer in the network is connected to the system through a single link only. On the other hand in a ring topology there are 2 paths to connect to a consumer. This is beneficial as it would not let power interruption even if one of the lines is down for maintenance or emergency reasons. But this increases the redundancy in an already complex system. If this process of system isolation and maintenance is made automatic then this is called as "self healing". Distribution networks are designed assuming a unidirectional power flow but this approach would have to be changed because of the increasing penetration by distributed generation sources.

Commercial and Industrial users require a large amount of power, hence they get power from 3 phase transmission system instead of the single phase distribution system. In India the voltage levels at 11 KV are stepped down to 415 V to feed the individual 3 phase consumers or at 240 V to feed the individual consumers. This stepping down of voltage is done by the distribution transformers where each transformer feeds a number of homes.

CONSUMPTION

We use electricity for so many different kinds of loads like lights, fans, heating and cooling appliances, electronic equipment, motors etc. These different types of loads are classified according to their impedance i.e. resistive, inductive and capacitive. However, most of the loads are purely resistive in nature (especially the heating appliances) or a combination of the resistive and reactive element. The reactive element can be both inductive or capacitive in nature. Such partly resistive loads consume both the active and reactive power hence the power generator has to supply the required reactive VARs apart from the real power. This puts unnecessary burden over the generators and transmission network as it reduces its power transfer capability. Motor loads are predominantly inductive in nature hence they draw a lot of reactive power. . In order to cancel these undesirable reactive power, , capacitors have to be installed at the load end as it is better to generate and supply the reactive power at the load end itself rather than supplying it from the power system.

Load Duration curve is the graphical representation of the variation in energy demand of the consumers with respect to time. If it is plotted on a time period of 24 hours it is known as the daily load curve. But it can be plotted weekly, monthly, yearly or even on an hourly basis also depending on the requirement. The area under the load duration curve shows the total energy consumed by the system. The Load Duration Curve gives an insight into the load profile or the number of hours it is above a particular value. It gives an idea about the peak load and average load of the system using which the load factor can be calculated.

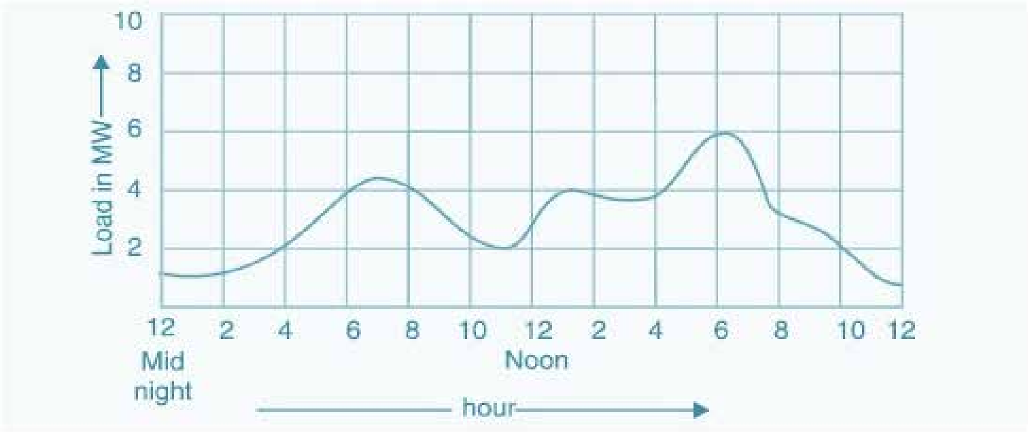

Figure 5: Load Duration Curve [5]

POWER FLOW CONTROL

The power flow in transmission line occurs according to Kirchhoff's laws. The power flow in the transmission line depends upon 2 important factors, the impedance of the line and the voltage difference between 2 points. The resistance of the line accounts for the power lost in the line and the reactance accounts for the power trapped in the line and which does not perform any useful work. This power is trapped in the line because of the electric and magnetic fields present in the line and keeps oscillating back and forth between the line and the generators. The resistance of the line depend upon the length, cross section and the properties of the conductor while the reactance depends upon the geometric properties of the line relative to each other and ground. Generally the resistance of the line is very small or negligible with respect to the reactance of the line.

Another factor which influences the power flow through the line is the voltage difference between the sending and receiving points. There is a difference in the voltage levels at senders and receivers end only if there is a phase difference between the voltages at the senders and receivers end because voltages at both the ends are kept as regulated as possible. Hence by increasing the phase difference between the sender and receiver end the power flow can be increased or decreased as the instantaneous voltage difference is varied by varying the phase. If the 2 voltages are in phase i.e. 0o phase difference, then no transfer of power occurs between both the ends. But this transfer of power can be increased upto a specified limit only i.e. the maximum phase difference between both the ends can be upto 90o. If the phase difference is increased above this value, the system may fall out of synchronism with the generators.

Power flow in the line varies directly with the sine of the phase difference and varies inversely with the impedance. Devices in general vary these 2 parameters in order to vary the power flow in the line. Power flow calculations in general are done by using advanced methods and calculations because the characteristics of the entire network collectively determines the power flows.

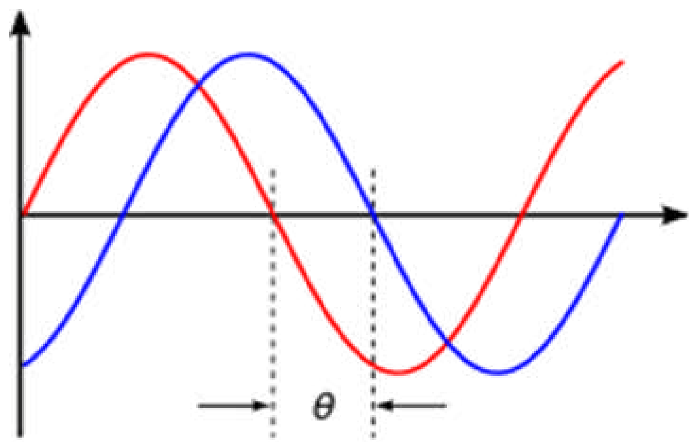

Figure 6: Phase Angle Difference of Sinusoids at Sending & Receiving ends of Transmission lines [6]

OPERATION OF ELECTRIC POWER SYSTEM [2]

The biggest challenge in operating the power system is maintaining the balance between generation and the load. The load is fluctuating and it keeps changing all the time. The balance between generation and load is maintained by using different control schemes which are enumerated under.

Protection

Protection is a very important aspect of the power system. It plays the very important role of protecting the expensive equipment and circuitry present in the power systems. Protective actions are taken within fractions of seconds in order to avoid equipment damage and human injuries. Relays and circuit breakers are employed to sense abnormal changes in currents and voltages and to open the switches if the need arises. Once the fault in the system is fixed the previously faulty section can be readily brought online by closing the circuit breakers. Now-a-days computers are also used widely in the decision making process for taking the best corrective action for each different case.

Real-time Operation

Real-time Operation of electric power systems plays an integral part in ensuring the demand and supply power balance in the electric power system. If this balance is not maintained, the frequency and voltage of the system can increase or decrease drastically and wreak havoc on the system. This change in the crucial parameters can damage the system equipment as they are not rated to run at such varying ranges of voltage and frequency. This problem can be tackled by the inertia of the system i.e. the generators connected to the system can speed up or slow down for brief periods of time providing a “ride-through” capability which provides enough time for the system controls to take over. This short time balance is maintained by governor control.

Governor Control

This is the first control which comes into the picture if an unbalance in supply and demand arises in the power system. The governor controls the amount of mechanical power driving the generator via the valve limiting the steam/water input into the turbine. The governor control reacts on changes in system frequency which in India is 50 Hz. If the electrical load is more than the mechanical energy supplied to the system, the generator slows down while giving some of its stored kinetic energy to the system. On the contrary if the mechanical energy is more than the electrical load present in the system, the generator speeds up storing some energy in the form of kinetic energy. This speeding up or slowing down of the generator is the cause of increase or decrease in system frequency which is undesirable in general but provides a decent indication regarding the system unbalance and corrective actions can be taken to open or close the valve in order to increase or decrease the input energy in the system. This error in frequency is controlled by Automatic Generation Control (AGC). Which is covered later briefly.

Voltage Control

Just like the difference in generation and supply of real power causes frequency changes, the imbalance of reactive power in the system causes changes in voltages. If the reactive power consumption of the load increases without much change in the supply of reactive power, the voltage in the system starts to decrease and if more than required reactive power is supplied by the generator the voltage in the system begins to rise. This imbalance in reactive power can be countered by changing the rotor flux by changing the rotor current or by employing capacitors, STATCOMs or another reactive power compensators at the load end in order to supply or absorb the requisite reactive power. Voltage control is a very fast control.

Automatic Generation Control

The governor control is a relatively faster control and leads to a change in system frequency for a short time. Hence the error in frequency and power flow between the control areas is controlled by somewhat slower Automatic Generation Control (AGC). The aim of AGC is to reduce the Area Control Error (ACE). ACE defines the error in system frequency and the difference between scheduled and actual power flows in the area. If the value of ACE is positive, it means that if the generation within the area is more than the load then the generation in that area needs to be reduced. On the other hand, if the value of ACE is a negative one then the generation needs to be increased in that particular area. The requisite signals are sent by area control centres to the generators for varying their generation accordingly.

Reserves

Reserves are the additional generating units in a standby mode in order to counter the uncertainties in power generation within the power system. These supply power when one of the generating station fails or is under maintenance. They are categorised by the time they take to start up their requested power supply. They are either spinning or non-spinning reserves. Spinning reserves are the one which are fully in synchronism with grid frequency but deliver power to the grid only when required. They are fast and enter into operation very fast. Conversely, non-spinning reserves are the ones which are offline and hence may take some time to start before they start feeding power to the grid.

SCHEDULING

Scheduling is the determination of which generation units should operate in the power system and at what power level in order to minimise the cost subject to the power generation and transmission constraints. Scheduling comprises of economic dispatch and unit commitment.

Economic Dispatch [7]

Economic Dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, subject to transmission and operational constraints. These optimised power levels are determined by computer run optimisation algorithms which constantly determine the dispatch for some future time frame and subsequently send these to power generators. Economic dispatch is not an essential requirement in a power system as sometimes power cannot be dispatched economically due to the physical restrictions or security constraints.

Unit Commitment [8]

The Unit Commitment problem (UC) in electrical power production is a large family of mathematical optimization problems where the production of a set of electrical generators is coordinated in order to achieve some common target, usually to either match the energy demand at minimum cost or maximize revenues from energy production. It is not a great idea to keep all the units online all the time because of the costs associated with them. UC problem determines when the generating stations should start up and shut down and the amount of power they should produce when they are online. UC is more complex than the Economic Dispatch and may cover dispatch forecasts from a few hours to few days.

WHOLESALE ELECTRICITY MARKETS [2]

An electricity market is a system enabling purchases, through bids to buy; sales, through offers to sell; and short-term trades, generally in the form of financial or obligation swaps. The process begins by the generators offering an amount of energy for sale during specific periods during the day for the upcoming day at a specific price. These are then arranged in an ascending or descending order called the “bid stack” and the stacks are sold till the generation matches the load. The real process is more complicated than this and incorporates factors like time required to start the generators and security constraints. This complex process determines the marginal cost of meeting an incremental change in load at each location in the transmission system to which load or generation is connected. These are termed as “locational marginal prices” (LMPs) and are costs at which the selling or purchase transactions take place. Distribution companies or large customers pay applicable LMP for the amount of energy consumed. Likewise generation is paid LMP at the point of location in the system. The LMP pricing structure ensures that the profitable choice for generators and loads is to follow the instructions of the economic dispatch. The use of LMPs exploits the natural explanation of an effective balance for a market, utilizes the inevitable central coordination, and avoids the need for market participants to individually track transmission flows or their individual need to understand the multiple constraints and requirements of the power system.

POWER SYSTEM PLANNING

As the population, consumption pattern of various users the economy grows there is a need for proper planning of the power system. The cost associated with the construction of new generating units and transmission lines is huge and therefore the planning process involves careful analysis based on the forecasts of 10-20 years. This is typically done by planners who evaluate various options in terms of capital and operating costs for meeting the future load demand. The decision can also be influenced by Government, regulators, incentives, policies and environmental restrictions. Planning allows for the accompanying risks in the future operating costs, load forecast and technological changes.

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#NOTES

Distribution networks have different topologies in which they join the substations and their connected loads. One of the topologies is a star topology in which there is only one power flow path between the distribution substation and a particular load. Another one is a ring topology in which there are 2 power flow paths between the substation and load. Another topology which is more popular in the highly dense regions is the 'mesh topology'. This gives us the advantage during servicing and maintenance processes as because of the redundancy in power flow paths, which are multiple in number the loads can be serviced by alternate opening and closing of the circuit breakers when there is a problem in the original path. If this process occurs automatically this is called as "self-healing".

Industrial and commercial consumers use three phase power from the line for their processes from the primary distribution feeder but residential consumers use only single phase power for their processes. Hence the distribution transformer steps down the high volateg to secondary distribution level which is safe for consumers. Most residential power consumption in India occurs at 240 V, 50 Hz.

NOTES

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