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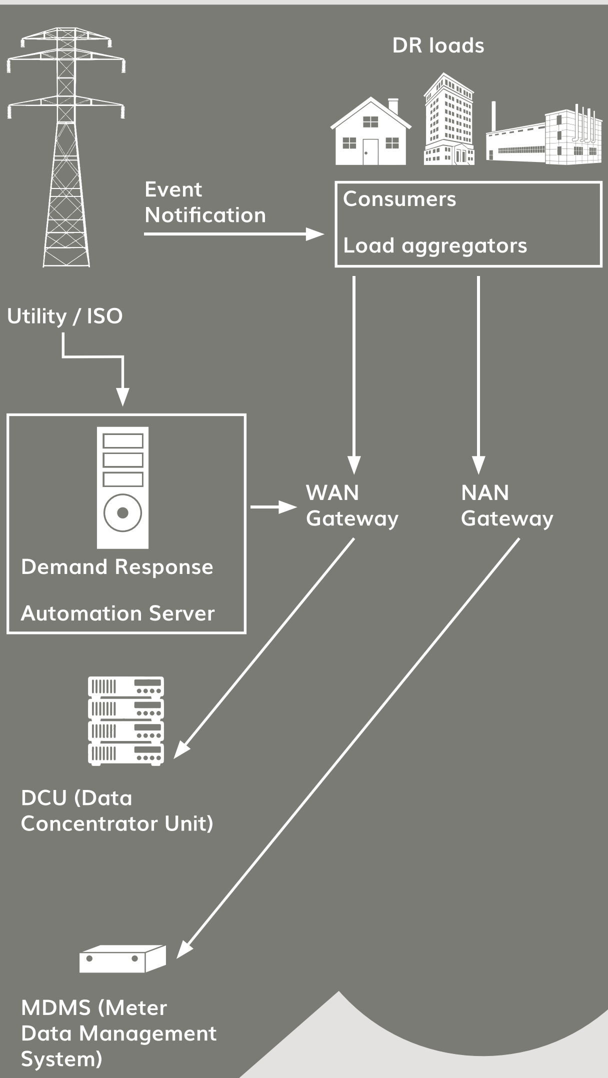
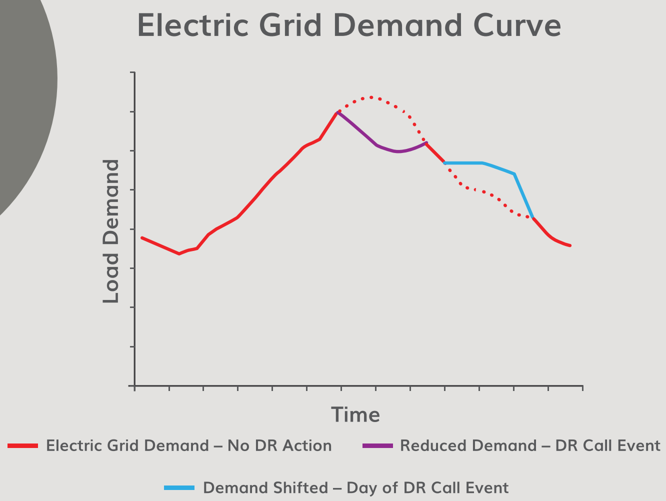
Demand Response in India



Technology Assessment, M&V Approach, and Framework for DR Implementation

2016



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Summary

Demand Response can leverage the capability of smart grid infrastructure by making the demand side more responsive to the varying gap between demand and supply. Demand Response 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 some importance as spinning reserves and frequency regulation resources. Demand response programs are designed to move the focus of power management practices away from the utility companies, and directly towards the customers. Demand response programs require a certain degree of technological readiness from the perspective of each of the stakeholders. Identification of technological credentials that would enable the implementation of demand response for a target load category is an important activity. 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.

This report is organized into three chapters. Chapter 1 provides a comprehensive insight into the various hardware and software technologies required for rolling out a Demand Response (DR) program for a particular load category. It also provides a comparative study of various communication technologies that are needed during deployment of DR program. DR strategies for some customer categories are also discussed. The significance of Measurement and Verification (M&V) practices of DR and a summary of M&V standards adopted for DR in the country and around the world is presented in chapter 2. A comprehensive case study is also presented that evaluates the performance of few standard baseline techniques by calculating and analyzing few metrics for a group of customers in Mumbai. A framework for implementation of DR in India is presented in chapter 3. This framework provides a structured approach to design and implementation of Demand Response (DR) allowing stakeholders in the planning process to keep track of the strategies, incentives and regulations developed for effective roll out of DR programs and make corrections if required.

It is hoped that this document meets its objective of facilitating the inclusion and growth of Demand Response in the power sector and serve as a map to refer the variety of DR programs implemented. The project team would like to acknowledge the support from regulatory commissions, utilities, distribution companies, designated agencies of various states in the country.

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CHAPTER 1

Technology Assessment for Demand Response in India

1.1 Introduction

Demand Response (DR) is a demand side management mechanism in which the end-users of electricity are encouraged to participate in reducing the peak load on the system by altering their normal energy consumption signatures. In return, end-users are given price or service incentives. Eventually, this process is expected to reduce the overall system peak load as end-users shift some of their loads from peak hours or high market price hours to off-peak hours or low market price hours.

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, DR has gained some currency 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 begin to be actively involved in reducing their electricity bills, and customizing their usage as per the system requirement.

A promising way to manage flexible demand is to communicate dynamic prices to the consumers and incentivize them to change their consumption amount or to shift load demand in time. This is done through price based DR programs. There also exist, incentive based DR programs that are designed by the utilities in which contracts are made with customers to increase their participation in demand adjustment during the system peak hours. These contracts specify the type and magnitude of the incentive to be provided to the customers. The incentives can be price based in which customers are given the pre-specified amount for the quantity of energy saving as mentioned in the contracts. However, some of these programs also levy penalties on the customers for violating the contracts.

Table 1.1 elaborates various DR programs under the price based and incentive based mechanism[1]. Real Time Pricing and Critical Peak Pricing are the dynamic pricing mechanisms

[1] Technology assessment of DSM in India, IIT Bombay, Shakti Sustainable Energy Foundation, June 2014

But the most significant challenges will occur due to the technological gaps that exist at the utility, aggregator and customer's site. Deployment of any DR strategy will require certain minimum infrastructure.

in which the utility continuously sends the price signal to consumers at a certain frequency. Time of Day pricing mechanism involve a day ahead or static pricing for different slabs of hours in a day. Different incentive based programs enumerated in the table detail the programs in which consumer directly and indirectly participate in the dynamic energy market. Trigger criteria for various DR program events are also listed along with the notification time window provided to the DR resources to respond to the DR signal by the Utility or aggregator. Case studies specific to the DR programs listed in Table 1.1 are also provided for reference.

Demand response has few hurdles before wide spread implementation in the existing power system. One of them is the issue of a utility company remotely controlling and monitoring power functionality which would require general public education. As customers have to actively participate in the dynamic market a minimum awareness is therefore a necessity. But the most significant challenges will occur due to the technological gaps that exist at the utility, aggregator and customer's site. Deployment of any DR strategy will require certain minimum infrastructure. This technology assessment for Demand response can equip the concerned implementing agency with the necessary information regarding technological readiness required to roll out a DR program.

The next section lays down the framework for DR implementation which can be broadly categorized into the following three categories.

- The stakeholders involved and their roles & objectives: Utility, Load aggregator & Customer.
- Technological prerequisites (Hardware/Software) at each of the involved stakeholder's facility.
- The communication tool (technology) used by these stakeholders to communicate with each other.

If appropriate consideration is given to each of the above themes, then complemented by an effective compensation mechanism for each of the stakeholders, demand response strategies can be made technically feasible and operational.

Table 1.1

Classification of Demand Response programs

DR Program Type	Description	DR event Trigger Criteria[2]	Notification time window	International Case studies[3]
	Price Based DR Mechanisms			
Time of Day (ToD)tariff	It proposes a tariff scheme that has different price slabs for usage during different periods of time. These prices are the average cost of generating the energy in the corresponding duration of the day. In this program, customers may shift some of their loads to off-peak or normal hours to reduce the net cost of energy consumption.	Triggering mechanism is the difference in tariff for off peak and peak timings of the day.	NA	17 States in India have commissioned ToD tariff till now.
Real Time Pricing (RTP)	The electricity prices vary dynamically for every demand interval based on the supply demand dynamics in the wholesale electricity market and the prices are communicated to the customers and aggregators on day-ahead or hour-ahead basis. These prices act as the basis for voluntary participation of the customers in DR.	Triggering mechanism is the dynamic electricity market prices.	NA	ISO New England. 72 MW of DR was enrolled. Dec 2009 to Jan 2012.
Critical Peak Pricing (CPP)	This is a mixed rate scheme of ToD and RTP, in which the price has three slabs. When utilities observe or anticipate high wholesale market prices or power system emergency conditions, they may call critical events during a specified time period. The price during the specified time periods is subjected to market dynamics. On other days of the year, ToD tariff is applicable.	Hot temperatures / prolonged heat waves. Loss of generating or transmission facilities. Generation unavailability (fuel shortages)	Day Ahead, Day of	San Diego Gas & Electric (SDG&E). Carried out 9 events of total 58 Hrs in 2012.
	Incentive based DR Mechanisms			
Direct Load Control	System operators such as aggregators manage the operation of the customer loads that include their curtailment and scheduling. This is widely suitable for residential customers and agricultural customers.	Peak electricity demand forecast.	Day ahead	Philadelphia Electric Company (PECO) Smart AC saver program

[2] Lessons Learned From Summer 2012 Southern California Investor Owned Utilities Demand Response Programs, May 2013.

[3] Demand Response Review, The brattle group, May 2011.

DR Program Type	Description	DR event Trigger Criteria[2]	Notification time window	International Case studies[3]
Interruptible/ Curtailable DR	Customers are offered rate discounts or bill credits for their participation in demand adjustment during the scheduled or unscheduled system outages. The customers who have agreed to abide by the contract but have failed to lower their consumption during the outage hours stand to be penalized as per the contract norms. The targeted customers for these programs are large industrial loads.	Peak electricity demand forecast Operating reserves falling below certain predefined limits.	Day of	South California Edison (SCE). Agricultural Pumping Interruptible (API) program. 2012
Demand Bidding	The customers place their willingness to lower their consumption as bids in the wholesale electricity market. The targeted customers for this category of programs are bulk loads whose consumption is in the order of MW.	Transmission or imminent system emergency or as warranted by the utility. Operating reserves falling below certain predefined limits.	Day ahead	San Diego Gas & Electric (SDG&E). Carried out 12 events of total 44 Hrs in 2012.
Emergency DR services	Customers are incentivized for the reduction of their consumption when the system is short of reserves. Emergency DR is executed in indirect load control mechanism.	System reserves falling below certain predefined limits.	Day of	New York ISO (NYISO) Emergency Demand Response Program (EDRP).
Capacity Bidding	End-users offer load curtailments in the form of system capacity as an alternative to the expansion of the existing infrastructure especially in the peak hours.	Potential market price spikes. Real Time Load becoming higher than Day Ahead forecast.	Day ahead, Day of	ISO New England. 2,681 MW of DR was enrolled. Jan 2010.
Ancillary DR services	Large rated customers place their capacity to lower the consumption as an operating reserve in the form of a bid in the wholesale electricity markets. It addresses the short-term imbalances in electricity markets by dispatching resources within seconds or minutes of an unacceptable imbalance.	Short term changes in overall capacity. Frequencies dropping below relay settings.	Day of (varies between 2 to 30 minutes)	New York ISO (NYISO). 2,400 MW of DR was enrolled. Sep 2010.

1.2 Framework for technology assessment of Demand Response

The first step in shaping the framework for technology assessment of DR programs is to identify the stakeholders involved and their need-cum-objective of involvement. Table 1.2 addresses these two components in detail. This report categorizes different players into three broad divisions namely: utility, aggregators and customers. Aggregators represent the pool of customers, in the Indian scenario various DISCOMS may act as load aggregators. Utilities are the independent system operator (ISO) which regulates the energy market.

Table 1.2
The role of stakeholders involved in a demand response program

Stakeholders Involved	Need-cum-Objective of involvement
Utility	Utility is the entity that triggers a DR event through various price-based and incentive-based mechanisms with the prime objective of peak-load reduction.
Load aggregator[4]	Many customers are unable to participate in DR programs because their curtailment volume does not meet the minimum load requirements fixed by the utility and also due to the penalty risk involved. A load aggregator acts as a broker and mitigates the penalty risk through aggregation by assigning other customers to take up the slack created by inability of a specific customer to provide the expected curtailment in such a way that the entire portfolio continues to meet its obligations. Third-party aggregators enlist end users to participate in demand response programs and sell the combined load reduction to utilities in lieu of a brokerage fee (percentage of the demand response incentive), and passes the rest on to the end user.
Customer	Customer/end user or load is the entity that responds to the DR event signal sent by the utility or load aggregator with the sole objective of earning/avoiding bill credits/penalties.

Demand response programs require a certain degree of technological readiness from the perspective of each of the stakeholders mentioned in Table 1.2. The second step involves identification of technological credentials that could enable the implementation of demand response for a target load category. 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.

Table 1.3 elaborates the technological prerequisites for enabling roll out of various DR programs for residential consumers. For instance, in order to carry out a Direct Load Control program, utility invites residential customers and load aggregators to enter into a DR contract which allows the utility to control the operation of a controllable appliance at the customer's end in lieu of incentive in form of bill credits. Based on the Day-ahead load forecasts, utility notifies the customer or aggregator about the DR event. A DR event is generated by the Demand Response Automation Server (DRAS) which is communicated either directly to the customer via the WAN gateway connected to the smart meter at customer's end or through the NAN gateway encompassing the load aggregator and finally to the customer. Once the DR event is notified at the smart meter, it communicates with the load controllers or smart appliances via the Home Area Network to dispatch the appropriate load. This categorization can be extended for other load categories with certain modification in the hardware, software and communication technology used at the load side.

The communication architecture for a typical demand response program involves interaction between various hardware and software entities at utility, aggregator and customer's end. Figure 1.1 depicts this architecture which makes it possible to carry out a DR shed initiated by energy management system (HEMS/BEMS) after an external communication signal is received from the utility/aggregator side.

[4] Enrolling With a Demand Response Aggregator, Siemens USA/ building technologies

TABLE 1.3

Technological prerequisites for implementation of various DR programs for Residential consumers

<table>
<tr><th rowspan="3">Target load categories</th><th rowspan="3">Perspectives</th><th rowspan="3">Prerequisites to Implement the DR program</th><th colspan="9">Types of Demand Response (DR) Programs</th></tr>
<tr><th colspan="6">Incentive based</th><th colspan="3">Price Based</th></tr>
<tr><th colspan="2">Classical</th><th colspan="4">Market based</th><th rowspan="2">Critical peak pricing (CPP)</th><th rowspan="2">Real time pricing (RTP)</th><th rowspan="2">Time of Day (ToD)/ Time of use (ToU) tariff</th></tr>
<tr><th></th><th></th><th></th><th>Direct load control (Auto DR)</th><th>Indirect Load control (Manual DR)</th><th>Demand bidding</th><th>Emergency DR</th><th>Capacity market</th><th>Ancillary services market</th></tr>
<tr><td rowspan="9">Residential & small commercial consumers</td><td rowspan="3">Utility</td><td>Hardware
Software</td><td colspan="8">Tools for load forecasting & Baselining, DRAS (Demand Response Automation Server), MDMS (Meter Data Management System)</td><td rowspan="3">Time of Day tariff structure</td></tr>
<tr><td>Communication technology</td><td colspan="8">WAN (Wide Area Network)</td></tr>
<tr></tr>
<tr><td rowspan="3">Load aggregator</td><td>Hardware</td><td colspan="8">Meter Data concentrator Unit</td><td rowspan="3">Not applicable</td></tr>
<tr><td>Software</td><td colspan="8">Tools for load forecasting & Baselining</td></tr>
<tr><td>Communication technology</td><td colspan="8">NAN (Neighborhood)/ MAN(Metropolitan)</td></tr>
<tr><td rowspan="3">Customer</td><td>Hardware</td><td colspan="8">Smart meter with a RF modem/PLC modem, Load Controllers/Load control switchgear, Home monitoring & control consoles& Smart appliances.</td><td>Trivector meter with multiple tariff capability</td></tr>
<tr><td>Software</td><td colspan="8">Energy Management System (HEMS/BEMS) integrated with DRAS client software.</td><td>None</td></tr>
<tr><td>Communication technology</td><td colspan="8">Wi-Fi/ZigBee based Wireless HAN (Home Area Network) or PLC based Wired HAN</td><td>None</td></tr>
</table>

Figure 1.1: Typical communication architecture for Demand Response

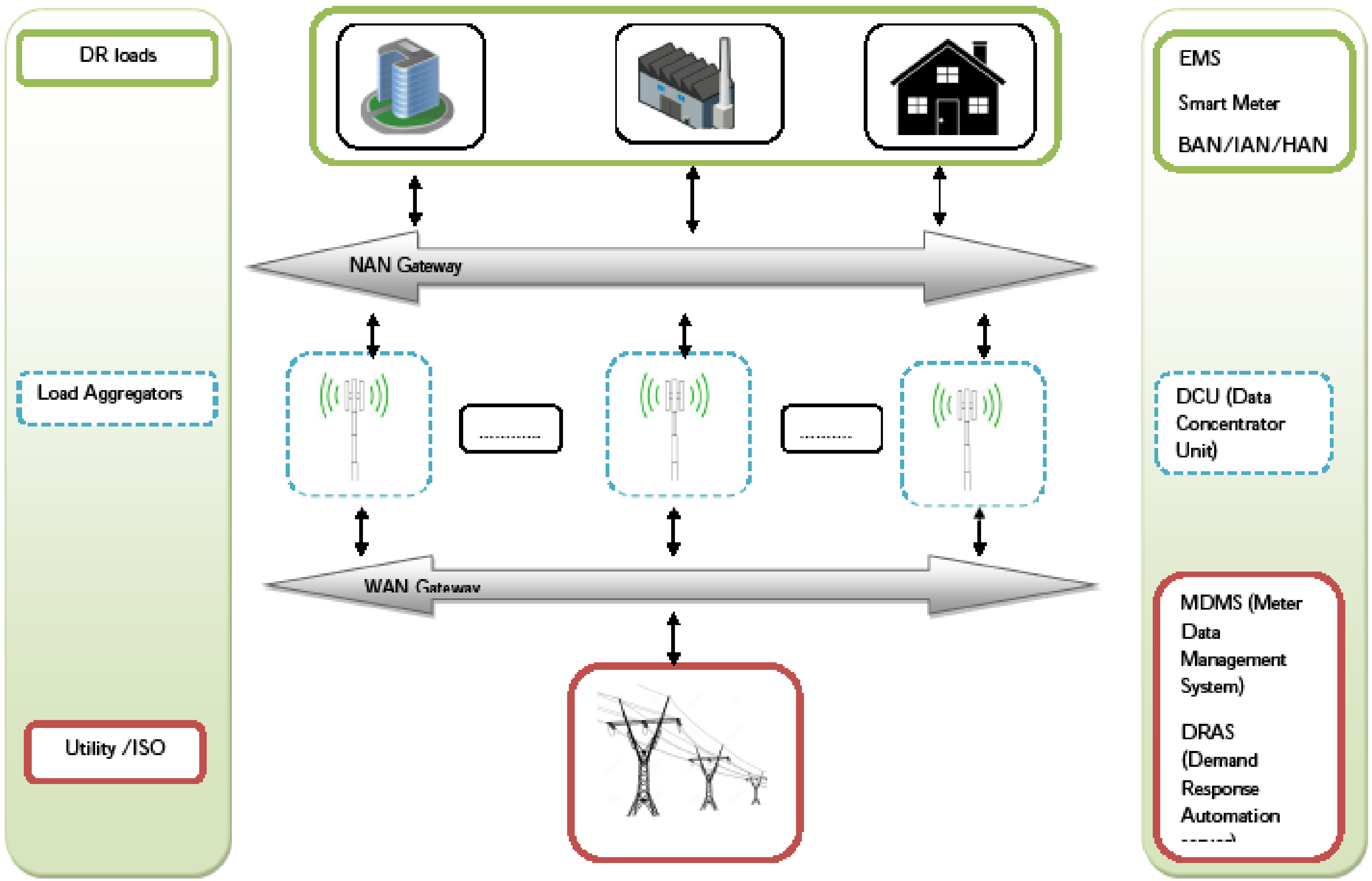
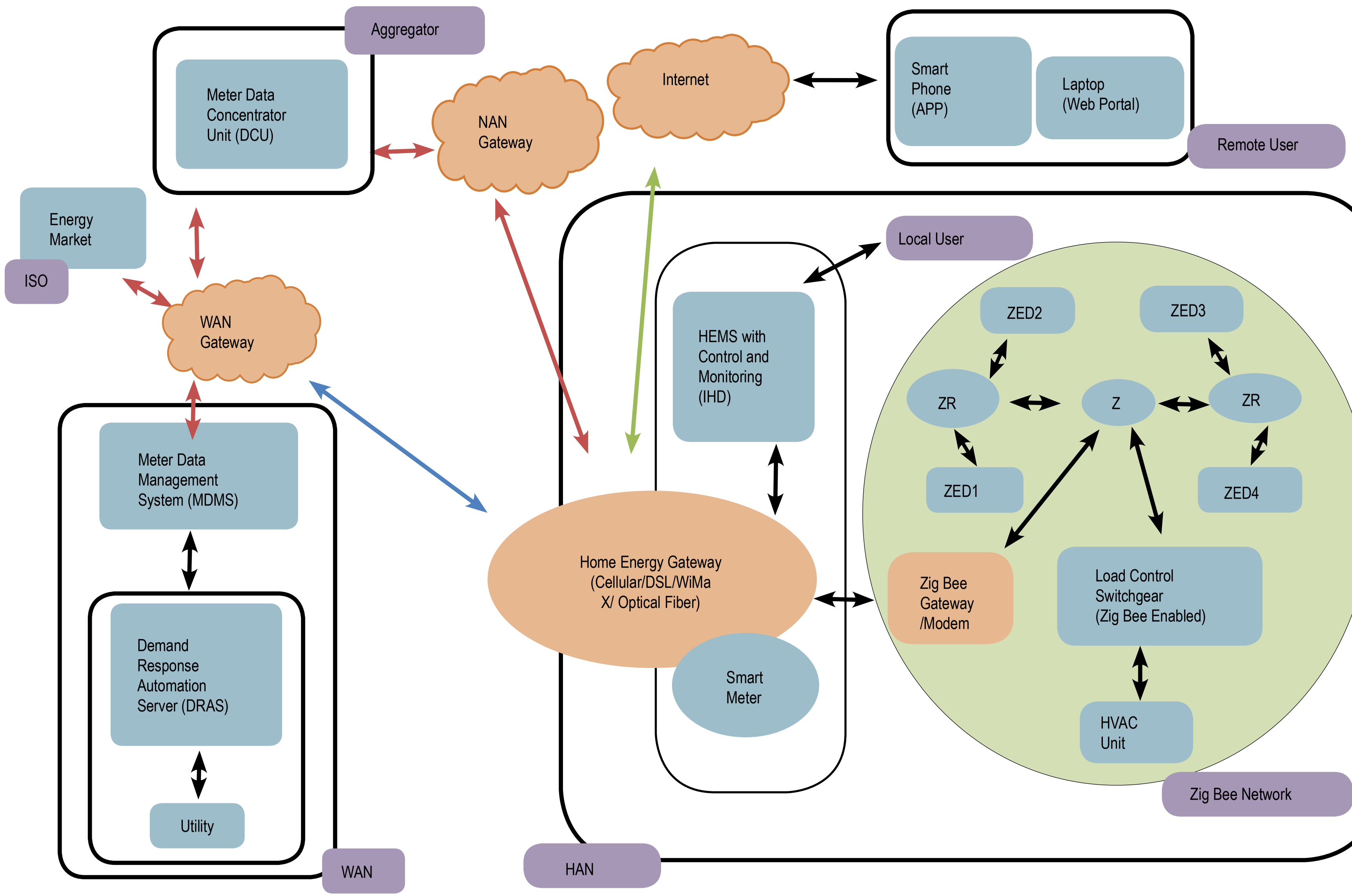


FIGURE 1.2:
Communication architecture for residential demand response



Residential sector is going to become more energy intensive due to widespread use of energy guzzlers such as water heaters, AC units and other such electric appliances in homes. Internet connectivity is poised to become a necessity in times to come. This will lead to increasing need to connect electric equipment to its user leading to web connected smart homes. Demand response can leverage the connectivity of these smart homes in order to meet their energy needs and of others. Figure 1.2 depicts the communication structure for a residential demand response program.

Demand response can leverage the connectivity of these smart homes in order to meet their energy needs and of others.

Personal Area Network (PAN) is formed by configuring the ZigBee devices as ZigBee coordinator, Router and end devices using PAN IDs. The end devices (ZEDs) in this network happen to be the electric appliances enrolled under DR. Router devices (ZRs)are battery powered and are used to extend range and increase device capacity so as to connect all shiftable (Ac units, Washer/dryer, Electric vehicle charger, Heaters, etc.) loads to the line powered ZigBee coordinator (ZC). ZigBee coordinator connects the appliances to the home energy gateway via a ZigBee modem which can also be a part of smart meter.

Smart Meters are electronic variants of old analog energy meters that are capable of two way communication between utility and customer. They record meter readings at intervals of one hour or less and update utilities about the energy usage pattern of customers on a daily basis. Typically, smart meters have two radios installed - one that utilizes the licensed 902-928 MHz band for connection to the utility and the other is a 2.4 GHz radio to transmit to devices in the customer premises (Home Area Network).

Home Energy Management System (HEMS) is an integral part of a smart home and allows appliances to be connected and controlled from a central point. It is usually embedded in the smart meter along with the home energy gateway and is operated through In-Home Displays (IHDs) installed inside the customer's premise. It collects real-time energy consumption data from the smart meter to control activation/deactivation of home appliances. The control and monitoring dashboard can be accessed through a secure web portal or a mobile app remotely by the user over the public web.

Data Concentrator Unit (DCU) collects/aggregates meter data of multiple such Home Area Network (HAN) in the neighborhood connected using a DSL/ PLC/ cellular connection forming Neighborhood area network (NAN). Many such DCUs further push the collected data to utility via a wide area network (WAN). At the utility end, Meter Data Management System (MDMS) monitors the data collected and takes billing/penalty actions based on the customer's response to DR signal sent by the utility. The Demand Response Automation Server (DRAS) is the central DR controller installed at utility. It broadcasts appropriate DR signals to consumers/aggregators based on utility forecast and critical load situations. An Independent System Operator (ISO) can also invite DR bids in the wholesale/retail power market via the WAN gateway.

1.3 Demand response for Commercial facilities

Buildings account for nearly 35% of total energy consumption in India[5] and its contribution continues to grow at 8 % annually. As the demand for power grows, the utilities will require an effective mechanism to meet the challenges of growing demand for power. Demand response can provide a viable solution by transforming these building loads into dispatchable resources for various load balancing mechanisms.

Building Energy Management System (BEMS) is used by commercial facilities for monitoring, automating, and controlling building systems such as HVAC and lighting so as to enhance building energy efficiency and improve comfort conditions for its occupants. In order to implement the control objectives of BEMS a Building Area network (BAN) is configured which basically is a local area network (LAN) that covers an entire building. It may be a collection of smaller local area networks. Each floor is configured as a single LAN leading to combination of floor LAN to set up the BAN. A data communication protocol enables the different nodes in BAN to communicate with the BEMS. BACnet (Building Automation and Control Network) is the ASHRAE, ANSI and ISO standard for building communication protocol is the preferred choice among commercial building automation systems.

BACnet allows the BEMS to communicate with utilities and is an effective option for deploying DR strategies at commercial facilities.

1.4 Comparative analysis of available communication technologies for DR

Table 1.4 shows the various network requirements for rolling out a DR program. Latency for DR programs represents the time interval between trigger and response. This varies between 500ms to several minutes as per the type of DR programs. Ancillary and emergency DR programs usually have low latency requirements.

Various communication techniques mentioned in Table 1.5 have been compared among themselves based on the various network attributes and can help in deciding the usability of a particular mode of communication for DR.

TABLE 1.4
Network requirements for Demand response

Network attributes	Demand Response
Latency	500ms to several minutes
Bandwidth	14 to 100 Kbps per node
Minimum reliability	99 %
Security	High
Power Back up	Not required

[5] Mitigation potential from India's buildings, GBPN, February 2013

FIGURE 1.3

Coverage range and data rate specifications for various networks used in DR.

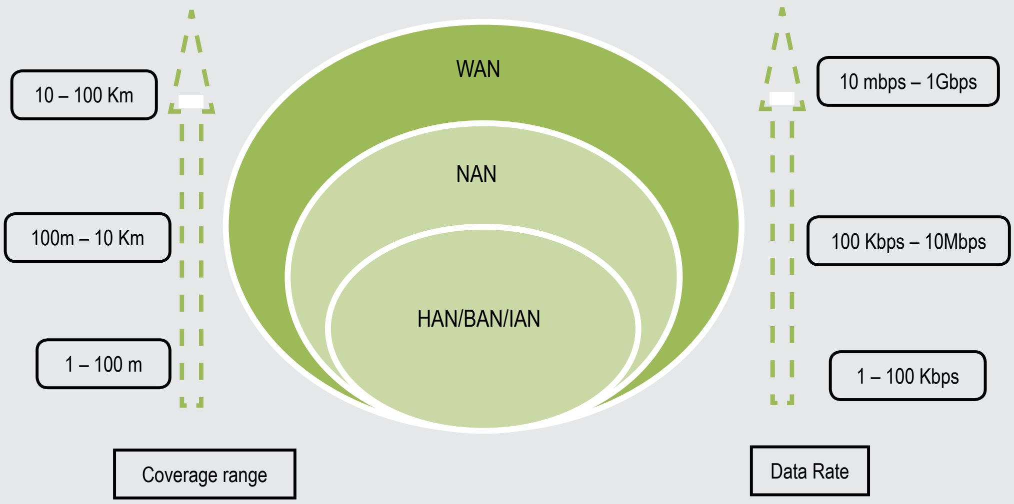


Figure 1.3 specifies the data rate and coverage range for various network configurations used for setting up communication between different entities at stakeholder's premises in order to carry out DR events.

The choice of communication depends on various features required for a particular information exchange. Features, such as range, data size, permissible delay and desired quality of communication and cost, influence the selection of the communication methodology. Along with this the use of existing support structure, age and life of technology, O&M cost, flexibility of future expansion are the parameters which need to be considered for long-term benefits.

As for a HAN, relatively short range and small data size communication will suffice the requirement. As illustrated in Table 1.5, ZigBee is cost effective for short range communication, it is also low power consuming, and has a long battery life. However it is prone to noise interruption and as the number of load controller increases, the quality of signal deteriorates, therefore for a large network such as Building EMS and Industry EMS, Wi-Fi or PLC communication is recommended. Few projects have successfully implemented RF based communication for neighborhood area network (NAN) and HEMS to Data concentrator communication. The countrywide existing network of RF, low cost and penetration into remote areas assert its application for DR communication. A dedicated band for DR and smart gird communication will also mitigate issues pertaining to noise and low data transmission capacity in an RF network. Security in RF network is a critical issue which needs to be addressed before its consideration for large scale smart grid and DR applications. At present RF technology is vulnerable to third party interference, data manipulation and user privacy threat and does not qualify as a reliable option for DR.

Wired communication technologies have better QoS (Quality of Service) and data transfer capacity than their wireless counterparts. Low latency and high data rate supports the case of wired communication for bulk data transfer. But the installation cost is very high and network become static as the setup is hardwired. The use of existing power lines as PLC communication

Different cellular technologies available have a general concern of security, as the system uses a public network which is subjected to third party intrusion, data manipulation and threat to user privacy.

channel saves the installation cost of network and also facilitates access to remote locations where other modes of communications have poor accessibility. PLC is suitable for integration of rural loads into DR spectrum. Ethernet based communication uses existing telephone network, however its poor penetration in rural region renders it suitable only for urban areas. For long distances, fast and large data communication Fiber optic based communication is recommended. The high cost associated with the installation of optical fiber network is justified and is recommended as it offers highly secure and fast communication.

Different cellular technologies available have a general concern of security, as the system uses a public network which is subjected to third party intrusion, data manipulation and threat to user privacy. The spectrum cost for private band is very high for advanced 3G and 4G networks. However, cellular communication has many benefits over other modes which assert their case for long distance communication such as HEM to Data Concentrator and DRMS to Consumer. Countrywide penetration of cellular (GPRS) services, reliable long distance communication, cheap access from customer point of view, multiple objectivity of technology are some salient features that support the case of cellular communication for DR.

TABLE 1.5

Comparative analysis of available communication technologies for DR

Features		Wireless				Wired			Cellular			
		ZigBee	Wi-Fi	WiMaX	RF	PLC	Ethernet (DSL)	Optical fiber	GSM	GPRS	3G	4G (LTE)
Range		Up to 50m	Indoor: 100m Outdoor 250m	10-50 Km	10-15 Km	Up to 15 Km	1-10 Km	Depends on bandwidth of signal	1-10 Km	1-10Km	50 – 70 Km	10-12 Km
Data Transfer	Latency	10-150ms	4-25 ms	~60 ms	~ 50ms	10- 15 ms	2- 5 ms	~ 1 ms	>50 ms	> 50 ms	~50ms	~5ms
	Data Rate	20-250Kbps	11-105Mbps	75 Mbps	100-250 Kbps	4-128Kbps , 2-3 Mbps [5]	> 100 Mbps	up to 100 Gbps	56-114 Kbps ,14.4 Kbps	160 Kbps	384 Kbps – 28Mbps	500-1000Mbps
	Frequency and Bandwidth	915/868 /2400 MHz (BW 22 MHz)	2.4- 5.8 GHz (BW 20-40 MHz)	2.5, 3.5, 5.8 GHz (BW 20-25 MHz)	~900 MHz, 2.4GHz	1.7 – 80 MHz (0.6-1.2 KHz)	> 1MHz	Cat 6a: 600 MHZ over 100 m Multimode: 1000 MHz over 100 m	800 -1900MHz	800 -1900MHz	1.92- 1.98GHz, 2.11- 2.17GHz	700-800 MHz
	Quality (QoS)	Noise Interruption	better then ZigBee	better than ZigBee	Interference with other RF signals	Noisy due to power line interference	Out of service very often as everything is hardwired	Highest among wired communications	Better than RF and Wi-Fi	Better than GSM	Better than GPRS	Highest QoS among cellular & wireless communications
Cost	Implem-entation cost	150-250 Rs/ unit	1500 Rs/Unit + 3500 Rs/Unit	1500Rs/Unit + 3500Rs/ Unit. High Initial Cost	100-200 Rs/ Unit	Module Cost Only	3500 + 1500 Rs/Unit Depending upon distance also)	Very costly optical fiber network + Module Unit cost Rs. 3500	GSM Module cost greater than Wi-Fi	GPRS Module cost ~Rs. 3500 per Unit	High Module cost	High - early adoption stage in pricing for equipment
	O&M Cost	Low. long battery life	medium for HAN	Low operation cost	Low	O&M High due to hard wiring	High Maintenance cost	High Maintenance Cost	Costly Spectrum fee	Costly Spectrum fee	Costly Spectrum fee	Costly Spectrum fee
Power Consumption		0.036W	0.210W	< 24 W	~ negligible	-	-	-	~ 0.08 W	~0.08 W	-	-
Existing Support Structure		Independent from network. No support structure available.	Wi-Fi is a mature, proven interoperable technology. Wide variety of vendors and pricing structures available	Mature; 500+ deployments worldwide. New 802.16m standard is proposed - up to 4x current speeds	RF comm. channel stretched country wide need to be upgraded for smart grid communication.	Existing grid, with little investment. Useful for remote and rural areas.	Existing telephone network is helpful without much investment on network stretching.	Costly Infrastructure. Only used for very essential, high speed, secure communication	Widely spread across the country (except remote locations) can use public network	Using Existing Public network and infrastructure reduces the initial cost.	Very mature but will be phased over to future Standards such as LTE over the next few years.	Currently in trial phase; large scale deployments in 2-3 years
Security		128bit symmetric encryption. Relatively new technology hence security research in nascent phase.	WPA2 Protocol	64/128 bit WEP,WAP/ WAP2	IEEE WPA2/802.11i security methods	IPv6 Internet Security Protocol for PLC Communication	IPv6 and IPv4 Internet Security Protocol	Fiber tapping can cause theft of data. Optical encryption solves this security concern.	64 bit – A5/1 stream cipher Algorithm	64 bit – A5/1 Encryption Security threat due to use of public network	Better than 2G. End to end security	Prone to threat as uses open architecture standard
Application [6](LAN/ NAN/WAN)		LAN, NAN	LAN, NAN	NAN, WAN	LAN, NAN	LAN, NAN	LAN, NAN	WAN	NAN, WAN	NAN, WAN	NAN, WAN	NAN, WAN

[6] Communication network requirements for major smart grid applications in HAN, NAN and WAN, Murat Kuzlu et al., 2014.

1.5 Demand Response strategies based on End-Use load types

It is also important to identify the load reduction potential of a particular DR strategy. The decision of which DR strategy is to be employed is usually taken by the energy management system installed at the facility based on the type and duration of DR event signal sent by the Utility/aggregator. Some of the potential load types for demand response are discussed below with the applicable DR strategies.

DR strategies for HVAC loads: The thermal flywheel effect observed in indoor environments presents a potential opportunity for load curtailment through DR without causing immediate change in comfort conditions to occupants. The DR strategies for HVAC loads can be categorized as per the target subsystem (zone control, air distribution, and central plant) for control adjustments. In order to map the DR strategies appropriately with the various types of HVAC systems, it is useful to list the various types of HVAC systems as presented in Table 1.6. Table 1.7 enumerates the various applicable DR strategies for the different HVAC types mentioned in Table 1.6. Rebound effect is also a common phenomenon in HVAC systems that undergo load curtailment under DR during which extra energy is used just after the completion of DR events in order to bring indoor conditions back to normalcy. DR strategies for avoidance of this rebound effect are also presented in Table 1.7. These DR strategies can be programmed as control adjustments in the building energy management system which automatically selects an appropriate DR strategy based on the occupancy levels and external weather conditions on receiving a DR signal from the utility.

TABLE 1.6
Classification of types of HVAC systems

Type	Primary feature	Secondary feature
A	CAV system with central plant (CAV-Central	Single zone / multi-zone ; Single duct / dual duct; With reheat / without reheat; Type of chiller
B	VAV system with central plant (VAV-Central)	Single duct / dual duct; With reheat / without reheat; Type of chiller
C	CAV system with package units (CAV-Package)	Single zone / multi-zone; Single duct / dual duct; With reheat / without reheat
D	VAV system with package units (VAV-Package)	Single duct / dual duct; With reheat / without reheat

CAV: Constant Air Volume; VAV: Variable Air Volume

TABLE 1.7

DR strategies for various building HVAC units[7]

Category	DR strategy	Description	Applicability to HVAC types A	B	C	D
Zone control	Global temperature adjustment	Increase zone temperature set points for an entire facility	✓	✓	✓	✓
	Passive thermal mass storage	Decrease zone temperature set points prior to DR operation to store cooling energy in the building mass, and increase zone set points to unload fan and cooling system during DR.	✓	✓	✓	✓
Air distribution	Duct static pressure decrease	Decrease duct static pressure set points to reduce fan power.	×	✓	×	✓
	Fan variable frequency drive limit	Limit or decrease fan variable frequency drive speeds or inlet guide vane positions to reduce fan power.	×	✓	×	✓
	Supply Air Temperature (SAT) increase	Increase SAT set points to reduce cooling load.	✓	✓	✓	✓
	Fan quantity reduction	Shut off some of multiple fans or package units to reduce fan and cooling loads.	✓	✓	✓	✓
	Cooling valve limit	Limit or reduce cooling valve positions to reduce cooling loads.	✓	✓	×	×
Central plant	Chilled water temperature increase	Increase chilled water temperature to improve chiller efficiency and reduce cooling load.	✓	✓	×	×
	Chiller demand limit	Limit or reduce chiller demand or capacity.	✓	✓	×	×
	Chiller quantity Reduction	Shut off some of multiple chiller units.	✓	✓	*	*
Rebound avoidance	Slow recovery	Slowly restore HVAC control parameters modified by DR strategies.	**	**	**	**
	Sequential equipment recovery	Restore HVAC control to equipment sequentially within a certain time interval.	**	**	**	**
	Extended DR control Period	Extend DR control period until after the occupancy period.	**	**	**	**

* The strategy can be applied to package systems by reducing shutting off some of the compressors.

**Applicability of rebound avoidance strategies is determined by the DR strategies selected.

DR strategies for lighting loads: Buildings equipped with day-lighting systems are potential candidates for DR. On a sunny summer day, when day light is abundant, using lighting controls, appropriate DR strategies can be designed in order to achieve significant DR shed. These strategies can include switching and/or dimming control for zone, fixture and lamp. Dimmer controllers can provide both stepped and continuous dimming features.

[7] Introduction to Commercial Building Control Strategies and Techniques for Demand Response, DRCC, LBNL, 2007

DR strategies can also be designed for various load types such as elevators, irrigation pumps, cold storages, industrial process loads and electric vehicles[8]. The decision to enroll such loads depends either on their individual peak load reduction potential or the availability of similar load types in the neighborhood for aggregation.

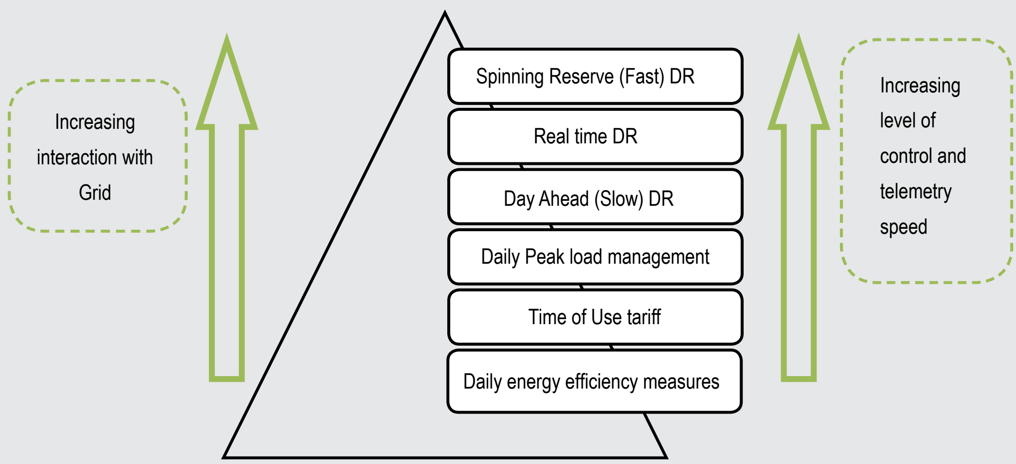
1.6 Open ADR standards

Open Automated Demand Response[9] (OpenADR) protocols provide an open (nonproprietary), standardized and secure way for Utilities and Independent system operators (ISOs) to communicate DR signals with each other and with their customers using a common language over any existing IP-based communications network, such as the Internet.

Open ADR 1.0 standards were designed for simpler devices such as residential thermostats. Many features have been added to new versions of OpenADR 2.0 such as handling the flow of information back from the buildings. This reporting feature has been strengthened to handle real-time results from end users. Real-time energy consumption changes in building loads can be confirmed with the same ease as verification of a home or small business thermostat or load-control device having received the DR signal and if they have responded as per the contract.

Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E) and Southern California Edison (SCE) have added and recommended OpenADR 2.0 certified products to implement their dispatch of emergency and price DR resources.

FIGURE 1.8:
Classification of Demand response programs based on level of interaction with grid, speed of communication & level of control.



[8] DEMAND RESPONSE for Small to Midsize Business Customers, Reference guide, CEATI International.

[9] Technical Meeting on Data/Communication standards and Interoperability of Building appliances, equipment, and systems; DOE, May 2014.

cost barrier that would ultimately determine the level of penetration of products based on these standards. Figure 1.8 clearly shows how the level of control changes from coarse to granular as DR program types vary from Time of Use tariff mechanism to spinning reserve DR programs. Increased levels of control can add significantly to the cost and also require close to real-time telemetry coming back from the building to the utility. More details about role of DR in electric system planning and operations are available at the following link[10].

Demand response for residential homes will have to wait for the smart appliance market to grow. Currently, smart appliances have very low market visibility in India and will see a boom only when smart grid technologies mature to provide effective DR deployment.

1.7 Conclusion

Significant efforts have been initiated in the direction of setting up technological infrastructure to enable deployment of DR programs as part of smart grid.

As many as 17 State Electricity Regulatory Commissions[11] (SERCs) have commissioned TOD tariff structure, for large industrial and commercial consumers in the country. The introduction of ToD tariffs is a small but effective step in the right direction to encourage customer participation in countering peak load challenges. This will surely pave the way for enhanced consumer awareness and readiness for other demand response strategies in the future. Extension of ToD tariff for domestic and residential category can be a big game changer in molding the energy usage pattern of consumers to meet the challenges faced by utilities in procuring the peak power from expensive and inefficient peaking power plants.

Demand response for residential homes will have to wait for the smart appliance market to grow. Currently, smart appliances have very low market visibility in India and will see a boom only when smart grid technologies mature to provide effective DR deployment.

Large scale deployment of DR programs can become a reality only when there is smart grid infrastructure in place. Machine to Machine[12] (M2M) communication technologies is the biggest enabler for achieving the smart grid vision in India. Some of the communication technologies such as PLC require frequency band allocation and need government intervention in passing the necessary regulations.

There seems to be no dearth of technology providers for DR in the country and there is clearly a huge potential for DR as well but it needs to be backed by the expeditious development of necessary regulations and technological infrastructure by the government.

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[10] Page No 13 & 15, Benefits of demand response in electricity markets and recommendations for achieving them, DOE, Feb 2006

[11] Assignment on Implementation & Impact Analysis of Time of Day (TOD) tariff in India, PwC, Forum of Regulators

[12] Technical report on M2M enablement in power sector, Department of Telecommunications, GOI, May 2015

CHAPTER 2

Measurement & Verification for DR

2.1 Introduction

The demand for electricity is rising, at the same time limitation in capacity addition of generation is increasing the supply-demand gap. The electrical energy consumption in various sectors in India is shown in Figure 2.1. The current peak demand shortage in India is 14% and the energy deficit is about 8.4% and energy efficiency plays a key role in such situations[13].

According to load generation balance report by the Central Electricity Authority, during the year 2014-15, the total energy availability increased by 7.4% over the previous year and the peak met increased by 8.7%. However, the shortage still prevails both in terms of energy and peak power availability as shown in Table 2.1.

FIGURE 2.1
Energy consumption share in different sectors

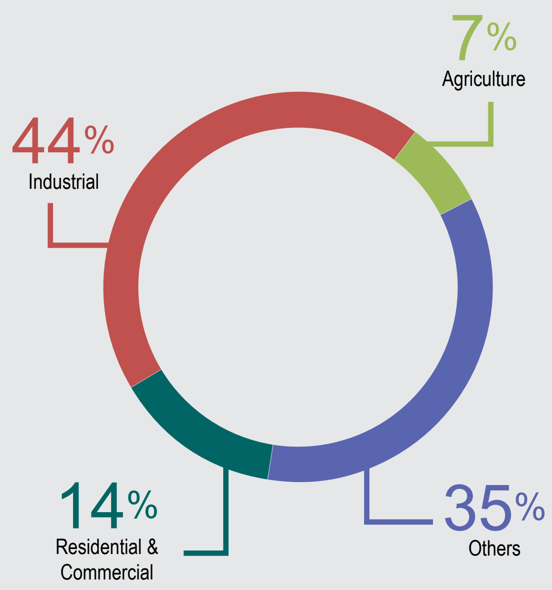


TABLE 2.1
India's Energy Requirement, Availability and Shortage of Electricity (2014-2015)[14]

	Energy (MU	Peak (MW)
Requirement	1,068,923	148,166
Availability	1,030,785	141,160
Shortage	38,138	7,006
(%) Deficit	3.6	4.7

[13] V. Jain (2015), "Analysis and Comparative Study of Energy Management in India", International Journal of Development Research, Vol. 5, Issue -4, pp. 4055-4060

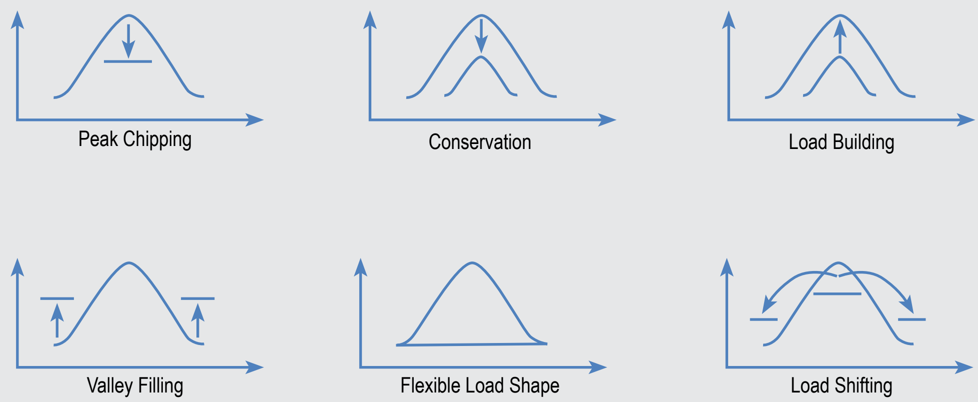
[14] Load Generation Balance Report 2015-2016, Central Electricity Authority, New Delhi

Demand Side Management (DSM) is an approach to reduce energy consumption by modifying the consumer energy consumption pattern by offering financial incentives and/or bringing about behavioural change through education[15-16]. Various approaches (load shaping objective) to achieve demand side management are shown in Figure 2.2. Most of the appliance exchange programs implemented in the country relate to conservation activity in the DSM category. Energy conservation generally shifts the load curve down while the peak clipping results in chopping the load curve (can be achieved using load shedding).It is possible to meet this load (from load shedding) by using the valley filling technique. Valley filling helps in improving the overall load factor of the system. The main goal of DSM program is to reduce the energy consumption of the consumer by taking energy efficiency measures. However, in case of peak demand management, it is possible that the total energy consumption may not decrease. This may help reduce the investment for network expansion and peak power generation.

The main goal of DSM program is to reduce the energy consumption of the consumer by taking energy efficiency measures.

FIGURE 2.2

Various load shaping techniques in DSM



For successful implementation of DSM programs, a special program design is required which focuses on cost-effective ways to save both electricity and peak demand. It is very well proven that cost-effective DSM programs have reduced use of electricity and peak demand by 20-40%.

DSM can be categorised into two broad segments: Energy efficiency and Demand Response (DR). DR is a mechanism by which the consumer load curve is modified to primarily reduce the peak of the system. The utility requests the customers to reduce the load in return for a price incentive or financial benefits. The consumers can then modify their electrical demand by shifting electric loads from peak hours to off-peak hours of the day or week. Network

[15] B. Davito, H. Tai, R. Uhlner (2010), "The Smart Grid and the promise of Demand Side Management", Mc Kinsey & Company, San Francisco

[16] A. Sesetti, S. Battula, H. S.V. S. Kumar Nunna and S. Doolla "Intelligent Agent framework for Demand Response Aggregation in Smart Microgrids" Presented at IEEE Industrial Electronics Conference, Dallas, Texas, USA, Oct 29- 1 Nov, 2014

The increase in demand coupled with limited energy resources, leads to energy resource exploitation.

congestion is generally decided by the frequency value of the system. Federal Energy Regulatory Commission defined Demand Response[17] 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 differs from the broad-based DSM as DR is event-based with the objective of altering customer load pattern eventually reducing the peak electricity requirement. The current electric grids are designed to meet the peak load requirements with high reliability and make the system more robust. DSM programs can act as a problem solver for the grids to make the system more reliable. The increase in demand coupled with limited energy resources, leads to energy resource exploitation. This has given rise to research in modern methods of DSM like demand response. Thus, DR will be a key enabler in the smart grid infrastructure by helping the integration of distributed energy sources and renewable energy sources.

Customers can participate in Demand Response program either through direct contract with a utility or Demand Response Providers (DRPs)/Load aggregators. These DR providers offer customers various DR options depending on the market condition and other constraints. DR strategies includes all intentional consumption pattern alterations by a customer designed to modify the timing, instantaneous demand level or total electricity load.

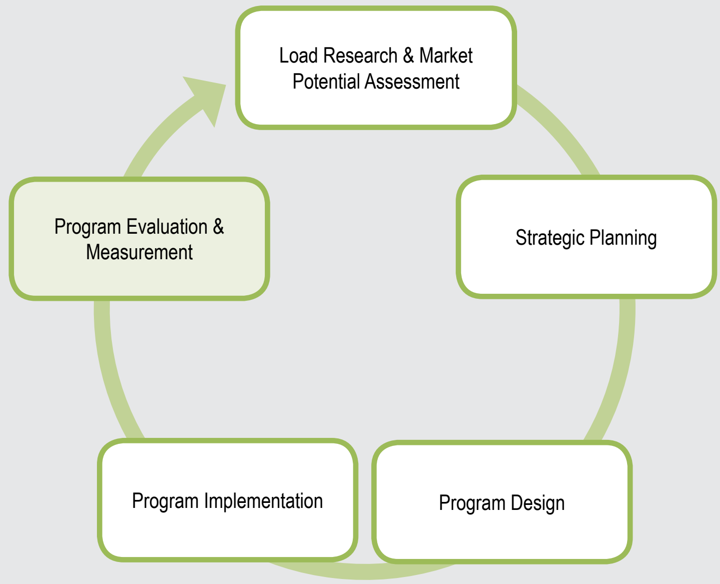
Earlier, implementation of Demand Response targeted only large industrial consumers with high demand by programs like Interruptible tariffs and Critical Peak Pricing. In more recent times, DR implementation has widened to include Commercial and Residential sectors. Utilities have started programs offering TOU (Time of Use) and RTP (Real Time Pricing). To make Demand Response more acceptable to end-Customers, modern automation and ICT technologies are being incorporated in Energy Management tools. Thus, Demand Response is considered to be well-designed solution to the problems of black outs and fluctuating power supply, as the potentially significant flexibility of demand can be extracted out to provide adequate power supply to the power systems[18].

Coming back to the sequence of events involved in DSM/DR project as shown in Figure 2.3, the first step involves load research and potential (technical/economic) assessment. This involves analysis of the load curve and identification of appropriate program for demand side management. Once the program is identified, strategic planning is made by the team implementing DSM, followed by program design. Program design involves the selection of technology and cost benefit analysis of the total program. One of the most important steps in DSM cycle is Evaluation Measurement and Verification. The success of the program and payments to the participating consumers depends on the EM&V report which is generally documented by a third party consultant. The real benefit-to-cost ratio to customers and utility, actual demand reduction are metrics for success of any DSM program.

[17] M. Albadi and E. El-Saadany, "A summary of demand response in electricity markets," Electric Power Systems Research, vol. 78, no. 11, pp. 1989-1996, 2008.

[18] U. S .Department of Energy (2006), "Benefits of Demand Response in Electricity Markets And Recommendations For Achieving Them", Report to the United States Congress Pursuant to Section 1252 for the Energy Policy Act of 2005.

FIGURE 2.3:
Sequence of events in Demand Side Management cycle



2.2 Measurement & Verification and Importance of baseline

Measurement and Verification in the context of DR aims at evaluating the actual amount of load that is curtailed during an event. This requires an estimate of the load that the customer is going to consume on the event day more precisely during the event period. This estimate of consumer's consumption is called the consumer baseline load (CBL) which can be defined more appropriately as the predicted amount of the electricity that would have been used by a customer in the absence of a DR event. DR program participants are then compensated financially for reducing electricity use, calculated as the difference between the customer baseline (CBL) and the actual metered usage.

Baseline is a challenging aspect as it should represent the exact usage of electricity by the customers in the absence of load curtailment during DR event.

2.2.1 Baseline Calculation

The categorization of existing baseline calculation methods are based on three elements[19]:

1. Data selection
2. Estimation
3. Adjustment

[19] California Energy Commission (2003), "Protocol Development for Demand Response Calculation – Findings and Recommendations

2.2.1.1 Data Selection

For data selection, a period of time called baseline window is identified, that usually precedes a DR event period over which electricity usage data is collected to establish a baseline. Some instances of baseline windows include:

- the last 10 non-holiday weekdays;
- the 10 most recent program-eligible non-event days;
- the 10 most recent program-eligible days beginning 2 days before the event;
- the last 45 calendar days
- the previous year

All the above baseline windows exclude some of the days from the baseline window so as to neutralize the effect of certain exceptional days/events on the baseline estimation. Some common exclusion rules include:

- Excluding days with DR events.
- Excluding days with outages.
- Excluding days with extreme weather.
- Excluding days with the highest or lowest loads.

These are days when demand does not follow the normal historical pattern as compared to the days in its neighbourhood. Including such days in estimation of baseline, can hugely affect the accuracy of the baseline. Hence such days need to be identified and be excluded from the sample days used for baseline estimation. Figures 2.4 to 2.7 depict the effects of festivals and holidays on the load curve and show how the load curve on these days differ from those in their neighbourhood.

FIGURE 2.4:
Effect of Kite festival of Gujarat load curve

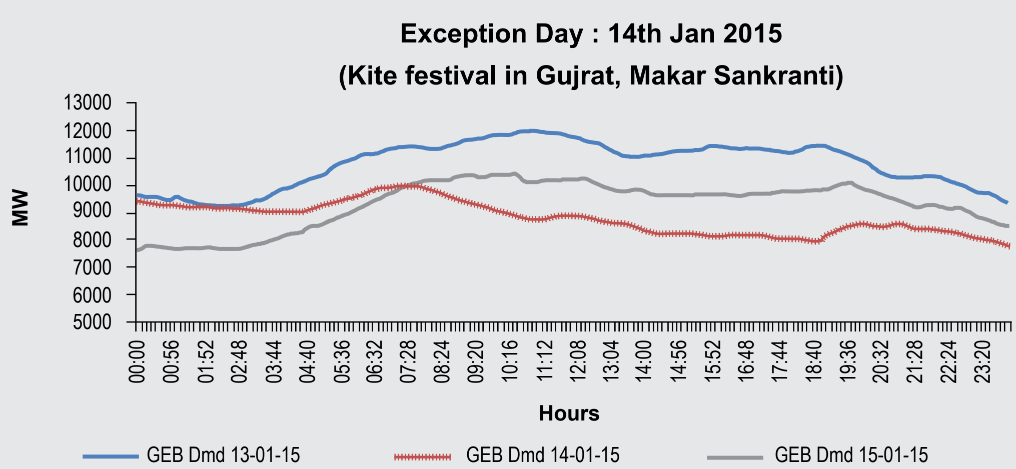


FIGURE 2.5:
Effect of Holi festival of Western Region (WR) load curve

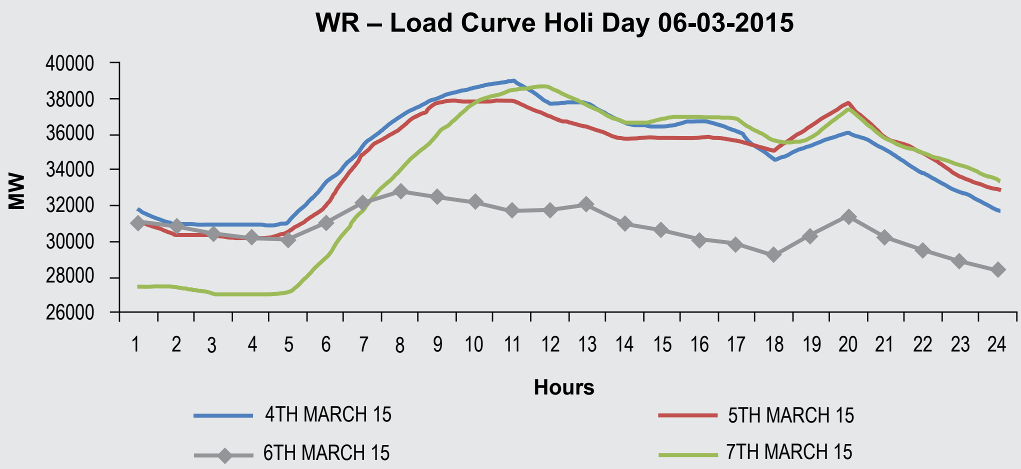


FIGURE 2.6:
Effect of Diwali festival of Western Region (WR) load curve

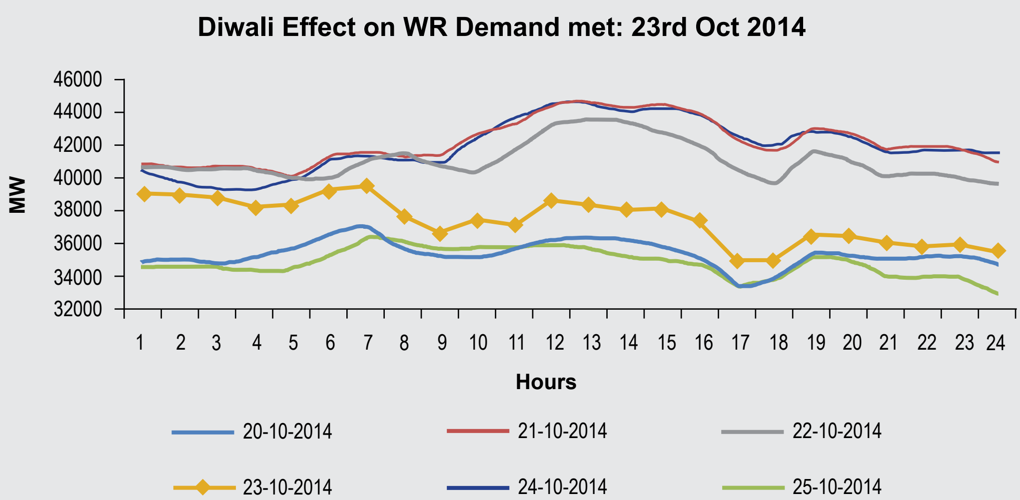
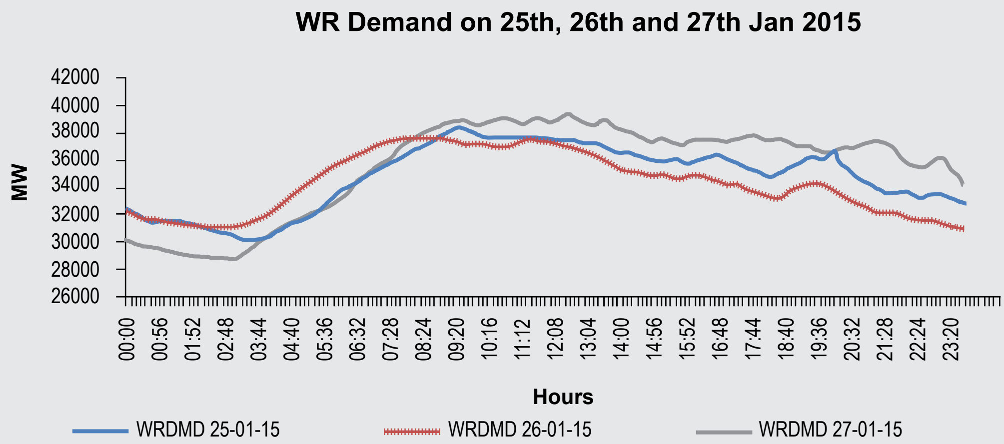


FIGURE 2.7:
Effect of Republic day holiday of Western Region (WR) load curve



2.2.1.2 Estimation

The methods of developing the baseline load curve using the data from the baseline window can be enumerated as below:

- **Averaging** method calculates for each hour/half-hour of the day, the average of the load at that hour over the included days.
- **Regression** method calculates load using linear regression model from the included days on weather and other variables, usually with separate regression coefficients by hour of the day.
- **Maximum value** method takes the maximum of the loads in the included period.
- **Rolling average** method uses the updated unadjusted baseline for an operating day which is equal to 0.9 times unadjusted baseline plus 0.1 times the most recent included day.

1. Averaging Method[20]

In averaging or "X of Y" or "X in Y" method, the baseline for each interval of curtailment day is calculated as the simple average, across all the days chosen by the data selection criteria. The most common "X in Y" baselines are as follows:

- **10 in 10 –** Out of 10 selected days, highest 10 day's data is taken and the baseline is calculated.
- **7 in 10 –** Out of 10 selected days, highest 7 day's data is taken and the baseline is calculated.
- **5 in 10 –** Out of 10 selected days, highest 5 day's data is taken and the baseline is calculated.
- **3 in 10 –** Out of 10 selected days, highest 3 day's data is taken and the baseline is calculated.

Table 2.2 and 2.3 shows the baseline types and the evaluation method used by various ISOs (Independent System Operators) in US for weekdays and weekends. The CAISO (California ISO) and MISO (Midcontinent ISO) implemented 10 in 10 baseline where, X=Y (no days were excluded). For weekday events, the baseline consists of average hourly loads of recent ten days excluding weekends and holidays. For weekend events, the baseline consists of the average hourly loads of the recent weekend or holidays.

TABLE 2.2:
Weekday "X of Y" Baselines Used by US ISOs

ISO	Baseline type	Average of	Out of
CAISO, MISO	10 in 10	10 most recent weekdays	10 most recent weekdays
ERCOT	Mid 8 of 10	10 most recent weekdays, dropping highest and lowest kWh days	10 most recent weekdays
NYISO	5-of-10	5 highest kWh days	10 most recent weekdays
PJM	4-of-5	4 highest kWh days	5 most recent weekdays

TABLE 2.3:
Weekend "X of Y" Baselines Used by US ISOs

ISO	Baseline type	Average of	Out Of
CAISO, MISO	10-in-10	4 most recent weekend days	4 most recent weekend days
ERCOT	Mid 8-of-10	10 most recent weekend days, dropping highest and lowest kWh days	10 most recent weekend days
NYISO	5-of-10	2 highest kWh weekend days	3 most recent weekend days
PJM	4-of-5	2 highest kWh weekend days	3 most recent weekend days

The ERCOT's (Electric Reliability Council of Texas) Mid 8 of 10 is similar to the other baseline methods except that the highest and lowest kWh days are not selected out of recent 10 days. The hourly loads are then averaged over remaining eight days.

The NYISO's (New York ISO) "5 of 10" is similar as well, except out of 10 recent days, highest 5 days is selected. The PJM's (Pennsylvania-New Jersey-Maryland Interconnection) "4 of 5" selects the highest 4 days out of 5 recent days.

Jaipur Vidyut Vitran Nigam Limited (JVVNL), for its DR project which covered July 2013 to March 2014, used "5 in 10" method for estimation of baseline.

2. Regression Method:

The regression baseline is calculated using a regression model consisting of daily energy equation, which include consumer's daily consumption (kWh) as dependent variable, and 24 hourly energy fraction equations. The explanatory variables in model include calendar variables (day of the week, holidays), weather variables (dry bulb temperature) and daylight variable (daylight saving time, time of sunrise and sunset).

2.2.1.3 Adjustment

The average method is not weather sensitive and does not depend on occupancy level, due to which it requires adjustments in baseline[21]. Adjustment factor is evaluated to align the baseline with observed conditions of the event day. Factors used for adjustment are usually based on

[20] DNV KEMA (2013), "Development of Demand Response Mechanism Baseline Consumption Methodology – Phase 1 Results", Australian Energy Market Operator, Project No. 20320008.

Energy consumption data of various consumer categories in Mumbai was used to evaluate various unadjusted baselines through the averaging method.

temperature, humidity; calendar data, Sunrise/Sunset time and event day operating conditions. Adjustment factors are either additive or scalar (multiplicative). An additive adjustment shifts the curve up or down by a constant amount whereas a scalar or ratio adjustment scales the shape by a constant amount. Common adjustments are as follows:

- Combination of the load in the hours between 1 and 4 hours prior to curtailment.
- Additive and scalar to load at hours between 1 and 2 hours prior to curtailment.
- Additive and scalar to load at hours between 3 and 4 hours prior to curtailment.
- Weather based adjustment of all loads based on the difference or ratio of regression estimated using curtailment period and baseline period.

The period of time for which the adjusted baseline matches the observed load is called the adjustment window. As per NAESB (North American Energy Standards Board) guidance, the adjustment window shall begin no more than four hours prior to deployment. Examples of adjustment windows include:

- The hour before the event
- 2 hours before the event
- Two hours that end two hours before the event

TPDDL (Tata Power Delhi Distribution Limited) during their Auto-DR project in New Delhi used 5 out of 10 baseline model and 5 in 10 with morning adjustment baseline. In "5 in 10" method, the highest 5 days load out of previous 10 days was averaged excluding the weekend, holidays. In 5 in 10 with morning adjustment baseline, additive factor was used .The morning adjustment factor was calculated as a ratio of the average load of the first three of four hours before the event to the average load of the same hours from the selected five baseline days[22].

Out of two models, 5 in 10 with morning adjustment baseline was felt to be a better option for baseline estimation as it shows a reduction in the Auto demand response measures compared to 5 out of 10 baseline model. In morning adjustment the loads were curtailed. The baseline estimated by 5 in 10 with morning adjustment was found to be closer to the actual load curve[5].

2.3 Case Study: Assessment of performance metrics for unadjusted baselines

Energy consumption data of various consumer categories in Mumbai was used to evaluate various unadjusted baselines through the averaging method. These baselines were plotted along with one of the actual days from the data sample which was not used for baseline

[21] Indian Energy Exchange (2013), "Demand Response Pilot Project for JVVNL DISCOM, Jaipur, India".

[22] R.Yin, G.Ghatikar, R.Deshmukh, A.H.Khan , "Findings from an Advanced Demand Response Smart Grid Project to Improve Electricity Reliability in India", Lawrence Berkeley National Laboratory, 2015

estimation, to investigate the baseline performance in predicting the load on a DR event day. In order to bring more analysis and clarity, the following three metrics were calculated to assess the performance of the baselines techniques in estimating the actual load curves from a sample that has been used to evaluate them.

1. Accuracy: Accuracy of a baseline is evaluated on the basis of how **closely** it predicts the actual customer load. Normalised Root Mean Square Error (NNRMSE) is used as a statistical measure of accuracy. It is the square root of the average of squares of the half-hourly errors divided by the difference between the maximum and minimum half hourly data points in the actual days.

The Consumption obtained from the baseline models were compared with the actual day consumption.

Steps followed for determining NRMSE

a) The baseline was obtained through 10 in 10, 7 in 10, 5 in 10 and 3 in 10 baseline models for an actual day load curve for various consumer categories.

b) The Consumption obtained from the baseline models were compared with the actual day consumption.

c) Following formula was used to determine RMSE/RMSD (Root Mean Square deviation):

$$\mathrm{RMSD} = \sqrt{\frac{\sum_{t=1}^{n}(x_{1,t} - x_{2,t})^2}{n}}.$$

Where, $X_{1,t}$ = Actual Consumption

$X_{2,t}$ = Predicted Consumption (10 in 10, 7 in 10, 5 in 10 and 3 in 10)

N = number of data points (here 48, half hourly data)

NRMSD is the normalized value of Root mean square deviation

$$\mathrm{NRMSD} = \frac{\mathrm{RMSD}}{y_{\max} - y_{\min}}$$

Where, Y_{max} = Maximum Consumption on Actual Day

Y_{min} = Minimum Consumption on Actual Day

d) Out of all baseline model, the model which had minimum value of NRMSD was selected, as it indicated less residual variance.

2. Bias: Bias is the tendency of a baseline to **over/under predict** the load curve on actual day. It is measured using the Average Relative Error (ARE) of the baseline calculated by dividing the prediction error at each half-hourly data point by the actual half-hourly load. The median of these ARE values gives a measure of bias in a baseline.

Steps followed for determining ARE

a) The baseline was obtained through 10 in 10, 7 in 10, 5 in 10 and 3 in 10 baseline models for an actual day load curve for various consumer categories.

b) The Consumption obtained from the baseline models were compared with the actual day consumption.

d) Following formula was used to determine NARE:

$$\textbf{ARE} = \frac{x_1}{x_2}$$

Where, X1 = Average of Predicted consumption – Average of Actual consumption

X_2 = Actual Consumption

NARE (Normalized ARE) = Median (ARE)

Out of all baseline model, the model which had minimum value of NARE was selected, as it indicated less biased compared to other baseline models.

3. Variability: Variability is the metric which helps in assessing the ability of a baseline in predicting half hourly load under many **different conditions** and across many **different customers**. Relative Error Ratio (RER) is used as a statistical measure of variability. It is calculated by dividing the prediction error at all half-hourly data points by the average of the actual load. The standard deviation of these RER values gives a measure of variability of a baseline.

Steps followed for determining RER

a) The baseline was obtained through 10 in 10, 7 in 10, 5 in 10 and 3 in 10 baseline models for an actual day load curve for various consumer categories.

b) The Consumption obtained from the baseline models were compared with the actual day consumption.

c) Following formula was used to determine NRER:

$$\textbf{RER} = \frac{x_1}{x_2}$$

Where, X_1 = Predicted consumption – Actual consumption

X_2= Average of Actual Consumption

NRER (Normalized RER) = Standard Deviation (RER)

d) Out of all baseline model, the model which had minimum value of NRER was selected, as it indicated less variability compared to other baseline models.

Figure 2.8 to Figure 2.35 shows a set of baseline load curves that have been estimated through 10 in 10, 7 in 10, 5 in 10 and 3 in 10 baseline models for an actual day load curve for various consumer categories. Tables 2.4 to Table 2.36, lists the evaluated values of NRMSE, ARE and RER for each of these consumer categories, The NRMSE, ARE and RER values in red are found to be least for various actual days (3 actual days are considered) for a particular baseline among the four baseline load curves. These least values in red, show the better performance of that baseline in the context of accuracy, bias and variability over the other three baselines.

Residential Colony

FIGURE 2.8:
Load Curve for Residential Colony

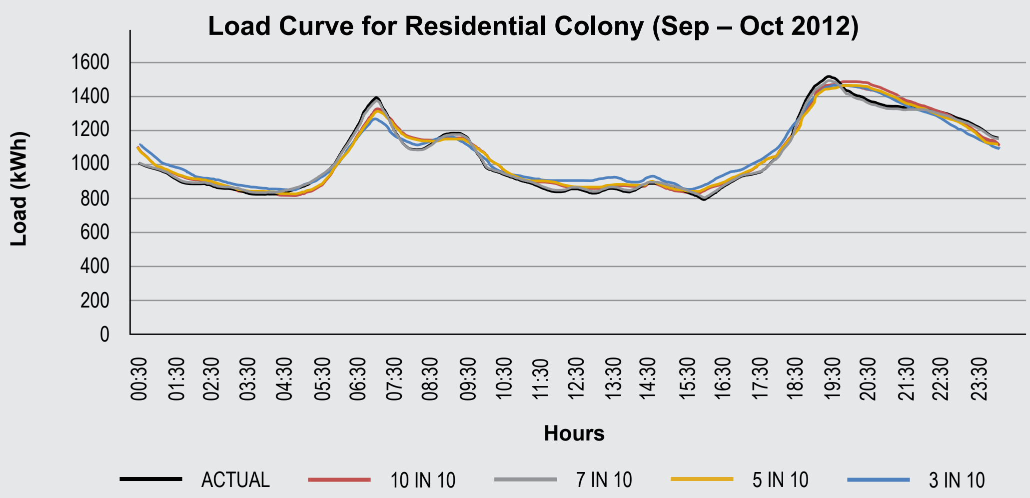


TABLE 2.4:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Residential Colony	19-10-2012	0.0498	0.0525	0.0590	0.0708
	22-10-2012	0.0702	0.0758	0.0822	0.0952
	09-10-2012	0.0979	0.1020	0.1085	0.1200

TABLE 2.5:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Residential Colony	19-10-2012	0.0133	0.0167	0.0197	0.0249
	22-10-2012	0.0385	0.0419	0.0448	0.0501
	09-10-2012	0.0498	0.0534	0.0564	0.0618

TABLE 2.6:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Residential Colony	19-10-2012	0.0325	0.0332	0.0369	0.0438
	22-10-2012	0.0268	0.0283	0.0316	0.0388
	09-10-2012	0.0538	0.0548	0.0586	0.0652

Hospital

FIGURE 2.9:
Load Curve for Hospital

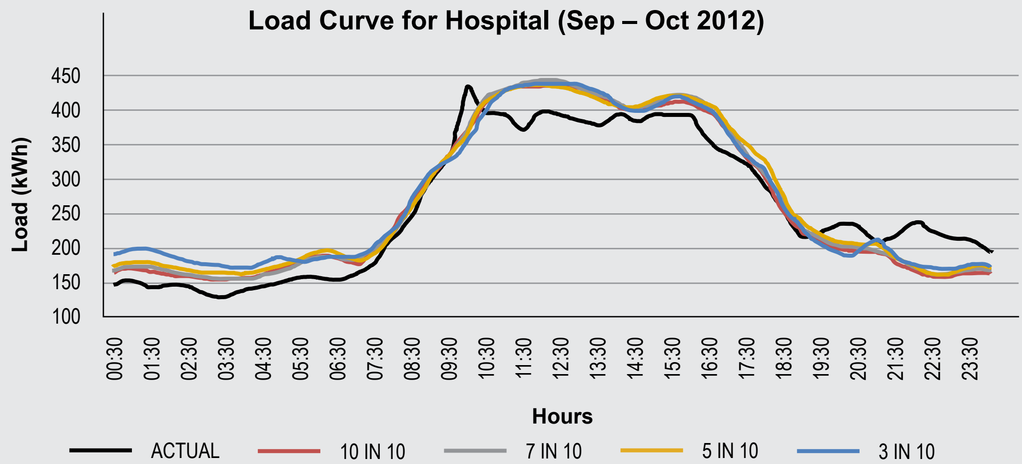


TABLE 2.7:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Hospital	03-10-2012	0.1028	0.1071	0.1110	0.1209
	12-10-2012	0.0594	0.0692	0.0792	0.0918
	26-09-2012	0.0832	0.0910	0.0970	0.1089

TABLE 2.8:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Hospital	03-10-2012	0.0338	0.0468	0.0555	0.0623
	12-10-2012	0.0596	0.0737	0.0831	0.0905
	26-09-2012	0.0726	0.0886	0.0993	0.1077

TABLE 2.9:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Hospital	03-10-2012	0.1188	0.1206	0.1227	0.1329
	12-10-2012	0.0445	0.0474	0.0557	0.0702
	26-09-2012	0.0684	0.0688	0.0697	0.0812

Printing Press

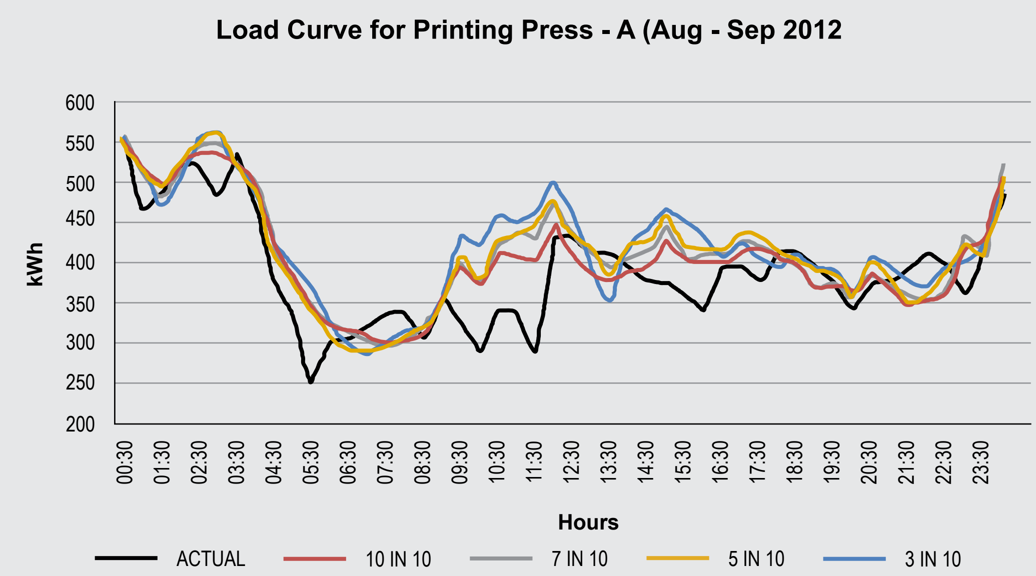


FIGURE 2.11:
Load Curve for Printing Press – B

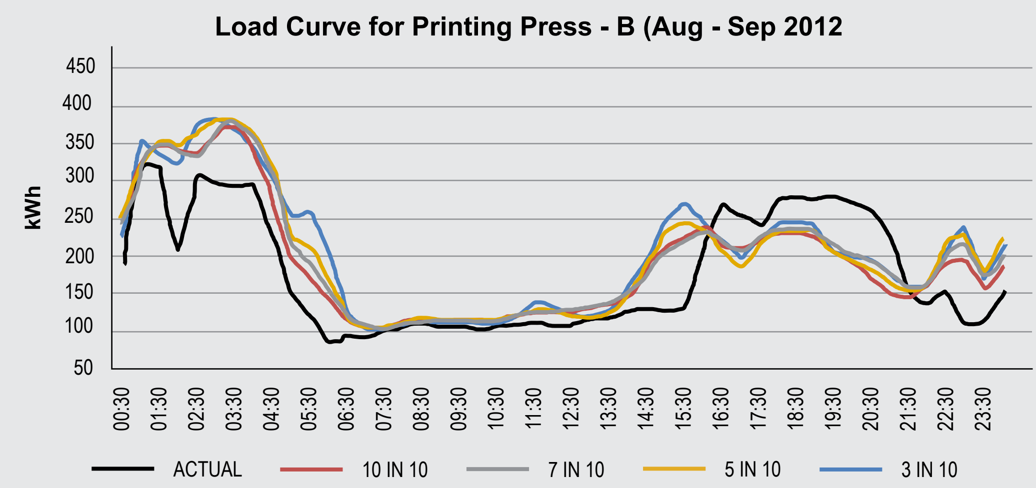


FIGURE 2.12:

Load Curve for Printing Press – C

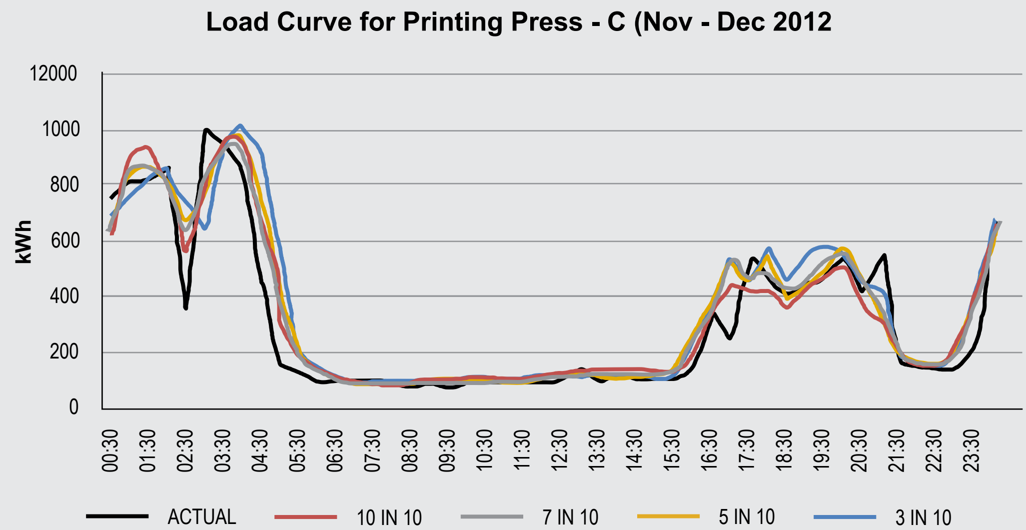


FIGURE 2.13:

Load Curve for Printing Press- D

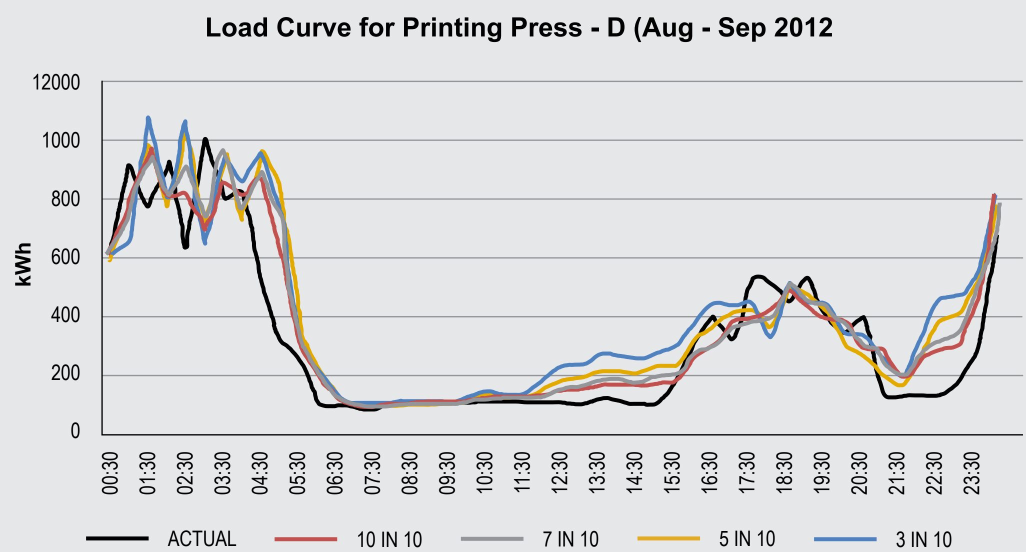


TABLE 2.10:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Printing Press – A	05-09-2012	0.1393	0.1547	0.1664	0.1938
	04-09-2012	0.1526	0.1696	0.1887	0.2060
	28-09-2012	0.2204	0.2464	0.2611	0.2844
Printing Press – B	07-09-2012	0.2104	0.2190	0.2495	0.2557
	20-09-2012	0.6668	0.6871	0.7167	0.7186
	24-09-2012	0.1634	0.1986	0.2196	0.2328
Printing Press – C	27-12-2012	0.0995	0.1074	0.1227	0.1499
	28-12-2012	0.1115	0.1335	0.1405	0.1534
	18-12-2012	0.1389	0.1340	0.1497	0.1763
Printing Press – D	18-09-2012	0.1301	0.1508	0.1767	0.1958
	17-09-2012	0.1646	0.1839	0.2127	0.2282
	11-09-2012	0.1643	0.1687	0.1876	0.2057

TABLE 2.11:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Printing Press – A	05-09-2012	0.0439	0.0581	0.0683	0.0804
	04-09-2012	0.0449	0.0591	0.0692	0.0813
	28-09-2012	0.1473	0.1629	0.1741	0.1875
Printing Press – B	07-09-2012	0.1078	0.1409	0.1617	0.1890
	20-09-2012	0.1677	0.2029	0.2251	0.2541
	24-09-2012	0.4557	0.4925	0.5158	0.5462
Printing Press – C	27-12-2012	0.1482	0.2020	0.2399	0.2932
	28-12-2012	0.1963	0.2554	0.2969	0.3556
	18-12-2012	0.2036	0.2608	0.3011	0.3579
Printing Press – D	18-09-2012	0.1953	0.2630	0.3344	0.4649
	17-09-2012	0.4778	0.5559	0.6382	0.7886
	11-09-2012	0.2643	0.3423	0.4246	0.5750

TABLE 2.12:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Printing Press - A	05-09-2012	0.1014	0.1083	0.1134	0.1316
	04-09-2012	0.1125	0.1212	0.1331	0.1423
	28-09-2012	0.1269	0.1436	0.1506	0.1664
Printing Press - B	07-09-2012	0.2699	0.2723	0.3098	0.3089
	20-09-2012	0.1873	0.2282	0.2517	0.2579
	24-09-2012	0.7394	0.7486	0.7797	0.7636
Printing Press - C	27-12-2012	0.2817	0.2984	0.3395	0.4146
	28-12-2012	0.3520	0.4192	0.4376	0.4737
	18-12-2012	0.3780	0.3564	0.3966	0.4663
Printing Press - D	18-09-2012	0.3522	0.4024	0.4663	0.4953
	17-09-2012	0.4513	0.4978	0.5772	0.5853
	11-09-2012	0.5081	0.5126	0.5632	0.5977

Engineering Firm

FIGURE 2.14:
Load Curve for Engineering Firm - A

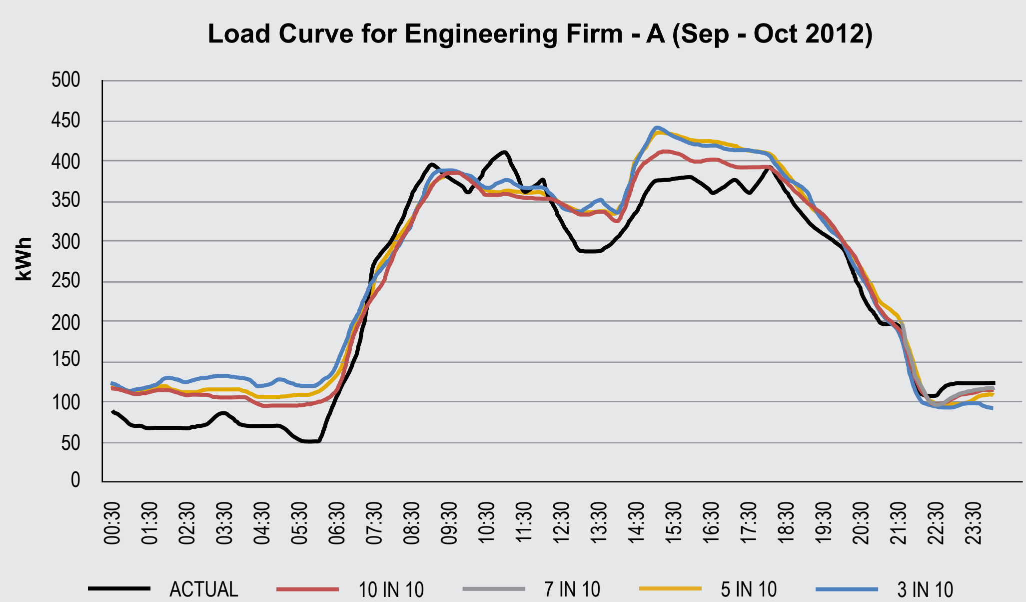


FIGURE 2.15:
Load Curve for Engineering Firm – B

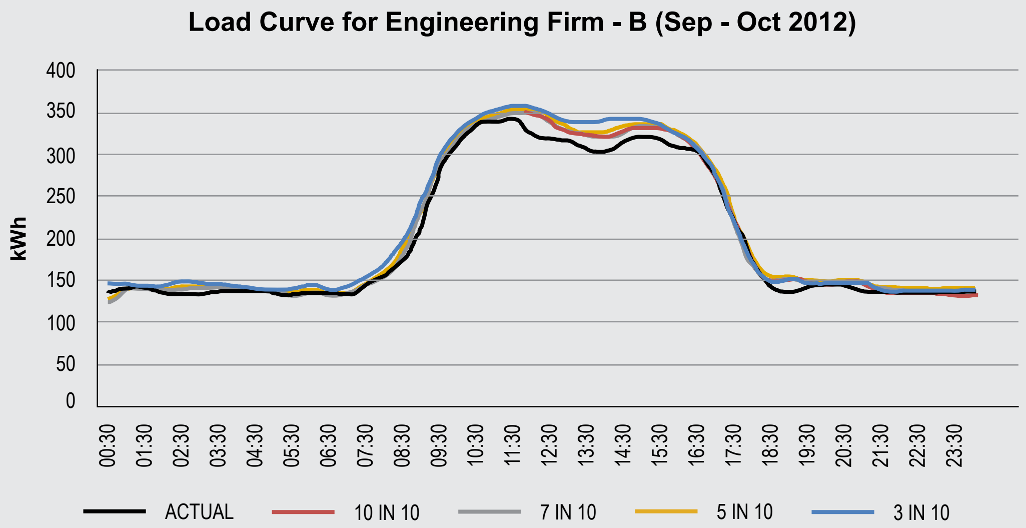


FIGURE 2.16:
Load Curve for Engineering Firm - C

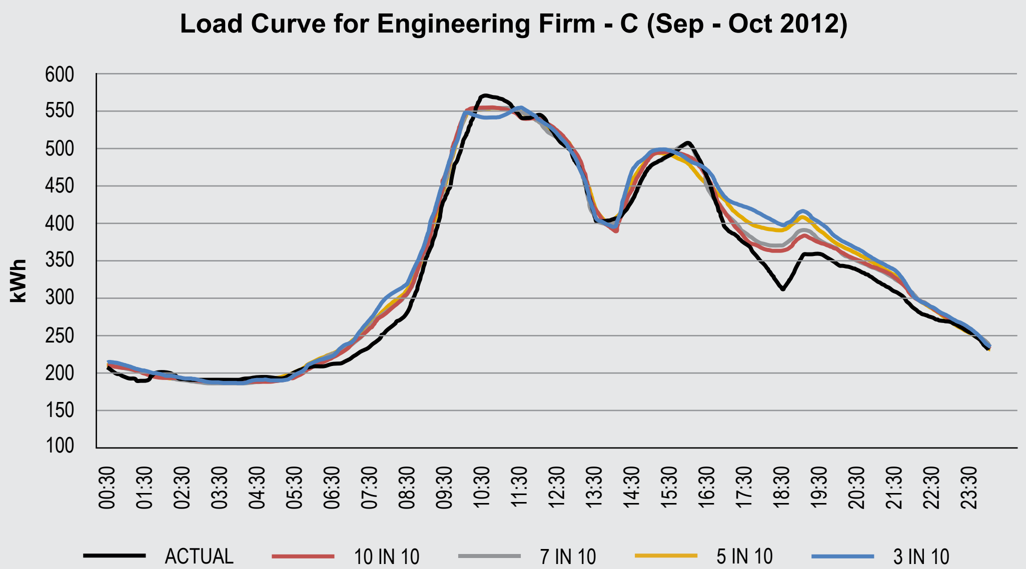


TABLE 2.13:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NMRSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Engineering Firm- A	16-10-2012	0.0838	0.0899	0.1002	0.1123
	12-10-2012	0.0900	0.0982	0.1083	0.1212
	26-09-2012	0.1968	0.2136	0.2287	0.2396
Engineering Firm - B	26-09-2012	0.0451	0.0494	0.0567	0.0700
	27-09-2012	0.1230	0.1308	0.1353	0.1341
	15-10-2012	0.0462	0.0488	0.0500	0.0616
Engineering Firm - C	03-10-2012	0.0782	0.0818	0.0959	0.1047
	28-09-2012	0.0781	0.0862	0.1001	0.1111
	29-09-2012	0.0457	0.0519	0.0641	0.0753
Engineering Firm - D	16-10-2012	0.1391	0.1550	0.1653	0.1661
	19-10-2012	0.1356	0.1474	0.1599	0.1802
	23-10-2012	0.0982	0.1076	0.1154	0.1290

TABLE 2.14:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Engineering Firm - A	16-10-2012	0.0533	0.0675	0.0750	0.0851
	12-10-2012	0.0804	0.0956	0.1036	0.1144
	26-09-2012	0.0985	0.1137	0.1217	0.1324
Engineering Firm - B	26-09-2012	0.0382	0.0518	0.0620	0.0775
	27-09-2012	0.1432	0.1569	0.1670	0.1826
	15-10-2012	0.0382	0.0518	0.0620	0.0775
Engineering Firm - C	03-10-2012	0.0282	0.0357	0.0422	0.0515
	28-09-2012	0.0392	0.0469	0.0535	0.0631
	29-09-2012	0.0293	0.0366	0.0429	0.0521
Engineering Firm - D	16-10-2012	0.0170	0.0225	0.0270	0.0327
	19-10-2012	0.0273	0.0327	0.0371	0.0427
	23-10-2012	0.0424	0.0479	0.0525	0.0581

TABLE 2.15:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Engineering Firm - A	16-10-2012	0.1103	0.1099	0.1226	0.1364
	12-10-2012	0.0952	0.0937	0.1059	0.1205
	26-09-2012	0.2050	0.2175	0.2330	0.2402
Engineering Firm - B	26-09-2012	0.0385	0.0359	0.0393	0.0476
	27-09-2012	0.1501	0.1570	0.1596	0.1464
	15-10-2012	0.0480	0.0450	0.0400	0.0484
Engineering Firm - C	03-10-2012	0.0445	0.0483	0.0609	0.0702
	28-09-2012	0.0773	0.0836	0.0975	0.1063
	29-09-2012	0.0741	0.0749	0.0878	0.0932
Engineering Firm - D	16-10-2012	0.0400	0.0423	0.0440	0.0479
	19-10-2012	0.0490	0.0517	0.0551	0.0616
	23-10-2012	0.0417	0.0459	0.0478	0.0422

Hotel

FIGURE 2.18:
Load Curve for Hotel – A

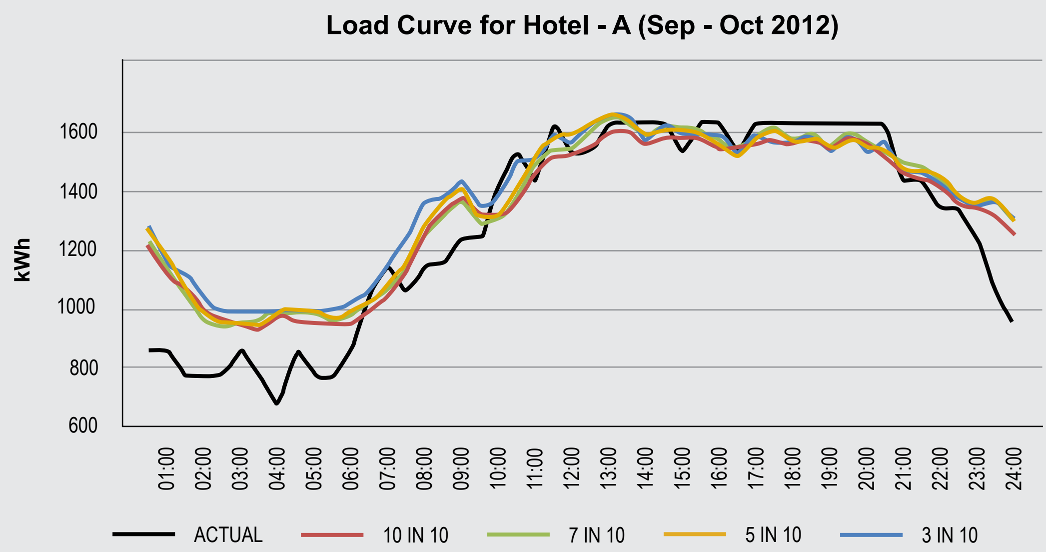


FIGURE 2.19:
Load Curve for Hotel – B

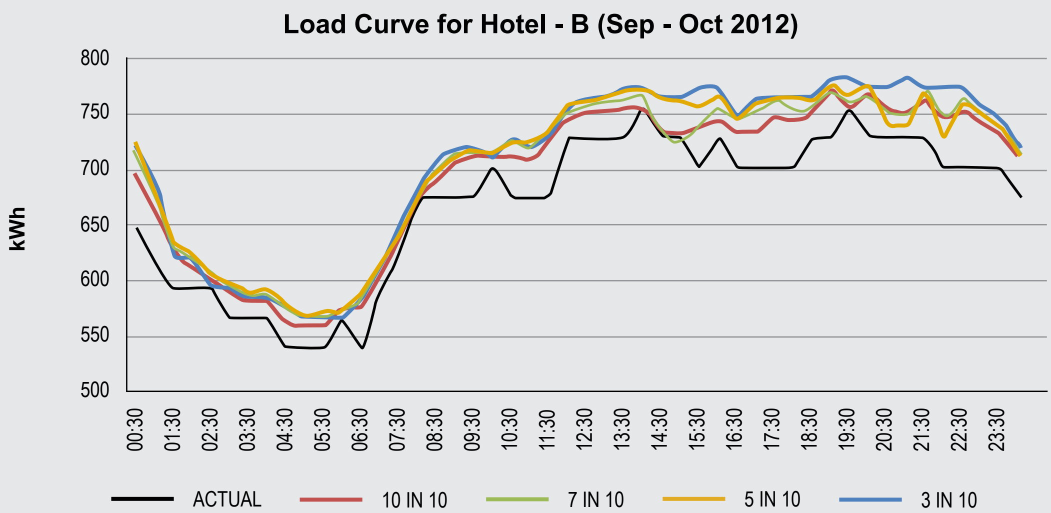


TABLE 2.16:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Hotel - A	08-10-2012	0.1474	0.1524	0.1626	0.1717
	23-02-2012	0.2920	0.3150	0.3289	0.3467
	25-10-2012	0.2090	0.2258	0.2368	0.2472
Hotel - B	09-10-2012	0.1828	0.2082	0.2237	0.2249
	22-10-2012	0.3451	0.3719	0.3854	0.3935
	24-09-2012	0.1359	0.1702	0.1857	0.2039

TABLE 2.17:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Hotel - A	08-10-2012	0.0361	0.0484	0.0547	0.0639
	23-02-2012	0.1820	0.1967	0.2043	0.2153
	25-10-2012	0.0374	0.0501	0.0567	0.0662
Hotel - B	09-10-2012	0.0367	0.0465	0.0518	0.0569
	22-10-2012	0.1361	0.1467	0.1524	0.1580
	24-09-2012	0.0407	0.0508	0.0563	0.0617

TABLE 2.18:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Hotel - A	08-10-2012	0.1037	0.1014	0.1062	0.1078
	23-02-2012	0.0475	0.0493	0.0564	0.0596
	25-10-2012	0.0856	0.0865	0.0878	0.0856
Hotel - B	09-10-2012	0.0213	0.0256	0.0257	0.0280
	22-10-2012	0.0500	0.0538	0.0546	0.0474
	24-09-2012	0.0529	0.0563	0.0588	0.0536

R&D Sector

FIGURE 2.20:
Load Curve for R&D Sector – A

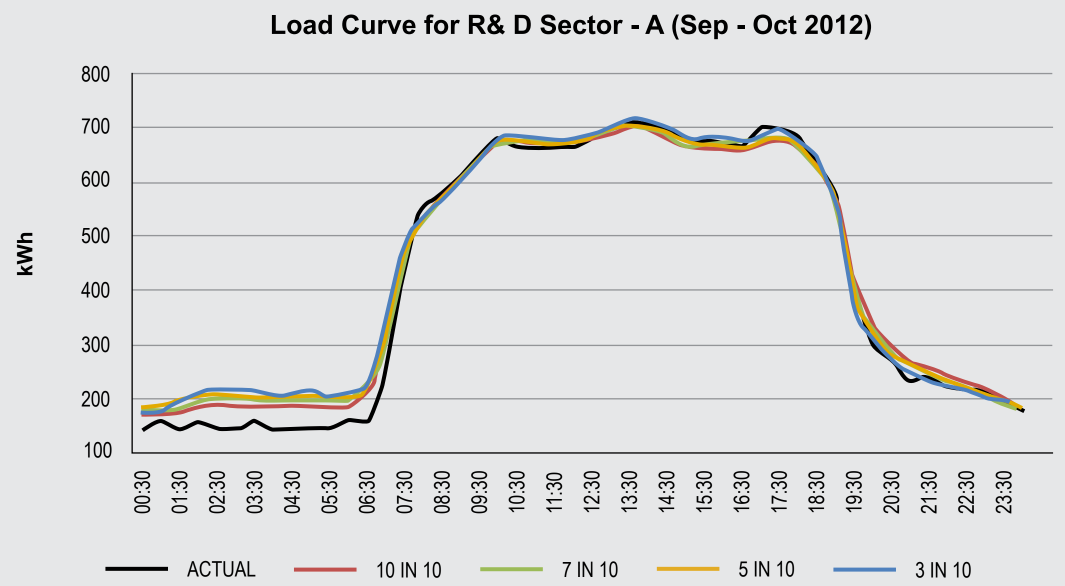


FIGURE 2.21:
Load Curve for R&D Sector- B

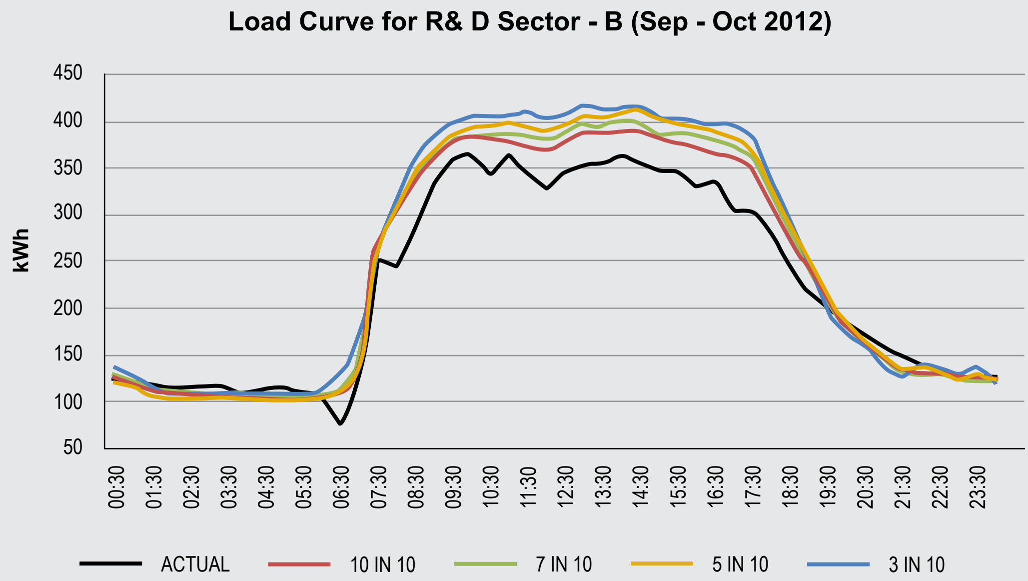


TABLE 2.19:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	**7 IN 10**	**5 IN 10**	**3 IN 10**
R&D Sector - A	03-10-2012	0.0641	0.0679	0.0730	0.0785
	27-09-2012	0.0609	0.0663	0.0690	0.0753
	26-09-2012	0.0614	0.0672	0.0698	0.0768
R&D Sector - B	25-09-2012	0.1231	0.1419	0.1628	0.1846
	24-09-2012	0.1263	0.1394	0.1624	0.1809
	26-09-2012	0.0902	0.1107	0.1282	0.1534

TABLE 2.20:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	**7 IN 10**	**5 IN 10**	**3 IN 10**
R&D Sector - A	03-10-2012	0.0398	0.0472	0.0517	0.0582
	27-09-2012	0.0389	0.0458	0.0500	0.0561
	26-09-2012	0.0473	0.0547	0.0591	0.0655
R&D Sector - B	25-09-2012	0.0652	0.0852	0.1077	0.1414
	24-09-2012	0.1306	0.1535	0.1793	0.2178
	26-09-2012	0.1143	0.1356	0.1597	0.1956

TABLE 2.21:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
R&D Sector - A	03-10-2012	0.0832	0.0864	0.0922	0.0977
	27-09-2012	0.0784	0.0838	0.0860	0.0926
	26-09-2012	0.0778	0.0832	0.0851	0.0925
R&D Sector - B	25-09-2012	0.0992	0.1185	0.1311	0.1470
	24-09-2012	0.1241	0.1293	0.1502	0.1494
	26-09-2012	0.1327	0.1502	0.1690	0.1792

IT Sector

FIGURE 2.22:
Load Curve for IT Sector – A

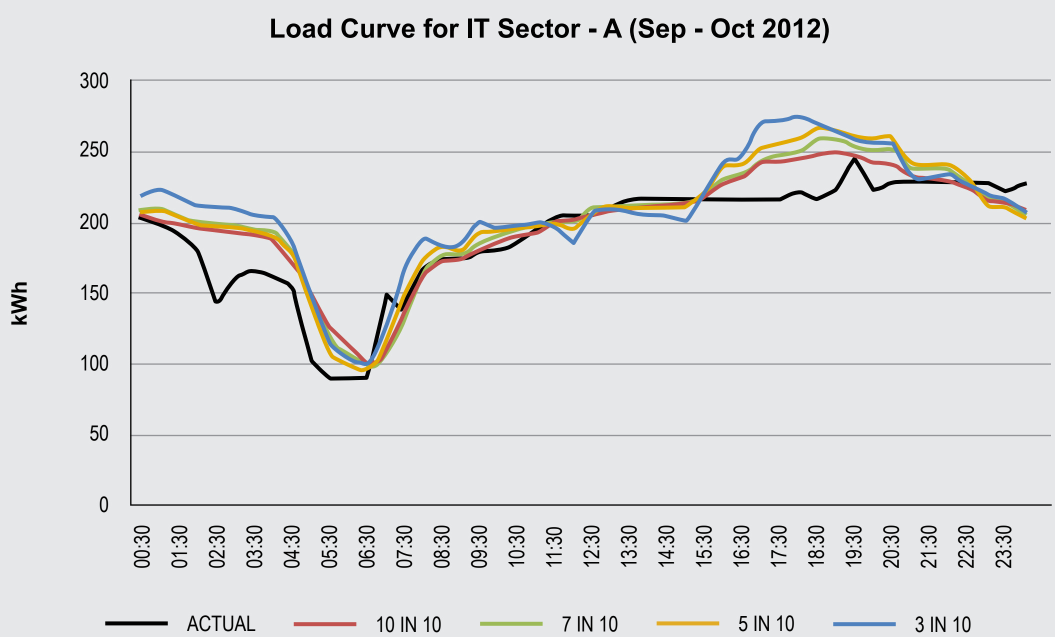


FIGURE 2.23:
Load Curve for IT Sector - B

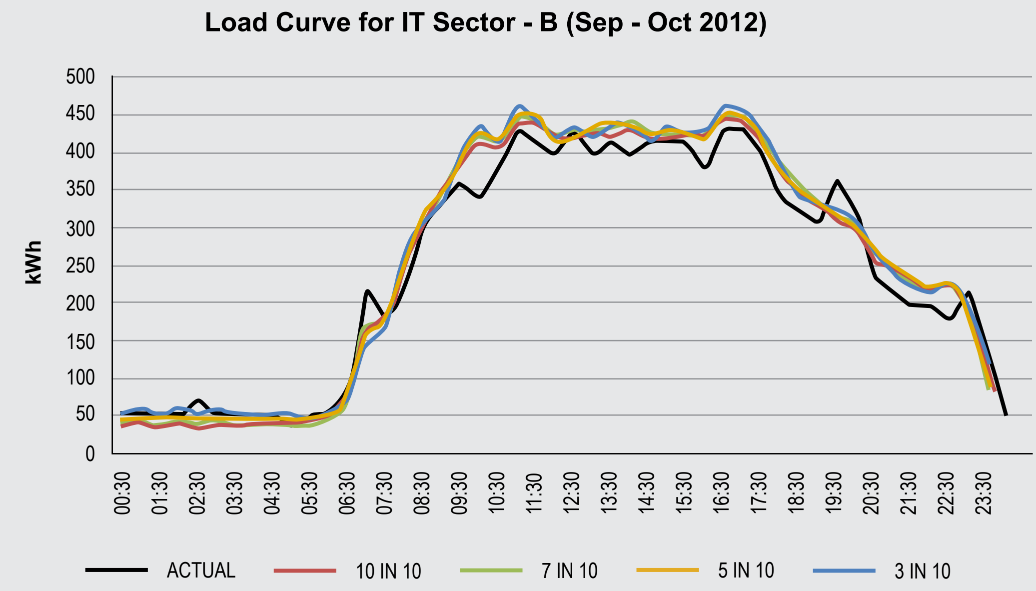


FIGURE 2.24:
Load Curve for IT Sector – C

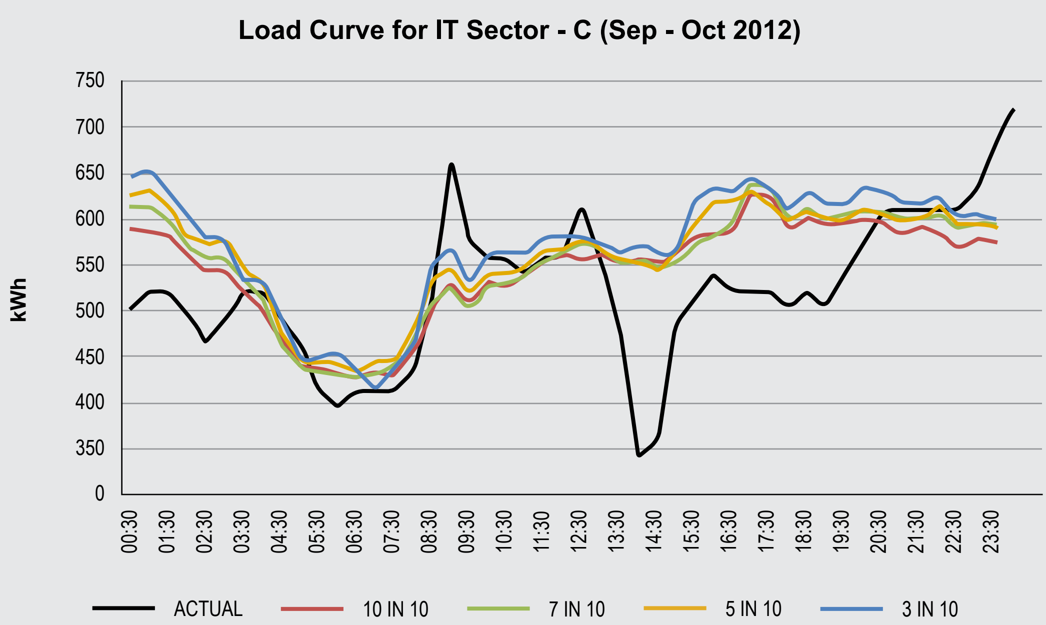


FIGURE 2.25:
Load Curve for IT Sector – D

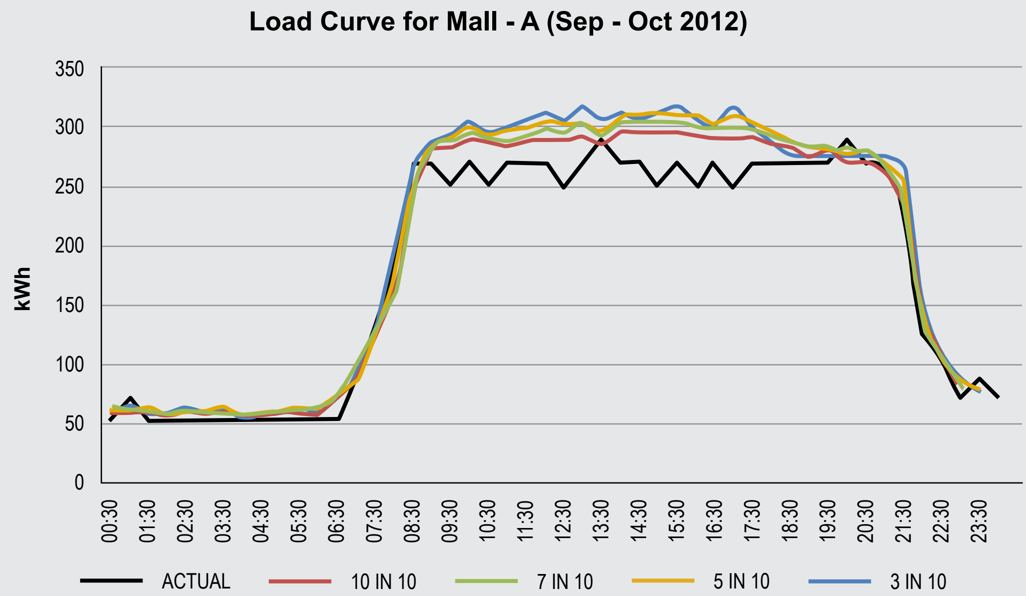


TABLE 2.22:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
IT Sector- A	10/12/2012	0.1212	0.1362	0.1488	0.1816
	10/22/2012	0.1777	0.1917	0.1959	0.2323
	10/15/2012	0.2043	0.2136	0.2133	0.2444
IT Sector- B	9/25/2012	0.1080	0.1148	0.1119	0.1066
	10/5/2012	0.1043	0.1133	0.1105	0.1097
	10/12/2012	0.0680	0.0737	0.0727	0.0746
IT Sector- C	10/16/2012	0.3728	0.3873	0.4054	0.4359
	10/23/2012	0.3788	0.3867	0.4011	0.4214
	10/9/2012	0.3306	0.3345	0.3382	0.3514

TABLE 2.23:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	**7 IN 10**	**5 IN 10**	**3 IN 10**
IT Sector- A	10/12/2012	0.0414	0.0547	0.0653	0.0846
	10/22/2012	0.0489	0.0627	0.0736	0.0934
	10/15/2012	0.0576	0.0730	0.0852	0.1074
IT Sector- B	9/25/2012	0.0232	0.0313	0.0404	0.0518
	10/5/2012	0.0732	0.0821	0.0921	0.1046
	10/12/2012	0.0393	0.0478	0.0574	0.0694
IT Sector- C	10/16/2012	0.0376	0.0513	0.0665	0.0892
	10/23/2012	0.0384	0.0517	0.0663	0.0883
	10/9/2012	0.0455	0.0592	0.0744	0.0971

TABLE 2.24:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	**7 IN 10**	**5 IN 10**	**3 IN 10**
IT Sector- A	10/12/2012	0.0893	0.0954	0.1003	0.1186
	10/22/2012	0.1440	0.1512	0.1498	0.1741
	10/15/2012	0.1677	0.1709	0.1656	0.1850
IT Sector- B	9/25/2012	0.1067	0.1138	0.1088	0.1065
	10/5/2012	0.1593	0.1718	0.1606	0.1506
	10/12/2012	0.1554	0.1635	0.1554	0.1411
IT Sector- C	10/16/2012	0.2398	0.2415	0.2419	0.2467
	10/23/2012	0.1831	0.1852	0.1892	0.1928
	10/9/2012	0.1543	0.1578	0.1614	0.1664

Manufacturing

FIGURE 2.26:
Load Curve for Manufacturing Unit- A

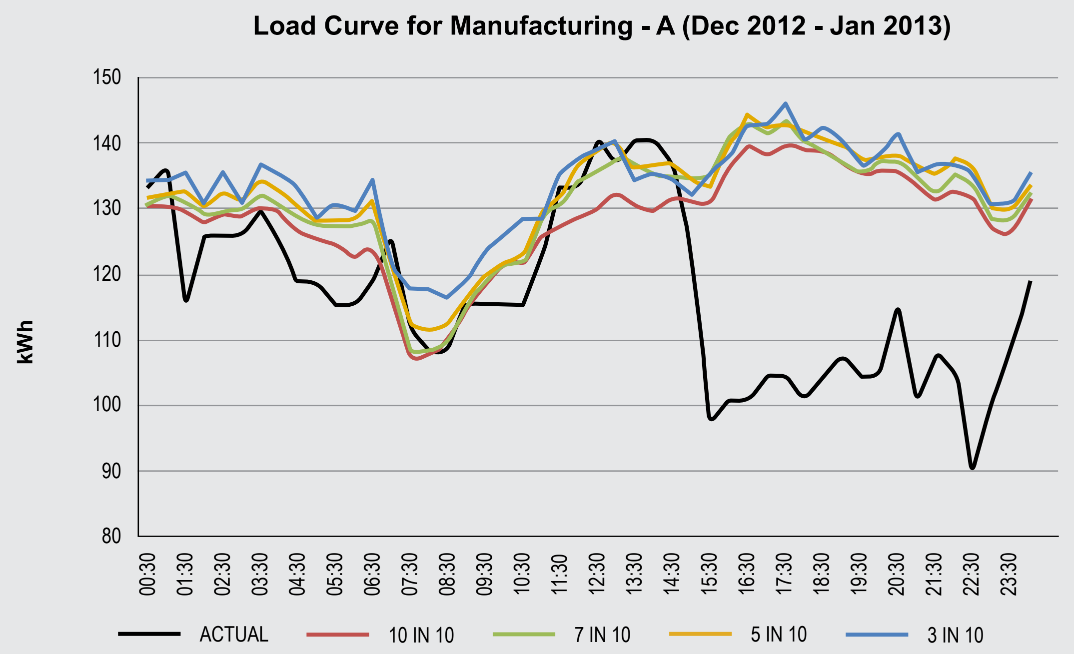


FIGURE 2.27:
Load Curve for Manufacturing Unit- B

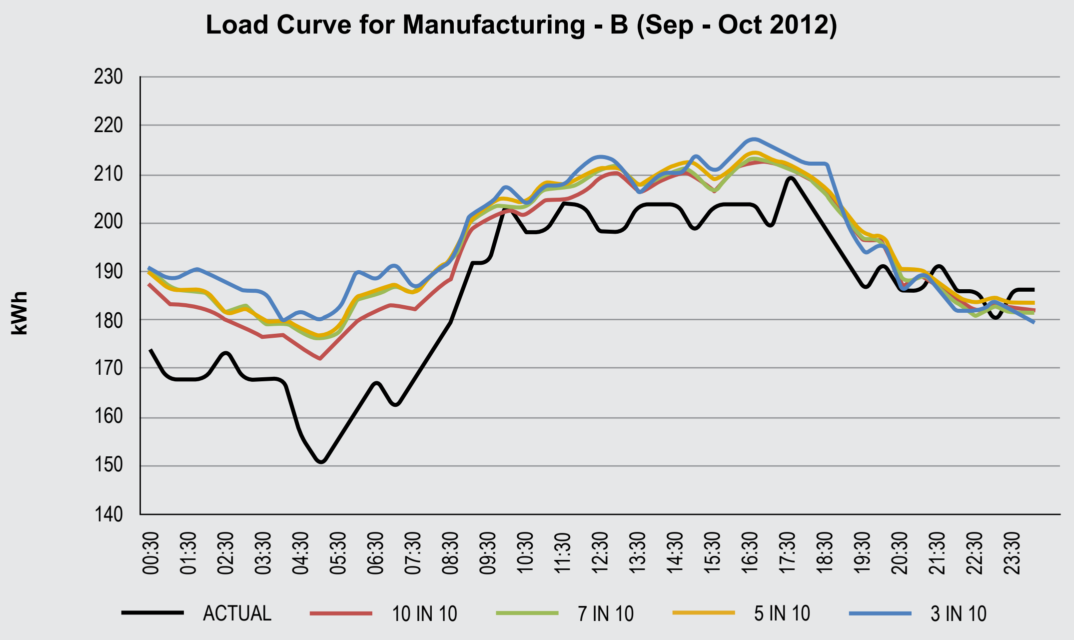


TABLE 2.25:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Manufacturing A	27-12-2012	0.3308	0.3570	0.3782	0.3937
	18-01-2013	0.3535	0.4038	0.4436	0.4681
	04-01-2013	0.3923	0.4153	0.4336	0.4458
Manufacturing B	11-10-2012	0.2431	0.2699	0.2789	0.3001
	25-09-2012	0.3723	0.3996	0.4080	0.4349
	18-10-2012	0.1729	0.2048	0.2099	0.2425

TABLE 2.26:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Manufacturing A	27-12-2012	0.1265	0.1453	0.1585	0.1688
	18-01-2013	0.1038	0.1226	0.1357	0.1460
	04-01-2013	0.1019	0.1212	0.1348	0.1454
Manufacturing B	11-10-2012	0.0422	0.0506	0.0546	0.0605
	25-09-2012	0.1105	0.1195	0.1237	0.1300
	18-10-2012	0.0724	0.0808	0.0848	0.0907

TABLE 2.27:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Manufacturing A	27-12-2012	0.1378	0.1350	0.1332	0.1297
	18-01-2013	0.0576	0.0576	0.0607	0.0568
	04-01-2013	0.1208	0.1193	0.1200	0.1191
Manufacturing B	11-10-2012	0.0369	0.0430	0.0406	0.0502
	25-09-2012	0.0660	0.0693	0.0676	0.0754
	18-10-2012	0.0489	0.0537	0.0532	0.0583

Commercial Office

FIGURE 2.28:
Load Curve for Commercial Office – A

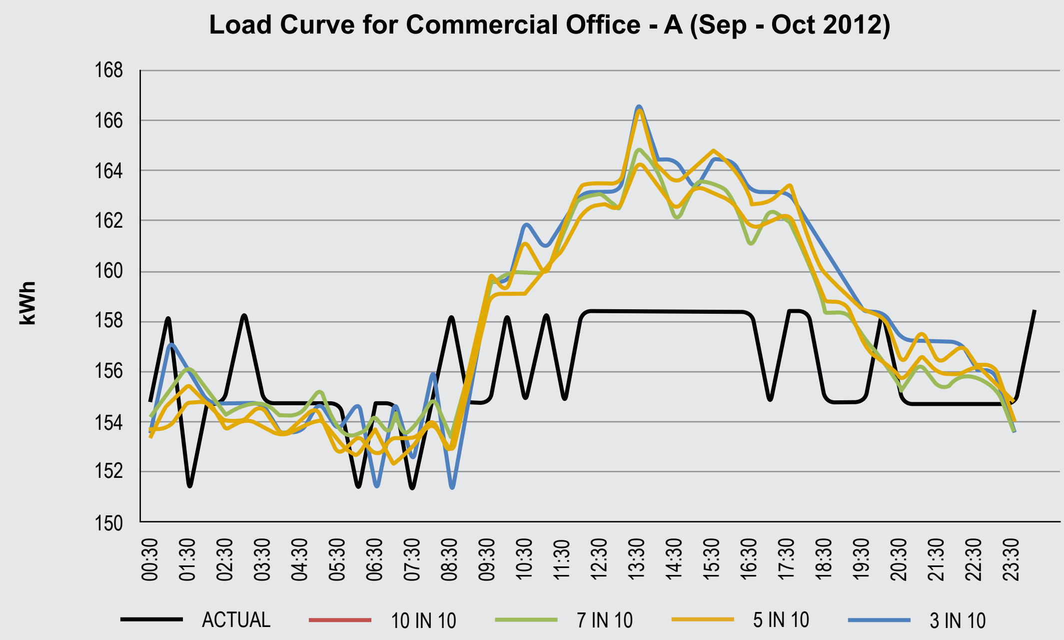


FIGURE 2.29:
Load Curve for Commercial Office – B

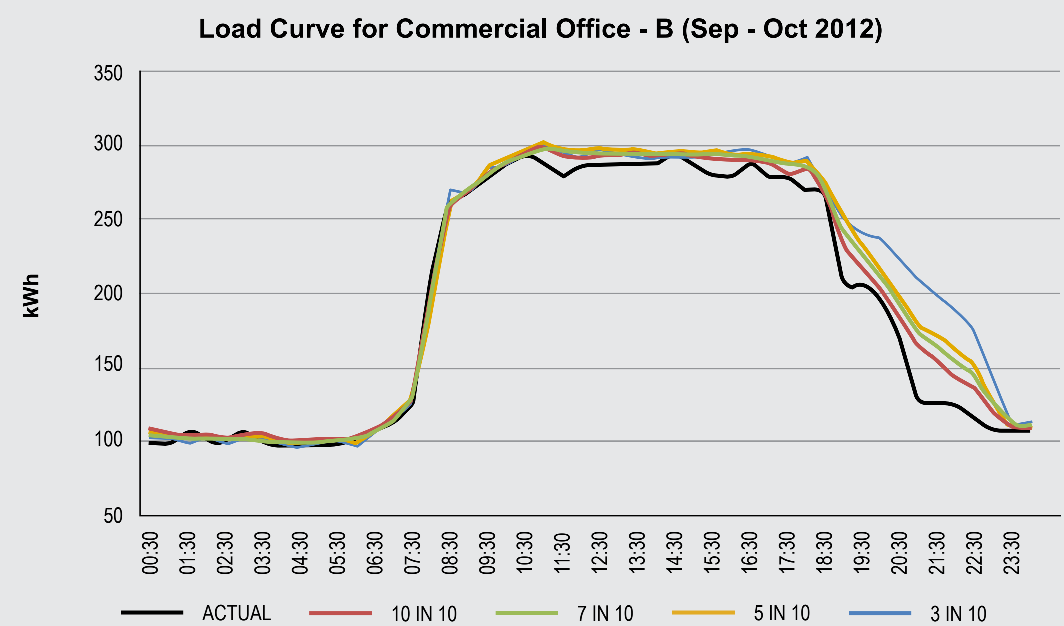


FIGURE 2.30:
Load Curve for Commercial Office - C

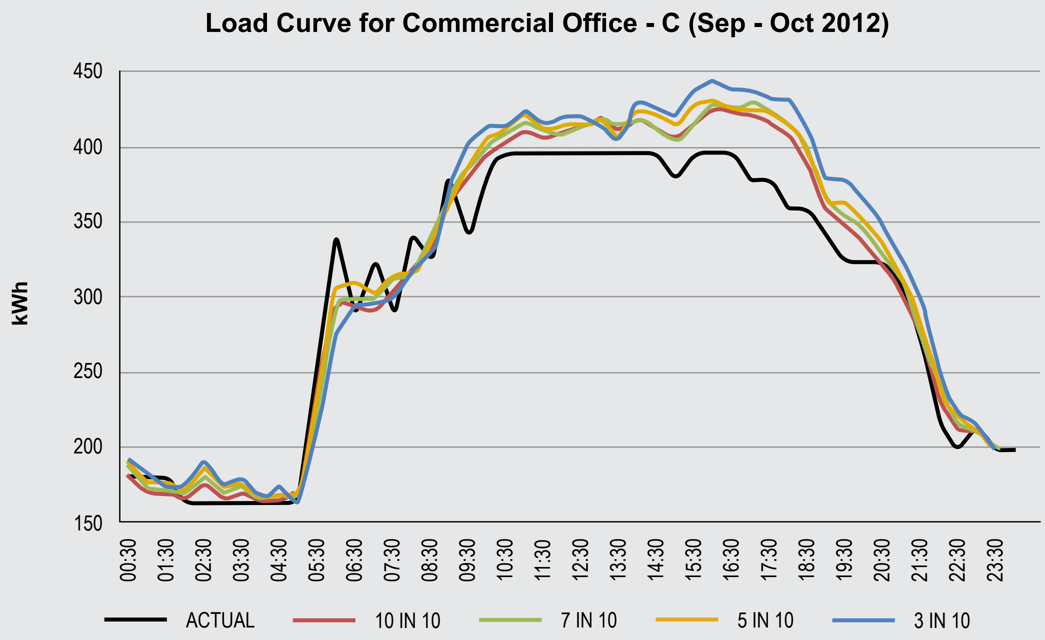


FIGURE 2.31:
Load Curve for Commercial Office – D

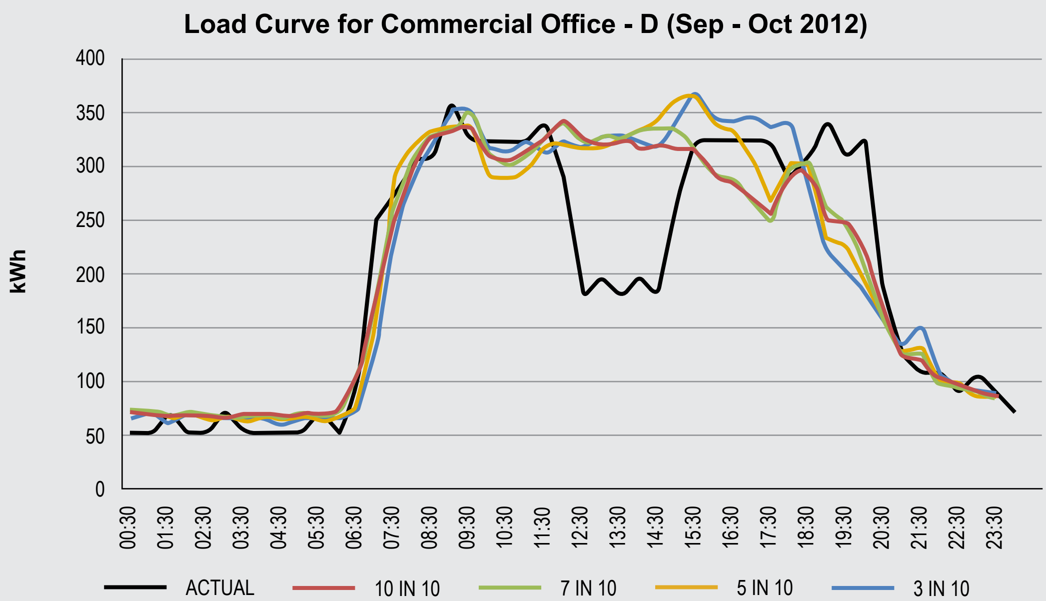


FIGURE 2.32:
Load Curve for Commercial Office –E

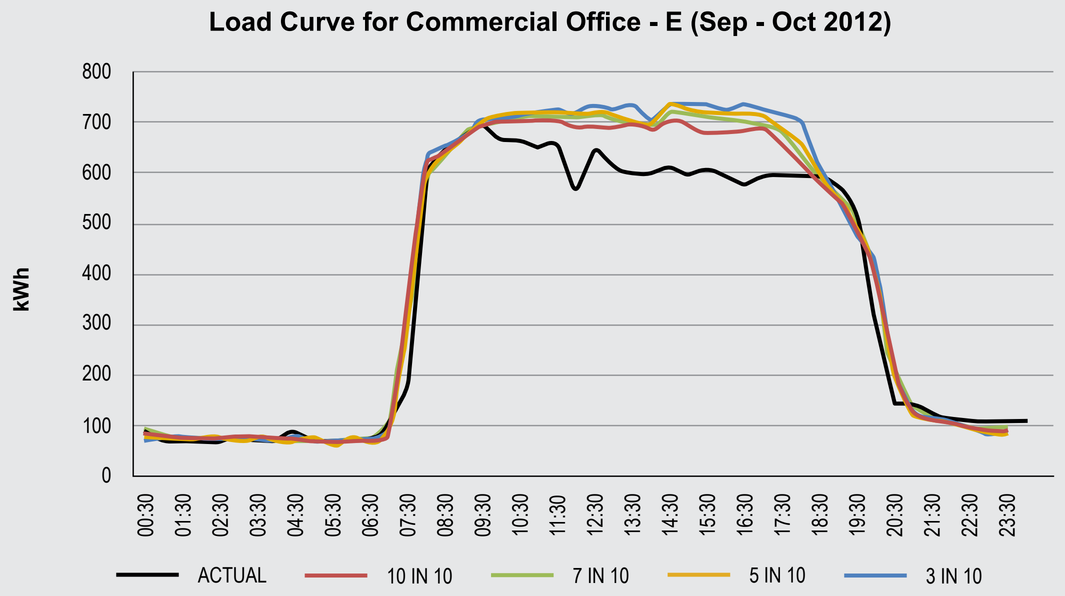


TABLE 2.28:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Commercial Office - A	04-10-2012	0.5735	0.5840	0.6532	0.6675
	08-10-2012	0.2694	0.2895	0.3210	0.3466
	03-10-2012	0.4585	0.4696	0.5454	0.5693
Commercial Office - B	16-10-2012	0.0553	0.0745	0.0878	0.1262
	28-09-2012	0.0538	0.0691	0.0826	0.1220
	25-09-2012	0.0798	0.0954	0.1101	0.1472
Commercial Office - C	19-10-2012	0.0880	0.0952	0.1016	0.1217
	23-10-2012	0.0932	0.1053	0.1111	0.1397
	04-10-2012	0.0867	0.0991	0.1057	0.1381
Commercial Office - D	24-09-2012	0.1815	0.1903	0.1974	0.1988
	12-10-2012	0.1598	0.1629	0.1389	0.1524
	26-09-2012	0.1573	0.1627	0.1627	0.1677
Commercial Office -E	26-09-2012	0.0773	0.0891	0.0976	0.1113
	18-10-2012	0.1339	0.1477	0.1557	0.1670
	17-10-2012	0.0883	0.1037	0.1116	0.1219

TABLE 2.29:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Commercial Owffice - A	04-10-2012	0.0091	0.0111	0.0132	0.0145
	08-10-2012	0.0144	0.0165	0.0185	0.0199
	03-10-2012	0.0140	0.0160	0.0180	0.0194
Commercial Office - B	16-10-2012	0.0308	0.0414	0.0506	0.0633
	28-09-2012	0.0355	0.0478	0.0584	0.0731
	25-09-2012	0.0676	0.0799	0.0904	0.1051
Commercial Office - C	19-10-2012	0.0301	0.0412	0.0498	0.0602
	23-10-2012	0.0381	0.0495	0.0584	0.0691
	04-10-2012	0.0405	0.0519	0.0608	0.0715
Commercial Office - D	24-09-2012	0.0483	0.0560	0.0633	0.0724
	12-10-2012	0.0610	0.0690	0.0768	0.0863
	26-09-2012	0.0593	0.0665	0.0736	0.0822
Commercial Office -E	26-09-2012	0.0760	0.0922	0.1020	0.1165
	18-10-2012	0.1648	0.1829	0.1938	0.2100
	17-10-2012	0.0710	0.0850	0.0935	0.1061

TABLE 2.30:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Commercial Office - A	04-10-2012	0.0193	0.0188	0.0217	0.0222
	08-10-2012	0.0121	0.0118	0.0127	0.0139
	03-10-2012	0.0229	0.0221	0.0246	0.0244
Commercial Office - B	16-10-2012	0.0469	0.0633	0.0732	0.1118
	28-09-2012	0.0450	0.0564	0.0665	0.1068
	25-09-2012	0.0560	0.0681	0.0803	0.1211
Commercial Office - C	19-10-2012	0.0598	0.0637	0.0630	0.0866
	23-10-2012	0.0749	0.0804	0.0803	0.1043
	04-10-2012	0.0680	0.0674	0.0667	0.0813
Commercial Office - D	24-09-2012	0.2829	0.2961	0.3064	0.3075
	12-10-2012	0.2500	0.2539	0.2139	0.2338
	26-09-2012	0.2465	0.2540	0.2525	0.2587
Commercial Office -E	26-09-2012	0.1351	0.1569	0.1669	0.1789
	18-10-2012	0.1953	0.2145	0.2249	0.2394
	17-10-2012	0.1079	0.1210	0.1322	0.1513

Dairy

FIGURE 2.33:
Load Curve for Dairy

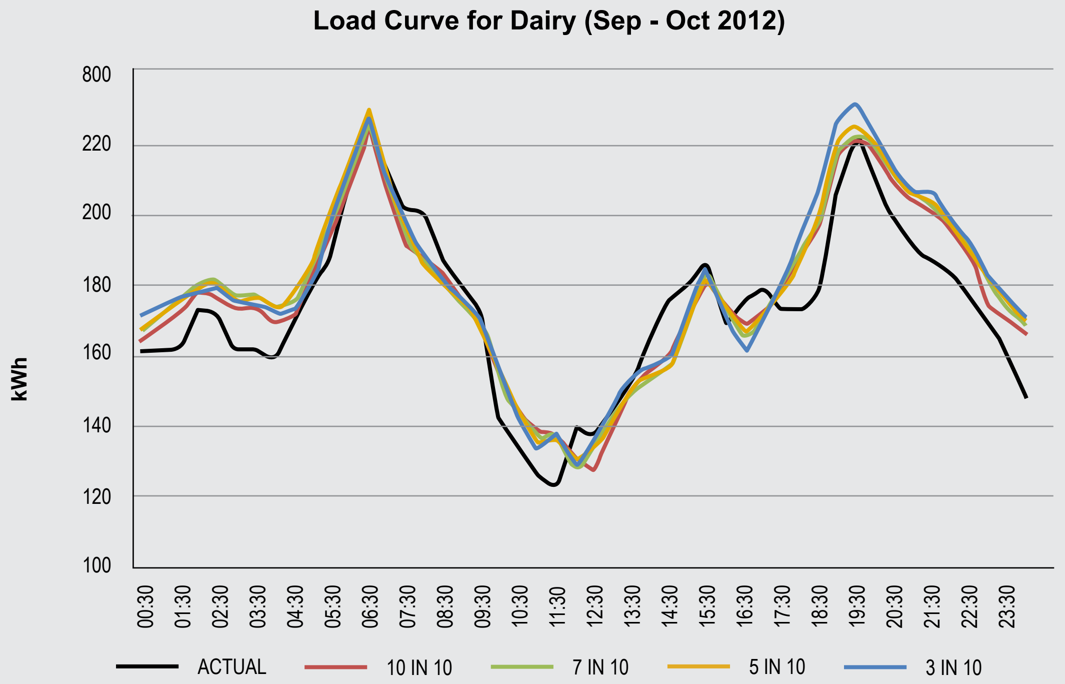


TABLE 2.31:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Dairy	05-10-2012	0.0929	0.1066	0.1085	0.1157
	10-10-2012	0.1185	0.1225	0.1250	0.1242
	12-10-2012	0.0990	0.1156	0.1196	0.1233

TABLE 2.32:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Dairy	05-10-2012	0.0194	0.0260	0.0307	0.0340
	10-10-2012	0.0325	0.0391	0.0438	0.0470
	12-10-2012	0.0267	0.0333	0.0381	0.0414

TABLE 2.33:

Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	7 IN 10	5 IN 10	3 IN 10
Dairy	05-10-2012	0.0529	0.0592	0.0581	0.0613
	10-10-2012	0.1418	0.1453	0.1471	0.1450
	12-10-2012	0.0542	0.0622	0.0623	0.0629

Shopping Centre

FIGURE 2.34:

Load Curve for Shopping Centre – A

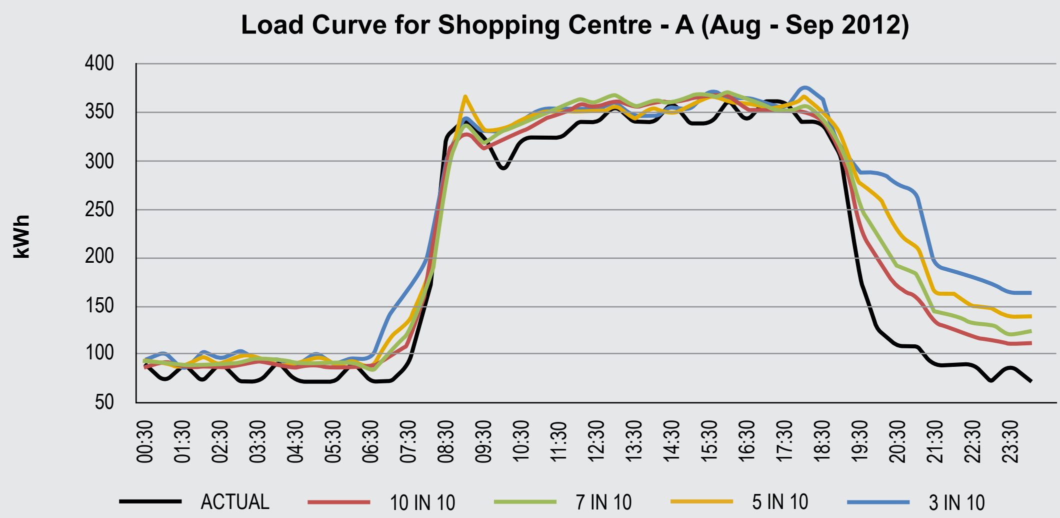


FIGURE 2.35:

Load Curve for Shopping centre – B

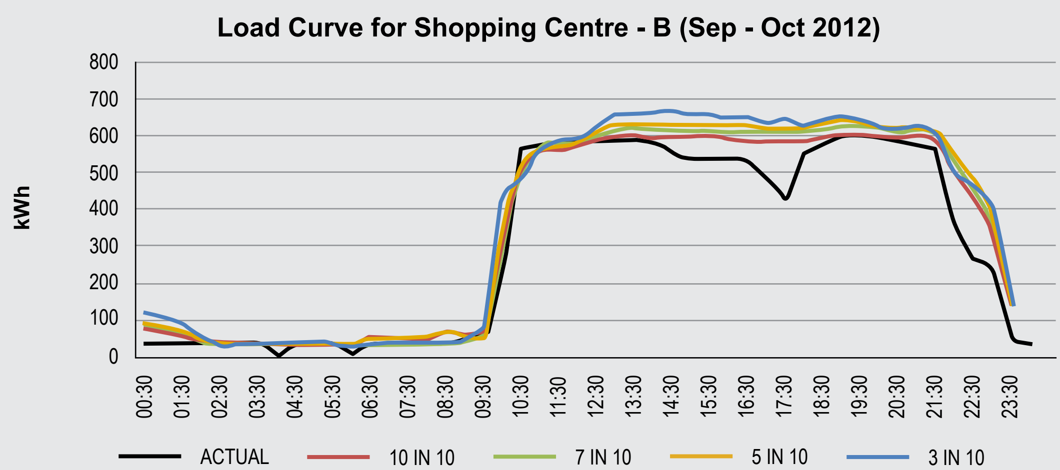


TABLE 2.34:
Comparison of NRMSE values for unadjusted baselines of three actual days

Facility Type	Actual day	NRMSE values for unadjusted baseline techniques			
		10 IN 10	**7 IN 10**	**5 IN 10**	**3 IN 10**
Shopping Centre – A	13-09-2012	0.0939	0.1185	0.1550	0.2065
	14-09-2012	0.1808	0.1902	0.2129	0.2651
	28-08-2012	0.1659	0.1818	0.2137	0.2706
Shopping Centre – B	18-10-2012	0.1790	0.1989	0.2093	0.2263
	27-09-2012	0.1230	0.1417	0.1558	0.1800
	26-09-2012	0.0949	0.1143	0.1313	0.1467

TABLE 2.35:
Comparison of ARE values for unadjusted baselines of three actual days

Facility Type	Actual day	ARE values for unadjusted baseline techniques			
		10 IN 10	**7 IN 10**	**5 IN 10**	**3 IN 10**
Shopping Centre – A	13-09-2012	0.1317	0.1625	0.2026	0.2698
	14-09-2012	0.2505	0.2830	0.3253	0.3962
	28-08-2012	0.2927	0.3303	0.3792	0.4611
Shopping Centre – B	18-10-2012	0.1225	0.1491	0.1751	0.2013
	27-09-2012	0.1110	0.1309	0.1504	0.1700
	26-09-2012	0.0954	0.1155	0.1353	0.1551

TABLE 2.36:
Comparison of RER values for unadjusted baselines of three actual days

Facility Type	Actual day	RER values for unadjusted baseline techniques			
		10 IN 10	**7 IN 10**	**5 IN 10**	**3 IN 10**
Shopping Centre – A	13-09-2012	0.0967	0.1245	0.1689	0.2252
	14-09-2012	0.1638	0.1556	0.1658	0.2153
	28-08-2012	0.1297	0.1336	0.1653	0.2253
Shopping Centre – B	18-10-2012	0.1506	0.1774	0.1989	0.2161
	27-09-2012	0.2025	0.2286	0.2438	0.2830
	26-09-2012	0.3014	0.3297	0.3392	0.3607

2.4 Conclusion

Energy/Peak savings are quantities that cannot be directly measured, hence the agencies that verify and report these savings to their clients can attract scepticism if there is a hint of subjectivity involved in the M&V process. So it is very crucial that M&V processes are standardized. Apart from restoring the confidence of clients and investors in the possibility of a project creating savings, M&V is important for several valid reasons. In some cases, it is necessary to verify savings so that suppliers/ESCOs and in case of DR, the participating customers can get paid. Many government agencies and utilities require monitoring and verification before releasing incentive payment. Finally, from an environmental perspective, M&V enables the creation of greenhouse gas emission-reduction credits. Although these carbon credits have lost their trade value owing to a landslide fall in their prices, they are still a credible index for measuring the reduction in carbon footprint.

The analysis reveals that there cannot be one baseline that is a best fit for all customers. Although, "10 in 10" baseline shows best values for accuracy, bias and variability metrics for most of the customer categories, it needs further analysis before declaring these values conclusive as the effects of temperature and other factors have not been taken into account.

This report has tried to present some of the baselining methods that have been used by ISO/utilities in other parts of the world and has used real time consumption data to analyse the performance of these techniques in estimating the actual day load.

The analysis reveals that there cannot be one baseline that is a best fit for all customers. Although, "10 in 10" baseline shows best values for accuracy, bias and variability metrics for most of the customer categories, it needs further analysis before declaring these values conclusive as the effects of temperature and other factors have not been taken into account. So far, '5 in 10' baseline have been used for two DR projects in the country. It will need more such empirical results to assess the performance of these baseline types. It should also be taken into account that averaging method of estimation of consumer baseline is simple to understand and evaluate and could encourage better DR participation. Although it is ideal to devise a standard baseline type and technique for a particular customer class, it can also lead to dispute in settling of compensation/incentives due to the participation of customers of different categories.

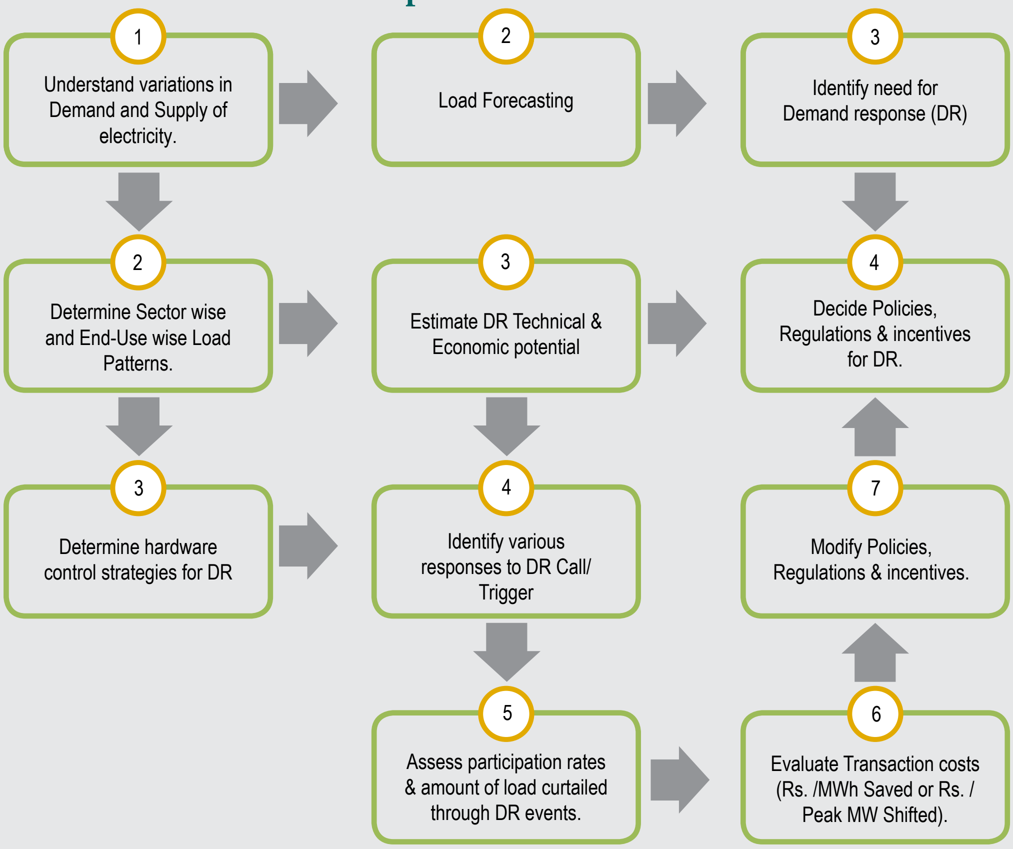
CHAPTER 3

Framework for Implementation of DR in India

3.1 Introduction

A structured approach to design and implementation of Demand Response (DR) allows stakeholders in the planning process to keep track of the strategies, incentives and regulations developed for effective roll out of DR programs and make corrections if required. Figure 3.1 shows in detail, various phases in the proposed DR framework that can help in identifying, assessing and evaluating the policies, regulations and incentives developed for Demand Response.

FIGURE 3.1:
Framework to identify, assess and evaluate the policies, regulations and incentives for Demand Response.



It also provides a roadmap for the necessary load research that needs to be done to effectively identify the need and potential of DR for a particular utility/State/Region. The steps shown in Figure 3.1 are explained in detail in the following sections with the help of appropriate case studies from different states. The objective of this framework report is to help utilities and regulators to develop their own framework as per the power scenario in their region.

3.2 DR Framework

1. Understanding variations in demand and supply of electricity.

The level of demand is mainly affected by factors like weather, daylight hours, working hours, holidays, and consumption patterns across various load categories. The variations in demand can be analyzed using the demand curve over different timeframes (daily, monthly average, annual average), across various load categories (residential, commercial, industrial, agricultural, etc.) and at various end-use levels (lighting, space cooling, refrigeration, pumping, etc.) to get useful insights into the cause of these variations. These insights can be coupled with energy audits to establish corrective measures to lower the cost of operation while maintaining or improving the system performance. Various interventions, on the demand side (DSM & DR) of the customer's meter can be tried as a part of these corrective measures.

Various interventions, on the demand side (DSM & DR) of the customer's meter can be tried as a part of these corrective measures.

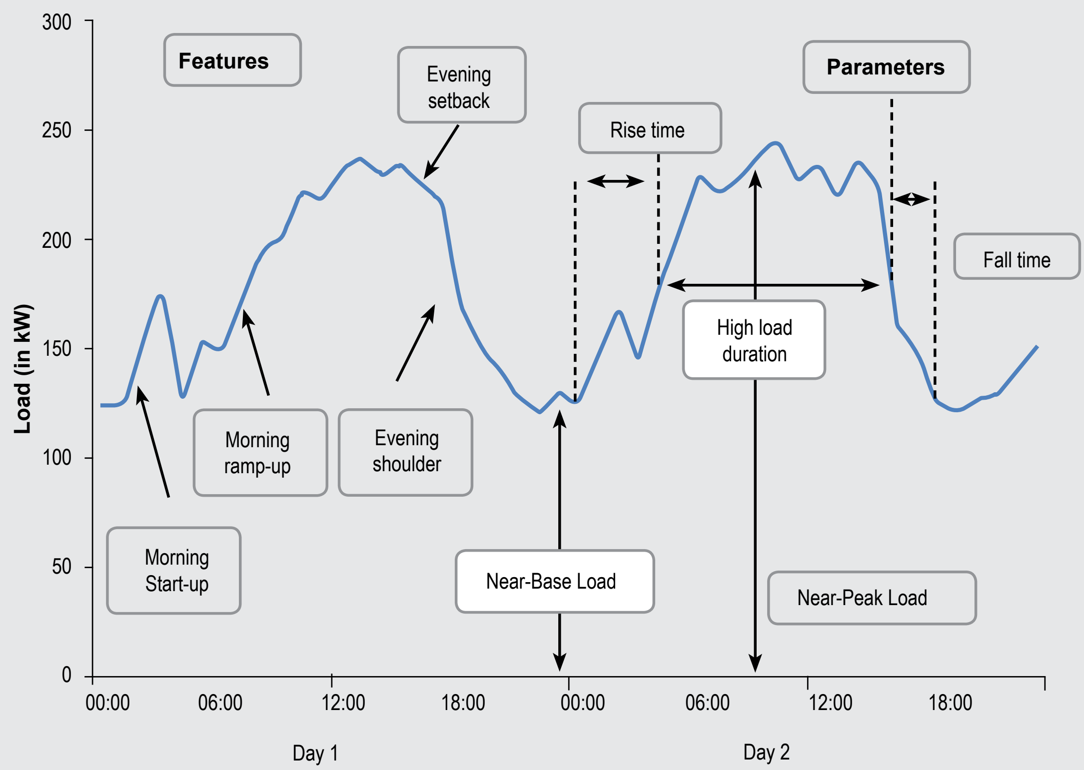
Analysis and comparison of load profiles can be structured better if certain load features and parameters, as shown in Table 3.1 and Figure 3.2, are identified. **Near-Base load** allows comparing peak load characteristics of two customers with similar consumption pattern while **Near-Peak load** helps in getting insights about the causes of variation in peak load over days in a week (effect of non-working days) or months in a year (effect of season/weather). **High load duration** occurring in a load profile can lead to inquiry into operations and end-uses causing them. This can later be used to identify timings for curtailment of such operations and end-uses during a DR event. Some operations and equipment take time to startup & shutdown and can be identified through the analysis of **Rise-time** and **Fall-time** in a load curve. Such loads cannot be dispatched easily during a typical DR event and should be identified and studied closely before they are enrolled in a DR program. With the increasing integration of solar and wind generation capacity to the grid, it becomes vital to encourage DR participation from customers who can support the intermittent nature of supply of these resources through dispatching loads when they are not **ramping up** in the morning (wind) and evening (solar).

Table 3.2 and Figure 3.4 show the monthly average electricity demand for Gujarat for all the months in 2011. The variations in average load and peak to average load ratio over the months can give useful insights about the changes in the base load and peak load at the system level which can be used to procure capacity through base load and peaking plants respectively. Peak to average load ratio is calculated and plotted with average load in Figure 3.3 for reference.

TABLE 3.1:
Typical Load shape parameters

Load Shape parameters[23]	Definition
Near-Base Load (kW)	2.5th percentile of daily load
Near-Peak Load (kW)	97.5th percentile of daily load
High-Load Duration (hrs)	Duration for which load is closer to near-peak than near-base load.
Rise Time (hrs)	Duration for load to go from near-base load to start of high-load period.
Fall Time (hrs)	Duration for load to go from end of high-load period to near-base load.

Figure 3.2:
Load shape features and parameters.
Source: Quantifying Changes in Building Electricity Use, with Application to Demand Response. LBNL, 2011



23 Quantifying Changes in Building Electricity Use, with Application to Demand Response. LBNL, 2011

TABLE 3.2:
Monthly average electricity demand for Gujarat in 2011

Time of the day	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11
1:00 AM	7720	8287	8828	9336	9305	9280	7716	7088	7343	9682	9501	8606
2:00 AM	7649	8254	8762	9254	9134	9115	7634	7029	7284	9597	9464	8508
3:00 AM	7665	8205	8664	9025	9000	8968	7505	6947	7134	9513	9352	8409
4:00 AM	7523	8074	8516	8943	8890	8803	7424	6866	7098	9362	9210	8338
5:00 AM	7422	7975	8402	8828	8890	8803	7389	6924	7157	9288	9164	8224
6:00 AM	7638	8123	8467	8926	8939	8968	7447	7074	7308	9355	9336	8425
7:00 AM	8081	8451	8730	8975	8927	9078	7738	7273	7552	9385	9546	8925
8:00 AM	8583	8795	8697	8877	9000	9115	7795	7238	7517	9320	9623	9309
9:00 AM	8854	8943	8861	9057	9232	9353	7946	7389	7575	9416	9795	9496
10:00 AM	8997	9025	9008	9352	9512	9610	8237	7609	7912	9702	10044	9682
11:00 AM	8982	9140	9221	9615	9720	9830	8503	7784	8062	9978	10216	9697
12:00 Noon	8940	9139	9287	9746	9671	9812	8561	7934	8190	10084	10188	9699
1:00 PM	8568	8811	9107	9582	9622	9830	8365	7691	7993	10028	10066	9299
2:00 PM	8413	8730	8992	9615	9768	10032	8517	7725	8005	10077	10134	9198
3:00 PM	8542	8877	9254	9844	9890	10124	8667	7876	8202	10059	10144	9341
4:00 PM	8455	8877	9221	9877	9793	9995	8701	7841	8143	9861	9975	9371
5:00 PM	8441	8828	9041	9648	9598	9794	8689	7853	8132	9672	9881	9301
6:00 PM	8485	8811	8926	9451	9293	9592	8630	7864	8144	9721	10062	9286
7:00 PM	8544	8730	8664	9123	9305	9518	8551	7829	8248	9912	10102	9658
8:00 PM	8629	9107	9221	9615	9463	9665	8818	8167	8632	9799	9856	9344
9:00 PM	8042	8615	8943	9385	9524	9775	8900	8108	8295	9791	9791	9015
10:00 PM	7984	8598	9025	9451	9695	9849	8749	8004	8213	9915	9925	8944
11:00 PM	7958	8730	9238	9746	9707	9794	8596	7923	8200	9945	9879	8788
12:00 Midnight	7716	8582	9107	9631	9518	9528	8306	7609	7934	9898	9647	8488
Average load	8243	8654	8924	9371	9384	9570	8224	7569	7845	9723	9788	9056
Peak to average load ratio	1.09	1.06	1.04	1.05	1.05	1.06	1.08	1.08	1.10	1.04	1.04	1.07

FIGURE 3.3:
Monthly variations in average load and peak to average load ratio for Gujarat (2011)

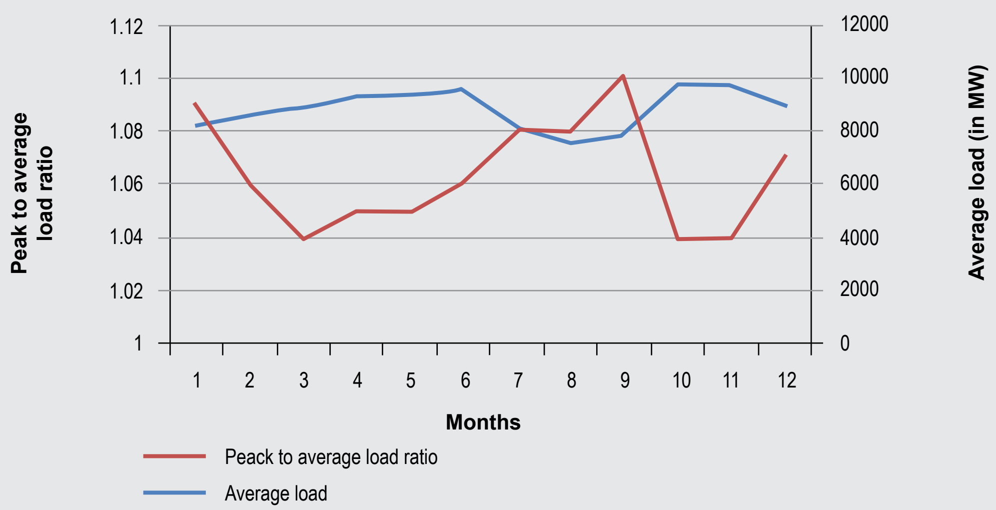
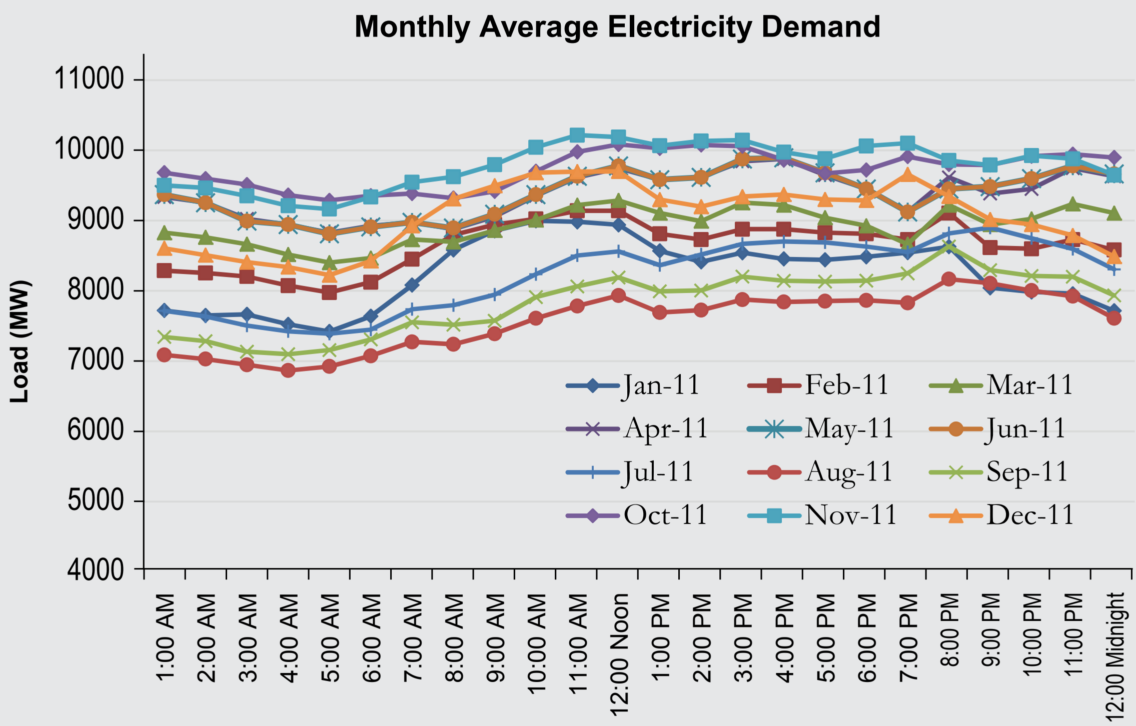
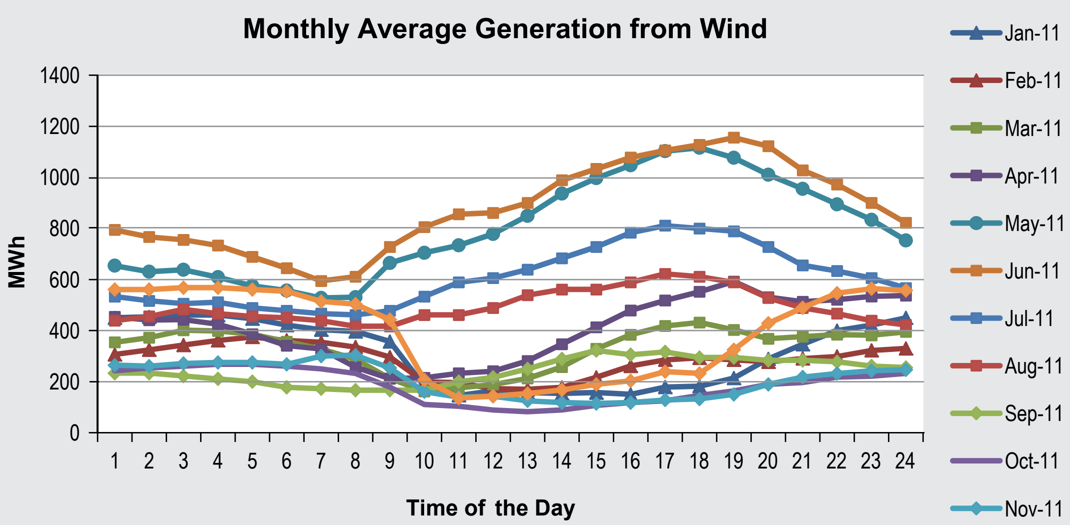


FIGURE 3.4:
Seasonal Variations in Electricity Demand in Gujarat[24]



The intermittent nature of many renewable resources such as wind and solar, as shown in Figure 3.5 and Figure 3.6, poses a big challenge to power system operators to manage these variable generation resources. System operators will need to arrange more ancillary services to fully accommodate the increasing penetration of these resources. Traditionally, ancillary

FIGURE 3.5:
Monthly average generation from Wind in Gujarat (2011)

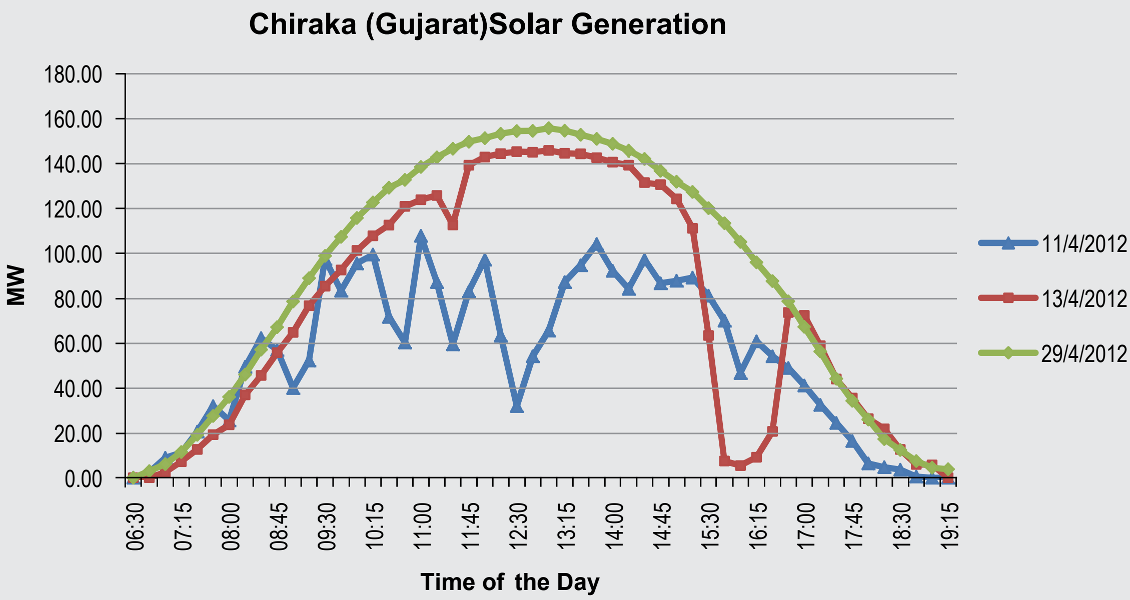


[24] Source: Policy and regulatory issues in the context of large scale grid integration of renewable energy in Gujarat, Jan 2013.

services have been provided by generators. Field implementation by various utilities across the globe[25] has successfully demonstrated the capability of Demand Response (DR) resources to provide various types of ancillary services.

Thus, prior assessment of these variations in demand and supply can help utilities/system operators to identify the need for procuring adequate capacity either from balancing and ancillary market or through DR.

FIGURE 3.6:
Solar generation data from Chiraka solar park (Gujarat)



2. Load Forecasting & Determining Sector wise and End-Use wise Load Patterns.

Forecasting demand for electricity in the Utility/State/Region can help in assessing if the existing and proposed generation and transmission infrastructures are sufficient enough to meet the forecasted demand for electricity. If the forecasted load doesn't match the installed generation capacity, the need to identify other alternatives such as Demand Response (DR) can be established. Loads enrolled under DR programs can be dispatched to serve as balancing or ancillary capacity depending upon the fact that whether the deficits are arising out of short term, medium term or long-term load forecasts.

Load forecasting can be short term (one hour to one week), medium term (one week to one year) or long term (more than a year) depending upon the time period for which it is intended. Short-term load forecasting takes into account time factors, weather data, and customer categories. The medium and long-term forecasts typically consider the historical load, weather data, the number of customers in different load categories, the various end-

[25] International Review of Demand Response Mechanisms, Australian Energy Market Commission, 2015

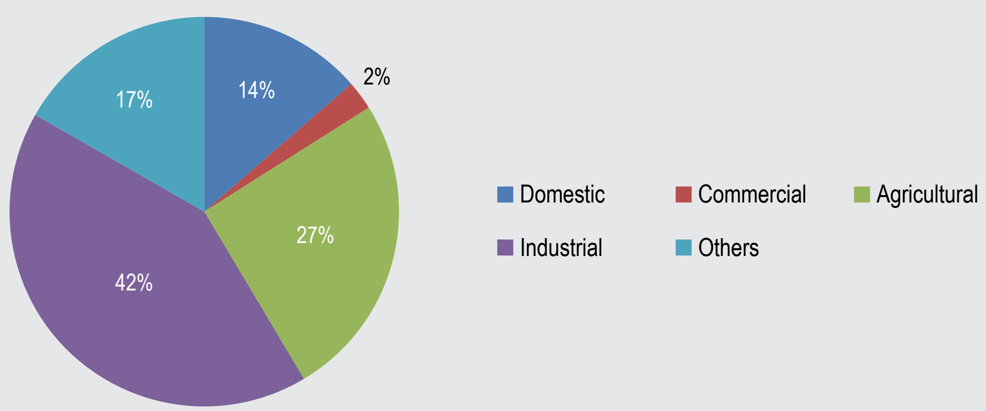
uses in those categories with the economic and demographic data of the customers & their forecasts, and the appliance sales data among other factors.

Many methods and mathematical models[26] are available in literature that can forecast the load with reliable accuracy. These are generally available as software packages by various vendors in the form of load management solutions.

If load forecasting can help in getting a quantitative estimate of additional generation capacity needed to meet the forecasted demand, then determination of sector wise and end-use wise load pattern can provide useful insights about the load sectors and operations/end-uses contributing to peak load. Figure 3.7 shows the percentage contribution of different load categories in total sale of electricity in Gujarat in Year 2011-12. In this case, industrial and agricultural sectors happen to be the major consumers of electricity in the state followed by domestic and commercial sector. Contribution of these load categories to system peak can be analyzed through Figure 3.8 & 3.9. Close observation of these sector-wise load profiles can be used to evaluate load factors for deciding the target load sector for DR programs. It should be noted that these load patterns are only for illustration purpose and do not represent the sector wise load patterns in absolute sense because there can be many variants of load curves for each categories.

Load research at feeder level can provide more accurate and specific information about the sector wise load patterns. Each distribution feeder has certain types of loads connected to it and this information is available with the utility. If this data can be mapped with the recorded hourly feeder data, then it can help utilities gain valuable knowledge about how the loads on a particular feeder are behaving. Hourly data of Bhandup (Urban) Zone[27] under MSEDCL (Maharashtra State Electricity distribution Company Limited), Mumbai has been plotted for some of its feeder has been plotted in Figure 3.10 to 3.19. The consumption pattern of various consumers during holidays, working days and weekends can be clearly observed in these plots.

FIGURE 3.7:
Percentage contribution of load categories to total sale of electricity in Gujarat (Year 2011-12)



[26] Load Forecasting Techniques and Methodologies: A Review, A K Singh et al.

[27] Hourly feeder load information, MSEDCL
http://www.mahadiscom.in/feeder-hourly-data/hourly-feeder-load-information.shtm

Load Categories	Electricity sale (In MWh)	% Contribution
Domestic	7473	14
Commercial	1320	2
Agricultural	13947	25
Industrial	22957	42
Others	9184	17
Total	54881	100

Source: Annual report (2013-14) on the working of state power utilities and electricity departments.

FIGURE 3.8:
Contribution of various load categories to system load

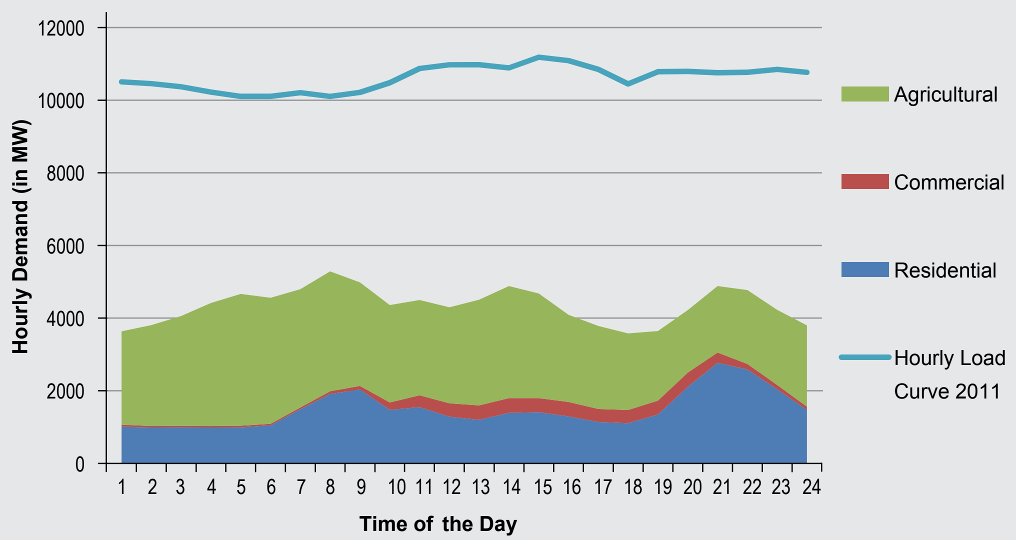


FIGURE 3.9:
Comparison of sector wise load profiles with system level load profile

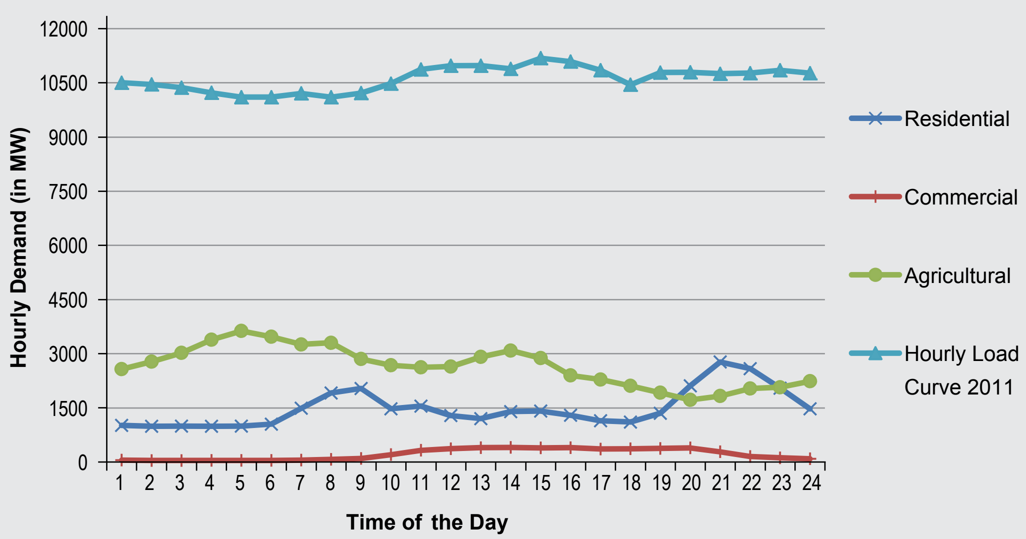


FIGURE 3.10:
Hourly data for Vidyut Mettalics Feeder

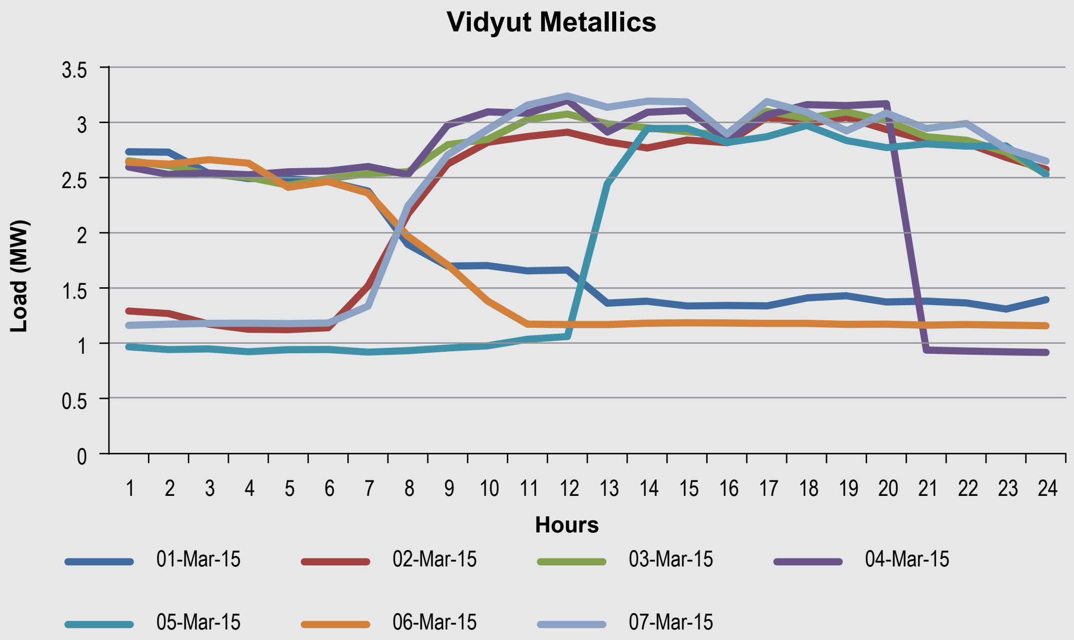


FIGURE 3.11:
Hourly data for Udyogkshetra Feeder

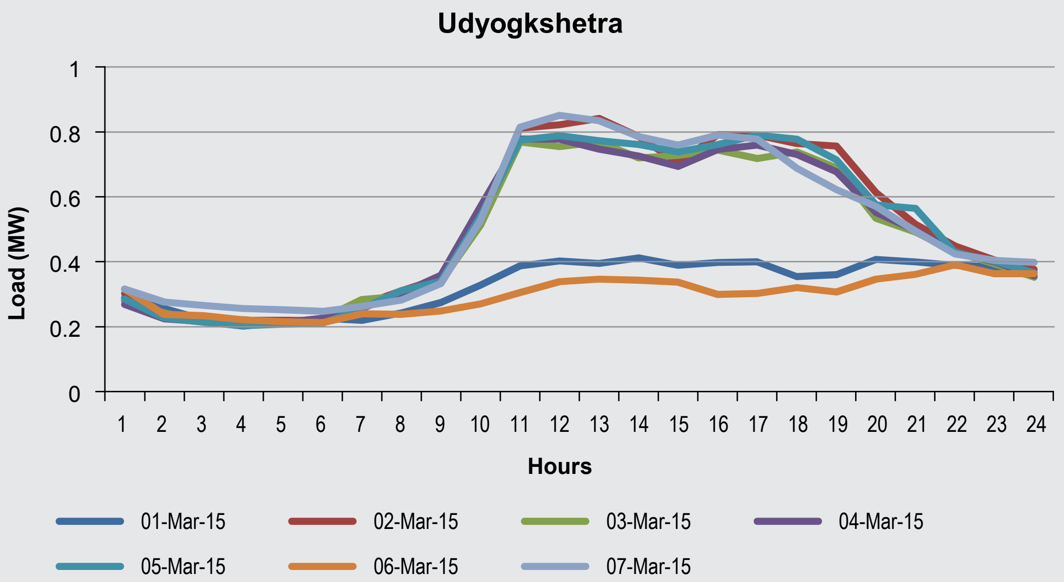


FIGURE 3.12:
Hourly data for Hanuman Silk Mills Feeder

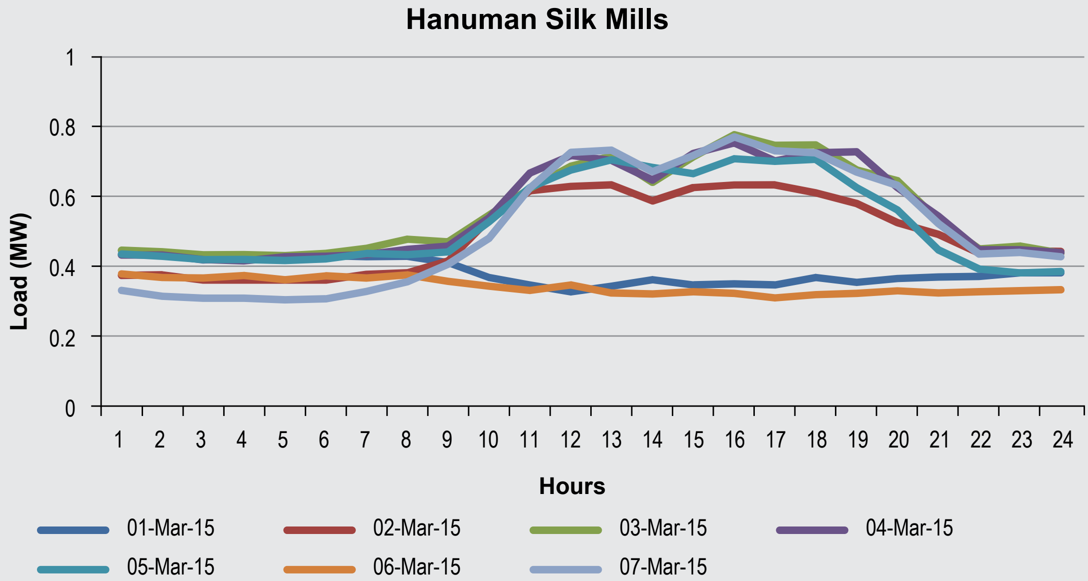


FIGURE 3.13:
Hourly data for MIDC Complex Feeder

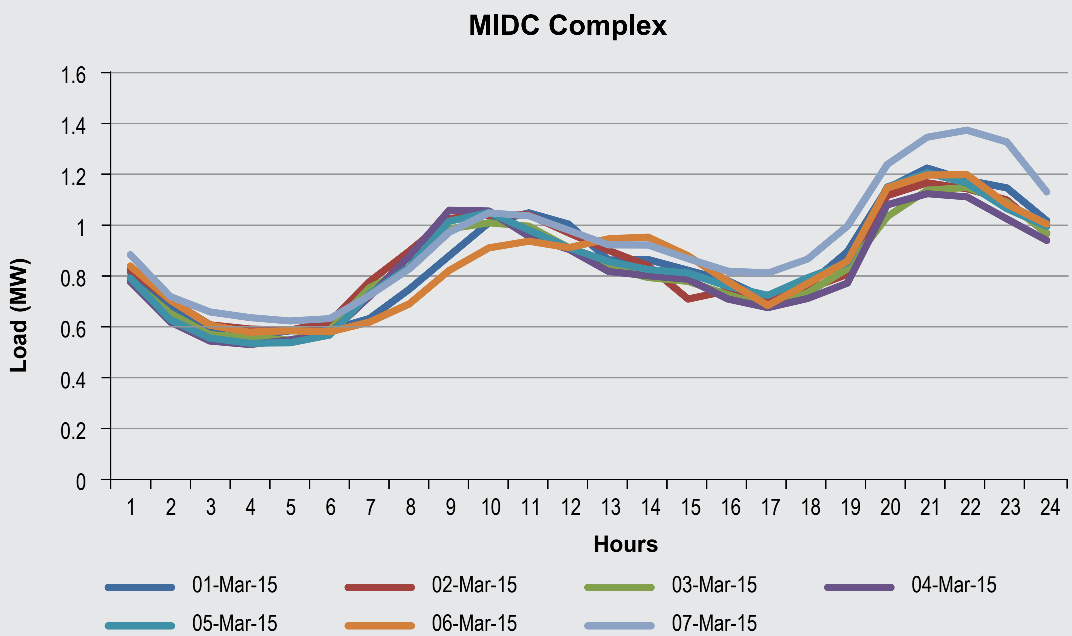


FIGURE 3.14:
Hourly data for Casablanka Feeder

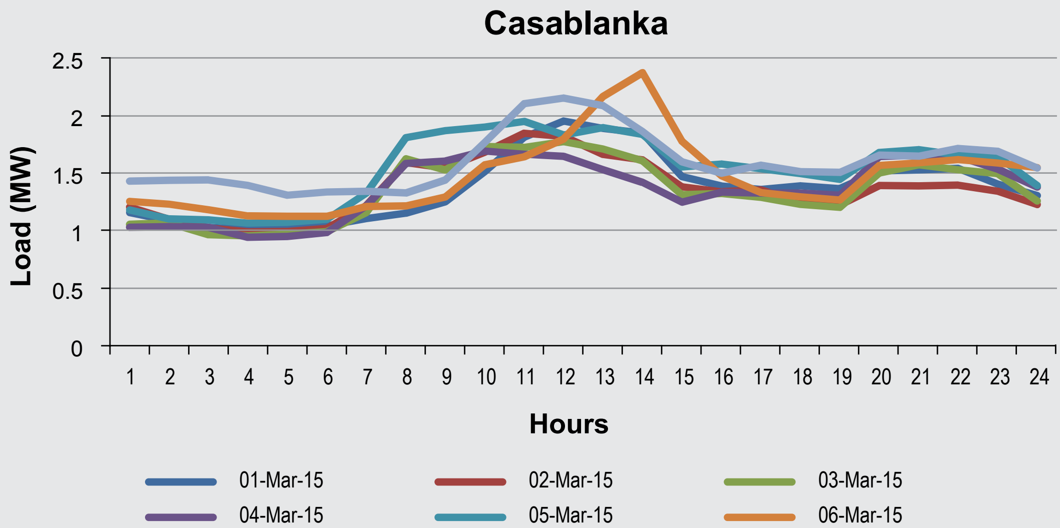


FIGURE 3.15:
Hourly data for Rutu Tower Feeder

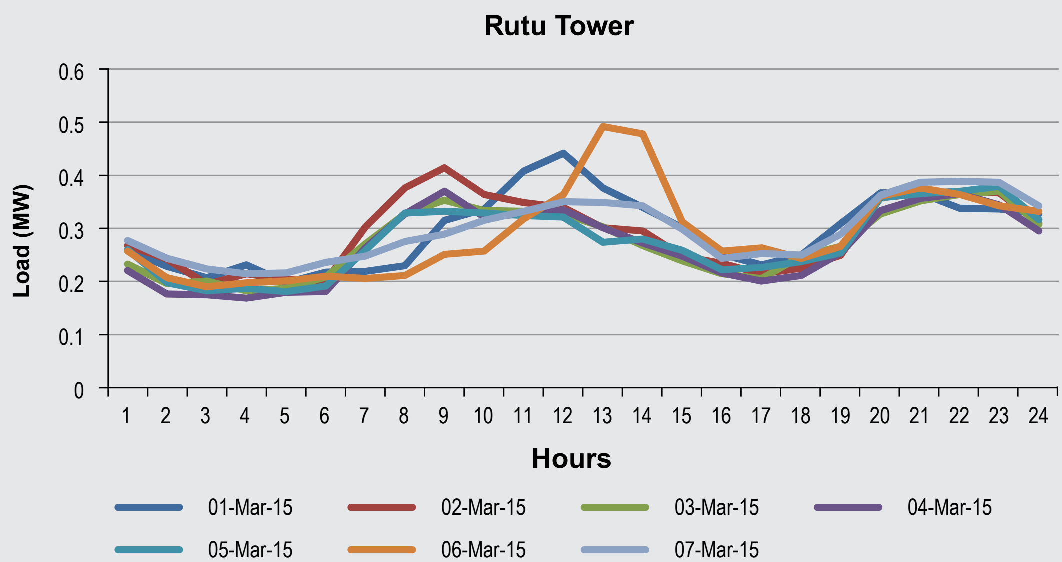


FIGURE 3.16:
Hourly data for Karara–II Feeder

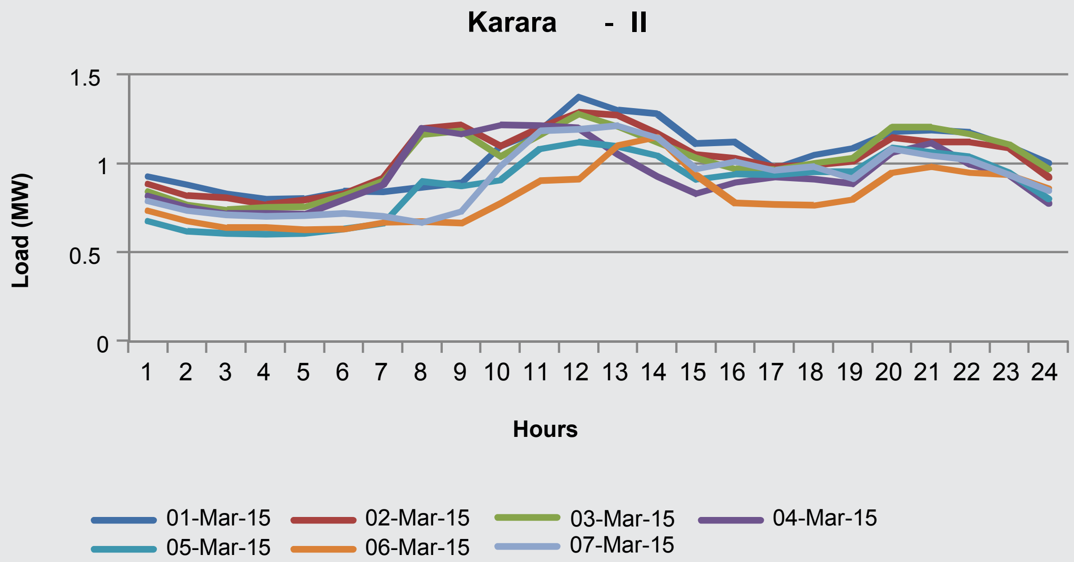


FIGURE 3.17:
Hourly data for Thane College Feeder

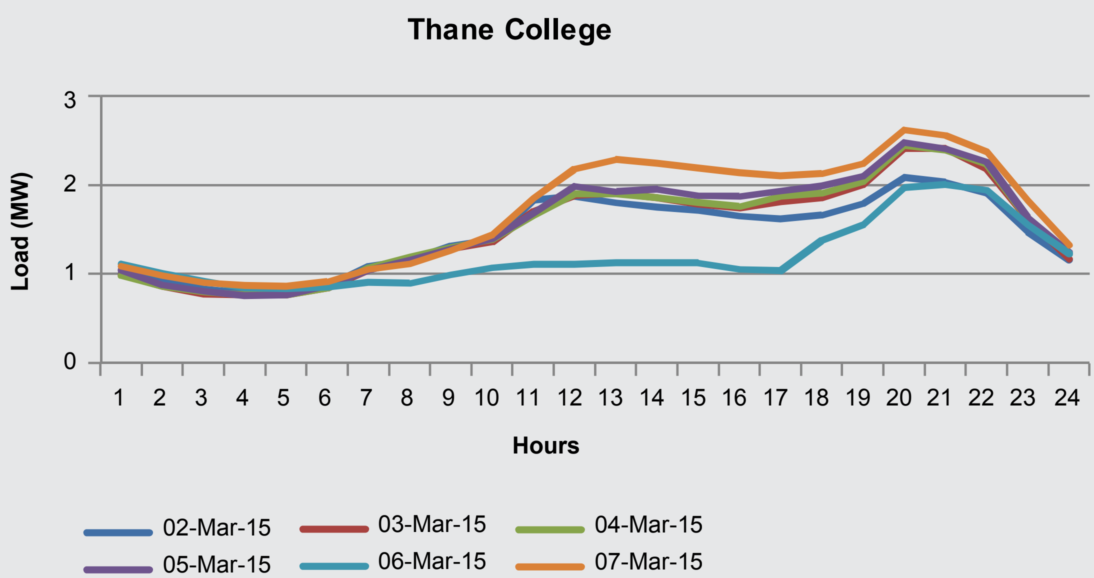
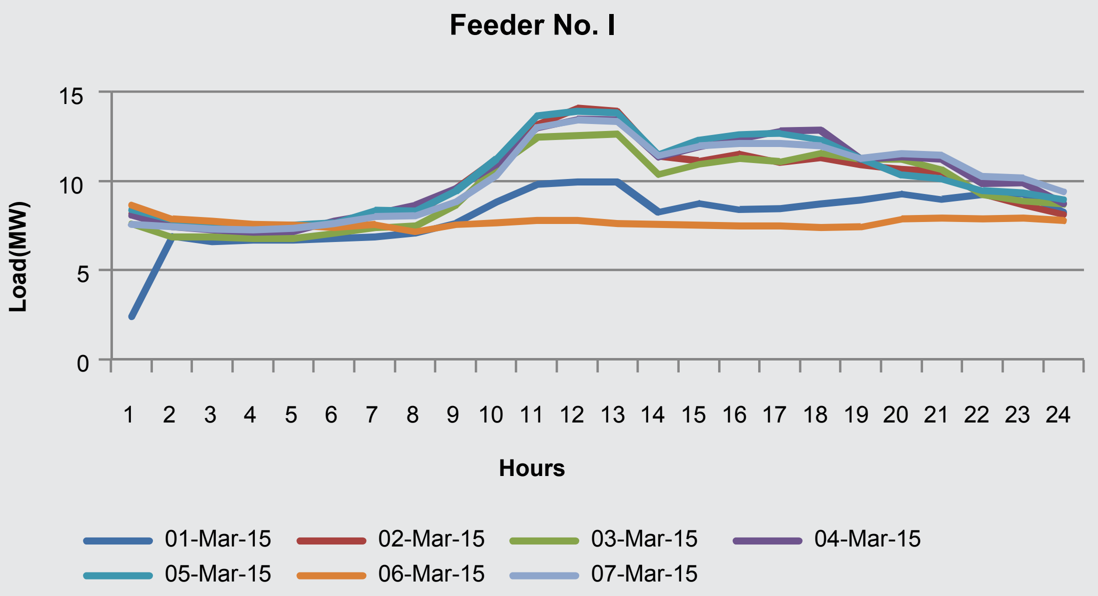
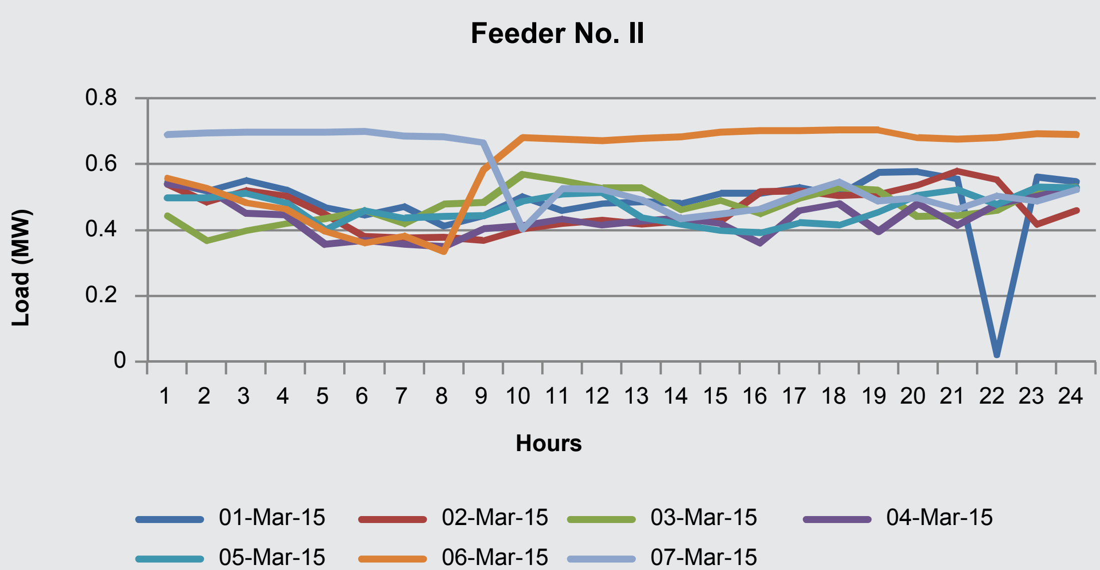


FIGURE 3.18:
Hourly data for "Feeder No. I" Feeder in Bhandup Zone



The load profiles shown in Figure 3.18 and Figure 3.19 are of Feeder no 1 and 2 in Bhandup zone under MSEDCL (Maharashtra State Electricity Distribution Company Limited). These are Industrial feeders where load staggering is done to flatten the load curve as evident from the load curve on 6th March 2015 of Feeder No. I shown in Figure 3.18. Load staggering involves customers inside the feeder to have a staggered weekly holiday rather than all of them closing on Sunday.

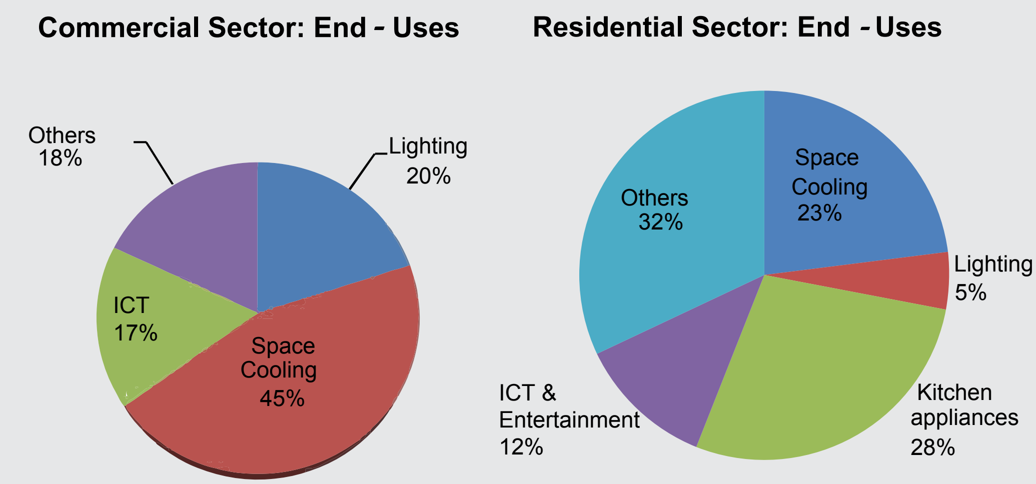
FIGURE 3.19:
Hourly data for "Feeder No. II" Feeder in Bhandup Zone



Residential & Commercial sector: End-uses

These two sectors witness a rise in electricity demand during the October-December period owing to the onset of the festival season in India. Figure 3.20 shows the contribution of various end-uses in residential and commercial sector for the state of Gujarat.

FIGURE 3.20:
Total connected load of various end-uses in Residential and commercial sector.



Source: Load research for residential and commercial establishments in Gujarat (ECO-III, 2010)

Agricultural Sector: End-Uses

Agricultural demand for electricity is not constant throughout the year and typically witnesses a growth in the Rabi season, onset of which is different in different regions in the country. Pumping for irrigation contributes to maximum electricity consumption in agricultural sector.

According to a study[28], the average electricity consumption per pump was estimated to be 8,150 kWh in FY2000 (Table 3.3). This was found to be significantly below the standard used by the state utility, the Haryana Vidut Prasaran Nigam Ltd (HVPNL), of 12,469 kWh per pump for FY 2000. Consumption rates per pump were found to be highest in the Kharif season (3,697 kWh/pump), largely due to the predominance of rice cultivation, a very water-intensive crop. Consumption rates also vary significantly from region to region, reflecting different cropping patterns and agro-climatic conditions. Knowledge of variations in pumping requirements as per season can help in planning and designing appropriate strategies and incentives for DR implementation in agricultural sector.

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[28] Source: India power supply to agriculture. Volume 1: Summary report, June 2001. Energy Sector Unit, South Asia Regional Office, World Bank.

TABLE 3.3:
Metering Study and HVPNL Estimates of Electricity Consumption per Pump (kWh/pump)

Season	Electricity Consumption Per Pump by Region (in kWh/Pump)					
	1	**2**	**3**	**4**	**5**	**All**
Summer	3123	1500	736	1490	3540	1855
Kharif	5728	3092	2532	2281	7503	3697
Rabi	3392	1251	1289	3764	5100	2622
Total FY 2000	**11842**	**5868**	**4621**	**7630**	**15978**	**8150**
HVPNL	**-**	**-**	**-**	**-**	**-**	**12469**

Source: India power supply to agriculture. Volume 1: Summary report, June 2001. Energy Sector Unit, South Asia Regional Office, World Bank.

Industrial sector: End-uses/operations

Industrial demand is at its peak during the last quarter of the financial year as there are targets to be achieved before the budget. These operations and processes vary from one type of industry to another with some basic end-uses like lighting, space cooling etc. remaining constant. Identification of end-uses/operations that can be dispatched or scheduled should be carried out for various types of Industries so as to devise DR strategies for implementation

3. Identify need for Demand Response (DR), Estimating DR Technical & Economic potential and Determining hardware control strategies.

Variations in demand and supply of electricity clearly push the case of DR as a resource to meet the requirement of balancing and ancillary capacity. Load forecasts also help in estimating the additional base load and short term capacity that may be required to ensure reliable operation of grid. In depth knowledge about sector wise and end-use wise load patterns can provide useful inputs for deciding the target sectors and end-use to arrest the peak load.

Load forecasts also help in estimating the additional base load and short term capacity that may be required to ensure reliable operation of grid.

The following points have been identified to clarify the need of demand response in the current power scenario:

a) Peak demand and traditional approach of buying power through expensive operation of peaking power plants to meet it. DR makes more sense in the Indian scenario where AT&C losses are high.

b) Effective tool for fast capacity addition as gestation period of dispatchable DR resources can vary from one day to almost instantaneous as compared to traditional power plants and even solar power plants.

c) Several successful demonstrations of DR being used as a spinning reserve and frequency regulation mechanism due to control over dispatchable loads enrolled.

d) DR can provide necessary capacity addition when the intermittent renewable generations resources like solar and wind are powering down. It is crucial to plan for DR when the Government has proposed to add 165 GW of renewable capacity through solar and wind by 2020.

e) Better load management alternatives to load shedding that currently plagues the country.

f) DR can provide huge environmental dividends at an affordable cost and also help in meeting carbon emission reduction goals promised by India during COP 21, Paris Climate Conference 2015.

The need for DR should be complemented by existence of its technical and economic potential so that the cost effectiveness of Demand response can be established in comparison to other alternatives. Technical potential of DR in a load category is an estimation of load curtailment volume. This can be realized through DR in that particular category, limited only by technical constraints. Economic potential is actually the technical potential constrained by financial limitations. Cost effectiveness tests[29] for DR can help ascertain the economic potential of DR at utility/state/region level. Customer participation rate plays an important role in defining this economic potential.

Smart appliances play an important role in hardware control strategies meant for loads enrolled in DR from residential sector. Since their market penetration in the country is still minimal, the technical potential of DR in residential sector is very low.

This can be better explained through the case of the smart appliances market in India. Smart appliances play an important role in hardware control strategies meant for loads enrolled in DR from residential sector. Since their market penetration in the country is still minimal, the technical potential of DR in residential sector is very low. Due to low market penetration, the smart appliances, even if available, are not affordable or cost effective owing to the less number of vendors thus the economic potential of such programs in the domestic category is limited.

Few pilot projects have been launched to establish the technical feasibility of fully autonomous DR. Tata Power Delhi Distribution Limited (TPDDL) in collaboration with Honeywell, IBM and Landis+Gyra launched an Auto-DR[30] program that lasted over a period of six months (May to October 2014) and witnessed participation from 173 commercial and industrial customers in Delhi. Utility customers having load greater than 100 kilowatts (kW) and a consolidated connected load of over 400 MW were included in the project. The project encompassed about one hundred 11 kV feeders, fed from 40 substations spread across the utility's distribution territory. TPDDL conducted 17 AutoDR events, ranging from 0.5 to 1 hour each during the period of six months and estimated the technical DR potential for various consumer categories as shown in Figure 3.21. The total non-coincident technical DR potential for the industrial customer categories was estimated to be approximately 25 MW.

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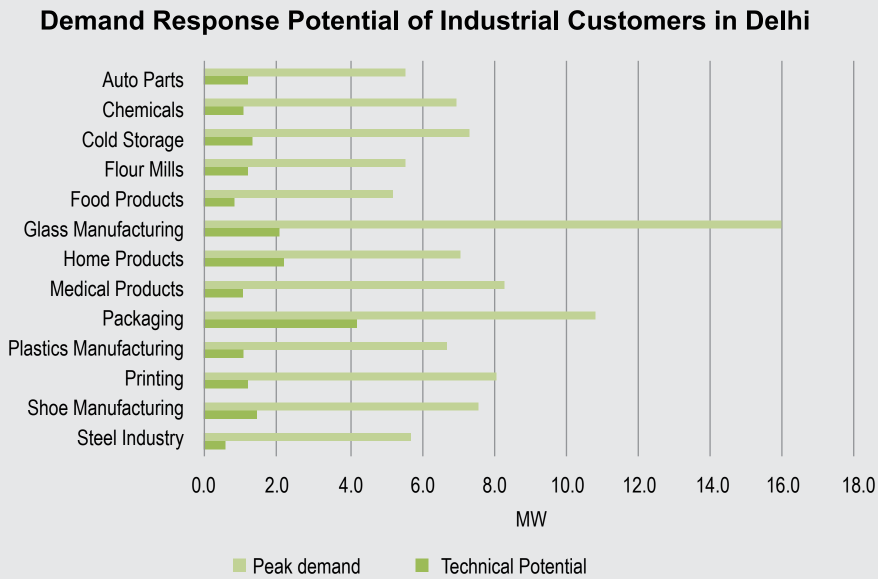
[29] A Framework for Evaluating the Cost-Effectiveness of Demand Response, Tim Woolf, Erin Malone, and Charles Goldman, February 2013

[30] Estimation of Potential and Value of Demand Response for Industrial and Commercial Consumers in Delhi, LBNL, March 2015

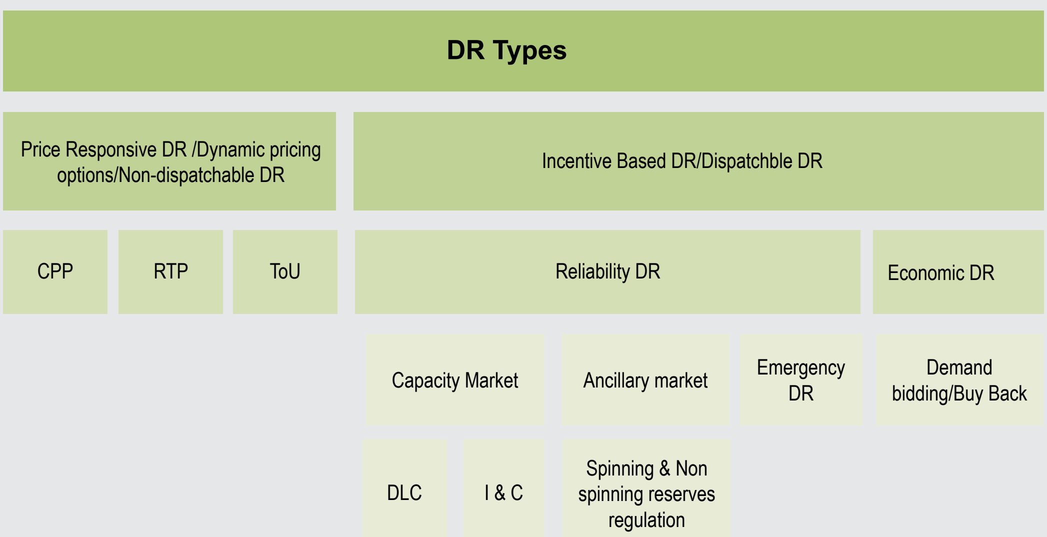
http://eetd.lbl.gov/sites/all/files/lbnl_6987e.pdf

FIGURE 3.21:
Technical potential for DR of Industrial consumer categories under TPDDL in Delhi.



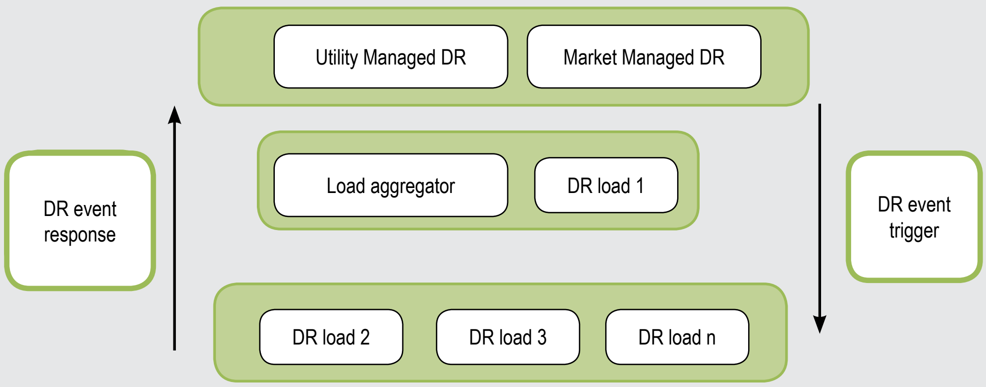
Once it is established that DR has significant technical and economic potential for the target load categories, hardware control strategies can be identified at end-use level (Lighting, Air, conditioning, etc.) in these load categories. Loads that are not dispatchable can be included under the ambit of DR through the price responsive DR mechanism by structuring various dynamic pricing options (ToU, CPP and RTP). A variety of DR programs, as shown in Figure 3.22, have been field tested and successfully implemented all over the world. A comprehensive detail of all these DR programs is provided in the Technology assessment report for demand response.

FIGURE 3.22:
Classification of Demand Response Programs



Understanding the flow of information initiated by DR event trigger and concluded by DR response signal, as shown in Figure 3.23 is crucial to understanding the role of different stakeholders in a DR program. DR load 1 represents a consumer that can meet the curtailment volume as per contract and DR load '2' to 'n' represent the small customers who need load aggregators to participate in DR. Market managed DR programs usually involve customers/ load aggregators with dispatchable loads. Market here represents the wholesale or retail market managed by an ISO where the curtailed Negawatts capacity can be traded. Utility managed DR programs include customers/load aggregators that can responds to price signal as well as have dispatchable loads to participate in incentive based DR programs.

FIGURE 3.23:
Flow of information among the stakeholders during a DR event



DR strategies for lighting loads: Building equipped with day-lighting systems are potential candidates for DR. On a sunny summer day, when day light is abundant, using lighting controls, appropriate DR strategies can be designed in order to achieve significant DR shed. These strategies can include switching and/or dimming control for zone, fixture and lamp. Dimmer controllers can provide both steeped and continuous dimming features.

DR strategies for Air Conditioning (AC) loads: The thermal flywheel effect observed in indoor environments presents a potential opportunity for load curtailment through DR without causing immediate change in comfort conditions to occupants. The DR strategies for AC loads can be categorized as per the target subsystem (zone control, air distribution, and central plant) for control adjustments. In order to map the DR strategies appropriately with the various types of AC systems, it is useful to list out various types of AC systems (as presented in Table 3.4). Table 3.5 enumerates the various applicable DR strategies for the different AC types. Rebound effect is also a common phenomenon in AC systems that undergo load curtailment under DR during which extra energy is used just after the completion of DR events in order to bring indoor conditions back to normalcy. DR strategies for avoidance of this rebound effect are also presented in Table 3.5. These DR strategies can be programmed as control adjustments in the building energy management system. This automatically selects an appropriate DR strategy based on the occupancy levels and external weather conditions on receiving a DR signal from the utility.

Direct Load Control (DLC) for air conditioning units is achieved through cycling units on-and-off or making thermostat adjustments throughout different times of the day. DLC has traditionally been used to turn on and off residential air conditioning compressors which typically make up 70% of the electrical load of a residential air conditioning system.

TABLE 3.4:
Classification of types of AC systems

Type	Primary feature	Secondary feature
A	CAV system with central plant (CAV-Central	Single zone / multi-zone ; Single duct / dual duct; With reheat / without reheat; Type of chiller
B	VAV system with central plant (VAV-Central)	Single duct / dual duct; With reheat / without reheat; Type of chiller
C	CAV system with package units (CAV-Package)	Single zone / multi-zone; Single duct / dual duct; With reheat / without reheat
D	VAV system with package units (VAV-Package)	Single duct / dual duct; With reheat / without reheat

CAV: Constant Air Volume ; VAV: Variable Air Volume

TABLE 3.5:
DR strategies for various building AC units[31]

Category	DR strategy	Description	Applicability to HVAC types			
			A	B	C	D
Zone control	Global temperature adjustment	Increase zone temperature set points for an entire facility	✓	✓	✓	✓
	Passive thermal mass storage	Decrease zone temperature set points prior to DR operation to store cooling energy in the building mass, and increase zone set points to unload fan and cooling system during DR.	✓	✓	✓	✓
Air distribution	Duct static pressure decrease	Decrease duct static pressure set points to reduce fan power.	×	✓	×	✓
	Fan variable frequency drive limit	Limit or decrease fan variable frequency drive speeds or inlet guide vane positions to reduce fan power.	×	✓	×	✓
	Supply Air Temperature (SAT) increase	Increase SAT set points to reduce cooling load.	✓	✓	✓	✓
	Fan quantity reduction	Shut off some of multiple fans or package units to reduce fan and cooling loads.	✓	✓	✓	✓
	Cooling valve limit	Limit or reduce cooling valve positions to reduce cooling loads.	✓	✓	×	×

31 Introduction to Commercial Building Control Strategies and Techniques for Demand Response, DRCC, LBNL, 2007

Category	DR strategy	Description	Applicability to HVAC types			
			A	B	C	D
Central plant	Chilled water temperature increase	Increase chilled water temperature to improve chiller efficiency and reduce cooling load.	✓	✓	×	×
	Chiller demand limit	Limit or reduce chiller demand or capacity.	✓	✓	×	×
	Chiller quantity Reduction	Shut off some of multiple chiller units.	✓	✓	*	*
Rebound avoidance	Slow recovery	Slowly restore HVAC control parameters modified by DR strategies.	**	**	**	**
	Sequential equipment recovery	Restore HVAC control to equipment sequentially within a certain time interval.	**	**	**	**
	Extended DR control Period	Extend DR control period until after the occupancy period.	**	**	**	**

* The strategy can be applied to package systems by reducing shutting off some of the compressors.

** Applicability of rebound avoidance strategies is determined by the DR strategies selected.

Thermal Storage systems as a resource to implement demand response:

Commercial facilities having a predominant air conditioning load signature and are a major contributor to system level peak. Mostly, the electrical load of these facilities follows their cooling load profile. A well-designed thermal storage system (TES) can be incorporated to shift this load, which is generally during the day time, to night time (Off peak hours). This leads to flattening of electric load curve, thus improving the facility load factor. Figure 3.24 shows the reduction in morning coincident peak by 34% under flat tariff and 39% under ToU tariff due to cool storage[32]. Tata Power-Mumbai Distribution also employed Thermal storage system to deploy DR[33] call during their Demand response program in 2012. The results are shown in Figure 3.25.

[32] Optimal cool storage capacity for load management: S. Ashok, R. Banerjee, August 2001.

[33] Tata Power Demand response program

https://beeindia.gov.in/sites/default/files/ctools/Shekhar%20Khadilkar%20Tata%20Power%20DR.pdf

FIGURE 3.24:
Effect of thermal storage on electrical load under flat tariff and ToU tariff

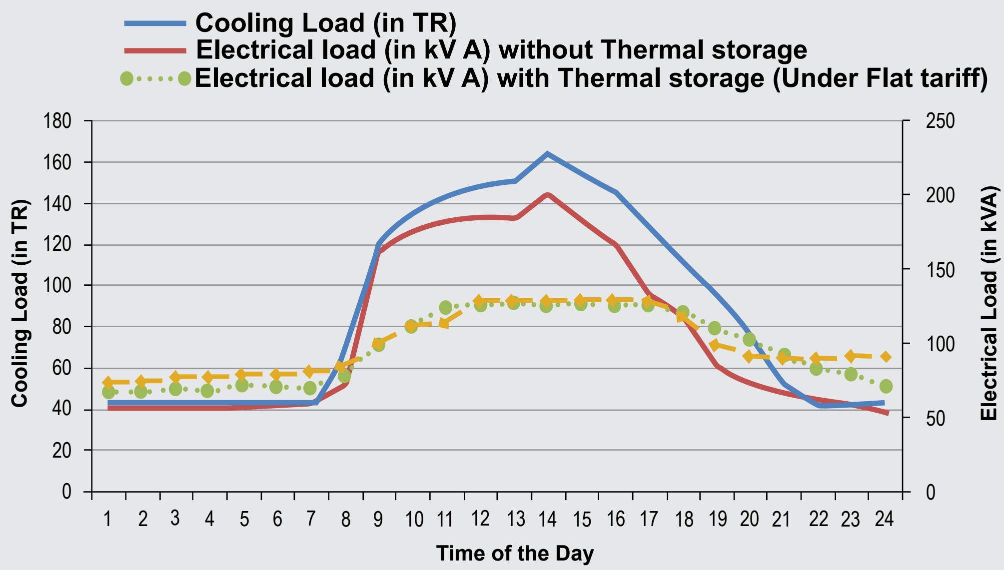
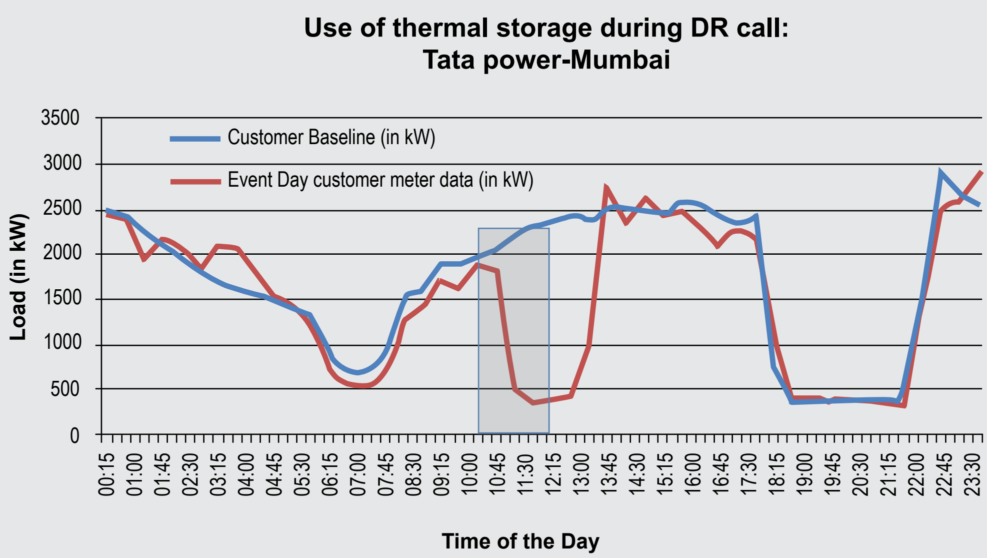


FIGURE 3.25:
Comparison of Customer baseline curve with actual load curve during a DR event called by Tata power



DR strategies for Agricultural pumping loads:

Direct load control (DLC) and interruptible pumping programs have been attempted in other parts of the globe and is very a possibility given the fact that agriculture feeders are being segregated in many parts of the country. Such DR programs require installation of a load control switch on agricultural water pumps. Night-time watering is typically employed during DR event days. Utilities or DR providers can also remotely curtail irrigation equipment using switches, enable curtailment using timers, or rely on manual DR by the farmers.

4. Deciding policies, regulations and incentives for DR and identifying various responses to DR Call/Trigger.

Favorable policies are always the biggest incentives to bring about development and growth. Inclusion and growth of DR in power system planning can be hastened through right kind of policies, regulations and incentive structure. Figure 26 shows the role that Policies, Industry standards and Technology plays in enabling the inclusion and growth of DR in the power sector.

Success of DR lies totally in its ability to enhance the customer responsiveness to increasing stress on grid. A right mix of financial and service incentives can go a long way in ensuring higher level of participation rates from the customer side.

Legislative and regulatory policies can be formulated to mandate utilities to include DR as a resource to meet their peak power deficit and also provide ancillary services. Appropriate financial tools can be devised to fund the growth of technological infrastructure (Smart meters, Communication devices, etc.). Success of DR lies totally in its ability to enhance the customer responsiveness to increasing stress on grid. A right mix of financial and service incentives can go a long way in ensuring higher level of participation rates from the customer side. A vast array of communication technologies[34] are available that can be used for DR implementation in the country but that would require necessary regulations regarding spectrum allocation and usage.

Policies can drive business entities to develop industry standards to meet the interoperability, communication and security challenges for demand response. Some of these standards are listed in the Figure 3.26 and can be reviewed for adoption or a platform can be developed so to enable interaction between regulators, vendors and experts from academia for development of India- specific standards. Once the policies and standards are in place, DR technology penetration at all stakeholders' level can witness an accelerated growth.

Urbanization has led to a boom in the sale of electrical appliances for lighting, air conditioning, kitchen use and entertainment. Market penetration of smart appliances is a possibility if their prices become affordable for urban domestic customers in the country. This can help in implementation of DR in the residential sector as most of these loads can act as dispatchable capacity for participating in DR programs. Currently, there are few smart grid projects being implemented in the country and as part of that, AMI (Advanced metering Infrastructure) and smart meters are being installed at customer's location. This is crucial for demand response as well and can be taken up in a large scale mode by the utilities in urban pockets of the country on cost sharing basis in collaboration with the customers. Integrated Power Development Scheme (IPDS) and Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) launched in November 2014, propose to connect 250,000 gram panchayats on a fiber network. There is also a plan to connect all 33 kV and above substations using optical fiber. This will help set up the necessary communication infrastructure for DR and help utilities, load aggregators and customers to have the technological readiness to execute/participate in DR programs in future.

[34] M2M enablement in power sector, Technical report, TEC, Ministry of communications and information technology, GOI, May 2015, Page no.22-37.
http://tec.gov.in/pdf/M2M/M2M%20Enablement%20in%20Power%20Sector.pdf

It is also essential to understand the timeline of actions taken during a typical DR event as shown in Figure 3.27 and also the nuances of various DR programs such as the event notification time window, event duration, trigger criteria, etc., more elaborately enumerated in Table 3.6, so as to decide which types of equipment can participate and what kind of DR strategies can be employed. Table 3.7 shows the minimum response time associated with various end-uses that can participate in typical load control DR programs.

FIGURE 3.26:
Role of Policy, Industry Standards and Technology in enabling the inclusion and growth of Demand response in power sector

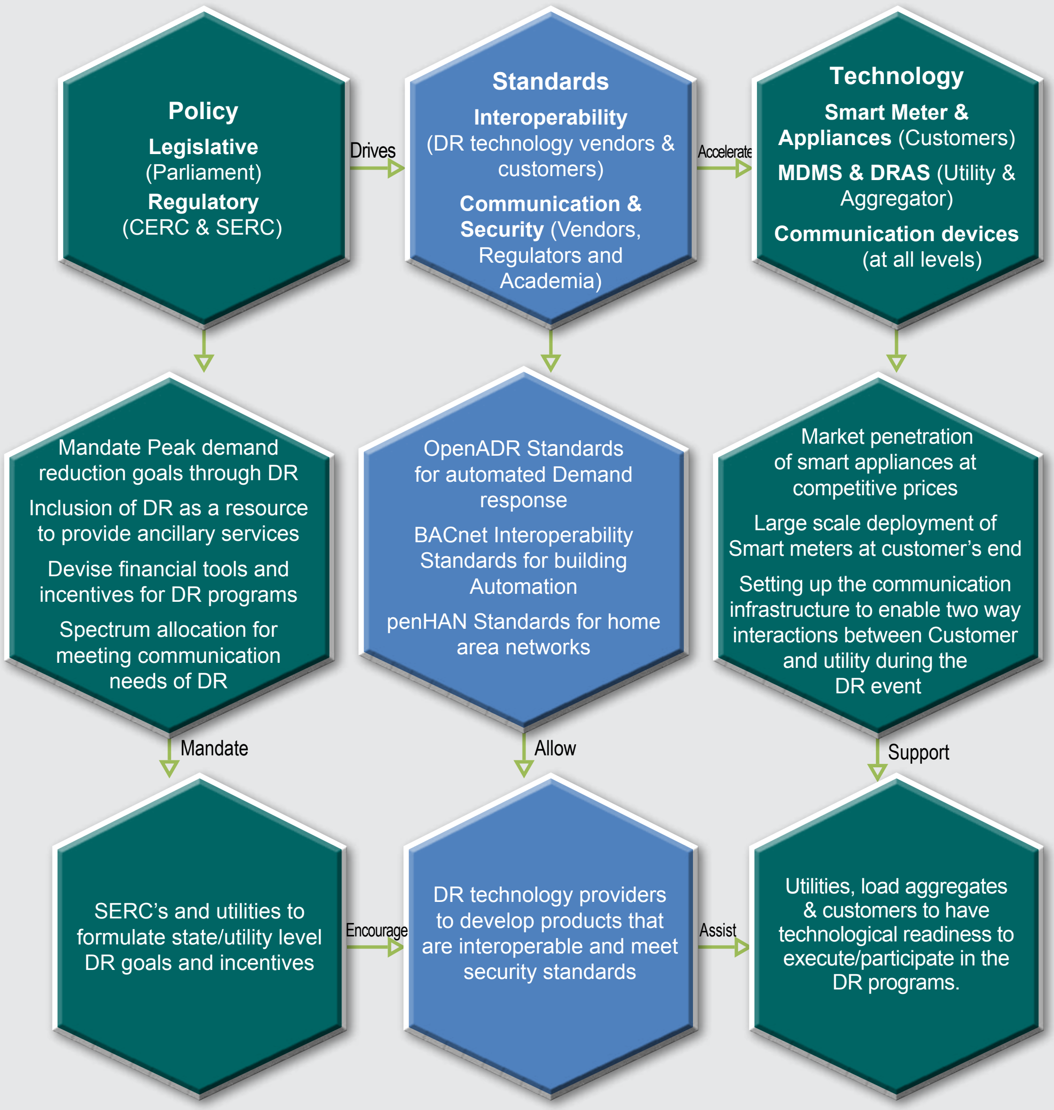


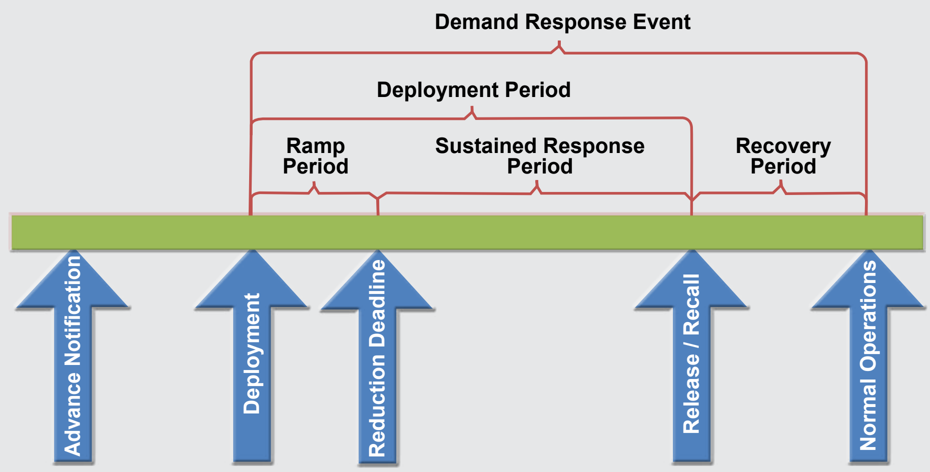
TABLE 3.6:

Minimum response time for various end-uses that can participate in Autonomous mode of DR[35]

End Use	Type	Ramp Down	Switching Off	Response Time
HVAC	Chiller Systems	Set point adjustment	-	15 min.
	Package Unit	Set point adjustment	Disable Compressors	5 sec -5 min
Lighting	Dimmable	Reduce lighting levels	-	5 sec -5 min
	On-Off	-	Bi-level/Off	5 sec -5 min
Refrigeration/ warehouses		Set point Adjustment	-	15 min
Data centers	-	Set point adjustment, reduce CPU processing	-	15 min
Pumping	-	-	Turn Off selected pumps	5 sec -5 min

FIGURE 3.27:

Timeline of actions taken during different phases of a typical DR event



[35] Source: Fast Automated Demand Response to Enable the Integration of Renewable Resources, LBNL,2012

TABLE 3.6:
Comparative study of various demand response programs[36]

Feature	DR program types					
	Ancillary Services	Capacity Market (DLC, I&C)	Economic DR (Demand bidding/buyback)	ToU pricing	Real Time Pricing	Critical Time pricing
Event notification window	Variable 10 to 30 minutes based on spinning or non-spinning reserve service	Day ahead for direct load control Intra-day for Interruptible DR	Day ahead	Notified through tariff structure embedded in meter	Day head forecasted market prices are notified	Day head
Event Duration	Variable	Depends on cycling settings of the equipment	Typically 2 hours	Varies with time of day and different seasons of year	Price signal varies as per the forecasted market price	Depends on the trigger criteria
Choice of participation	Mandatory if entered into a contract	Mandatory for DLC& Voluntary for I&C	Voluntary	Mandatory	Voluntary	Voluntary
Trigger Criteria	System emergencies, frequency regulation violation	Price spikes Peak load time	Forecasted demand less than the available generation capacity	Applicable throughout the year	Applicable throughout the year	High temperature and high forecasted spot market power prices
Target Load category	Customers with dispatchable loads that can be fully controlled remotely.	Small residential customers for DLC Agriculture & pumping For I&C	Small, medium and large commercial facilities whose maximum demand usually crosses a particular threshold value (say 200 kW).	Large commercial and industrial customers. Also available for small customers	Large commercial and industrial customers. Also available for small customers.	Customers whose maximum demand usually crosses a particular threshold value (say 200 kW).
Incentives	Energy and capacity payment	Monthly bill credits, rebates.	Energy and capacity payments at forecasted Market price with adjustments	Cheaper rate during off peak and more expensive during peak time	Customers are able to defer their usage to take the advantage of low market prices	Discount on all part and on-peak usage on all other days of the year/season.
Penalties	Compliance violation	Varies from no penalty to application of excess energy charge during the event	No penalties	High usage price during peak load periods.	High usage price during periods of high market price.	High usage prices during CPP events
Pre-requisites	Depends on types of Ancillary services. Under frequency relay for responsive reserves. Real time telemetry	Load control switches and smart metering infrastructure	Internet access and AMI capable of recording usage in 15-minute interval.	Meter that registers cumulative usage during different time blocks	Meter that registers cumulative usage during different time blocks	Meter that registers cumulative usage during different time blocks
International Case Studies	Load Acting as a resource, Texas	Economic Load Response program – PJM	Demand Bidding Program – California	ToU rate, Texas	Commercial/Industrial Schedule RTP-2 (California)	CPP, Texas

[36] Classification of control for Demand-side participation, Authors: Yun Tiam Tan, Daniel Kirschen, 2007. http://www.ee.washington.edu/research/real/Library/Reports/Classification_of_Demand-Side_Controls.pdf

Various end-use level response strategies have been identified and explained in the previous section. But these mechanisms work for dispatchable/interruptible loads that are controllable and need a lesser degree of customer intervention. There are high priority loads and operations over which a facility wants to have total control. These facilities can be encouraged to participate in DR through price response options that allow customers to defer/schedule their usage to more favorable time duration during which utility offers lower electricity tariffs.

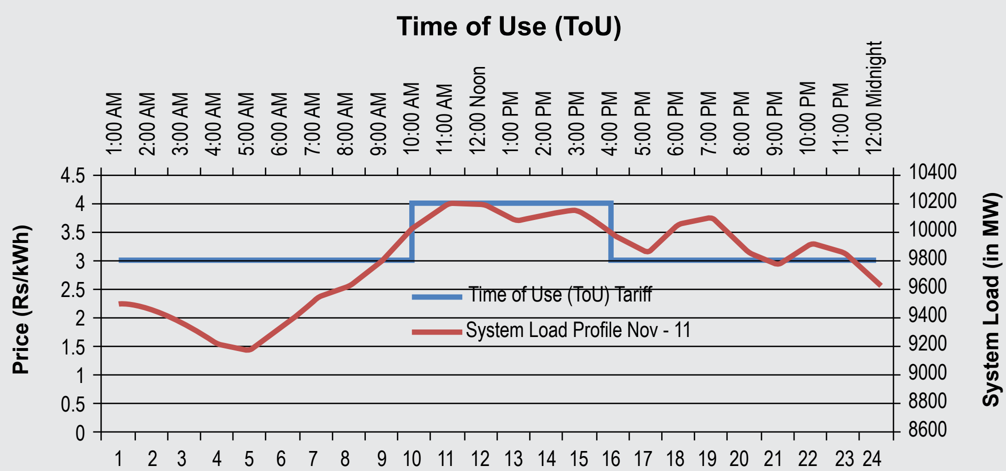
A high load factor reflects relatively constant power usage. Low load factor shows an occasional occurrence of high demand. To service this peak/high demand, generation capacity sits idle for long periods, thereby imposing higher costs on the system.

Price-based DR options can be exercised through implementation of RTP, ToU and CPP tariff mechanisms on the consumer categories that have significant contribution to the system peak. These options try to counter the ill effects of flat tariff mechanism in load categories, which cause the system peak without being economically accountable for it. These options present a more justified electricity pricing model which discourages the consumers responsible for system peak, to lower their consumption during peak time and incentivizes the shifting of consumption to off-peak time, thus improving the load factor leading to the much required flat load curves at the consumer level as well as system level.

A high load factor reflects relatively constant power usage. Low load factor shows an occasional occurrence of high demand. To service this peak/high demand, generation capacity sits idle for long periods, thereby imposing higher costs on the system. The idea behind price based DR options is that the electricity tariff rates are designed in such a way that customers with high load factor are charged less overall per kWh.

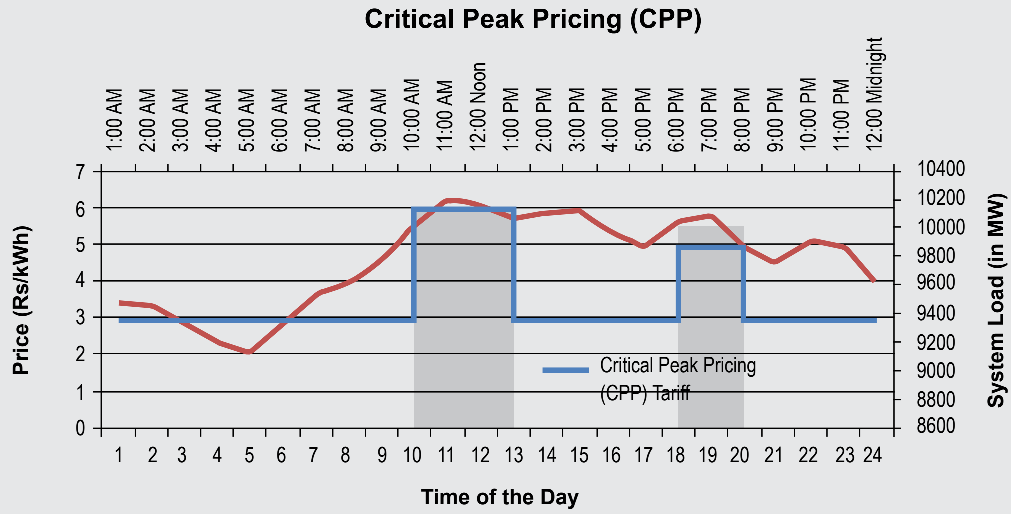
An illustrative depiction of various price responsive DR mechanisms along with the system level load curve is given in Figure 3.28 to Figure 3.30. The tariff levels used in these illustrations are not according to the system level load and are shown here to give an idea of how they work. ToU tariff as shown in Figure 3.28 has been designed to discourage usage during peak time by an increased level of electricity price (Rs. 4/kWh) from the tariff level of Rs. 3/kWh from the off peak time.

FIGURE 3.28:
Illustration of ToU tariff in flattening the load curve



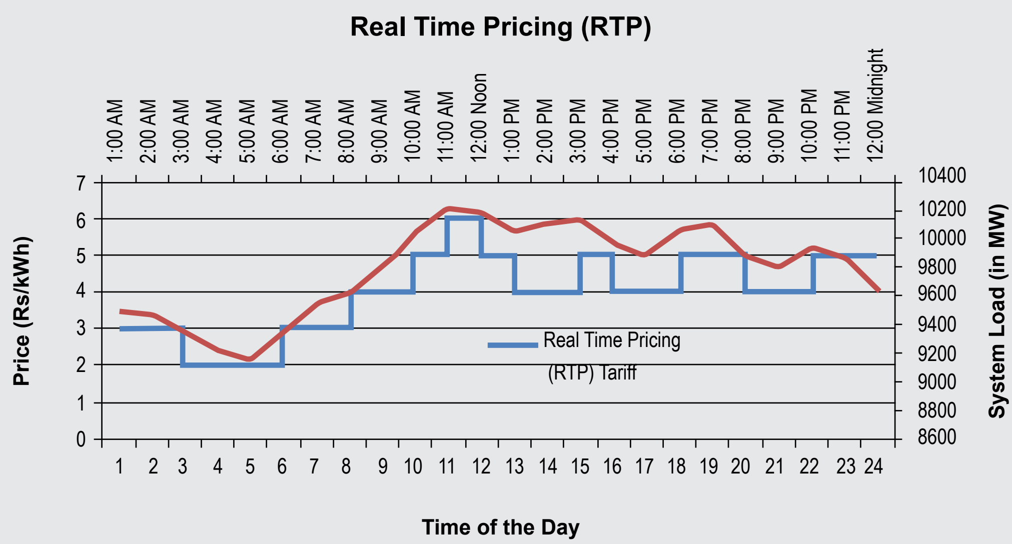
CPP (Critical Peak Pricing) tariff as illustrated in notifies DR participants in advance about the time period in which tariff level would be high owing increase in temperature level or some extreme system condition. The time period when the tariff is high is shown in Green in Figure 29 are called CPP events.

FIGURE 3.29:
Illustration of Critical peak pricing in flattening the load curve



RTP (Real Time Pricing) mechanism as shown in Figure 30 uses day ahead forecasted market price of electricity to notify its customers in advance about the periods when they can reduce their electricity bills and also earn incentives by deferring their consumption by using a differential time varying pricing signal.

FIGURE 3.30:
Illustration of Real Time pricing in flattening the load curve



5. Carrying out Impact assessment and evaluating participation rates.

Customer enrollment in voluntary programs and their exposure to default/mandatory pricing programs needs to be investigated to estimate the level of demand response expected from the target population at a reference price/incentive. Mapping of participation rate of various customers in different customer categories with their type of end-use (Lighting, Air conditioning, refrigeration, pumping, industrial process loads, etc.) can bring forward various specifics about the reasons behind the interest/indifference towards the voluntary DR programs. The actual data on customer participation from the already implemented DR programs can assess the effect of incentives and policies on the amount of peak load shift. This can be later used as correction factors to modify future policies and regulations and thereby provide more encouraging participation levels thus closing the loop.

6. Evaluating Transaction costs (Rs. /MWh Saved or Rs. /Peak MW Shifted).

Demand response requires a minimum level of hardware and communication infrastructure for its technical feasibility. This cost is either distributed across all stakeholders or is borne completely by the utility. The investment used to cover these upfront costs has to be justified through reduction in electricity bills for customers, earning of brokerage fee by load aggregators and reduction in peak power procurement by utility. Transaction costs in terms of Rs./MWh Saved or Rs./Peak MW shifted enables the stakeholders to keep an eye on their business interest apart from their contribution to reduction in environmental externalities (pollution, carbon emissions, etc.) of traditional power plants.

7. Modify Policies, Regulations & incentives.

Results obtained after impact assessment of DR projects and the assessment of incurred transaction costs can be used to modify policies and incentives. It would be useful if certain reliability indices are developed that act as alarms to trigger these modifications. These indices can be formulated on the lines of distribution system reliability indices shown in Table 3.8, or the same can be used to assess the effectiveness of DR in mitigating the peak power deficit and its ramifications on power system reliability.

TABLE 3.8:
Distribution System Reliability Indices[37]

Index	Index Definition	Mathematical Calculation	Typical Values (IEEE 2004)
CAIDI	Average duration of sustained customer interruptions	Total customer outage duration/total number of customer interruptions	1.26 hours per interruption
SAIDI	Average total duration that a customer was interrupted by sustained interruptions	Total customer interruption duration/total number of customers served	1.5 hours per customer
SAIFI	Average number of times that a customer was interrupted by sustained interruptions	Total number of customer interruptions/total number of customers served	1.1 interruptions per customer
MAIFI	Average number of momentary (less than 5 minutes) interruptions per consumer during the year	Total number of momentary interruptions in a year / Total number of consumers	-

CAIDI = Customer Average Interruption Duration Index
SAIDI = System Average Interruption Duration Index
SAIFI = System Average Interruption Frequency Index
MAIFI = Momentary Average Interruption Frequency Index

3.3 Conclusion

This framework report will fulfill its objective if it helps utilities in identifying the need for DR in their states and facilitate the in-house capability to undertake load research aimed at successful design and implementation of appropriate DR strategies. It is also hoped that it will provide useful points for the regulators and policy makers to formulate the right kind of policies, regulations and incentive structure that can ensure a positive participation of customers towards DR and at the same time help different stakeholders and DR technology vendors to develop effective standards to counter the challenges of interoperability, communication and security commonly associated with DR.

[37] IEEE Guide for Electric Power Distribution Reliability Indices,2004

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