Ashden India
Renewable Energy Collective

SHAKTI
SUSTAINABLE ENERGY FOUNDATION

Briefing Paper Serieson Decentralised Renewable Energy for Sustainable Energy Access

Hybrid Systems in Decentralised Distributed Generation of Electricity: Potential and Challenges

Decentralised distributed generation (DDG) satisfies energy demand in-situ, thereby avoiding the need for long transmission and distribution infrastructure. It can also be customised to serve a variety of different load patterns using renewable and clean energy sources such as solar, wind, biomass, and hydro. However, the deployment of DDG technologies such as solar and wind faces a major bottleneck in terms of intermittent availability of resources resulting in reduced energy availability and reliability.

Hybrid power systems combine two or more energy conversion mechanisms, or two or more fuels for the same mechanism, that when integrated, overcome limitations inherent in either. Hybrid systems provide a high level of energy security and reliability through the integrated mix of complementary generation methods, and often incorporate a storage system (battery, fuel cell) or fossil-fueled power generation to ensure consistent supply. This paper outlines the potential role of hybridisation in decentralised renewable energy (DRE) initiatives for electricity generation and discusses several key challenges. As DRE scales up, hybrid systems are expected to expand considerably.

Why hybrid systems may be necessary and where they are useful: Features and limitations of hybrid systems

The need for hybridisation in distributed electricity generation in India is based on a number off factors. One is the need to reduce fuel consumption by the diesel generators that are common in rural electrification and captive power applications. The rising cost of diesel plus the logistics of fuel access, transportation, handling and storage, support efforts to combine diesel generators with biomass-based minigrids or other DRE technologies such as solar photovoltaic (PV), concentrating solar power, or wind.

Another rationale for hybridisation is the need to address the intermittent nature of some RE resources. For instance, solar energy is available only during daylight and power generation is typically possible only for a portion of that time. Figure 1[1] illustrates the mismatch between a typical load curve and availability of solar energy. While solar energy availability is confined to the period between 06:00 and 19:00, energy load is dispersed throughout the day, with a peak load from 19:00 to 20:00 when solar energy is not available.

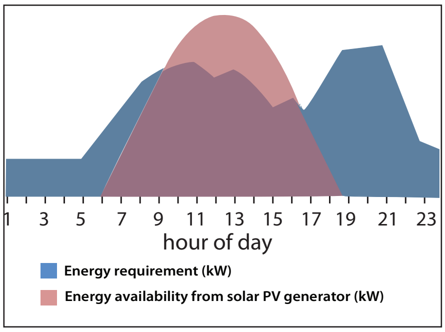

Figure 1: Typical load curve and energy available from solar

Wind energy can be both seasonal and variable during each day, depending on the location. Biomass-based power generators provide a relatively continuous supply of power, but in certain months during the rainy season the supply of dry biomass can become an issue. Hybrid power systems can address

[1] Source: Alliance for Rural Electrification brochure, *Hybrid power systems based on renewable energies: A suitable and cost-competitive solution for rural electrification.*

>> Highlights

- Hybrid systems combine various renewable or fossil fuels or complementary energy conversion methods, and often include energy storage systems.
- Hybrid systems overcome the limits of a single energy source, especially the intermittency of solar and wind systems.
- Fuel consumption and fuel costs can be reduced if diesel generators are hybridized with renewable energy systems.
- Flexibility, reliability, and efficiency typically improve with hybrid systems.
- Technical sophistication of some systems can pose a challenge for operations and maintenance in remote and rural locations.
- A decision-making matrix is an essential tool when considering the adoption of hybrid systems.

This briefing paper series has been conceptualised and prepared by the Ashden India Renewable Energy Collective (AIREC) with support from the Shakti Sustainable Energy Foundation. AIREC is a not-for-profit company set up by a group of India-based winners of the Ashden Awards for Sustainable Energy. Shakti Sustainable Energy Foundation works to strengthen the energy security of the country by aiding the design and implementation of policies that encourage energy efficiency as well as renewable energy. For more information, please visit <www.shaktifoundation.in>

Authors: Sivagurunathan Shankaran, Sougato Dasgupta, and Akanksha Chaurey of IT Power Consulting India Pvt Ltd (an AIREC member) with inputs from S P Gon Chaudhuri, Svati Bhogle, and Rekha Krishnan.

Contact email for feedback: rekhak.work@gmail.com or ashdenindiarec@gmail.com

Ashden India
Renewable Energy Collective

SHAKTI
SUSTAINABLE ENERGY FOUNDATION

such intermittency issues and improve reliability through complementary generation methods.

Below are two examples of hybridisation through complementary DRE sources.

- Where wind is limited during summer months or on windy days with limited sunshine, a hybrid system of solar PV plus wind turbines will tend to accommodate fluctuations in resource availability. Figure 2[2] shows typical availability of solar and wind resources.
- Similarly, if there is a hybrid system consisting of micro hydro plus solar PV, power generation from hydro could be maximised during the rain or monsoon seasons, and power generation from solar PV could be maximised during the summer months. In this case, the renewable energy sources complement each other well.

To further address the problem of intermittency, hybrid systems are often integrated with storage solutions, enabling the dispatch of energy as it is required. However, battery capital costs are high and as a practical matter, only short-term intermittency can be overcome. Consequently, not all intermittency issues can be solved by battery storage.[3] Arguably, the capacity of storage systems could be reduced significantly under hybrid systems. For example, solar PV batteries provide power for a few hours after sunset, but with a hybrid system using a biomass power generator, storage requirements could be minimised as the biomass system generates power after sunset. Estimates indicate that battery storage for 3 hours results in a 50% escalation in capital expenditures for a solar PV plant and such escalation could be avoided by integrating the solar PV plant with complementary DRE systems.

Hybrid systems with power ranges between a few kW and several hundred kW can be integrated with small electricity distribution systems or retrofitted in diesel-based power systems. They can provide steady community-level electricity service as part of rural electrification, while offering the potential to be upgraded for grid connection in the future. Their high level of efficiency and reliability over the long term also make hybrid systems effective backup solutions to the public grid in the case of blackouts or weak grids, and for dedicated energy solutions in such settings as telecommunication stations or emergency rooms at hospitals. Commercial and industrial establishments, as well as community services that require continuous power supply (and represent stable energy demand), increase the overall economic viability of a hybrid DRE project.

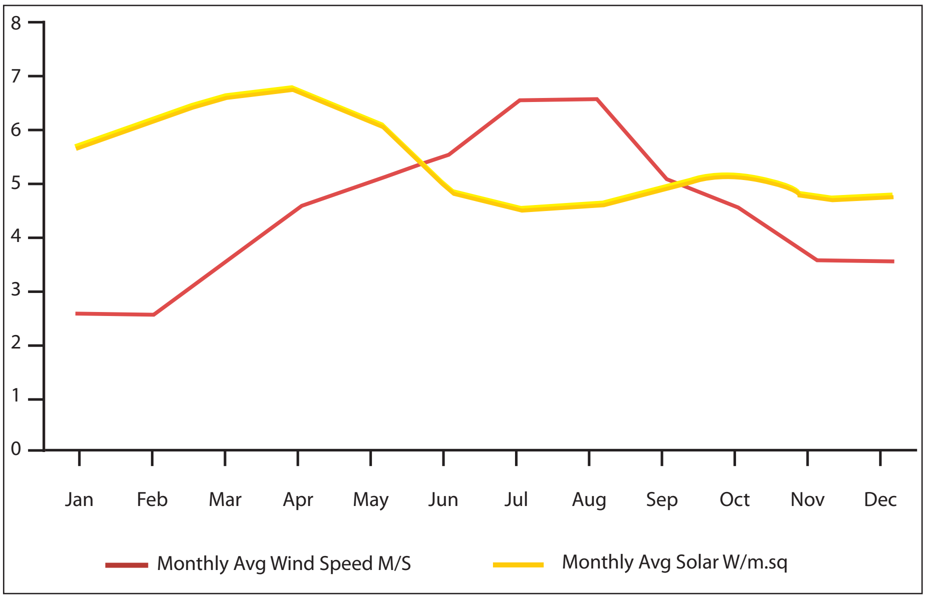

Figure 2: Annual wind and solar resource availability

Types of hybrid systems

Hybridisation in the Indian rural context can happen in the following two ways:

- Hybridisation among renewable energy (RE) sources depending on the complementary nature of the source(s): In this case, RE sources are available with no fuel cost involved. For example, the fuel cost is nil with a combination of solar and wind power. This kind of hybridisation is primarily focused on improving the reliability of the power generating system.
- Hybridisation of a diesel or biomass-fuelled system with any other RE source(s): In this case, whenever demand is high or power from other RE systems is low, the diesel or biomass system must meet demand. This type of hybrid system is focused on reducing fuel consumption. A diesel-fuelled system is able to generate only 3–4 electricity units with a litre of oil, the cost of which is around Rs 60. With biomass-based power, 1.2–1.5 kg of biomass is required to generate one unit of electricity. The cost of biomass ranges from Rs 1 to as high as Rs 4 per kg in most locations in the country.

[2] Source: Luminous Renewable Energy website ***http://luminousrenewable.com/wind-solar-hybrid.php.***

[3] Battery-backed single DRE technology is not considered hybrid because the battery is not a generator of electricity, it is only storing the electricity already generated by the DRE. However, hybrid systems may use battery storage to enhance the overall reliability of the system.

The most common options for hybrid power systems in the Indian rural context are:

- Solar PV plus diesel
- Biomass plus solar PV
- Wind plus solar PV plus diesel
- Wind plus biomass plus diesel
- Biomass plus diesel
- Biomass plus solar PV plus diesel
- Hydro (micro or mini) plus diesel

The design of systems (exact configuration and the level of hybridisation) depends on the site-specific conditions. In the case of renewable plus diesel hybrids, the systems can be designed in such a way that less diesel fuel is required for power generation. All the systems mentioned generally have battery storage and a control system for optimal utilisation of all the installed components. Electricity generated from solar PV is direct current (DC), while that from other renewable sources and a diesel generator is alternating current (AC). A rectifier converts AC power to DC, and a charge controller ensures that the battery is neither overcharged nor drained.

A wind plus solar PV plus diesel hybrid system with battery storage can potentially run continuously. In this case, solar PV or the combination of solar PV and wind energy charge the batteries from 7 am until 6 pm, and depending on the availability of wind resources, wind turbines continue to charge the batteries overnight. If they are fully charged, the wind turbine can be shut down during the night, or excess power could be fed into the grid. If the power generated from RE is not sufficient, the diesel generator will commence its operation to generate power.

In the case of biomass plus diesel hybrids, only one power generation unit (the engine) is required. Both diesel and the biofuel generated through biomass gasification is directly burnt in the engine. In the future, hydrogen-based storage (fuel cells, currently under research) can be used instead of batteries. The excess energy generated from RE sources can also be utilised for hydrogen generation through electrolysis. Hydrogen is a clean fuel that can be burned in engines whenever generation from RE sources is reduced.

In addition to electricity generation, hybridisation has significant potential for heat generation. Thermal energy is required in large quantities for various rural applications, including cooking and drying agricultural produce. There are also thermal requirements for various domestic and industrial applications (known as process heat), and low temperature thermal energy can be utilised in vapour absorption refrigeration and cold storage systems for preserving the agricultural produce. The 'cold chain' has the potential to transform and modernise Indian agriculture, with a cascade of economic and food security benefits.

ASSESSING BENEFITS OF HYBRID SYSTEMS

Cost of electricity in hybrid system vs. single source RE systems

The cost of electricity generated from hybrid systems reflects numerous factors, including the type of RE system and the availability of resources; the configuration of the system; location and operating conditions; the degree of hybridisation; fuel costs; capital costs of various components of the system; and operations and maintenance expenses.

The cost of electricity also depends on why and how hybridisation is done. For example, in order to enhance the reliability of existing power generating systems, the existing system may need to be augmented. In case of such augmentation, there is a need for additional capital expenditure and the power generation cost will also increase. In the case where a DDG system has to be designed and installed, a detailed techno-economic analysis should be carried out to find the cost effective option for power generation. In this scenario, in spite of the higher capital expenditure, the power generation cost of the hybrid system could be much lower than the standalone diesel-based hybrid system and would be comparable with many standalone RE-based systems. Figure 3[4] shows the lifetime costs (initial capital investment and operational costs for a period of 20 years) of various systems for a typical location in a developing country. Table 1

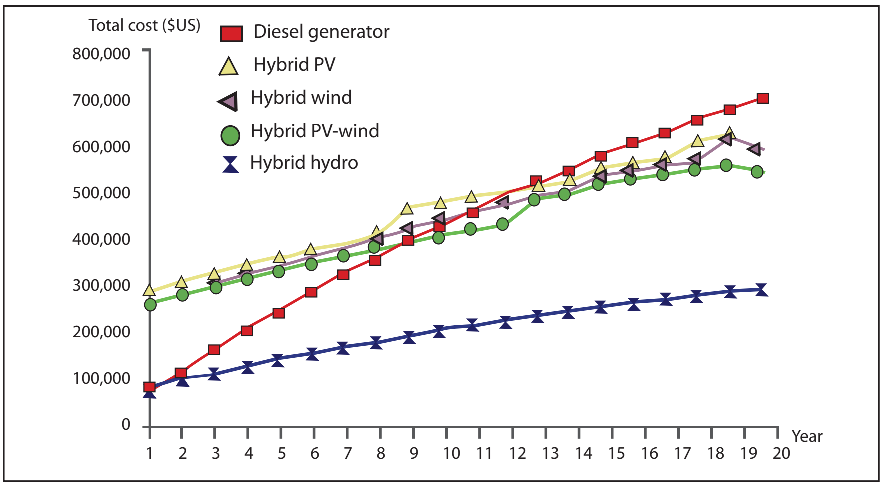

Figure 3: Total costs of various systems through their lifetime

[4] Source: Rolland and Glania, 2011. In the report, ARE developed a case study for establishing a hybrid mini-grid in a village in Ecuador and the findings are provided in this graph. It was also mentioned that the solar, wind, and hydro resources available in this village are typical of many locations in developing countries.

Ashden India Renewable Energy Collective

SHAKTI SUSTAINABLE ENERGY FOUNDATION

(Cust et al., 2007) provides some basic details on the cost of power generation from various sources.

Hydro power generation systems are the most economical but they are highly dependent on resource availability. Power generation from biomass systems is also economical and such systems generally provide power continuously throughout the year except for the rainy season when it is difficult to procure dry biomass. Wind-based systems are highly dependent on wind resource availability, which can vary throughout the year. Solar PV systems can be installed in most parts of India but the initial investment cost is high. Interestingly, Table 1 indicates that a hybrid system with RE source plus diesel is more economical than the cost of operating a single-source diesel generator.

Table 1: Cost of power generation from various sources

Source	Cost of power generation (Rs/kWh)
Micro hydro	3–7
Biomass	6–8
Diesel generator	20–22
Wind (when hybridised with diesel/biomass)	8–10
Solar PV (with batteries)	15–20

Efficiency and reliability improvement factor of hybrid systems

Hybrid systems combine the best features of individual RE resources and they are able to provide dispatchable[5] and reliable power. The efficiency and reliability of the system is directly related to its CUF (capacity utilisation factor). The CUF of the system is a function of the availability of fuel (in the case of biomass/diesel) and the site-specific conditions (in the case of other RE sources such as solar, hydro, and wind), design and implementation of control logic for combining, storing and utilising the output of each RE component, and the capacity of the storage. Table 2[6] provides the CUF of various individual power generating systems.

Table 2: CUF of various power generating systems

Power generator	CUF (%)
Hydro (mini/small)	30–60
Biomass	50–80
Diesel generator	50–80
Wind	15–30
Solar PV	15–25

As a result of hybridisation, the CUF of the individual system will not increase, but combining two or more RE sources will result in effective usage of resources and also increase the reliability of the overall system. Detailed simulation studies have to be carried out in order to determine the exact reliability improvement of the hybrid system at any given location.

CHALLENGES OF HYBRID SYSTEMS

Technical challenges

Solar PV and biomass resource assessments can be completed relatively quickly, but this is not the case for wind and hydro. Therefore, resource assessment is an issue for hybrid systems that include wind and hydro energy.

The procedures for the design and installation of solar PV, wind, biomass, and hydro systems are well established, but the design and operation of hybrid systems is a slightly more complex issue. The operation and maintenance of a hybrid plant by rural communities might be difficult and may require a dedicated team to operate such systems. The hybrid system has to include a smart controller to effectively utilise the output of RE component(s) of the system and in some cases of a diesel generator. For example, a solar PV plus diesel system should not be running on diesel power during a clear sunny day. Control logic must be developed so that the solar PV system can respond to the demand for most of the time, and the diesel generator should function only during times of non-availability of solar power. Proper technical investigation must therefore be completed prior to making a decision on the configuration of the RE hybrid system, the contribution from each RE resource, and the required control logic. Highly sophisticated control logic and control systems must always be in place.

The following checklist may be employed to examine whether hybridisation is a

Question	Yes/ No
Is RE resource available?	Yes
Is that single RE resource that has the maximum potential intermittent?	Yes
Will the provision of battery storage ensure stable energy supply?	No
Are more RE resources available?	Yes
Does the availability of any of these resources complement the availability of the single largest RE resource?	Yes
Is hybridisation among these resources technically feasible?	Yes
Does this hybridisation make economic sense?	Yes

[5] Dispatchable generation refers to sources of electricity that can be supplied at the time of demand.

[6] Source: ICRA, 2012 and the MNRE website.

possible solution or not. If the answers to the questions are exactly the same as mentioned in the table, hybridisation is feasible for an application at any location.

Policy, regulatory, and institutional challenges

While there are policies and programmes for RE-based distributed generation, there are as yet no specific policies for hybrid systems in India. In the rural electrification sector, the Ministry of New and Renewable Energy (MNRE) is sponsoring various programmes separately on solar PV, small hydro and biogas, and biomass gasification-based power generation. For large-scale power generation, the MNRE is considering hybrid biomass-based power plants with solar thermal systems to increase the plant load factor. Similar programmes would be needed for DDG in remote areas. The lack of clear central government policies for hybrid DRE, for instance, lack of clarity on tariff setting for hybrid RE systems, is an impediment.

A decision-making guide is necessary for project developers to determine when to hybridise, and with what and to what extent. Annex 1 presents a quick analysis for capital and operating expenditures for various hybridisation options. However, such decision support systems need to be developed for various scenarios representing different energy load curves, resource availability, financial assumptions, and policy contexts. Such a tool would be useful not only for project developers but also for policy makers to ensure that hybrid systems based on DRE are able to deliver economical and reliable energy.

ANNEX 1: Preliminary decision-making guide for hybrid systems

In the tariff orders, capital and operating expenditures are provided in megawatts and those values are linearly extrapolated (i.e., divided by 1000) and provided in kilowatts in Table 3[7]. Operating expenditures are inclusive of fuel costs. The Central Electricity Regulatory Commission (CERC) has provided benchmark costs for initial capital expenditure (CAPEX) and operating expenditure (OPEX) for grid-connected large-scale RE power plants. The costs provided in the table are taken directly from CERC tariff orders; however, these costs would change for DRE systems based on their size and location. The CAPEX provided in the table include only the cost of power generating system and is exclusive of battery storage and power distribution network costs. The OPEX provided in Table 3 are also inclusive of fuel costs.

A preliminary decision-making table[10] (Table 4) is generated to understand the variation in CAPEX and OPEX for a number of predetermined hybrid configurations. The methodology adopted for developing Table 4 is as follows:

- The hybrid power plant has a total capacity of 100 kW
- Various configurations are developed and this total capacity is equally distributed among the RE systems and/or diesel generator depending on the configuration (for example, Option 1 is a combination of solar and wind, each with a capacity of 50 kW)
- It is assumed that even after hybridisation, the individual systems would continue to work with the same plant load factor (see Table 3). Total energy is calculated as follows:
    - In Option 1, total kWh = solar capacity * related kWh/year (from Table 3) + wind capacity * related kWh/year (from Table 3) = 50 * 1660 + 50 * 1750 = 170,500 kWh
- Total CAPEX and total OPEX/year are calculated based on the capacities provided in Table 4 and the CAPEX/OPEX values provided in Table 3. CAPEX and OPEX values per kW basis are calculated by dividing the total values by 1000
- OPEX/kWh is calculated by dividing total OPEX by the number of units generated

Table 3: Cost and performance of various power generation technologies

Power generation technologies	CAPEX/ MW (lakh)	OPEX/MW/ year (Rs)	kWh/MW/ year	Plant load factor (%)
Solar	1000	11	1,660,000	19
Wind	575	9	1,750,000	20
Hydro	600	20	2,600,000	30
Biomass[8]	400	270	6,700,000	85
Diesel[9]	100	940	5,694,000	65

[7] Source: Central Electricity Regulatory Commission, 2012. Final Tariff Orders.

[8] The CAPEX and OPEX provided are for biomass gasification systems. Biomass cost is taken to be Rs 2.5/kg.

[9] Diesel genset price is taken to be Rs 1 Crore/MW. Diesel price is taken to be Rs 55/litre (in Delhi). These values are based on internal discussion.

[10] This is only a preliminary decision-making table developed for a few selective hybrid configurations. Table 4 is developed purely based on values provided in Table 3 and the outlined methodology.

Ashden India
Renewable Energy Collective

SHAKTI
SUSTAINABLE ENERGY
FOUNDATION

Table 4: Preliminary decision-making matrix for DRE hybridisation

Options	Solar (kW)	Wind (kW)	Hydro (kW)	Biomass (kW)	Diesel (kW)	Total kWh/ year	Total CAPEX (Rs)	Total OPEX/ year (Rs)	CAPEX/ kW (Rs)	OPEX/ kW/ year (Rs)	OPEX/ kWh (Rs)
Option 1	50	50				170,500	7,875,000	100,000	78,750	1,000	0.59
Option 2		50	50			217,500	5,875,000	145,000	58,750	1,450	0.67
Option 3	33	33			33	303,467	5,583,333	3,200,000	55,833	32,000	10.54
Option 4	50				50	367,700	5,500,000	4,755,000	55,000	47,550	12.93
Option 5	50			50		418,000	7,000,000	1,405,000	70,000	14,050	3.36
Option 6				50	50	619,700	2,500,000	6,050,000	25,000	60,500	9.76
Option 7		50			50	372,200	3,375,000	4,745,000	33,750	47,450	12.75
Option 8			50		50	414,700	3,500,000	4,800,000	35,000	48,000	11.57
Option 9		50		50		422,500	4,875,000	1,395,000	48,750	13,950	3.30
Option 10	33	33		33		337,000	6,583,333	966,667	65,833	9,667	2.87
Option 11	100					166,000	10,000,000	110,000	100,000	1,100	0.66
Option 12		100				175,000	5,750,000	90,000	57,500	900	0.51
Option 13			100			260,000	6,000,000	200,000	60,000	2,000	0.77
Option 14				100		670,000	4,000,000	2,700,000	40,000	27,000	4.03
Option 15					100	569,400	1,000,000	9,400,000	10,000	94,000	16.51

From the table, it is inferred that diesel generation has the least CAPEX and the most OPEX/ kWh; if diesel generation is hybridised with any RE source, OPEX/ kWh decreases drastically and there is a marginal increase in the CAPEX of the system. The reverse is also true, for example when any RE source is hybridised with diesel generation, the number of units generated increase (because the system is more reliable), CAPEX decreases and OPEX/ kWh increases.

References

Cust J, Singh A, and Neuhoff K, (December) 2007. **Rural Electrification in India: Economic and Institutional Aspects of Renewables.** Cambridge: Cambridge working papers in economics, CWPE 0763, University of Cambridge.

ICRA, (May) 2012.**Steady Growth in Small Hydro Power; However Significant Challenges Remain....** http://www.icra.in/Files/ticker/SHP%20note-.pdf

Rolland S, and Glania G, Alliance for Rural Electrification, 2011. **Hybrid Mini-Grids for Rural Electrification: Lessons Learned**, Chapter 3, First Edition. Report submitted to USAID.