Case Study of a Hybrid Power Microgrid in Rural India

Arunachalam. K
Avinash Nandakumar
Fichtner Consulting Engineers (India) Pvt. Ltd.
Chennai, India
arunachalamk@fichtnerindia.com
avinash.nandakumar@hotmail.com

Ramachandra. K
Aklavya Sharan
Decentralised Energy Systems (I) Pvt. Ltd.
Bangalore, India
kr@desipower.com
aklavya@desipower.com

***Abstract*—Hybrid Power Plants and Microgrids can play a vital role in accelerating the rural development process with reliable power supply, reduced pollution & CO2 emissions. The case study analyses such a project in Bihar, India, which uses renewable energy to promote, empower villages and accelerate rural development. It reports on the experience of reliable and affordable systems and hardware for hybrid power plant microgrids and enterprises suitable for village applications.**

The paper covers a Hybrid Power Plant which powers a microgrid for a rural village in India. Going beyond the traditional goals of electrification (lighting and pumping), the microgrid also covers productive, energy-services, agro-processing enterprises for income generation and meeting social needs of the locality.

Two key challenges are discussed:

1. Design and Optimisation of the Hybrid Power Plants and Microgrids to ensure that loads are met reliably, on demand with profitability.

2. Participation, training, and capacity building of villagers to take full advantage of such projects.

The experience of working with villagers during the planning and operational phases of rural power systems and the training and capacity building programs needed to enable them to carry the responsibility for running plants and other local businesses and enterprises will be described.

Keywords-Hybrid, Solar PV, Biomass Gassifier, Battery, Microgrid, Rural Electrification

I. INTRODUCTION

Mere presence of power distribution lines in villages without availability of reliable and adequate amounts of power by itself does not lead to economic and social progress of villages. Chakai village in the Araria district of Bihar, India, was no exception. Due to unavailability of grid supply, villagers were dependent on diesel and kerosene to meet the needs of irrigation water and lighting. The experience of setting up rural microgrids started with the development of a renewable energy-based power plant in the village of Baharbari, India in 1999-2000 with a biomass gasifier and a dual fuel internal combustion (IC) engine. Initially the power was supplied to several irrigation pumps located in the agricultural fields and to agro-processing machines located in nearby centre. Subsequently power was further distributed to shops and small business of a marketplace located further away and finally a microgrid was completed in 2006 to connect over 200 households.

The challenge of a decentralised microgrid is to meet widely fluctuating day and night loads reliably and profitably throughout the year. Ideally, a power plant should sell a minimum annual amount of electricity at affordable prices to meet its financial targets. But villages do not have many productive and energy-service enterprises and many microgrids are, therefore, over-invested, under-loaded and unprofitable. The lack of productive and energy-service enterprises also results in a lack of local jobs and income which perpetuates rural poverty.

The experience gained from setting up the first microgrid was used to set up a Hybrid Power Microgrid in the village of Chakai in 2015 which initially consisted of a biomass-based power plant and later a solar PV power plant was added. Presently, the system consists of a 37.5kWp Solar Photovoltaic (PV) Power Plant along with a 11kWe biomass gasifier and a 100% producer gas engine.

This case study analyses various aspects of a hybrid microgrid covering planning and design, operation and maintenance experience, potential advantages, opportunities, and challenges for large scale usage of renewable energy-based hybrid power microgrids to accelerate the social and economic progress of villages in India.

II. HYBRID POWER PLANT PLANNING AND DESIGN

Chakai village has a population of about 10,000 and about 1500 households. The main occupation of the village is farming, and farmers also grow vegetables, which require water throughout the year. Initially, there was no electricity and proper roads in this village. Villagers used to grow mostly traditional crops like wheat and paddy. For irrigation, farmers were dependent either on rain or diesel pumping sets.

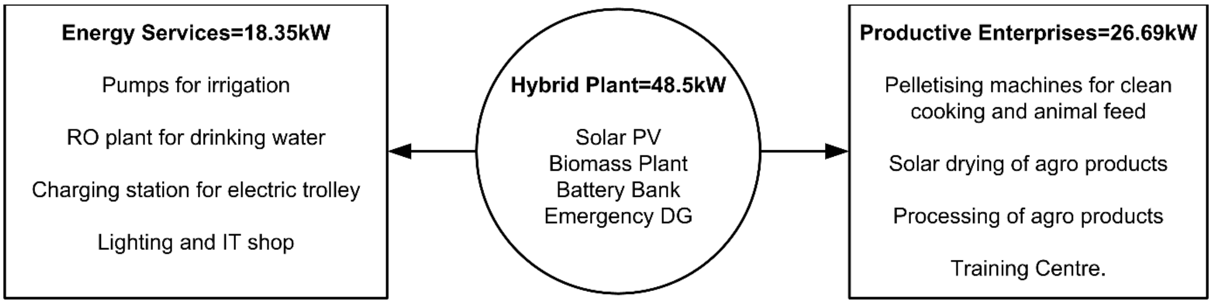

Figure 1. Representative Block Diagram of the Hybrid Power Plant Microgrid

Prior to setting up of the power plant, a detailed survey was carried out of the village to ascertain sustainable availability of biomass raw material, solar irradiation potential load assessment, growth potential and availability of local manpower who can be trained to manage the power plant operation & maintenance.

It was also essential to educate the villagers about the advantages of the upcoming microgrid to inform them on how it will improve the economy of the village and improve their wellbeing. The unity among villagers is very high: it is key to the business that the villagers accept a microgrid in the village and pay for the required services.

Based on the site survey, a biomass gasification plant coupled to a 100% gas engine generator plant was originally conceived to meet the load demand. However, it was soon realised that the operation of the plant to supply power on a 24x7 basis may warrant a stand-by unit with additional investment along with other maintenance costs and underutilisation resulting in high generation cost. Added to this, was the problem of availability of biomass feed stock throughout the year at a reasonable price.

To decrease the financial risk of the project and increase the reliability of the microgrid a hybrid microgrid with a second source of generation was added. Since hydro and wind power are very site specific and biogas plant involves sourcing adequate quantities of feed stock, they were not considered. Hence, a Solar PV power plant was considered as the other source of generation which forms the primary source. Incidentally, this decision was supported by features like global distribution, pollution free nature, and virtually inexhaustible supply of energy from the sun which was an attractive and sustainable option with a well-established technology. Thus, the renewable energy sources available here for hybrid generation are Biomass and Solar PV.

Load planning and generation cost was estimated, and for supply of power to the consumers a suitable tariff was fixed, which was mutually accepted by the villagers. Load management was done manually as per the load profile and agreed with the customers.

The hybrid power plant consists of Biomass Generation plant of 11kW, Solar PV Power Plant of 37.5 kWp and Battery Energy Storage of 240V, 300Ah. The main loads served by this hybrid microgrid include irrigation pumps, process loads, drinking water RO unit, agro-based industries, electric-trollies, a training centre, kiosks for cell phone & battery charging, plant auxiliaries and lighting and other appliances in households and businesses in the village. Detailed Load list is given in Table I.

A microgrid was setup in the village by laying underground power cables to distribute and supply power to the various consumers through strategically located distribution boards (DBs). Underground cabling, though more expensive, was preferred to overhead lines considering the advantages like protection against electricity theft, safety, better life of the cables and much less maintenance. Certain loads are also served using overhead transmission lines, wherever underground cable was not feasible.

The plant is operated manually, and solar PV power is utilised to the maximum possible extent with the objective to conserve the biomass for non-sunshine and cloudy hours. If the generated power falls short of the demand either marginally or for a short duration of time, it is supplemented by the battery bank. On the other hand, if the shortfall in power generation is large or for a longer duration of time, a producer-gas engine coupled to the biomass gasification plant is started. Any excess generation is used for charging the battery energy storage bank. The efficiency of the gas engine is very low when it is loaded below 50% and hence it is always recommended to maintain gas engine operation above 50% loading even if the requirement is only to meet the shortfall.

TABLE I. POWER PLANT CONFIGURATION AND LOAD LIST OF THE HYBRID POWER PLANT MICROGRID

S.No	*Description*	*Rated Power (kW)*
	Power Plant	
1.	Solar PV Power Plant	37.5
2.	Biomass Gassifier Engine	11
	Total Power Generation Capacity	48.5
3.	Battery Energy Storage	72
	Loads	
1.	Evening Village Loads	2.1
2.	Irrigation Pumps	11.25
3.	RO Pump	3.0
4.	Pelletising Machine for cooking fuel and cattle feed.	7.47
5.	Hammer Mill	7.47
6.	Training Centre	4.0
7.	Biomass Cutting Machine	2.25
8.	Food Processing Unit	2.5
9.	Solar Hybrid Dryer	3.0
10.	E- Trolley	2.0
	Connected Load	45.04

Figure 2. Biomass Gasifier Power Plant at Chakai village

Energy plantation is promoted in the villages not only as a source of sustainable biomass supply for the power plant but also to create a better income for the villagers.

Biomass types such as Ipomea, Dhaincha (local name), Corn Cob, Kadam, Bamboo etc are promoted.

III. OPERATIONAL EXPERIENCES OF A HYBRID POWER PLANT MICROGRID

Reliability of electricity supply through renewable energy based local generation and microgrids is one of the major drivers for accelerating rural economy and social progress in countries like India where centralised grids are not yet able to assure uninterrupted and reliable power supply for productive enterprises, energy, and social services in rural areas.

The challenge of a decentralised microgrid is not only to meet widely fluctuating load for various seasons but also 24 hours of the day efficiently and profitably throughout the year. Ideally, a power plant should sell a minimum annual generation of electricity at affordable prices to be able to sustain its business. The microgrid at Chakai must meet various loads during the day and night and a single source technological option is not cost effective to meet all types of the load at a given time.

Solar PV based microgrid developers need to increase the size of the solar field and the battery bank considerably if they want to meet all demands reliably for entire year. Hybridisation with biomass, biogas and wind is one of the ways to reduce the size of the solar PV fields and battery banks, reduce costs as well as ecological impacts of power systems with microgrids. Biomass-PV hybrid plants with smaller battery banks are also likely to be more economical and profitable for investors in large parts of the country.

Figure 3. Solar PV Power Plant at Chakai village

Figure 4. Solar inverter and batteries at Chakai plant

Sizing the individual power generating units in a hybrid plant supplying a microgrid in such a way that the daily and monthly variation of demand can be always met reliably at the least cost is a challenging and a complex process. Capital and generation costs must be calculated for different combinations of generator capacities to meet different combinations of loads at any given point of time for a range of input data on performance and costs. In addition to the demand profile, calculations must consider many parameters such as local solar irradiation, efficiencies for varying loading, investment costs, cost of biomass, and cost of operation and maintenance. The complexity of the sizing process increases greatly: many calculations must be done in an iterative process to optimise the levelised cost of generation for achieving the desired profitability of a power system with a microgrid. Conditions in different parts of the country are so varied that such optimisation calculations will need to be done for the local conditions of each project.

A. *Challenges in Operating a Microgrid and its Potential*

It was a big challenge to ensure reliable and affordable power to the micro enterprises.

The following are some of the challenges faced in the development of a hybrid power microgrid

- Competition with national grid which is highly subsidized and is often preferred even though unreliable and inadequate.
- Demand assessment and load forecast in the planning stage is critical in optimizing the design of a hybrid microgrid. Oversizing the generation and/or storage capacity will result in poor cost-effectiveness of the proposed microgrid solution, while undersizing will result in inability to supply all demands and customer dissatisfaction
- Low utilisation factor due to diverse and varying load patterns with time and seasons in the villages decreases profitability of projects.
- Use of poor-quality equipment and untested technology due to lack of sufficient funding, and lack of spares and services from suppliers, combined with lack of, or shortage of, local skills for maintenance of the microgrid make it difficult to

sustain reliability and profitability of the project over its lifetime.

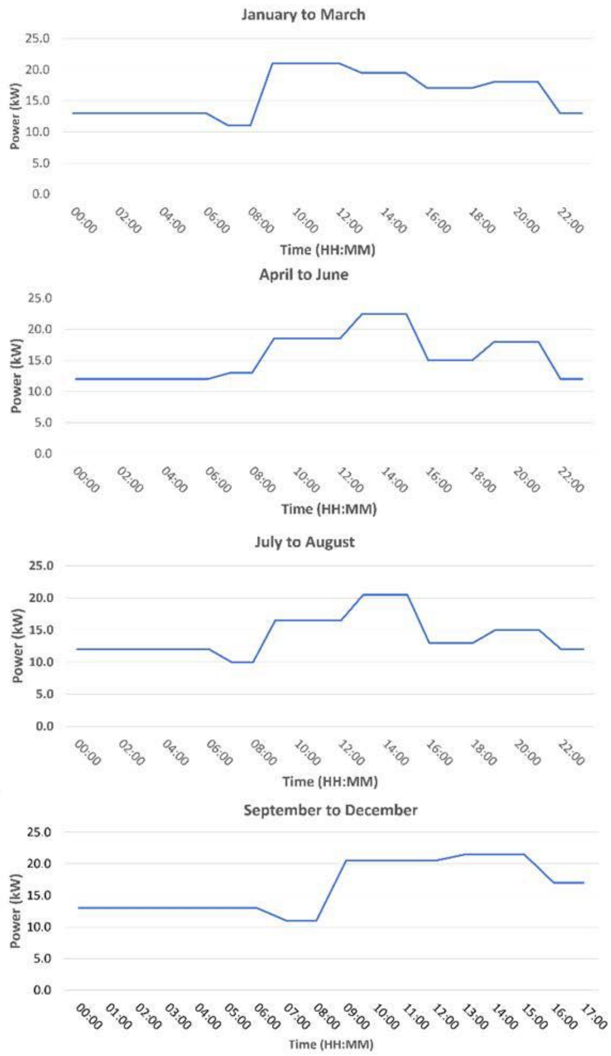

Figure 5. Daily Load Profile of the Microgrid in four different seasons.

- Biomass gasification based microgrids may face challenges in finding sustainable sources of biomass and operating effective supply chains for biomass feed stocks. Therefore, for a biomass or biogas-based plants, a proper raw material planning is essential for sustainability.
- In the case of solar microgrids, variations of insolation due to local micro-climatic conditions lead to unreliability of supply.
- The storage batteries seem to be technically vulnerable. This has created additional challenges for the whole operation and sustainability of the solar microgrids.
- Un-structured tariffs for the consumers from microgrids is mostly done on a mutually consent basis without any policy support. In remote rural locations, a sustainable hybrid RE microgrid electrification tariff should cover O&M costs of the system and provide incentives for a fair profit to attract private investors.
- In India, microgrids have been completely ignored to be linked with the Saubhagya (Electrification of every village and district) scheme which is proposed for 100% electrification of villages. Only a policy can help to mitigate the tariff challenges.
- Parallel operation of microgrid with distribution grid is not recommended to avoid duplication of Public Distribution Network
- Lack of demand for micro-enterprises is mainly due to lack of policy framework for capital support and non-availability of trained/skilled manpower.

According to a UN Foundation report published in 2014[1], unnecessarily oversizing a microgrid increases the CAPEX and OPEX whereas under-sizing will lead to consumer frustration and dissatisfaction with service quality, a dissatisfaction that can easily lead to the loss of consumers and the inability of the remaining consumers to cover costs. Our experience corroborates the views of the UN Foundation.

B. Advantages and Opportunities of Operating a Microgrid

- Microgrids have potential of linkage with Discoms for better economics of rural energy systems.
- It has potential of linkage to other energy services such as clean cooking and irrigation & drinking water.
- Reliable electricity for productive purposes is essential for job creation for the villagers and increased income for the farmers.
- They make very substantial impacts on decarbonization (global and national) and create much lower pollution (local).
- Benefits of renewable energy based microgrids range from technical and environmental advantages to social and financial advantages. Properly designed and optimally sized microgrids offer the financial advantage of lower generation cost of electricity. Better electrical services with reduced breakdowns and more reliable supply lead to customers who are more satisfied overall, and thus willing to pay for the services provided by microgrids.
- Microgrids can industrialise rural India by promotion of efficient energy services and reduce huge diesel consumption by telecom tower and irrigation pumps.
- They also strengthen the community while having less or no adverse impact on the environment.
- Microgrids are relatively quick and easy to implement in rural areas without electricity. They can also be used to improve existing electrical grids that are ineffective or unreliable by providing additional power or by replacing them completely. Microgrids are also more efficient because they can provide low load at night when less electricity is needed.

- Renewable energy based microgrids have environmental and social benefits also in addition to economic benefits. They generally replace the use of kerosene and diesel, reducing greenhouse gas emissions. Also, burning biomass in open stoves with detrimental health impacts (such as respiratory disease) as well as possible fire risk in rural communities can be avoided. Further, extended daylight hours made possible by electricity allow people to continue working, for children to study after sunset and for schools to provide training on subjects that require electric tools, such as computers.

At Chakai village, microgrid supplies power to irrigation pump sets which has helped to irrigate about 200 acres of land. Earlier, the farmers who were either dependent solely on rain or unreliable national grid supply used to cultivate only two crops in a year, have increased one more crop due to the availability of water. Also, the rice / flour / chura mills help them to process the raw material to the end product and sell at a better price in the market directly.

Earlier, the villagers used to grow Jute, which is a cash crop. Jute needs more cash and care and for any reason, if the crop is not good, the villagers used to incur heavy loss. Dhaincha a local weed was promoted during 2007-08 to grow in place of Jute. The advantage of Dhaincha is that it grows very fast and it can be planted between two crops also. Dhaincha cultivation doesn't need a high investment and serves as a useful feedstock to the gasifier. The seeds are provided to the farmers to grow Dhaincha and today, Dhaincha is being grown in that area on a large scale.

The power plant and the microgrid have helped to generate both direct and indirect employment opportunities. The power supply to the pelletising unit has helped to provide clean cooking fuel.

C. Training, Capacity Building and Community Engagement

Success of a rural microgrid is also dependent on trained manpower and support of the community. Before setting up of Chakai plant, discussions with the community were ensured to increase their knowledge and involvement. Community engagement was also crucial to ensure they were willing to pay for the services at a mutually agreed price.

Trained manpower is very important for a proper operation and maintenance of the microgrid. To cater to this requirement training was provided to competent candidates through the in-house training center. Training was provided not only on technical aspects but also on how to make use of the various services (such as saving water, electricity, etc) in an effective manner.

In addition to this, training and support to the farmers were provided to adopt modern farming practice to enhance their income.

TABLE II. TYPICAL GENEATION COST OF CHAKAI POWER PLAN

Description	***Unit***	***Value***
Solar plant capacity	kWp	37.5
Biomass plant capacity	kW	11
Running hours of biomass	Hrs/Day	8
Solar irradiation (16% CUF)	kWp/kWh	3.84
Debt compostion	%	70
Interest rate	%	10
Payback period	Years	7
LCOE	**Rs./kWh**	**11.89**

Figure 6. Photograph of a Community Discussion at Chakai village.

Community is actively involved in the process, and this helps to ensure there is benefit to every stakeholder. This is a continuous process and regular refresher courses are also provided.

IV. CONCLUSION

Based on the ground experience, a dynamic modelling tool for design and optimisation of hybrid microgrids is currently being developed which can enhance efficiency of the plant and reduce CAPEX and OPEX. Typical generation costs are given in Table II.

System dynamics techniques (an MIT based systems analysis process)[2] are ideally suited for the calculation of such complex power systems. Design of new plants with local optimisation with local data and conditions become much less time consuming once the dynamic model is established and validated. It can generate options and enable decision makers to examine consequences when parametric data may change over the years and collect more reliable data on assumptions which show a substantial effect on results.

The model will be tested in a village plant in India in coming months and will be useful not only to promoters/owners of decentralised power plants and microgrid companies but also to investors in local enterprises, villagers and planning authorities.

The objectives of the Design and Optimisation tool currently being developed are to enable planners, promoters, and decision makers of decentralised biomass-PV hybrid power plants to:

- The primary goal of design and optimisation modelling is to ensure reliable power supply by hybrid power plants to meet daily and seasonal 24x7 load demands at the least generation cost.

- Decide about the ratings of the biomass and PV generating plants for a given set of conditions regarding loads, demand profile, resources, technologies, costs, and other relevant parameters.
- Examine the options for operating strategy for each generating unit (time of the day and time of the year) to ensure reliable power to each customer with the smallest battery bank and at the lowest generating cost.

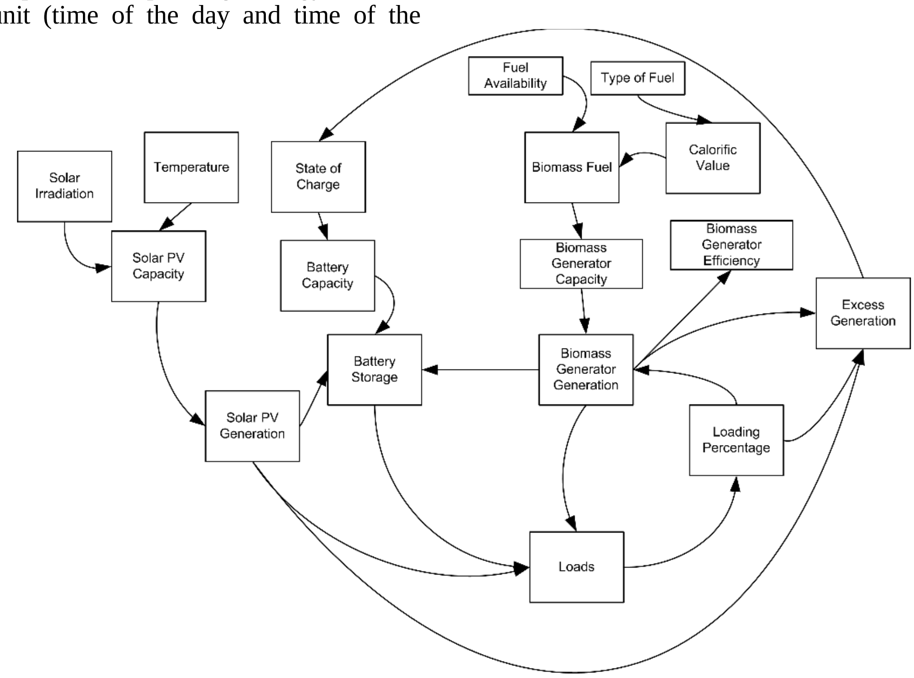

Figure 7. Typical System Dynamics Modelling

- To fix tariff rates
- Identify risks and options for mitigation

Data from this operational hybrid power plant microgrid are being used for developing the model. They cover:

- Geography and demography.
- Solar Irradiation
- Biomass Availability
- Loads and demand profile
- Technical specifications of solar field, inverters and storage batteries.
- Performance data of a producer gas engine at various loads.
- Capital investment and capital service costs.
- Cost of operation and maintenance.
- Annual cost escalation

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