

Approach for Designing Solar Photovoltaic-Based Mini-Grid Projects: A Case Study from India

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Abstract Having the largest rural population in the world, India confronts a huge challenge for rural electrification, especially for electrifying remote, forested and tribal habitations. Solar Photovoltaic-based mini-grids have emerged as a viable option for the provision of electricity in such remote rural locations, where grid extension is either not techno-economically feasible or electricity supply is intermittent. Very often such projects are purely technology-driven and several attempts at delivering electricity services to such remote locations have not succeeded, owing to the lack of adequate attention given to important socio-economic factors such as promotion of livelihoods or the creation of strong local institutions that can own, operate and manage the project over its lifetime. This chapter aims to present an interdisciplinary framework for the development of mini-grid projects in remote rural locations, developed from field experience of actual implementation of projects by TERI. Using this framework as a guide, TERI has commissioned solar photovoltaic-based mini-grids in a cluster of five villages in the state of Odisha. The detailed design methodology, including modifications to standardised practices in order to customise and improve the performance of these solar mini-grids is presented in this chapter as a case study. It is expected that the

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process followed and the resulting design will serve as a useful guide for renewable energy practitioners and researchers working in remote rural locations for provisioning of electricity services.

1 Introduction

Achieving universal electricity access has become a key target or policy objective for India as well for all other developing countries, especially after the launch of sustainable energy for all initiative [34]. This has been recognised both from the point of view of equitable access to resources, and the use of renewable energies to create the necessary access to modern energy services, in an environmentally benign manner. There are numerous studies closely examining the vital role of electrification for facilitating sustainable development especially in rural areas. They all point out how both human and economic developments rely on the access to reliable, affordable and socially acceptable energy services [1, 11, 18, 33], and lay special emphasis on decentralised modes of electricity delivery in developing countries [10, 13, 14, 19, 32].

For example, electricity contributes in a variety of ways to improving living conditions, from powering rural health clinics, to providing entertainment and communication services. Electricity allows improvements in farm and non-farm productivity through electric motors, the mechanisation of production to enhance scale, and power for water pumps, rice mills, agricultural or industrial production, among other benefits [5, 7, 9, 13, 17, 24, 26, 32, 33, 35].

A large number of projects and programmes, led by both Government agencies and private and non-governmental organisations have therefore taken up the responsibility of enhancing electricity access in remote rural areas through decentralised power plants based on locally available renewable energy. Very often, however, the emphasis is placed on delivery of the technology only, with lesser attention given to a demand led and customised approach to design, among a range of other factors impacting business models and institutional robustness, which add to the long-term sustainability of the project [16]. Lack of field expertise, absence of partnerships on the ground, standard approaches to implementation with an emphasis on speed of execution and the lack of long-term financing to maintain the system have frequently ended in frustration and disappointment on part of users and executing agencies.

Hence, it is not only important to focus on the whole range of technical, regulatory, socio-economic and financing issues that are linked to the implementation of rural energy access projects, but also prepare for the entire life-cycle of activities and costs that are associated with such projects. In this chapter, we present a standardised framework for the execution of off-grid rural electrification projects, based on the experience gained by TERI from designing and implementing such project over the last many years. Using this framework and by

customising it to suit a particular context, we present and discuss the methodology used for the design of an off-grid electricity project in the Dhenkanal district of Odisha.

The case study of the project sites in Dhenkanal district of Odisha, being presented here, is being implemented as part of a multi-consortium action research project, titled ‘Decentralised off-grid electricity generation in developing countries: Business models for off-grid electricity supply’, known as ‘OASYS South Asia Project’. The project aims to find appropriate local solutions, which are techno-economically viable, institutionally feasible, socio-politically acceptable and environmentally sound, for sustainable electricity supply to off-grid areas. An important component of the project is to develop an off-grid delivery model framework and implementation of a demonstration project covering un-electrified villages in order to test the framework. The methodology followed for this design process is presented in the chapter.

Section 2 outlines a step-wise standardised approach for the execution of off-grid village electrification projects. Using this approach from **Secs. 2, 3** and **4** present the processes followed for the execution of the case study from Dhenkanal district of Odisha, focusing on the pre-installation, design and installation phases of the project. Since the project in Dhenkanal district has been commissioned during writing of this chapter, the post-installation experiences from the project has not been covered in this chapter.

2 Approaches for Execution of Village Scale Off-Grid Electrification Projects

A standardised approach for off-grid rural electrification projects is presented briefly in this section. The range of tasks/activities mentioned is not exhaustive, but gives an indication of the type of inputs or the investments that are needed in order to make an electrification project sustainable in the long run. The framework presented here is an adapted version of the approach for standardisation of off-grid electrification projects developed in ‘Approach for standardisation of off-grid electrification projects’ [16] through an extensive study of projects and programmes and inputs from TERI researcher’s own experience in the design and implementation of similar projects.

The various phases of the project can be categorised as below, each stage involving different actors with varying degrees of contribution.

- A. Project development and Pre-Installation
- B. Design, Procurement, Installation and Commissioning
- C. Post-commissioning and sustaining the project.

Each of the stages mentioned above can further be divided into specific activities as detailed out in Annexure A. It should be noted here that some of these

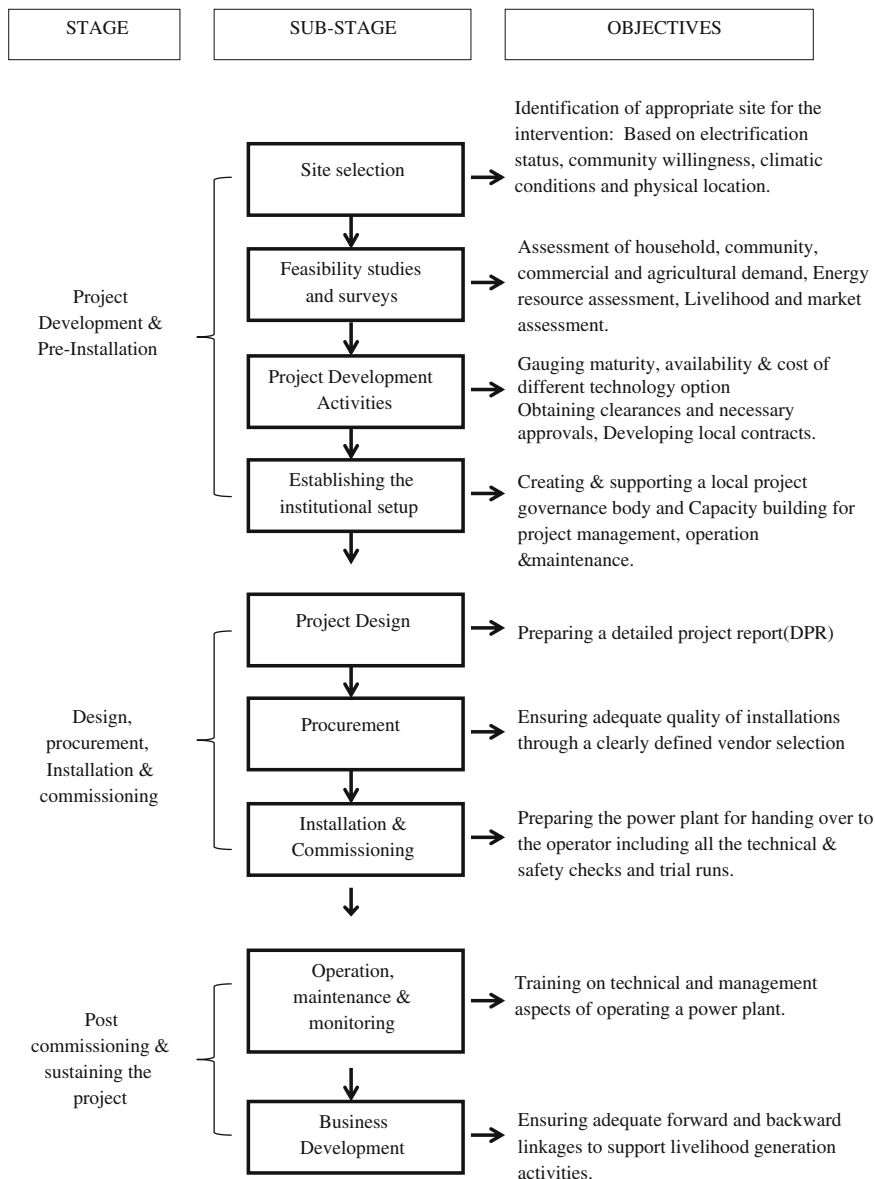


Fig. 1 Project execution methodology for rural electrification projects. *Source* Adapted from [16]

activities may not be strictly confined to the broad stage under which they are categorised and may run through the entire lifetime of the project. Figure 1 presents this process in the form of a flow chart for easy reference.

In the subsequent sections, the step-wise methodology described above is applied to the identified project sites in Dhenkanal district of Odisha. The

installation and commissioning of the power plants in these sites has been completed in February 2014, and hence the focus of this chapter will be on the project development and pre-installation, and design, procurement, installation and commissioning activities described above. As mentioned in the previous section, the post-commissioning activities and impacts of the project are beyond the scope of this chapter and will be assessed over the next one year and the research outputs will be subsequently published.

It should be noted here that approach described above has been customised to suit the particular site conditions, ground and market realities and other externalities such as weather and project timelines. In this chapter, we attempt to present not just the basic steps followed for design, but also lay emphasis on and highlight the specific requirements of the sites and the manner in which they have been addressed, from a practitioner's viewpoint. We have attempted to illustrate the challenges faced and some possible solutions adopted during the actual implementation of the project, which are based on frameworks such as the one mentioned above. For readers looking for a more detailed methodology for technology design, we have cited other suitable sources of information through the chapter.

3 Project Development and Pre-Installation and Design

3.1 Site Selection

A critical component of the project, i.e. a structured framework for the selection of the sites has been developed as part of an analytical framework for off-grid electrification projects under the OASYS project [23]. Using this framework, a three-level process has been followed for the selection of sites, starting at the selection of the State and narrowing down to specific clusters of villages. While the focus of the analytical framework is largely on the local contexts and its characteristics, choice of the states was contingent upon multiple determinants operating at the sub-national scales.

Odisha was selected as the State for implementation based on the high number of un-electrified villages (approximately 10,000 un-electrified villages in the year 2010) and for being an experimental ground for many donor agencies, leading to greater opportunities for electricity development synergies on the field. Secondly, from the policy and institutional support perspective, Odisha was one of the earliest states in India to adopt power sector reforms and active participation was assured by various state agencies working in the electricity sector such as renewable energy development agency, electricity distribution companies (DISCOMS) and electricity regulators, which are important factors in determining the extent to which projects can get support and achieve scale.

Mapping Level 1: There are four DISCOMS operating in Odisha. In the first level of mapping, districts were divided into four regions based on the area of

operation of these DISCOMs. Since the mandate for providing rural electrification lies with the DISCOMs, a mapping based on area of DISCOM operation was preferred over an administrative mapping based on district boundaries. This would aid in identifying DISCOMs, with a strong inclination to work on off-grid interventions and new business models, and enable future linkages with the DISCOM for possible scaling up of such projects. Two project sites (cluster of villages) from each DISCOM's area of operation were selected, based on criteria such as proximity to district/block headquarters, community interest, resource availability and potential for livelihood generation activities.

Mapping Level 2: At the second level of mapping, the eight identified village clusters were assessed based on the criteria mentioned in Box 1 and the list was narrowed down to three village clusters using the process of elimination.

Box 1 Level II criteria for mapping of villages

- Community related parameter:
 - Vibrancy
 - Participation
- Demand assessment:
 - Multi-resource availability
 - Robust supply chain of identified resources
 - Supply chain for spare parts
 - Availability of local skill-sets
- Financial gradients
 - Extent of equity contribution
 - Ability to pay for electricity services
 - Ability and willingness of local financial institutions such as rural banks, cooperative banks, etc.
- Status of grid connectivity
 - Strength of local institutions and possibility of private participation

Regarding the parameters in Box 1, it is worth mentioning that as all villages have to be electrified either by grid extension or using available renewable energy resources to provide universal access to all, the site selection criteria for the project was not technology dependent, as in many government funded projects, but technology was considered as neutral. The selection focused more on two locally embedded elements, which are more critical for success, i.e. (a) strength and ability of local community structures and (b) possible economic linkages. In case the local community structure is weak and immediate economic linkage is not

possible, both these elements can be developed in a village cluster over a period of time. Depending on the availability of energy resources, the appropriate technology can be designed accordingly.

Mapping Level 3: The three village clusters were subjected to a third level of mapping. While these sites ranked similarly on most aspects discussed in the second level of mapping, key differences such as proximity to the district headquarter (for ease of monitoring a pilot project), extent of remoteness and spread of households (one site had very dispersed houses, making a mini-grid unfeasible) and extent of electrification (one site had reached stage of partial electrification towards the end of the mapping process) lead to the selection of a cluster of five villages and hamlets in the Dhenkanal district of Odisha, described in greater detail in the following sections.

3.2 Description of the Project Area

The village cluster, namely Rajanga village (and its Hamlet), Kanaka village, Chadoi village and Baguli village, having a total population of 555 inhabitants, are in the Dhenkanal district of Odisha. The district is identified as one of the backward districts in India by the Ministry of Panchayati Raj, Government of India [20].

The selected villages are all un-electrified villages and also not considered under the national rural electrification scheme, Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), steered by the Ministry of Power. These villages also have the least chance of getting access from central grid-based electricity in the coming decade as they lie inside a reserve forest (Kandhara Reserve Forest). As per forest regulations in India, taking electricity lines through the reserve forest is not permitted [22]. However, electricity grid may be drawn in the inhabited areas within the designated village. The demographic details of the villages are shown in Table 1. The map in Fig. 2 shows the location of the project district in the state of Odisha.

3.3 Institutional Arrangements

Owing to the remoteness of the sites under consideration, the first focus of the intervention was establishing a clearly defined institutional setup for managing and sustaining the project in the long term. An often neglected factor, but one which adds to the long-term sustainability of rural electricity systems, is the strength of the institution which is intended to manage the system over its lifetime. The local institution may or may not include the main project implementing agency, but it should include the local actors. There are a number of local actors in rural areas, leading to a variety of ways in which such institutions may be established. Some of

Table 1 Summary of information from selected sites in Dhenkanal district

Name of village	Rajanga	Kanaka	Baguli	Chaddoi	Rajanga hamlet (PuranaSahi)
Latitude/Longitude	N 20.56 E 85.27	N 20.54 E 85.26	N 20.55 E 85.29	N 20.54 E 85.27	N 20.57 E 85.27
Total households	34	43	35	12	12
Total population	178	189	142	46	Included in Rajanga

Source Authors' compilation



Fig. 2 Project location in Dhenkanal district of Odisha. Source TERI

these actors include members from the local community, energy entrepreneurs selected from within or outside the village, local government representatives, utility company representatives, NGO and CSO representatives and independent private operators of distributed generation power plant [3, 15].

3.3.1 The Village Energy Committee

In the case of the Dhenkanal project, it was observed that being a tribal community living inside the forest, the people in the villages under consideration were isolated from the local village level governing body (called the Panchayat) with its headquarter in the nearest large village, about 10 km from the tribal village cluster. Additionally, owing to the location inside a forest and without sufficient cash income for the villagers, it was found that private operators of distributed energy systems were not willing to install and operate systems in the location. However, a few NGOs (such as Wildlife Society of Odisha) had some presence at these sites owing to their development related initiatives.

It was thus decided that a village level group, comprising of representatives from these villages, will be constituted to hasten decision making and better co-ordination of project implementation. Since the community itself has no experience in managing electricity projects, representation from external agencies such as the local NGOs (active in agriculture development programmes and training and another one on forestry and wildlife, which have a strong presence in the villages owing to their location), was included in the group. The committee is called a Village Energy Committee (VEC) and a constitution defining its regulatory role over the operations has been formulated. Some of the responsibilities include:

- Identify and donate land for the construction of the community centre and power plant;
- Overseeing construction and installation activities and wherever possible, encouraging the community to contribute in the form of labour;
- Identify the operators of the systems who will be trained by TERI and the technology supplier;
- Be the point of contact for external agencies responsible for monitoring and maintenance of the system;
- Collect revenue from the project beneficiaries as per set tariff and maintain proper record of collections (see Box 2);
- Be responsible for payment of remuneration to the power plant operator(s), and petty maintenance of the solar mini-grid system and associated equipment, or other relevant developmental initiatives in the village.
- Grievance redressal of consumers and take suitable action in cases where the operator is not providing service, charging higher revenue than agreed upon, excluding certain users and so on.

In order to adequately orient the VEC to the finer points of operational management of an electricity business, monthly VEC meetings have been held throughout the process of design and commissioning and training was given through exposure visits to existing solar power plants, implemented by TERI in neighbouring districts. Training also included the basics of record keeping and banking, required for the long-term sustainability of the project. While working with VECs, this extended process of capacity building is often missing in the case

of government driven projects leading to mismanagement of projects by the VEC, upon exit of the implementing agency [28].

While we have created the institution of VEC for this project, the suitability of the institutional setup must be gauged based on the specific features of the sites under consideration. Each institutional arrangement comes with its own pros and cons and associated costs. A VEC is in that sense, a low cost arrangement, but may not be the best suited institution for tackling technical challenges and some of the institutional challenges. Also, since the committee is local, efforts need to be made to ensure adequate representation and minimise the risk of takeover of the entire system by powerful members (either socially or financially) from among of the community. Literature indicates that such VEC have seen limited success in past projects [6]. However, taking into consideration site-specific conditions in the Dhenkanal case, the VEC model emerged as the most feasible option. Therefore, an important focus of the project has been on the development of a clear exit strategy, with potential for linkages with the local DISCOM, i.e., central electricity supply undertaking, to facilitate transfer of the power plant to a technically competent authority in the future.

Box 2 Tariff setting in the village

While the tariff collection process is yet to be initiated as the project has recently been commissioned, conversations regarding the recommended tariff have been ongoing with the VEC since project inception. This tariff includes a INR 500 (~USD 10) towards connection fee per household and INR 150 (~USD 3) as monthly tariff for two light points and one mobile phone charging point per household. The project aims to collect enough monthly revenue to cover operator salaries and to set aside a fixed sum of money in a savings bank account, to meet battery replacement costs at the end of the fifth year. A margin on this minimum amount is also factored into create some additional revenue for project expansion.

3.4 Demand, Resource and Socio-Economic Assessment

During and after the establishment of the VEC, the project team focused on an detailed assessment of resources, energy demand and livelihoods.¹ Due to the economic situation of the rural community and especially in regions like the

¹ A comprehensive assessment exercise requires several visits to the sites and adds to the cost of project execution. This may not be feasible for a private operator whose primary focus is the installation of the electricity production system and distribution/sale of electricity. However since this pilot project was a action-research based activity with a focus on integration of energy and livelihoods options which can assist in growth of local economy, the detailed survey was essential for selection of suitable livelihood activities.

selected cluster in Dhenkanal, there is a preference for fuel that can be acquired with little or no money transactions. This makes it difficult for modern sources of energy to compete with the traditional sources [16]. To enhance the abilities of rural poor to pay for electricity services from renewable energy power plants, it has been suggested that the power plant itself must contribute to the increase in overall income of the community, through the inclusion of productive applications and greater community contribution and participation [2, 4, 31, 36]. In other words choosing to promote off-grid electricity by strengthening the economic position of its future buyers means that the issue of rural energy supply cannot be tackled on its own, but only as part of a broader scheme for general development.

The livelihood options explored fell into two broad categories, as explained below:

- (a) New livelihood options using locally available resources: these may require the purchase of certain appliances (such as grinders) and providing the local community the necessary training required to operate the system, process the raw material and package the finished product. It is important to note here that locally available resources and familiar raw materials are always preferred to the option of sourcing raw materials from elsewhere or introducing new agricultural or other practices. For example, if the local farmers are currently selling raw chilies to the local market at low rates, a potential opportunity lies in drying, grinding and packaging of these chilies and their direct sale to city markets. This limits the involvement of middle-men and the farmers earn higher revenues on their produce.
- (b) Improving the efficiency of production of existing livelihood activities: It is very common to have small scale businesses operating in rural areas, with linkages to the market either established by NGOs or government marketing departments. Owing to lack of electricity, the producers may currently be using hand tools or may be travelling some distance to get their raw materials processed. In such a case, the provision of electricity and processing equipment can significantly hasten the production process, add scale, as well as reduce costs of transport and other costs associated with operations occurring at small scales.

A number of methods can be employed to gather data on resource availability, demand and other factors important for the design of mini-grids. For the purpose of this project, data on all three aspects, energy resources, energy demand and socio-economic status was required in order to make a comprehensive assessment of the development opportunities that an energy intervention can bring to the selected sites.

Resource assessment is a subject in itself and more details on the same can be found in technical books, hence an overview is presented in this chapter. “[Technical Aspects of Mini-Grids for Rural Electrification](#)” and “[Smart Design of Stand-Alone Solar PV System for Off Grid Electrification Projects](#)” of this book also provide some details of renewable energy resource assessment methodology. A solar resource assessment was done using average monthly values of horizontal

solar radiation obtained from the online database [25] and data released by the India Meteorological Department (IMD).² During the village scoping, the potential for biogas and biomass energy was also evaluated. The absence of a sufficient number of livestock and restriction on use of biomass within a reserve forest, however, eliminated the option of using the bioenergy sources. As regards micro hydropower, there was no stream in the village cluster with sufficient head to generate electricity from water. In addition to this, it was also felt that solar PV would result in a lower requirement of maintenance and thus lesser dependence on external resources, as compared to other technologies with electric generators and other mechanical moving parts, an essential factor to consider owing to the remoteness of the community.

The rest of this sub-section will focus on the methodology used to collect data to assess demand, socio-economic conditions and livelihood activities that could be promoted with use of energy. Before delving into the assessment methodology, a short note on the linkages between energy and livelihoods is provided in the following section.

3.4.1 Assessment Framework

In the assessment process, the project team focused on the categories of data mentioned in Fig. 3. This list is indicative and must be adapted to suit the specific sites under consideration. While the main data categories and sub-categories are presented here, the significance of each of the mentioned categories is presented in Annexure B.

3.4.2 Summary of Information Collected for the Sites Under Consideration

The baseline survey conducted by TERI showed that the inhabitants of these villages are primarily dependent on subsistence agriculture, goat rearing and collection of forest produce for their income. Some are employed as labour by the Forest Department or MGNREGA³ (Mahatma Gandhi National Rural Employment Guarantee Act).

While paddy is the main crop grown, horsegram, arhar (split red gramme), ginger, turmeric and other vegetables such as cucumber, ladies finger and eggplant are also grown. Villagers also collect Non-Timber Forest Produce (NTFP) from nearby forests which include mahua (*Madhuca longifolia*: seeds are used to extract oil), karanj (source of *Pongamia* oil), honey, saal leaf (*Shorea robusta*: the leaves

² India Meteorological Department, Pune. [15 Jan 2014] <http://www.imdpune.gov.in/>.

³ A programme of the Govt. of India which guarantees a minimum of 100 days of paid work in the rural areas.

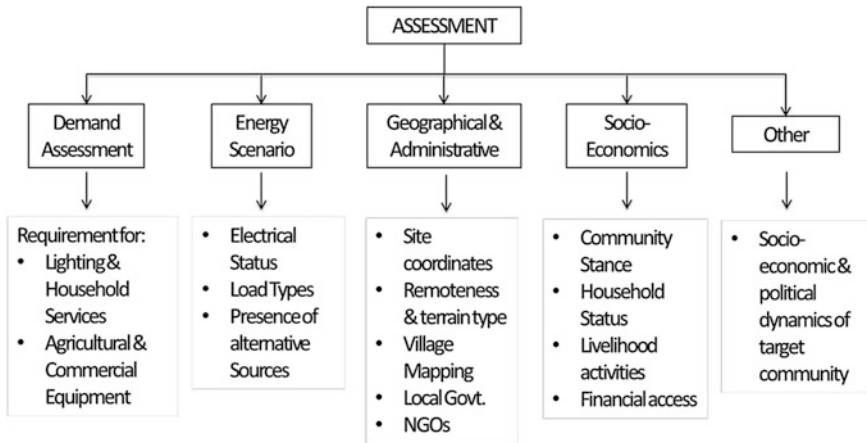


Fig. 3 Key components of the assessment framework

are dried and stitched together into plates), tamarind and amla (Indian Gooseberry). Most households also rear poultry and livestock, but in most cases the livestock belong to the relatively richer farmers from other areas who lease them out to the locals for grazing.

All the villages being inhabited by the tribal community and inside a reserve forest, limited development assistance has been channeled into these villages. Due to the lack of opportunities, in recent years the younger generation has started migrating to other states to look for better sources of income. Owing to the remoteness of the villages, the farmers are primarily dependent on middle-men, who come to the village to buy their produce and then sell the produce to towns and cities at higher prices. In such a process, the prices are usually dictated by the middle-men as farmers have little information on current market prices. In addition to this, with no provision for weighing or measuring the produce accurately, a barter system exists for many products, which is often disadvantageous to the local producers.

In addition to the lack of access to electricity and resulting limitations to growth, the area is also highly malaria prone and children also often suffer from water-borne diseases. The impacts of such childhood diseases usually lead to damaged immunity and growth over the life of the individual. Hence, there is a large scope for improving health services in this area.

The summary presents the broad findings of the survey. For the purpose of design of an intervention, the next section will focus on the methodology followed for the selection of certain livelihoods from the larger list of options identified during the field survey.

Table 2 Selection of appliances load for the village cluster in Dhenkanal district

Appliances	Capacity	Purpose
Grinder	1 HP at Rajanga	For grinding turmeric and chilli powder
Electronic weighing scale and sealing Machine	Weighing Scale—10–20 W at Rajanga Sealing Machine—150 W at Rajanga	For accurately weighing and packaging of ground turmeric and chili powder. These have wider application since users can use the machine for other products as well and bring about standardisation through accurate weighing, delinking them from the middle-men
Saal leaf plate pressing machine	0.5 HP at Rajanga	The community is currently engaged in the stitching of basic Sal leaf plates, called Khalis. By pressing two Khalis together in the machine, a firm plate can be moulded which has a much higher value in the market
Water pumps for agriculture	2 HP each at Rajanga and Kanaka	Agricultural is possible only during the monsoon and the farm lands lie unused during the dry season. Hence, to improve agricultural yield, especially of high value crops such as eggplant, water pumps have been provided to initiate activities during the non-monsoon period

Source Authors' compilation, 2013

3.4.3 Assessing Household, Community, Commercial and Agricultural Loads

Household load. for each household, based on the most prominent needs and the size of rooms, provision for two LEDs lights of 3 W each has been made in the design. In addition to this, it is noted that owing to low income levels, the household do not have any other high wattage appliances and therefore a household socket with a 10 W limit has been factored into the design. These household loads will also serve as the most consistent stream of revenue for the power plant as each household will pay a monthly fee for the use of such services.

Commercial load. based on a cost-benefit analysis of the potential livelihood options, the activities listed in Table 2 were selected for the design of the power plant. Some activities such as oil extraction and honey processing were excluded owing to their seasonality, low volumes and the involvement of small sections of the community in the collection of raw material from the forest.

Community load: In addition, provision for the following community services has also been included while designing the power plant:

- Street lights in all villages—the villages fall in the elephant corridor and so the street lights are expected to ensure safety at night;

- TV-DVD at the community centres (for educational and training purposes)
- Community centre lighting and fans (to create a resource/community centre for people to work and also for meetings, discussions, trainings, etc.)
- Water Purifier (50 LPH)—one each at Rajanga, Kanaka and Baguli for provision of potable drinking water and address some of the health related issues

4 Designing the Power Plant

This section focuses on the process by which data collected from the field has been used in the design of solar photovoltaic power plants. The design process presented here looks at the broad considerations that go into making certain decisions about how the power plant must be sized, and distributed, while presenting an overview of the technical details.

4.1 Solar Radiation Data

Accurate solar radiation data from ground weather stations is usually not available for remote locations. Therefore, in order to get an estimate of how much solar radiation is available, project designers usually use data from the nearest available ground weather station, or use a reliable online resource such as the NASA database, which requires only the coordinates (i.e. latitude and longitude) of the location as input. For the location described here, data from the NASA-RETScreen database has been used, which indicates that the daily average global horizontal solar radiation is close to 4.82 kWh/m²/day (Table 3). For calculations, a more conservative figure of 4.5 kWh/m²/day has been assumed. Although more accurate data from ground weather stations may be required for commercial scale solar power projects, factoring in the cost of establishing ground stations, readily available data may be utilised for village scale systems.

4.2 Optimising Loads

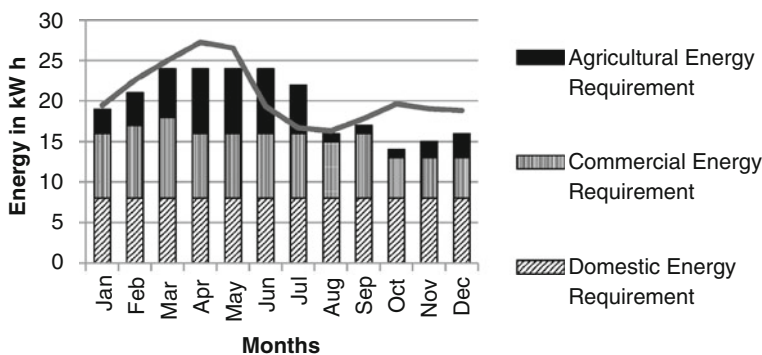
Once the range of possible loads and the estimated time during which the load will operate has been identified, the data needs to be mapped onto a load curve as depicted in Fig. 4.

Figure 4 depicts the energy required for domestic, commercial and agricultural loads throughout the year and also the maximum amount of energy that can be derived from a power plant to cater to these loads. This graph represents a scenario before the load has been optimised. We observe that the energy requirement is practically uniform throughout the year for the domestic segment (which will be

Table 3 Radiation data for the village cluster in Dhenkanal district

Month	January	February	March	April	May	June
kW h/m ² /day	4.53	5.26	5.82	6.34	6.18	4.50
Month	July	August	September	October	November	December
kW h/m ² /day	3.88	3.80	4.15	4.57	4.43	4.38

Source NASA-RETScreen online database for coordinates 20.55 N, 85.28 E (i.e., for Rajanga village)

**Fig. 4** Load curve before optimization. Source Authors' compilation

the case for lighting loads but will vary in case higher wattage equipment are being used in the homes), while there is variation in the agricultural and commercial segments. In the agriculture segment, water pump usage begins to drop during the rainy season (August to October), rises from November onwards and is high during the summer months (April to June). Commercial loads will vary depending on a larger number of factors, including seasons, the availability of raw materials for processing, the demand for finished goods, labour availability and so on.

For two months of the year, June and July, the demand is greater than supply and therefore all the demand would not be catered to. And in other months (October–December and April–May), the plant is not being utilised completely. Wherever possible, project designers must re-schedule loads to avoid these two situations. Although perfect matching of demand and supply may not be achieved, efforts to ensure that the demand is not greater than the supply are essential. In this case, such a shift has been indicated in Fig. 5, where the commercial loads have been either reduced or increased. Working with commercial loads is often simpler since domestic and agriculture demands are generally fixed (domestic loads may be constant through the year and agricultural loads may only be used during dry seasons). Such adjustments can be done by either moving a commercial activity from one month to another, finding alternative low energy intensive activities or finding more efficient machinery to carry out the same activity as before. This

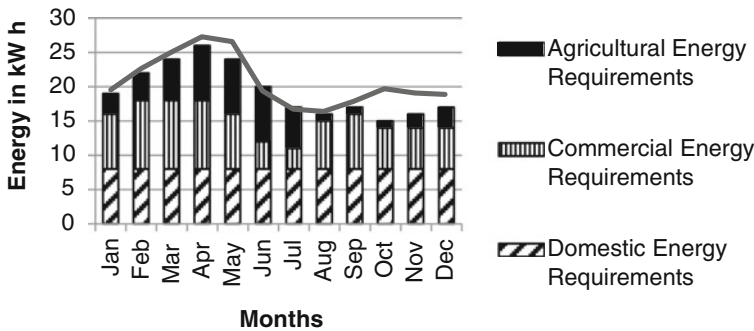


Fig. 5 Load curve after optimization of loads. *Source* Authors’ compilation

helped in optimising the capacity of the power plant and at the same time provisioning energy for all identified loads, without the need to add extra capacity for the agricultural load (which may require energy only for few months).

4.3 Technical Design

It should be noted here that a detailed technical design (one which includes details on PV array/string sizing, wire selection, distribution losses and so on) is beyond the scope of this chapter and not presented here. However, the process described here is essential to preliminary project design and evaluation and can be used by donors, government agencies and project developers/implementers whose core area of expertise is rural development/energy access/implementation and not technical design. Readers can, however, refer to “[Smart Design of Stand-Alone Solar PV System for Off Grid Electrification Projects](#)” for details on off-grid solar power plant design. The following section briefly outlines the different components of a solar photovoltaic system and some design improvements that can significantly enhance the efficiency of a village scale power supply system.

4.3.1 Solar PV Plant Components and Assumptions for Design

Photovoltaic modules

There are a number of factors that impact module selection, apart from the efficiency and type of module technology. While deciding the minimum performance criteria for modules for the Dhenkanal sites, one important factor was the number of cells (wattage of each module). Larger modules with a higher number of cells are preferred as they usually have higher module efficiency and the relative length of wiring between modules is reduced, therefore reducing the associated losses in the system.

Also, the degradation of power over the module lifetime should be within acceptable limits. A good quality module should not degrade more than 10 % over the first 10 years of its life and by maximum 20 % over 25 years. Finally, the choice between these modules will also depend on their availability and cost in the country of installation.⁴

Battery Bank

Despite their long existence and widespread usage, lead-acid batteries have one of the lowest energy-to-weight and energy-to-volume ratios. In essence, this means they are too large in size and heavy for the energy they provide. However, their prime advantage is that they are cheaper, robust and well-tested for rural use. As an alternative, Lithium Ion batteries are more expensive, but have high charge density with longer useful life as compared lead-acid batteries and are significantly lighter in weight (refer “[Smart Design of Stand-Alone Solar PV System for Off Grid Electrification Projects](#)” for details).

In the Dhenkanal project, lead-acid tubular plate batteries have been utilised. Although sealed lead-acid batteries require little maintenance, flooded lead-acid batteries were selected, owing to their longer deep-cycle discharge life, high discharge rate capability and better performance at partial states of charge as compared to sealed batteries. In such batteries, the need for refilling the batteries with distilled water exists, which is often unavailable in rural areas. Hence, a solar still is being installed for the production of on-site distilled water. Also, the equipment being under warranty for 5 years, the technology supplier is expected to take care of the maintenance of the batteries.

Power Conditioning Unit (Charge Controller and Inverter)

The charge controller selected for off-grid application must have reverse polarity protection, overvoltage protection, deep-discharge protection and temperature compensation feature. Deep-discharge protection helps in protecting the battery from deep-discharge, and temperature compensation feature sets the charging point as per the operating temperature hence reducing the charging stress on batteries during charging.

Solar modules generate DC power which is either stored in the battery or can be directly fed to the load. However since most appliances available in the market operate on AC power, a conversion from DC to AC power is required, which is achieved through the inverter. Pure sine wave inverters are the most preferred option as they enhance the performance of appliances used and while an inverter’s basic function is to convert one type of power to another; smarter inverters also play an important role in enhancing the life and efficiency of the system as a whole. Such inverters have an inbuilt battery management system, and a power–frequency control system which automatically adjusts the PV power from the PV inverter as

⁴ Project implementers should choose solar PV modules that conform to the latest edition of IEC (International Electrotechnical Commission) Standards, such as IEC61215 for Crystalline Silicon Terrestrial PV Modules or IEC 61646 for Thin Film Terrestrial PV Modules.

per the desired load. Also these types of inverters are grid-interactive and therefore when the grid does reach an off-grid site, such inverters can feed extra power into the grid and in addition, the grid can be used for battery charging as well.

Smarter inverters also include a feature of load shedding wherein certain loads can be disconnected through a load shedding contactor in case the battery is drained beyond a recommended and set limit. The load shedding limit can also be set as per system requirements. While very high efficiency inverters are now available in many countries with efficiencies in the range of 97–98 %, in the ideal case for rural electrification project, an inverter should be selected such that its weighted average efficiency is over 90 %⁵ (please refer “[Smart Design of Stand-Alone Solar PV System for Off Grid Electrification Projects](#)” for more detail on inverters).

4.4 Power Plant Design

This section highlights some of the key assumptions and design decisions taken by the authors for the design of the AC and DC grids. While the design methodology is adopted from existing IEEE standards, a step-wise design process is beyond the scope of this chapter [12]. The attempt here is to illustrate the ways in which standardised design processes may be altered to suit specific field conditions, user requirements, project budgets and timelines.

Cluster-based approach for decentralisation. The guidelines for decentralised distributed generation (DDG) released by the Ministry of Power, Government of India recommends, that to the extent possible, selection of the villages/hamlets is to be carried out in a cluster to take advantage of the clustering effect and the merit of setting up a local distribution grid covering all these villages/hamlets with a central power plant as against setting up of individual village/hamlet level systems [21]. Clustering could, however, be seen in different ways; technical clustering wherein a single power plant is installed and distribution network is drawn to supply power to different villages and institutional clustering wherein a single operating entity, such as the VEC with representatives from all villages, is established but discrete power plants are installed in each village.

While clustering has its own advantage of economies of scale and scope, it is imperative to assess the benefits—both from technical design and investment perspective as well as operational and maintenance costs and also ease of managing the project institutionally. Further, the feasibility of adopting cluster approach may also depend on the technology selected and the results may not be same for a solar PV project design and other renewable energy technologies such as biomass gasifier or mini-hydropower-based projects.

Therefore a comparative study of the technical design and investment required in two scenarios was conducted, one with a central power plant at Rajanga village

⁵ Minimum 95 % efficiency (at full load 0.8PF) and 80 % for partial load (at 50 and 75 %).

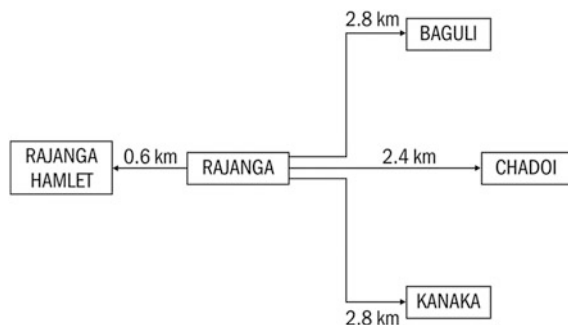


Fig. 6 Distances between villages in the project cluster in Dhenkanal district

Table 4 Costs of implementing five individual power plants at each site versus implementing a single power plant at Rajanga

Particulars	Costs (in USD)	
	Five distributed systems	Centralised system at Rajanga
Solar power plant	51,000	47,100
Distribution line	28,200	84,500
Household connections	4,400	4,400
Construction requirements	32,000	24,500
Annualised O&M cost over a 5 year period	3,900	1,600
Total	119,500	162,100

Source [28, 29]

with distribution lines to all other villages and a second scenario in which five individual power plants at each village (AC & DC) are to be designed [29]. Figure 6 shows the distances between villages in this cluster.

For this comparative study, the technical designs of the two scenarios were first developed and then using actual cost estimates quoted by the vendors, the costs of executing the two scenarios were calculated. Some important factors considered were: cost of salary of operator(s) (five operators for the case with five systems and a single operator for the centralised system), capital costs for solar power plants, civil construction and distribution network, and annualised operation and maintenance costs for a period of 5 years post-installation. While for a centralised system, the cost of civil construction, the operation and maintenance costs and solar power plant was found to be lower owing to the centralised installation and operation, this benefit was completely offset by the high cost of putting up the inter-village distribution network to all five sites (Table 4).

Table 4 clearly shows that there is high difference in cost (around 36 %) owing to almost 200 % increase in the cost of laying the inter villages transmission line cost from a centralised solar power plant. This is, thus, not a feasible option for such small power plants and low demand and so a decentralised approach is preferred from technical point of view vis-à-vis a clustered approach for electricity

supply. However, there might be some operational benefits to having a centralised power plant, mainly accruing from ease of operation and maintenance of a single system. But with a good system design that ensures infrequent maintenance, even managing multiple power plants may not be a difficult proposition. Owing to such technical and economic limitations, a strong case can be made in favour of technical design of distributed systems. However for ease of management of the system, a single institutional entity can be formed covering the group of villages.

While the analysis carried out for solar PV technology clearly demonstrates the efficacy of having decentralised power plants with a possible institutional clustering for better management, the same may not be said for biomass gasifier technology. While solar PV technology is a truly modular technology with sizing from Wp to a scaled-up capacity of MWp, there are design capacity constraints existing for other renewable energy technologies. For example, the minimum commercial capacity available for a biomass gasifier in India is 10 kWe and so clustering of load for best utilisation of rated capacity may be useful for the gasification technology [27]. Similar is the case of small wind aero generators and mini-hydropower. Also, while this analysis was done for cluster of villages within a forested area and a small population, in case of area with higher population and density, a larger power plant may be more feasible.

Choosing between AC and DC systems. The choice between an AC or a DC system is based on the type of application being served, the scope for system expansion, requirements for future grid connectivity and budgetary constraints among other factors such as spread of households and distribution losses. DC micro grids for lighting and mobile charging (both of which can be operated easily on DC supply, especially with the availability of LED bulbs) have become a popular option in India when no other service is to be provided and the number of households is limited to a small cluster [30]. Since the inverter is excluded, this results in a cost saving while providing the same service quality to the users.

For two sites in the case presented here, Rajanga Hamlet and Chadoi, it was found that the number of households was limited to 15 (12 households when the survey was conducted). In addition, these two sites are not very close to the other larger sites where AC power plants were being constructed. Extending the AC grid from the larger sites to these smaller sites proved to be expensive proposition, as explained later in this chapter. Hence, considering all the above points, a DC micro grid was designed to cater to lighting and mobile phone charging need at these sites.

In Rajanga (the main village excluding the hamlet), Kanaka and Baguli where the number of households was larger and the scope for commercial and agricultural applications existed, an AC system was designed. It is to be noted here that the number of light points and quality of the final service (lighting) for households served by AC and DC power plants has been kept similar (i.e. the type of lamp and the lumen output of the lamps have been selected as same for households) so as to avoid any issues of deprivation. Thus, the metric chosen here for residential services is energy services (final output), and not energy (kWh) or how the energy is delivered, to ensure equitable services. This is important because users are often

not concerned with what the source of power is,⁶ but rather with the quality of the service they are receiving. Users getting services from the same project will compare the quality of service being received by them with others, which could potentially lead to conflict and hence it is important to ensure that the end-user is not impacted by the choice of system being designed.

Provision for demand growth. In the case of the project cluster, although the actual requirement is 3 W per light and 3 W per mobile phone plug point (in total 9 W), the design value per household is taken as 30 W. This has been done to address future increase in demand (some household may install fans) owing to enhanced income from the livelihood generation activities being promoted. Secondly, LED bulbs are expensive and not readily available in rural markets. Although at the beginning of this project, these LED bulbs are arranged by TERI as part of the project, there is no guarantee that in case the bulbs get damaged, the users will replace them with similar LED bulbs, owing to cost and availability constraints. The alternative bulbs available and used in the area are 7–10 W CFLs and users may choose to install these instead. In addition, some new productive or agricultural load may also be required in future or the number of households in the village may also increase.⁷ Hence, to ensure that there is no overloading of the system in the future, some spare capacity has been built into the design.

However, any attempt to include additional capacity for demand growth must also consider the increase in project cost owing to this higher capacity. Instead of 30 W, as mentioned above, if 10 W per household had been considered as the household load, the project cost would have reduced by about 20 %. However, factoring in the reasons for increase in per household capacity mentioned above, leads to a definite need for a higher system size in the near future. For a system designed to cater to 10 W per household, this would require a significant investment in the future, not just in terms of increased solar module capacity, but also new inverters, an increase in battery bank size and possibly new cables to carry the higher current required by more households and higher loads.⁸

Factoring in days of autonomy of the solar power plant. The capacity of the solar modules in kW needs to factor in both day and night loads (i.e. after producing enough electricity to cater to the day loads, the solar panels must be of enough capacity to charge the battery during the day to cater to the night loads). In the design process used here, the solar panels have been sized to completely charge the battery during the day, to cater to loads being switched on the same night.

⁶ However, in one of the DC micro grid sites, the operator of the system was initially concerned about the quality of service from the DC grid, as the electrical poles used for the AC grid were larger in size (as per standard AC distribution requirements). His perception was that the quality of power was related to the size of the pole. The issue had to be addressed carefully and through repeated engagement with the person and the community so as to avoid future conflicts.

⁷ While the total number of households during the demand survey was around 130, it increased to 135 households during the actual installation of power plants, within a period of 6 months.

⁸ Being an action-research project, the project team also want to understand the load growth phenomenon in the remote villages.

For the extra ‘night’ of autonomy, the solar panels have been sized to charge the battery over a period of 5 days, therefore lowering the total PV capacity required. This has been arrived at from noting the number of continuous sunny days in the region for most part of the year (i.e. the possibility of having a day with no sunshine at all, occurs on average once every 5 days for most part of the year), giving the plant sufficient time to charge the batteries for the extra night of autonomy.

Practical consideration for design of the DC micro grid. A DC micro grid is a visibly simple looking system working at low voltages. Hence, the chance of users sometimes interfering with the system does exist. For example, a motivated user may directly connect a high wattage device to the battery (such as another battery) for charging. To minimise such user-interference, the battery and the charge controller have been placed inside a secure wooden box, equipped with a number-lock. Additionally, a timer circuit has been included to automatically switch on and off the system so as to avoid any human interference on the run time of the systems.

Smart system designs for AC mini-grids. Since nighttime loads include household lighting, it is crucial that the energy being fed to the batteries is not compromised on account of over-usage of day time loads. Additionally, the system should be designed such that it remains partly functional even if the battery is almost fully discharged. This can be ensured in two ways:

(a) Over-design and load management—at the time of design, a little extra capacity of solar modules can be built in so that if the day load increases, it can be served directly during the daytime without draining the battery.

Through load management, the loads are segregated into essential and non-essential loads. The non-essential part of the load is connected to the system via a load shedding contactor which in turn is connected to the battery terminals. During cloudy or rainy days, when the battery is not fully charged, the non-essential loads can be automatically disconnected through the load shedding contactor as described in the section on smart inverters.

(b) Alternative solar PV system topologies: Alternative topologies not only improve the battery health but also improve system efficiency, reliability and flexibility for future expansion. The issues with standard configurations and one such improved configuration is presented below:

If we observe the dominant design for solar photovoltaic systems in India today (Fig. 7), a series configuration is usually adopted, which means the solar PV array is used to charge the battery first through the charge controller and then the DC power is inverted to AC power. In such design, the battery has to be healthy in order to provide the required power. The author’s experience and other observations from the field show that with such system design, if the battery is in poor condition (low voltage owing to deep-discharge), it is likely that the entire system is also non-functional even on sunny days. Additionally, with such a design, since the entire power is provided through the battery the overall efficiency of such system is also not optimal (considering maximum watt hour efficiency of battery) because of battery losses.

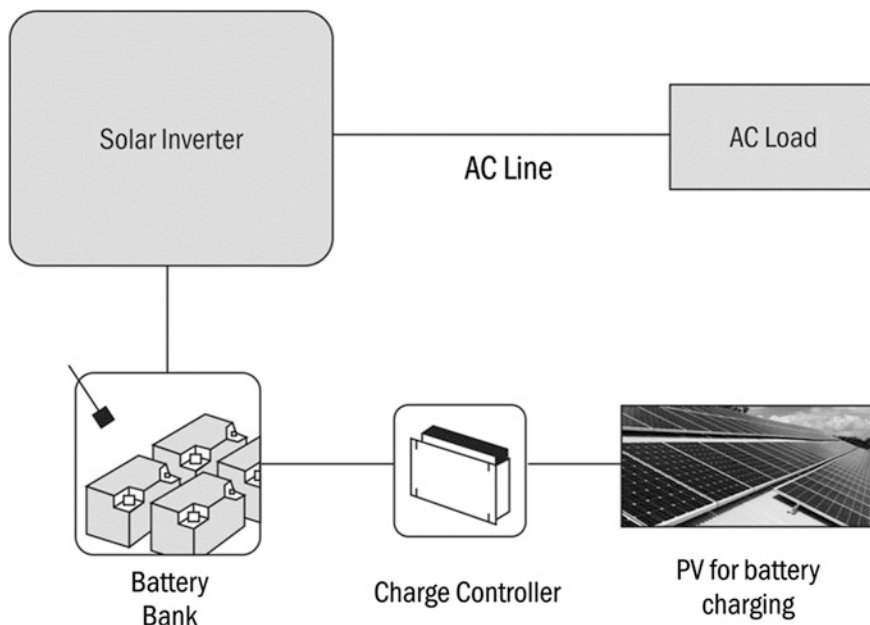


Fig. 7 Series configuration of solar photovoltaic system. *Source* TERI

Experiences clearly show that clean energy systems in rural and remote locations need to be designed taking into account that access to frequent service, repair and maintenance is difficult, that is, the system should be reliable. Also, since the capital cost of clean energy systems is high, it is imperative that the efficiency of such systems is optimised so that cost per every unit of electricity generated is optimum.

The above requirements can be met with proper planning, optimum design and reconfiguration of the system which leads to some incremental cost. But this incremental cost can be easily repaid through improved efficiency, reliability and flexibility of the system in the long run, lower monitoring requirements and improved battery life and lower replacement costs. For example, changing the configuration (moving from series to parallel configuration), adds more flexibility and enhances the probability of supply of power, even in poor weather and local operational conditions.

In a parallel design, the inverter is split into two as per the day load and night load requirement (Fig. 8). One inverter is a grid tied inverter which is responsible for feeding power directly from the solar PV to the day time loads. The other inverter is responsible primarily for (a) charging the battery (b) and providing the reference grid to the grid tied inverter for feeding power. In this configuration, the grid tied inverter can continue feeding power even if the battery goes into the fully discharged condition (low voltage disconnect point). Hence such an arrangement adds reliability into the system.

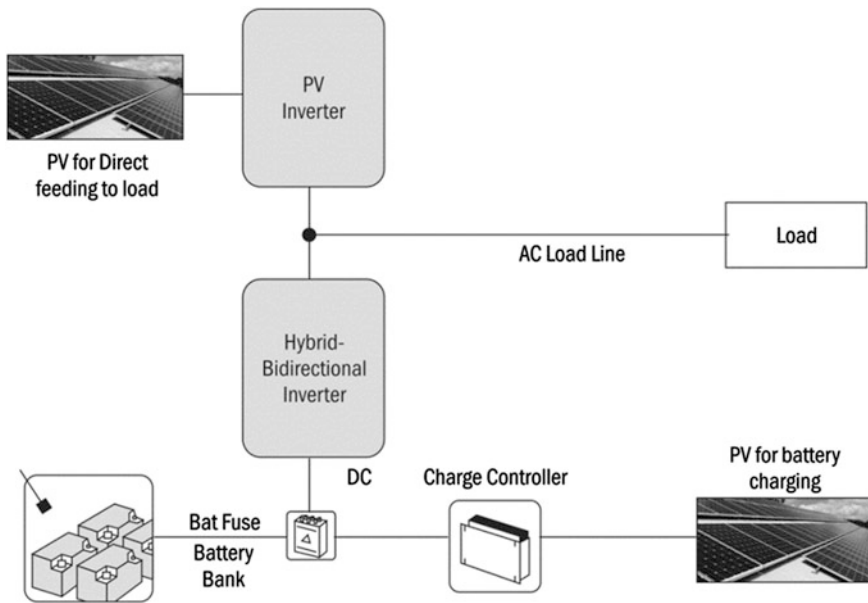


Fig. 8 Parallel configuration of solar photovoltaic system. *Source* TERI

Such inverters are selected in such a way that grid integration and integration of additional renewable energy sources at a later stage are also possible. In addition to this, these inverters are made with remote monitoring features through which daily output and utilisation data can be recorded remotely. Such data is especially useful for planning of future systems in areas where cloudy and rainy weather conditions are prevalent for long periods of time.

At the Rajanga site, a parallel configuration of inverters has been utilised as most of the livelihood generation activities (which operate during the day) are located in Rajanga and hence a robust system which can cater adequately to both day and night loads without putting strain on the battery is essential. Additionally, the loads themselves have been segregated such that the household loads are all on one feeder and the community and livelihood loads are on a separate feeder. In case the battery is in a heavily discharged state, the system will automatically cut-out of the community/livelihood loads through a DC contactor placed at the origin of the feeder.

Distribution network and water pumping facility. For each power plant, an independent power distribution network within the village has been planned. In the villages of Baguli, Rajanga Hamlet and Chadoi, this distribution network caters only to household and productive loads (if present). In Rajanga and Kanaka, the distribution network also connects to a water pump, located at some distance from the households. Rather than adopting a stand-alone system for the water pump, it has been connected to the main power plant in the village through a distribution line. Although the distribution line contributes to additional cost, such a connection has

Table 5 Day and nighttime energy requirements per village

Site	Day load (kW h)	Night load (kW h)
Rajanga	11.67	6.07
Kanaka	7.66	6.88
Baguli	0.30	5.84
Chaddoi	Nil	0.58
Rajanga Hamlet	Nil	0.58

Source Authors' compilation

Table 6 Design of 5 independent solar power plants in the Dhenkanal cluster

Site	AC/DC	Plant design	Total length of the distribution line (m) ^a
Rajanga	AC	6 kWp SPV power plant, 6 kVA inverter (grid tied), 48 V 500 Ah battery bank	2100
Kanaka	AC	5 kWp SPV power plant, 5 kVA inverter, 48 V 600 Ah battery bank	1400
Chadoi	AC	2.5 kWp SPV power plant, 2 kVA inverter, 48 V 500 Ah battery bank	1100
Baguli	DC	400 Wp, 24 V 200 Ah battery bank, 15 A charge controller	300
Rajanga Hamlet	DC	400 Wp, 24 V 200 Ah battery bank, 15 A charge controller	300

Source Authors' compilation

^a The length of distribution line along the longest feeder has been kept within 1 km to keep the technical loss at the minimum

been preferred to (i) cater to any future requirements of increase in pump size and (ii) cater to inrush current required by the pump when it is switched on.

Provision for future grid interconnection. At the Rajanga site (one of the three AC mini-grid sites), a grid tied inverter has been installed. Regular solar inverters have been installed at the other two AC mini-grid sites to keep the project cost within reasonable limits (considering the higher costs of grid tied inverters). The grid tied inverter provision has been built into the largest and most accessible (by road) village, keeping in mind the possibility that some years in the future, the grid might reach this village. In case of grid extension, it is expected that the households will take grid connection and in such a case, the electricity can then be fed to the 11 kV grid, using the grid tied inverter and the VEC can continue to earn revenue from the DISCOM. The non-grid tied inverters can continue to operate on a stand-alone basis to support the productive and community load in the villages using the solar power capacity. They, however, have provision to get supply from the grid to charge the batteries with preference to solar charging.

Using standardised design methodologies and factoring in the considerations mentioned in this section, the day and nighttime energy requirements and final designs of the five systems implemented in the Dhenkanal sites in presented in Tables 5 and 6 respectively.

The system has now been installed, tested and commissioned. Box 3 provides some considerations used in this process.

Box 3 Installation and Commissioning of systems

A few important points considered by the project team during the installation and commissioning process are mentioned below:

- Following the guidelines of the Indian Electricity Act on safety and electrical supply [8] a comprehensive safety check has been conducted by a certified electrical inspector.
- 72 h (or 3 days) of complete trial run has been conducted to evaluate system performance during both day (charging cycle) and night (discharging cycle)
- Mobilising labour early in the project is a practical way to involve the local community, solicit their participation and also reduce implementation costs.

5 Concluding Remarks

The aim of this chapter was to present a case study of mini-grid implementation, based on a standardised framework. However, while working within this standardised framework, we have also attempted to highlight aspects where innovation is required, so that the final product is customised to suit the needs of the end-user, the availability of technology in the market, site-specific boundary conditions owing to weather, transport, user community characteristics and so on.

While the design and implementation of the project is complete, the impacts of these innovations are yet to be assessed. Under the OASYS project, our attempt over the next one year after project commissioning is to assess the performance of the systems from both technical and institutional points of view. Further research output on these aspects will be published as part of the OASYS project to provide actual field level data and analysis, which we believe will add further value to the work being done on mini-grids by practitioners across the globe.

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Annexure A

Detailed List of Project Implementation Activities

Project Development and Pre-Installation

Site selection

- Identification of the sites for the intervention: includes collecting information on electrification status of the State (such as Odisha in this case), progress of rural electrification programmes over the last 3–5 years, distance/remoteness of the sites from district headquarters or other well-connected towns, distance of electricity grid from the sites, terrain and climactic conditions.

Feasibility studies and surveys

- Field visit and primary survey for collecting household information, existing and future load scenarios, key livelihoods and other sources of income and site-specific boundary conditions
- Secondary data collection and its authentication
- Stakeholders consultation meetings: with village residents, prominent members of the community, locally active NGOs, local government officials
- Electricity demand assessment for household, street lighting, agriculture, commercial and industrial segments
- Energy Resource assessment (such as hydro, solar, biomass, wind, biogas, etc.)
- Electricity linked livelihood assessment (examples include water pumping, grinding, food processing, etc.)
- Market assessment and surveys for products and services resulting from electrification
- Cost-benefit analysis of proposed interventions.

Project development activities

- Industry surveys to gauge maturity, availability and cost of different technology options
- Techno-economic assessment and tariff determination
- Contracting with local partners
- Inter-agency co-ordination, clearances, application, approvals
- Procurement of land and infrastructure for power plants, community hall, etc.

Establishing the institutional setup

- Formation of a local electricity project governance body, based on specific site conditions
- Drafting guidelines and responsibilities of this local institution
- Ensuring sustained involvement of this local institution through regular meetings and training programmes in order to transfer decision-making responsibilities to the local institution.
- Communication of installation charges, tariffs and management of electricity project funds through a transparent process to the entire consumer group.
- Based on specific site conditions and project requirements: required: capacity building for financial management, awareness on benefits of clean electricity use (as compared to existing fuels such as kerosene), involvement of NGOs and other local bodies for synergizing energy and livelihoods.

Design, Procurement, Installation and Commissioning

Project design

- Assessment of resource options such as hydropower, biomass, small wind and solar photovoltaic among others to arrive at a feasible technology option
- Assessment of the public distribution network requirements (length of feeders and total distribution network length)
- Estimation of project costs including costs of the power plant, distribution network, household wiring, land, civil construction, transport and professional costs
- Preparation of the Detailed Project Report (DPR) which contains all the information collected above (resources, demands, institutions) and the design options and costs.

Procurement

- Preparation of a detailed Bill of Materials (BoM) for the power plant and other appliances being considered for the project
- Identification of suitable vendors/suppliers of renewable energy-based power systems (and other components of the project such as distribution and civil construction) and soliciting of quotations against the Bill of Materials.
- Vendor selection possibly using quality and cost-based selection process
- Quality assurance through inspection of previously established projects
- Site visit for finalisation of design and costs with the selected vendor.

Installation and commissioning

- Mobilisation of labour: crucial step in remote areas where a paucity of skills labour for activities such as civil work exists and costs of sourcing labour from towns and cities are high
- Civil works and site preparation for installation of distribution network
- Installation of the power plants and associated distribution network
- Technical and safety checks
- Trial run and commissioning of the system.

Post-Commissioning and Sustaining the Project

Operation, maintenance and monitoring

- Hands-on training on operation, maintenance and repair
- Organising the supply of spare parts
- Record-keeping for faults, energy generation and consumption and revenue
- Handing-over of the commissioned system to the local institution.

Business development

- Integration with complementary development schemes
- Skill development for income generation
- Raw material procurement for secondary activities
- Market development for finished goods.

Annexure B

Assessment Framework

Category	Sub-categories	Significance
Geographic and administrative information	Exact location and coordinates of the sites	For estimating the availability of resources such as solar, hydro or biomass energy from renewable energy atlases Design of the electricity distribution system using software

(continued)

(continued)

Category	Sub-categories	Significance
Electricity/energy scenario	Terrain and distance of the sites from nearest block headquarters or large town. Nature and quality of roads and impact of weather conditions on access to sites	Assessment of transport requirements, especially in the context of transport of heavy materials such as power plant equipment Estimation of project completion time and impact of weather on the same
	Village mapping—location of individual households, schools, hospitals, local government offices, agricultural land, water bodies, fallow land, forests, etc.	Design of power plant and distribution system Availability of space for construction of power plant Assessment availability of government services and natural resources
	Type of local government and current and proposed development schemes (government or NGO led)	To understand potential partnerships and plan for synergies with existing or forthcoming government/NGO programmes
	Grid electrification status of the village and hamlets. Quantity and quality of power, number of connections, potential for electrification	Often the main village is electrified but the hamlets are not. Although the electrical lines may have reached the village, it is important to assess the quantity and quality of power being received and the estimated time by which the grid will reach the sites, if it has not already
	Alternative sources of energy/electricity—existing decentralised renewable sources in the form of solar lanterns, solar home systems or others and Diesel Gensets, kerosene lamps, batteries, etc. And the quantity and cost of each option on a per household basis	These sources will provide the assessor information on current usage patterns and also the costs being paid for availing the services. These costs can be treated as benchmarks for project design
	Types of loads, household, commercial and agricultural loads currently in use	To assess which existing loads need to be provided with electricity (in case they are operating on diesel or other source currently) and the potential load profile of the area

(continued)

(continued)

Category	Sub-categories	Significance
Socio-economics	Composition of community, community leadership.	In the case where the power plant is to be community managed or community involvement is important, it is important to understand community dynamics and leadership, to better facilitate an intervention in the area and minimise risk of conflict Even for privately operated power plants, such data is essential before proposing an intervention in the area to ensure cooperation from the community as a whole
	Income profiles, key occupation, type and area of houses, household size, land, livestock and other capital ownership, education, proximity of market and other commercial establishments, key agricultural crops grown, other livelihood activities such as NTFP collection and labour Access to finance	This data is key to identification of potential livelihood activities that can either be started or be scaled up Rural communities often do not get easy access to finance owing to low incomes and unavailability of documentation of assets. Power projects that require investment would need to assess the availability of finance either through FIs or MFIs in the region before making an investment decision.
Demand assessment	Duration of time for which lighting and other household services are required Daily, monthly and yearly requirement of commercial and agricultural equipment	Daily household load patterns in rural areas are general uniform throughout the year and the assessment should also aid in estimation of the cap on energy consumption per household and the prospective loads that could be added over the next few years For larger loads such as commercial and agricultural loads, accurate data on time, day and season of usage can lead to a more optimised system design and higher capacity utilisation factor of the power plant through intelligent load management

(continued)

(continued)

Category	Sub-categories	Significance
Other factors which contribute to understanding the socio-economic and political dynamics of the community	Access to markets or other avenues for sale of produce.	
	Involvement of local middle-men or organised agents in the collection of produce from the sites.	
	Availability of modern communication facilities including cellphones and internet	
	Existing community-based initiatives such as water conservation, forestry, etc.	
	Extent of involvement of local governing institutions and NGOs	
	Presence of local youth for employment at the power plant	

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