Prospects for Electricity Access in Rural India using Solar Photo-Voltaic based Mini-Grid Systems

Leena Chandran-Wadia (leena.wadia@orfonline.org)
Observer Research Foundation (ORF) Mumbai
NKM International House, 178 Backbay Reclamation, Mumbai 400 020, India

Shruti Mahajan Deorah (shruti.deorah@berkeley.edu)
Visiting Scholar, Goldman School of Public Policy, University of California Berkeley
(On leave from Observer Research Foundation Mumbai, India)

Sameer Nair (sameer@gramoorja.in)
Gram Oorja Solutions Private Limited
NCL Innovation Park, Pashan, Pune 411 008, India

Anshuman Lath (anshuman@gramoorja.in)
Gram Oorja Solutions Private Limited
NCL Innovation Park, Pashan, Pune 411 008, India

Abstract

Of the 300 million Indians or so Indians who do not have access to electricity as yet, up to 10 million live in villages and hamlets that are too remote for the Grid to reach. Solar Photo-Voltaic (PV) based mini-grid systems have the potential to be an environmentally friendly and sustainable long term solution at these places. *However, the high upfront costs of these mini-grids present policy makers, entrepreneurs and consumers alike with difficulties in paying for them.* Other challenges to their implementation stem from socio-economic issues such as poverty and the paucity of educated youth among the rural population. We assess the potential for Solar PV based mini-grids to dispel darkness in about 50,000 remote villages within say 5-8 years, based on a detailed assessment of over 100 villages. We describe one very high-quality installation in detail, which is running for some 20 months now and which highlights many of the challenges involved in providing end-to-end solutions in rural India. We review the policy measures of the Indian government in the context of scaling out such innovative solutions, and argue that government must work together with the State Electricity Boards and the entrepreneurs to create an Energy revolution akin to the Green revolution in India in the 1970s.

Keywords: Energy Access, Solar Photovoltaic, Mini-grids, Rural India

Introduction

Off-grid mini-grid solutions based on renewable energy sources, particularly Solar Photo-Voltaic (PV), hold great promise to bring energy access to the 80 million or so households in India that are currently doing without it (Census of India, 2011). India is blessed with tremendous solar potential, with an annual solar reception of 5000 trillion kWh[1]. Solar PV systems are relatively easy to install, scale well with increasing demand, and require minimal day-to-day intervention, which make them particularly suitable for use in rural India. There is currently a lot of ongoing activity in India with regard to distribution of solar lanterns and other kinds of lamps for lighting purposes. However, an extremely compelling reason to deploy mini-grids[2] is the opportunity to provide *'on-demand electricity beyond lighting'* to rural homes and businesses, so that livelihoods can be enhanced.

It is estimated that there are a minimum of 20,000 (likely close to 50,000), hamlets and villages that are too remote for the grid to reach and another 100,000 villages that are grid-connected but short of electricity. The latter can also benefit from grid-interactive versions of these Solar PV mini-grids but the considerations in this case are more complex. We restrict our discussion to just the standalone villages and hamlets where sustainable electricity access can be a long term solution rather than just a stop-gap one - 'till the grid arrives'. We emphasize here that the goal is to provide electricity that is indistinguishable from that of Grid, 24x7, and with the provision to accommodate growth in usage. This would require appropriately sized AC Solar PV mini-grids, optionally hybridized with other renewable sources such as wind and biomass.

Research Objectives

We attempt to outline the obstacles in implementing Solar PV mini-grids in rural India, and discover innovative ways to overcome them. Although there are several sociological and technological challenges, the main difficulty is financial - the high upfront costs for the panels, the balance-of-system, and the costs for installing, servicing and maintaining them in such remote locations. The government subsidizes 30% of the costs of such systems under the Jawaharlal Nehru National Solar Mission (JNNSM). Another program, called the Decentralized Distributed Generation (DDG) provided 90% subsidy, but through state government procedures. Notwithstanding the subsidies, due to benchmark costs

[1] Theoretical value based on total land area

[2] The Government of India distinguishes between micro-grids (< 10kWp) and mini-grids (between 10kWp and 250kWp). For the purposes of this paper we refer to both as mini-grids.

being low and policy being unclear on important questions, not many private developers have set up Solar PV mini-grids. The focus of this paper, which is based on a detailed research report (Deorah & Chandran-Wadia, 2013), is to highlight fundamental challenges as well as innovative solutions that address them. The overriding objective is to discover replicable end-to-end solutions that can be rapidly deployed by entrepreneurs working together with government and the corporate sector.

Methods

We have studied mini-grid installations around the country - the technology and financial models used, and the challenges faced. Gram Oorja has also conducted detailed surveys in about 100 villages to assess the potential for mini-grids and the capacity and willingness on the part of the villagers to pay for them. The results clearly indicated a strong desire for electricity beyond just lighting. Importantly, there was little resistance to the concept that these services would come at a cost. On an average, monthly billings of around Rs 100 to Rs 150 seemed very feasible with the number being even higher for some of the more prosperous villages.

Here we present a detailed case study of a 9.36 kWp mini-grid at Darewadi, a small breakaway hamlet nestled in the Western Ghats of India, near Pune, which is not even recorded in the Census of India. The installation which is very innovative in several aspects is also illustrative of many of the implementation related challenges.

Darewadi is inhabited by 39 families of Mahadev Koli tribals, totaling approximately 200 residents, who practice rain-fed farming (single crop a year) and gather wild herbs for their livelihood. For about 20 months now these villagers have been enjoying access to electricity, 24/7.

Costs and Tariff

The tariff at Darewadi has been designed to create a corpus that will cover the cost of maintenance and battery replacement in 4 to 5 years[3]. While the effective tariff works out to Rs 20/kWh, it must be noted that the amounts collected are retained by the villagers in a trust account so they do not rely on further rounds of external/government funding for battery replacements. In theory, if at a later date, the government were to take care of battery replacements, the surplus that has been created through monthly collections could be potentially used to enhance capacity of the plant or indeed any other common asset that the village chooses to invest in.

Equipment and installation costs amortized over 25 years, which is also the lifetime of the panels, would have meant a minimum cost of Rs 36 per unit (Deorah & Chandran-Wadia, 2013). Clearly, recovering costs from revenues generated is not a viable option for a business model. With a fixed charge of Rs 90 to pay for street lighting and common usage, the monthly bill for households that use basic lighting and mobile charging is usually around Rs 120. For homes with televisions it goes up to Rs 150-200.

The state of Chattisgarh probably has the largest number of AC based mini-grids designed to provide electrification beyond mere lighting. As of December 2013, a total 600 + villages had been electrified using Solar PV, with sizes ranging from 4 kWp to 12 kWp. The Chattisgarh model subsidises capital expenditure entirely, and for operational expenses a nominal charge of Rs 5 per month is levied per household. There is no metering of usage and each user pays the same fee. Over time, this model has resulted in indiscriminate usage by a section of the villagers making it difficult to sustain the level of service originally envisaged. Also in several cases electricity can be provided only for a few hours in a day given current loads are much higher than planned loads. In our view, this issue is best addressed by a system of metering usage based tariff.

Tariff serves multiple purposes -

a. Creates a sense of ownership of the asset.
b. Creates a demand for quality service.
c. Ensures a degree of self regulation in usage, as lack of usage discipline in off grid systems would almost inevitably result in project failure.
d. Creates a corpus for battery replacement.

System Design Aspects

Darewadi receives at least three months of very heavy rainfall each year, during the monsoons, with high wind speeds and some continuous rain spells lasting for over a week. Gram Oorja set the solar panels in concrete to withstand winds up to 200 km/hr. It also created three separate feeder lines, one each for households, street lights and commercial loads so as to cope with periods of low generation. A local caretaker trained by Gram Oorja manually prioritizes supply of electricity to households during heavy rainfall days. The strategy has worked very well and the villagers have had to go without lights for as little as just five days in 2013! Sizing the system with a much larger battery component may have worked just as well, but it would have driven up both initial costs as well as replacement costs substantially. Besides separate feeder lines, another key design aspect is sizing the battery for just over one nights' usage rather than three nights that most designs provide for. The battery bank comprises of a 600 aH, 48 volt system that at 100 % capacity can store 28.8 kWh of electricity. At a prescribed depth of discharge of 50 % this provides usable electricity of 14.4 kWh which is sufficient to meet the overnight needs of common street lighting and household consumption. A battery of this size would cost about Rs 2.5 lakhs and would need to be replaced every 4 to 5 years.

The Darewadi system was designed not just to minimize battery, but also to accommodate substantial growth in usage over time. The initial usage, during the first year, has been just 30% of capacity. With the recent addition of a couple of water pumps, utilization has crossed 50%. Given the existence of feeder lines and the option to move all commercial loads into daytime use there is still plenty of room for growth for some years, although the exact growth curve remains to be seen.

[3] A 10kWp system is expected to generate approximately 12,000 units of billable electricity annually.

Each home has a metered connection and is fitted with a circuit breaker that cuts off unusually high loads. The distribution wiring at Darewadi has been done completely professionally, as per the regulations of Maharashtra's State Electricity Regulatory Board. Notwithstanding the ease of installation by simply stringing wires over trees (Ferris, 2014), it is best for the safety of the village and the long-term sustainability of the assets, that wiring to individual homes is done as per standards prescribed for the Grid. Although this has driven up costs, it has also ensured that Darewadi is completely Grid-ready. Hence, this infrastructure can be integrated into the Grid, should the government decide to. We believe that this important innovation must be adopted as a key requirement by the government and incorporated into its policy framework.

System Management and Maintenance

A village trust, consisting of 7 members, has been created to take charge of the assets and to oversee its care. Everyday maintenance for the panels and battery and management of the feeder lines when necessary is done by a young man from the village, who is paid nominally from the village corpus. Gram Oorja has in effect moved out of the hamlet handing over control to the community which was their intention. They continue to remain available on call as needed. The land for the panels and constructing the safe room for balance-of-system has been taken on a 25-year lease from a family who are given free electricity in lieu of rent. It is critical that villagers are made stakeholders in this way, through initial ground-work towards building a trust based relationship. Ownership by the community not only ensures safety of the installation, but also minimizes payment default.

Another novel model of payment collection has been deployed by USAID funded company, Gram Power, which uses the familiar pre-paid model to provide 'electricity as a service' to several villages in the state of Rajasthan. Gram Power has developed smart technology to wirelessly manage a network of resellers who sell credits to households against which electricity is supplied in a metered way. The meter keeps the end user informed of their usage. Smart grid prevents thefts and energy losses, which are a major issue in India. Gram Power has been able to raise funding and they are setting up mini-grids by investing capital in addition to availing (30%) subsidy from the government. However, the effective price/unit being charged by them is not disclosed, and is suspected to be quite high.

Livelihoods and long-term sustainability

On-demand electricity is critical for creating livelihood opportunities, as well as for the provision of healthcare, education, entertainment and clean water supply. While DC micro-grids (typically of size less than 1 kWp) are providing lighting and mobile charging to households in several villages in power starved states, the equivalent price/unit they charge cannot scale with consumption (e.g. for a television). It has been observed that once electricity is supplied, villagers discover latent needs and new applications, driving up the average consumption per household. This is true of Darewadi, where the water-pumps added recently by the villagers will enable several farmers to graduate from just a single-crop to growing two or even three crops a year. Another example is the village of Meerwada in Madhya Pradesh, where SunEdison has set up a 14 kWp Solar PV mini-grid. This plant provides electricity to approximately 400 people in 70 households. Funded by SunEdison as a demonstration project, utilization of this plant climbed quickly from the initial 15% to about 70% within a few months (Neelakantan, Deorah, & Chandran-Wadia, 2012).

Although utilization of the mini-grid inevitably increases, first for entertainment purposes and later for livelihood options, many of the latter are also knowledge intensive. For instance computer education, milk chilling plants, cold storage for fruits and vegetables, are some examples of livelihood enhancing options that can follow. In fact it is these very opportunities that are more likely to generate revenues for the energy entrepreneurs should they choose to stay engaged with the community.

Results

As seen earlier, to recover capital costs, service providers would have to charge very high price/unit to the end user. Maintenance costs alone are equivalent to a high price/unit (in conventional terms), especially once we include the losses of a standalone system. Nevertheless, charging on the basis of consumption is important to maintain consumer integrity. 'Electricity as a service' models that charge users flat monthly fee per light (or fan) are quite difficult to scale when consumption per household increases. Hence, we conclude that creating a business out of charging end users a transparent price/unit is very difficult, unless the capital costs are heavily subsidized.

Secondly, employment of local youth can make a tremendous difference to the last mile implementation and servicing of these systems. However, entrepreneurs installing small standalone mini-grids will not be able to leverage economies of scale with respect to training a few youth at a time, in the absence of availability of skilled manpower.

Thus, we argue that 'assisted entrepreneurship models' promoted by the government and the corporate sector can take on the scale challenge of reaching electricity to millions of Indians going without electricity today, especially in the remote hamlets and villages where the Grid is unlikely to reach. The assistance required chiefly takes the form of capital subsidies to cover the high capital expenditure costs, which should be rightly considered as an infrastructure investment, rather than a pure industry subsidy. We also need other changes in the policy environment that will encourage more entrepreneurs to come forward and programs for training local youth. A national programme, perhaps as part of the National Skill Development Mission[4] will be required to train tens of thousands of technicians, and possibly thousands of indigenous entrepreneurs. Activities such as disbursement of subsidy as well as maintaining a service network can gain economies of scale from aggregation. In

[4] See http://www.nsdcindia.org/index.aspx

fact, franchise models are already being used by state distribution companies for rural areas in several states.

Nearly 290 million of the 300 million living in darkness and using kerosene for lighting live in villages where the Grid has technically already reached[5]. The issues that prevent reliable supply of electricity in the Grid are much more complex, primarily connected with the fact that most state Distribution Companies (DisComs) are financially unviable. Here entrepreneurs could get involved in setting up grid-connected mini-grids using net metering, provided the policy environment is conducive.

Discussion

Solar PV mini-grids are attracting attention as a plausible solution for providing electricity in remote off-grid regions in India. We have attempted to isolate the avant-garde components of two delivery models that can be incorporated in future installations for increased effectiveness and efficient implementation..

Some of the key innovations made by Gram Oorja ensure quality and long term viability of the standalone mini-grid installation in Darewadi. These include:

- Feeder Line separation
- Minimal Battery support
- Local involvement and ownership of assets
- Grid-ready installation

These features in the design seemed to have played an important role in the smooth functioning of the system over the last 20 months and could be incorporated while drafting the new set of specifications for Solar PV mini-grids[6].

Asset ownership as well as economic stake by villagers plays a critical role in ensuring the success of a capital investment such as this. People tend to value a service more and use it judiciously if they are paying for it. Specifically, the self-regulation of consumption during the monsoon weeks by the villagers is also a unique achievement. While it might be partly due to the homogenous composition of the village which enabled coherence, it is also attributable to the village trust that did a good job of managing the set-up. The design component of separating the feeder lines among various types of loads provided a setting for this. Prioritization of loads and appropriate sizing of the system (to anticipate an increasing load over time) resulted in reduced battery requirement.

Gram Power has designed an innovative delivery and collection model. Their model increases financial viability by eliminating payment default, and facilitates local support through hiring of indigenous people as reseller agents. This is an example of assisted entrepreneurship that we advocate above, though franchise models are feasible at several levels.

We conclude by briefly outlining the financing and policy elements that would be required for replicating these mini-grids across the country.

A typical 10 kWp system at an average cost of Rs 30 lakhs per village would imply that the upfront capital outlay on 50,000 mini-grids would be a total of Rs 15,000 crores. Under the proposed model, the money for operations, maintenance and battery replacement is fully collected from the villagers thereby eliminating the need for any further external financial support. Staggered over a period of 5 years, the allocation for this would be Rs 3000 crores per annum. Given that the government spends several times this figure on annual kerosene and diesel subsidies, the number in itself is not very high.

Implementation of tens of thousands of mini-grids would warrant speedy coordination between Central and State governments. Additionally, policy needs to be clarified on a few important points that would ensure long term sustainability of the systems. Metered tariff collection to meet operating expenses should be permitted. The primary subsidy method of awarding projects to the lowest cost bidder can compromise the quality of installation. Arriving at practical benchmark costs and then making funds available to entrepreneurs would substantially lower barriers to entry.

Replicating Solar PV mini-grids across thousands of remote villages and hamlets in India is potentially a quick path to provide electricity access and hence catalyze development in these regions that are very difficult to electrify via the Grid. Implementation needs to be meticulous, and the innovations called out in this paper can go a long way in making the installations successful.

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[5] Assuming 50,000 villages where grid will never reach, with 40-50 households i.e. ~200 people per village => 10 Million people

[6] Currently under draft, as per conversation with Mr. Tarun Kapoor, Joint Secretary, MNRE, in November 2013