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Assessing the business case for rural solar microgrids in India: a case study approach

Final report

Prepared for Azure Power

October 30, 2014

Energy+Environmental Economics

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Abbreviations

BPL: below poverty level

CREDA: Chhattisgarh Renewable Energy Development Agency

CAPEX: capital expenditure

DISCOM: state electricity distribution utility

FiT: Feed in tariff

FOR: Forum of Regulators

INR: Indian national rupee

IREDA: Indian Renewable Energy Development Agency

JNNSM or NSM: Jawaharlal Nehru National Solar Mission

kWh: kilowatt-hour

kWp: kilowatts peak

MNRE: Ministry of New and Renewable Energy

O&M: operation and maintenance

ODGBDF: off-grid distributed generation based distribution franchisee

OPEX: operating expenditure

PV: photovoltaic

REC: renewable energy certificate *or* Rural Electrification Corporation Limited

RGGVY: Rajiv Gandhi Grameen Vidyutikaran Yojana

RPO: Renewable Portfolio (or Purchase) Obligation

RVE: Rural Village Electrification programme

SERC: State Energy Regulatory Commission

UPNEDA: Uttar Pradesh New and Renewable Energy Development Agency (also called NEDA)

USTDA: United States Trade and Development Agency

USD: United States dollar

VAT: value-added tax

WIP: willingness to pay

Wp: Watts peak

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Abstract

We studied the feasibility of rural solar based microgrids in the Indian context using a case study approach in which solar microgrids were designed and evaluated for two villages in India (Bar Village in Chhattisgarh and Devari Bharat in Uttar Pradesh). We conducted detailed site assessments, including door to door surveys and community gatherings to assess the desire and interest in electricity and electricity services, demand, willingness and ability to pay for these services. The appetite for electricity and willingness to pay is relatively robust with a strong desire for a tariff that reflects actual consumption (rather than a flat tariff), although the willingness to pay (WTP) and ability to pay varied between the villages and was correlated with the socio-economics of each village. The WTP on an absolute basis ranged from INR 50-200 per month for essential services, to INR 100-500 for additional services. On a unit basis, these translate to ~ INR 4/kWh to INR 40/kWh. A spoiling effect was found in one village due to the fact that some of the residents have access to utility service at subsidized rates. Using the survey results, we developed demand profiles and used these as inputs to an integrated design approach.

Several AC-based microgrid designs were evaluated, consisting of solar PV arrays, inverters, batteries and backup diesel generation. An investment grade economic model was developed that determined the tariffs to be charged the villagers, given a set of financing criteria. The microgrid's economic feasibility was significantly better for the village in which a higher demand was estimated. We found that for higher demands (~ 400 kWh daily summer load), with favorable financing criteria, the microgrid is economically feasible. However, we found that for lower demands, as was the case with the village with poorer socio-economics the cost of the system was dominated by fixed costs (distribution network, site preparation, etc.) and we were unable to establish a tariff within the willingness to pay.

More broadly, economic and regulatory barriers may prevent widespread developer investment in microgrids of the type we evaluated. There is a significant risk of stranded asset to the developer in the event the grid reaches the village and villagers switch to utility service, even if the quality of service is superior from the microgrid. A significant gap exists between the tariff at which microgrid service can be offered and the WTP for smaller villages with lower loads, where fixed costs will dominate. In these cases, assuming the Indian government has a long term plan to provide grid access, more cost-effective intermediate measures may be better suited, such as solar home systems or DC-based "skinny" grids.

1 Executive summary

This report summarizes the findings of a 21 month study, supported by a grant through the United States Trade and Development Agency (USTDA) to develop the business model for rural solar PV microgrids in India. The grantee of the USTDA grant is Azure Power, a solar developer based in India. The project team was led by Energy and Environmental Economics (E3), a US based consulting firm, in collaboration with Black and Veatch, Schatz Energy Research Center, Varesh Energy, Chris Greacen, Christopher Freitas and Ranjit Deshmukh.

In this study, the E3 Team evaluated the feasibility for two specific villages in India; Bar in the eastern state of Chhattisgarh and Devari Bharat in the northern state of Uttar Pradesh.

The scope of this study was to address the feasibility of Alternating Current (AC) based solar PV microgrids, and hybrid solar PV-diesel microgrids, that could be interconnected into the utility grid at some point in the future. A variety of other rural electricity solutions exist, such as such as solar home systems, solar water pumps, DC-based microgrids or “skinny grids”. However, these were outside of the scope of this study.

Site characteristics

The villages we surveyed represented diverse social-economic demographics, awareness of electricity and solar energy, electricity access. Both villagers showed a strong appetite for electricity and a preference for a metered tariff or consumption based tariff. Overall, both villages showed promise in terms of willingness to pay (WTP) and stronger willingness to pay (WTP) for essential services (lighting, fans, mobile charging) with the following distinctions:

- Bar: WTP for essential services ranges from ~ INR 100-200 ($1.6-$3.3) per month; for higher service, generally between INR 300-500 per month (~$5-$8). These values translate to unit prices of INR 8-42/kWh ($0.13-$0.70/kWh) with a median INR 19/kWh ($0.32/kWh).
- Devari Bharat: WTP for essential services ranges from ~ INR 50-150 (~$1-$2.5) per month; for higher service, generally between INR 100-300 per month (~$1.6-$5). These values translate to a unit price of INR 4/kWh to INR 10/kWh ($0.07/kWh to $0.16/kWh).

The villages differ in terms of solar energy awareness and electricity access. Several residents in Bar Village have household solar systems and are familiar with solar energy because of the efforts by the

Chhattisgarh Renewable Development Agency (CREDA). Due to its proximity to a national forest, the electricity grid is unlikely to reach Bar in the near future. By contrast, Devari Bharat Village has partial access in which about 30% of residents have either legal or illegal connections. The utility electricity tariffs are low, and widely acknowledged to be below the cost of service, creating a "spoiling effect" whereby the un-electrified majority is reluctant to pay more than subsidized retail service.

We conducted individual surveys to identify the services desired by households and when these services are desired. Using this data, we constructed demand profiles for input to the design process. The demand was dominated evening consumption for lights and fan. This is expected, given that the economic activities for both villages are agriculturally dominated. A small number of customers desired daytime usage, such as medical facilities and shops; however, these are relatively small in number. We developed a few sensitivities, with the base case daily summer demand for Bar Village of 400 kWh per day and 160 kWh per day for Devari Bharat.

Approach

A key goal of this project was to develop a microgrid design and implementation strategy that meets the needs of the community. In contrast to utility scale generation projects, microgrids require greater attention towards the demand side of the equation. What electricity services are desired, when is electricity needed, and how much, are key considerations. We applied an integrated and iterative design approach that consisted of the following elements:

+ Needs based design approach, beginning with the electricity services desired by the village
+ Optimized for affordability and scalability
+ Integrated design approach in which economic, technical and implementation aspects were considered collectively and iteratively

Figure 1 illustrates the project flow of an integrated design approach. Beginning with the needs of the community, the technical design is iterated to achieve a design that is affordable and attractive from a business perspective.

Figure 1: Integrated design approach

An integrated design that begins with the needs of the community, and simultaneously addresses economics and technical design simultaneously, is essential to achieve an optimally designed solution. Unlike utility scale solar power design, microgrids have to continually achieve balance between supply and demand, without the 'storage' capacity of the grid.

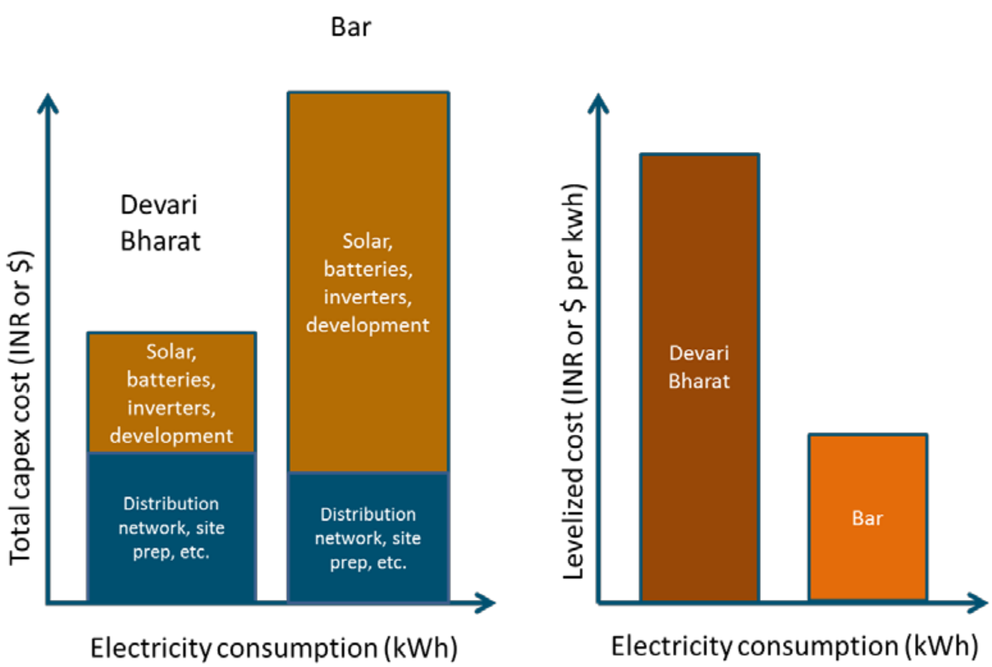
Our team utilized a combination of tools. The HOMER microgrid software tool was used to evaluate various microgrid configurations —sizing of the PV array, battery, diesel generator. HOMER converts future costs to a present cost using a discount rate, and reports this present cost of the various configurations. We selected the top configurations identified by HOMER, conducted more refined analysis for engineering details not considered in HOMER, and developed a detailed engineering cost estimate in which all components were priced, including the fixed cost components, such as meters, distribution network and site preparation. The total system cost over the lifetime of the system was then exercised through a detailed economic model that solves for the revenue requirement and tariff that would be charged to the customers, given a set of financing criteria — debt/equity share, cost, terms. Several financing scenarios and tariff designs were evaluated. At the final assessment, the tariff and monthly bills are compared to willingness to pay to assess feasibility. In our project execution, we repeated the whole cycle several times to improve the feasibility.

Feasibility results

In the case of both villages, the demand profile is not coincident with the solar shape. As a result, in order to meet the demand requirements, either battery backup or diesel generation is required. Both batteries and diesel fuel are expensive. By using HOMER, we were able to identify the optimal combination of solar, battery and diesel generation to meet the demand requirements of the villages. This process resulted in a solar-diesel system of 75 kWac for Bar and 15 kWac for Devari Bharat.

The base case lifecycle cost was INR 30/kWh for Bar Village and INR 80/kWh for Devari Bharat Village. The cost on a Watt basis was INR 285/Wac for Bar and INR 830/Wac for Devari Bharat. A number of sensitivities were performed that are described in the main report. To put the lifecycle costs in perspective, the capex cost for the Devari Bharat system is INR 1.3 Cr (INR 13 Million) or $210,000; for Bar INR 2.1 Cr (INR 22 Million) or $365,000[1]. The solar, battery, inverters and development costs, which are the key capacity-dependent costs constituted ~65% costs for the Bar design and ~30% for the Devari Bharat system. In other words, those costs which are unavoidable regardless of the capacity of the microgrid, such as the distribution system, meters, site preparation, drive up the unit cost of the electricity, as shown in Figure 2.

Figure 2: Relationship between fixed, capacity-dependent costs, lifecycle cost and consumption



As electricity demand is more coincident with the availability of solar, the cost of the microgrid decreases, since the battery size can be reduced. This was found to be a challenging factor in the two

[1] The panel cost of solar was assumed at $0.66/W or INR 41/W; BOS of the PV plant at $0.43/W or INR 27/W; batteries at $156/kWh or INR 9760/kWh, PV inverter at $0.3/Watt or INR 17/Watt; battery inverter at $0.66/W or INR 42/W; and development costs of 10% total capex.

villages we studied since most villagers are outside doing agricultural work during the day and require services mainly at night.

Inclusion of an anchor tenant load is beneficial. At one point, a Forest Department resort was a potential customer. We do not emphasize the results including the anchor tenant load in the executive summary as they are no longer a viable customer. However, we note that including their load had significant benefits towards project feasibility. Including the Forest Dept resort load in the design reduced the overall lifecycle cost by INR 6/kWh (~20%) and the village customer tariff by INR 7/kWh (25%).

We encountered very few technical challenges in the feasibility assessment. However, we faced one noteworthy obstacle in the design process. It was challenging to find a suitable meter. Our criteria includes an AC-based prepaid meter; one that is cost-effective (we were targeting $30-50 a meter); one that could support a consumption-based tariff with a minimum monthly payment; and one that does not require internet access for recharging. We eventually found two suppliers that would qualify, one US-based and one Indian-based, however, a majority of the prepaid meters available and used in microgrids are DC based and most of the qualifying AC-based meters are very expensive.

Regulatory barriers and scalability

There are a number of barriers that need to be addressed in order to achieve scalability. Although the overall market potential is large, given the lack of access in India, the risks to the developer are significant. If the grid eventually reaches the village, then the microgrid runs the risk of becoming a stranded asset. The 2003 Electricity Act also calls for regulation of the microgrid sector. Although model regulations for microgrids have been adopted by the Forum of Regulators, state regulatory commissions have not taken action. The model regulations provide some protection to the developer as they require the utility to use the microgrid's distribution system and compensate the developer for the distribution system book value, should the grid be extended to the village.

Scalability of AC-based solar-PV microgrid is challenging. The larger village, Bar, is an ideal candidate for microgrid deployment, particularly if the anchor tenant load had become viable. The village is unlikely to receive the utility grid soon because of its proximity to the national forest, the villagers are familiar with electricity (from a prior microgrid) and solar energy, and have strong willingness to pay. It's possible to work with the Forest Department to identify similar villages across the country. We found the second village, Devari Bharat to be a challenging case. Although the willingness to pay is higher than typical utility tariffs, a spoiling effect is present because some villagers have access to highly subsidized grid electricity. The overall load was estimated to be relatively small, and as a result, the fixed costs of the microgrid dominated the overall cost. This scenario is potentially a common condition, since there are a number of villages in India with partial access (some classified as electrified, some classified as unelectrified).

To the developer, assuming the grid will be extended eventually to the village, microgrid approaches or rural electricity approaches that serve as transition or "stop-gap" solutions may be more attractive to the developer. Solar home systems or DC-based "skinny" grids that focus on essential services and are easy to dismantle are more likely to provide the basic services below the willingness to pay threshold (i.e., 100-200 INR per month). The AC-based solar microgrid can be part of a long-term solution since all the microgrid components can be utilized in a grid-connected arrangement—though some are less valuable with grid connectivity. A franchisee arrangement with utilities that compensates the developer for the value of their assets can help ensure that the AC-based solar microgrid becomes a part of a long-term path towards electrification.