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CONCEPT OF OFF-GRID SOLAR MULTI-ULTILITY CENTRE FOR LIVELIHOOD GENERATION IN RURAL AREAS

Nivedita Thakur[1], Parimita Mohanty, Akanksha Chaurey, Arvind Sharma and A.S.Srinidhi
Decentralized Electricity Solutions Division, The Energy and Resources Institute, New Delhi, India
[1]Corresponding author
Phone: 91-11-26122222, Fax: 91-11-24682144, e-mail: nivedita.dasgupta@teri.res.in

Abstract
Solar Photovoltaic technology has proven itself as a promising option for grid-connected as well as stand-alone source of power in India. It is believed to be viable for off-grid usage in the remote villages in the country. The Energy and Resources Institute has developed the concept of Solar Multi-Utility centre that acts as a solar photovoltaic based energy and services centre for livelihood generation for the villages as beneficiaries. A pilot project under this concept that has been designed developed and demonstrated in a remote village in Assam, India. Scoping study of the field-level demands, willingness to pay and suitable motorization of the appliances were carried out for designing the SMU with facilities being provided on a fee-for-service basis. This system complimented with state-of-the-art remote monitoring system provides services such as bamboo stick making, bamboo slivering, spice pulverizing, battery charging, water purification and solar lantern charging. This paper presents the various stages involved in design, development and utilization of the SMU covering scoping study, demand assessment, customization of the SMU design according to available appliances, description of the various sub-systems and services and utilization monitoring.

Keywords: Solar Photovoltaic, Stand-alone renewable energy system, Centralized solar charging station

1. Introduction
Access to electricity is one of the most vital instruments for promoting economic growth and social equity. Despite this well-established link between development and electricity provision, over 1.4 billion people in the world lack access to electricity; roughly 25% are in India alone. An adverse impact of this is that millions of communities are deprived of access to basic activities for all of which reliable electricity supply is one of the most essential prerequisites. This in turn affects the standard and quality of living in the long run. Intervention of renewable energy resources is gradually establishing as viable alternate methods for providing basic electricity services to these disadvantaged rural communities. Case studies and viability of stand-alone energy systems have been extensively reviewed and presented by Kaundinya et. al. Further, the viabilty of rural electrification of rural India with renewable energy sources have also been extensively studied and presented in the work by Urban et. al. Kanase-Patil et. al. have utilized typical cases from Indian villages for optimization of integrated renewable energy systems for off-grid electrification of remote rural areas. Even beyond the technical aspects of such projects, decision making tools involving approaches for planning and formulations have also been developed by Kumar et. al. Solar Photovoltaic (SPV) energy has come across as a feasible source for remote rural areas mainly due to the easy availability of solar energy and the modular nature of SPV systems, especially in standalone mode. Feasibility of energy services such as solar lighting have also been established in works by Kamalapur et. al., Chaurey et. al. and Rubab et. al. Stand-alone solar charging stations have also been showcased as a viable and affordable energy service for the village community as described by Mohanty et.al.

In order to ensure long-term benefits to the communities, especially for livelihood generation, it is essential that renewable energy technology services be appropriately packaged and delivered through an effective service delivery network. This paper presents one such Solar Photovoltaic (SPV) based project that has been designed and implemented in a remote village in India by The Energy and Resources Institute. This serves as an eminent example of stand-alone SPV based system catering to the local livelihood generation requirements of the villagers. The techno-economic economic viability of such a project is ensured through scoping studies and institutional models involving local entrepreneurs and Self-Help Groups. This is a solar photovoltaic (SPV) energy based Solar Multi-Utility concept whereby appliances and gadgets are suitably powered in a SPV based standalone system to meet the requirements of such communities to improve their livelihood generation and standard of living. The design, features, applications and performance assessment of the c-Si SPV based SMU with battery back-up and monitored through a state-of-the-art Remote Monitoring System are presented.

Section 2 presents the concept of SMU while section 3 presents the various aspects of the pilot project discussed in this paper. Section 4 gives the utilization of the SMU and section 5 presents the conclusion.

2. Concept of Solar Multi-Utility Centre (SMU)

A SMU is basically a stand-alone off-grid SPV energy based centralized charging station that is optimally designed to provide electricity to operate appliances under one roof and also charge battery based utilities. Centrally located within a village, the applications and facilities included in this SMU centre is maintained by a local entrepreneur and provided at affordable fee-for-service to the beneficiaries of the villages. Thorough scoping exercises in the village resulted in the identification of range applications such as powering of bamboo stick making machine, turmeric grinding machine, water purifier and charging of small batteries, solar lanterns etc. The appliances were suitably motorized and customized for efficient integration into the SMU along with suitably sizing and designing the other BoS components such as PCU, charge controllers, junction boxes etc. for powering the various AC and DC appliances. While retaining the flexibility of interconnection of solar modules as per requirement, the SMU was divided into three sub-systems with exclusive SPV array capacity dedicated to each sub-system so that the solar power could be optimally utilized with ensured operational hours for each application. The entire SPV capacity of 5kWp was not utilized with current appliances for providing an option for additional loads in future. The operating voltages of the sub-systems were suitable decided (96V, 12V etc.) based on the types of AC and DC loads. Battery-bank as a backup power source adds to the reliability of the system by bringing in the flexibility of availing the facility even during non-sunny hours of the day. DC charging applications, such as centralized charging of solar lanterns, prompted the design of customized junction boxes with suitable protection circuits as a part of an efficient centralized charging station concept. Figure 1 illustrates the concept of an SMU centre as a standalone system. State-of-the-art Remote Monitoring System (RMS) has been further integrated into the SMU to capture electrical parameters in order to remotely monitor the operation, functioning and utilization of the SMU. Data from RMS based monitoring help analyse the real time utilization pattern of the services and also monitor the technical failures leading to prompt repair and maintenance.

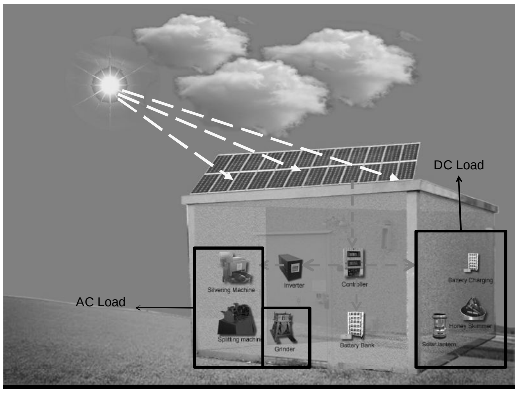

Figure 1. Concept of Solar Multi-utility Centre (SMU)

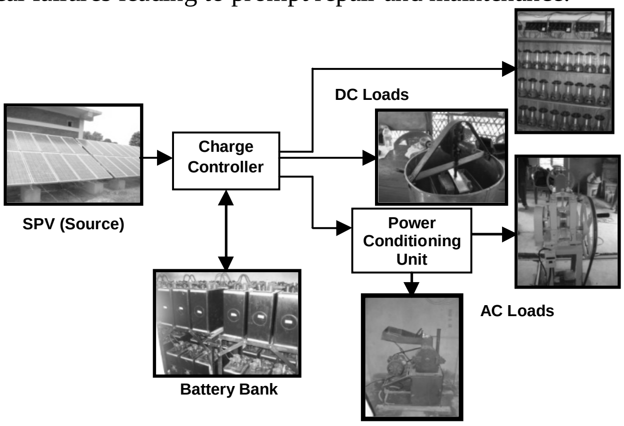

Figure 2. Schematic of the particular SMU in Assam presented as a case study

3. Design and Development of SMU in Assam

Scoping studies in the field resulted in identification of several potential activities that lead to livelihood generation of the local community at and around the project site. Some of the gadgets often operated manually were motorized to be suitably powered in the SMU. The applications involved DC and AC appliances including Water purifier, Bamboo splitter, Bamboo slice maker, Spice grinder and charging applications such as small size battery charging, solar lantern charging etc. Provision of The SMU was then designed as a standalone solar photovoltaic system with suitable SPV array, Power Conditioning Unit, Battery charge controllers and other interfacing circuitry. Figure 2 shows a schematic of the system under study. The community avails these facilities at a nominal fee and incorporates the resulting material into their livelihood generating business and other health related consumption.

3.1 Scoping results

The key outcomes of the initial scoping results are consolidated in Table 1. Various applications were identified for different times of the year with differing durations and power consumptions. Therefore, the design of the system was such that the total array capacity is optimally utilized in every season towards providing best suitable livelihood generating opportunities.

Table 1. Applications identified and the related details obtained during scoping study

Sr. No.	Possible livelihood generation activities	Months of operation	Load requirement (W) & type of load	Daily hours of operation
1	Battery charging	Across the year	DC	Whole day
2	Either Bamboo machines or Pulverizer (Turmeric/Black pepper/Red chilly)	Across the year	2 HP (AC)	3
3	Solar lantern	Across the year	30 W DC	5-6
4	Water purifier	Across the year	100 W (AC)	5

3.2 Description of the Sub-systems

While retaining the flexibility of interconnection of solar modules as per requirement, the SMU was divided into three sub-systems with exclusive SPV array capacity dedicated to each sub-system so that the solar power could be optimally utilized with ensured operational hours for each application. Table 2 describes the sub-systems with the important components, applications and specifications. These are broadly dedicated to DC appliances, battery charging (batteries belonging to the community are brought to the SMU for charging), AC appliances and Solar lantern charging. Solar lanterns were charged in centralised charging stations within the SMU with 5 modular charging stations capable of charging 10 lanterns simultaneously during the sunny hours. These were then rented out to the users for utilisation at night time, Figures 3, 4 and 5 illustrate some of the sub-systems.

Table 2. Configuration of the sub-systems of the SMU

	Sub System -I	**Sub System -II**	**Sub System-III**
Applications/appliances	12V/ 40 Ah battery charging	• Pulverizer • Bamboo stick making • Bamboo Slivering • Water purifier	Solar lantern charging
Solar PV module capacity	1280 W	3200 W	480 W (6 charging units power by 80Wp each)
Battery bank	-	96V/ 200 Ah	Battery within individual lanterns
PCU	-	5 kVA	-
Centralized solar charging stations for lanterns			6 junction boxes with protection circuitry to charge 10 CFL lanterns simultaneously

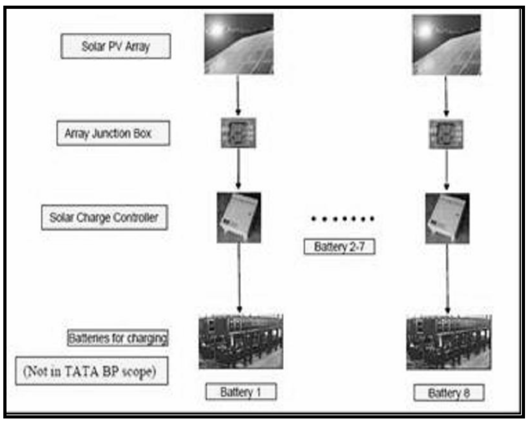

Figure 3. Schematic - Sub-System I

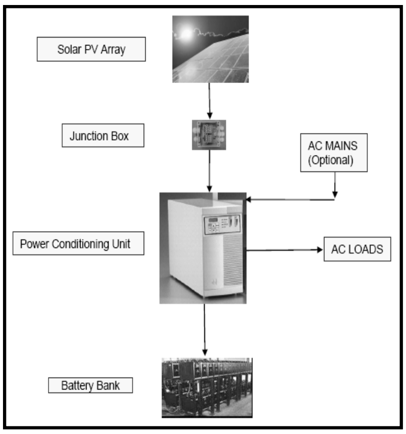

Figure 4. Schematic - Sub-System II

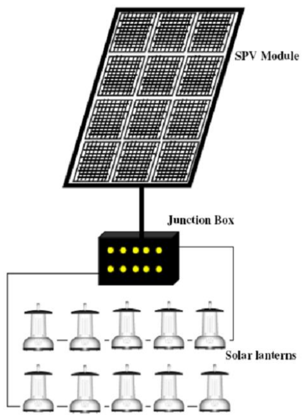

Figure5.Schematic-Sub-SystemIII

The system was designed based on the wattage of the loads, the seasonal requirement, Equivalent Sun-shine Hours at the project site and the typical losses incurred in each component based on the power ratings. The key technical specifications of the system are presented in Table 3.

Table 3: Specifications of the components of the SMU

SPV Modules (each)	
Rated power	80 W
Nominal Voltage	12 V
Open circuit voltage	22 V
Short circuit current	5.2 A
Total array capacity	
Sub System – I	1280 W
Sub System - II	3200 W
Sub System -III	480 W
Power Conditioning Unit	
Array input voltage (nominal)	96V DC
Battery voltage (nominal)	96 V DC
Inverter AC Output (nominal)	240V AC, Single phase, 50Hz.
PCU Inverter rating	5.0 kVA
PCU charge controller rating	5.0 kW
Solar Charge Controllers	
Solar Charge Controller Type	Solid State
Solar array input voltage(nominal)	12V
Solar array input current(maximum)	40 A (For Sub-System I) ; 10 A (Sub-System II)
Battery charging voltage(nominal)	12V DC
Operating Temperature	0º to 50º C
Battery Bank (For Sub-System II)	
Type	Lead Acid Flooded Electrolyte Tubular Plate Batteries
Total battery bank voltage - nominal	96V DC
Total battery bank capacity - nominal	450 Ah @ C120 or 300 Ah @ C10

3.3 Remote monitoring

The SMU has been incorporated with a state-of-the-art Remote Monitoring System (RMS) that is responsible for performance monitoring of the various components of the SMU by sensing and logging the important electrical parameters. This remote sensing data acquired and processed through this RMS, provides performance monitoring and analysis of the utilization of the facilities extended through the SMU. Figure 6 illustrates the concept of RMS and Figure 7 presents an example of the data on solar module voltage of one of the sub-systems logged over a period of time showing the performance and utilization trend during the period.

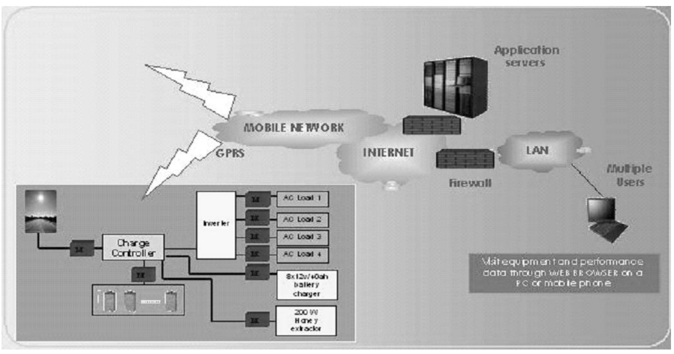

Figure 6: Remote Monitoring System

4. Utilization of the services of the SMU

Typical utilization of the services offered at the SMU is monitored through the RMS system. Daily usages vary with season and daily number of beneficiaries. The income of the entrepreneur and the self-help groups responsible for operating the SMU depend upon the daily usage of the SMU. The utilization for three consecutive days in the month of May has been reported here. Table 4 presents the usage pattern and daily income generated along with the representative unit fee charged by the operators against each service.

Table 4. Applications utilized per day and the income generated from the SMU

Machine	Cost/unit	Day-1		Day 2		Day 3	
		Duration of operation	Income generated	Duration of operation	Income generated	Duration of operation	Income generated
Bamboo Slicer and Bamboo Stick Maker	Rs.7/Stick	10:30 am-11:30am	Rs.175*	10:30 am – 11:30 am	Rs.175*	10:30 am-11:30 am	Rs.175*
Pulveriser	Rs.3/Kg	11:45 am-12:45 pm	Rs. 36	12:30 pm-13:30 pm	Rs. 45	12:30 am-1:30 pm	Rs. 39
Lantern Charging	Rs.3/lantern	10:15 am – 5:00 pm	Rs.24	10:15 am – 5:00 pm	Rs.33	10:15 am – 5:00 pm	Rs.30

*cost of raw material not included

Figures 7 and 8 show the utilization of solar and battery bank as sources by the various appliances and the solar lantern charging services in the SMU according to the operation of the appliances according to Table 4. The appliances were operated systematically to avoid overloading the solar array. The bamboo machines and the pulveriser were not operated simultaneously but alternately. The battery bank acts as a back-up power source whenever the power from the solar array is insufficient to operate the loads; on the other hand, when the load is less, the solar power is utilized to recharge the battery bank. These characteristics along with the charging and discharging instances of the battery bank are captured in Figure 7. The solar lanterns were kept on charge in the charging station during the entire day for utilization at evening and night times. Lanterns that did not get fully charged during cloudy days were charged for another day to reach the fully-charged condition before being rented out to the beneficiaries as per the fee mentioned in Table 4. However, the number of lanterns connected to each charging station and thus the utilization of SPV in each charging station, also depended upon the number of lanterns returned by the beneficiaries in the morning for recharging.

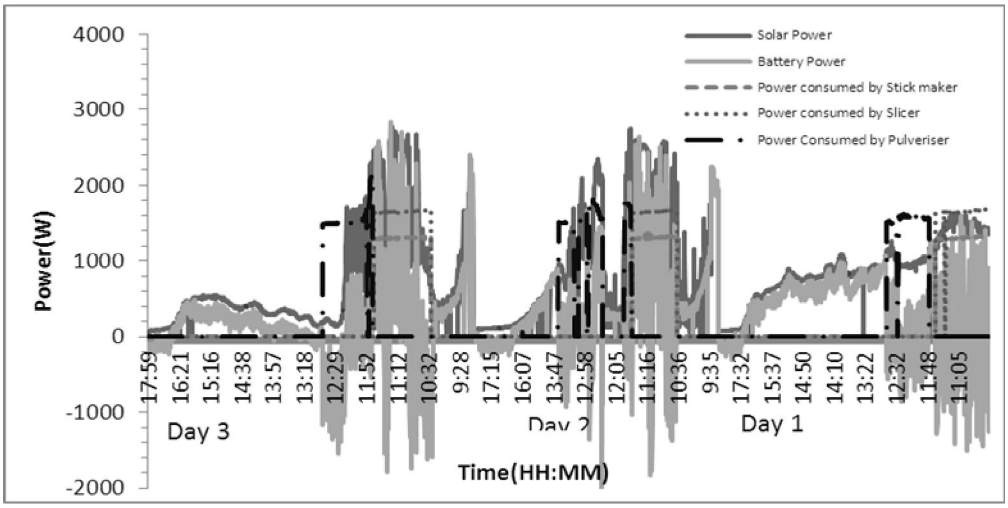

Figure 7. Utilization of solar and battery-bank for operation of the appliances in SMU

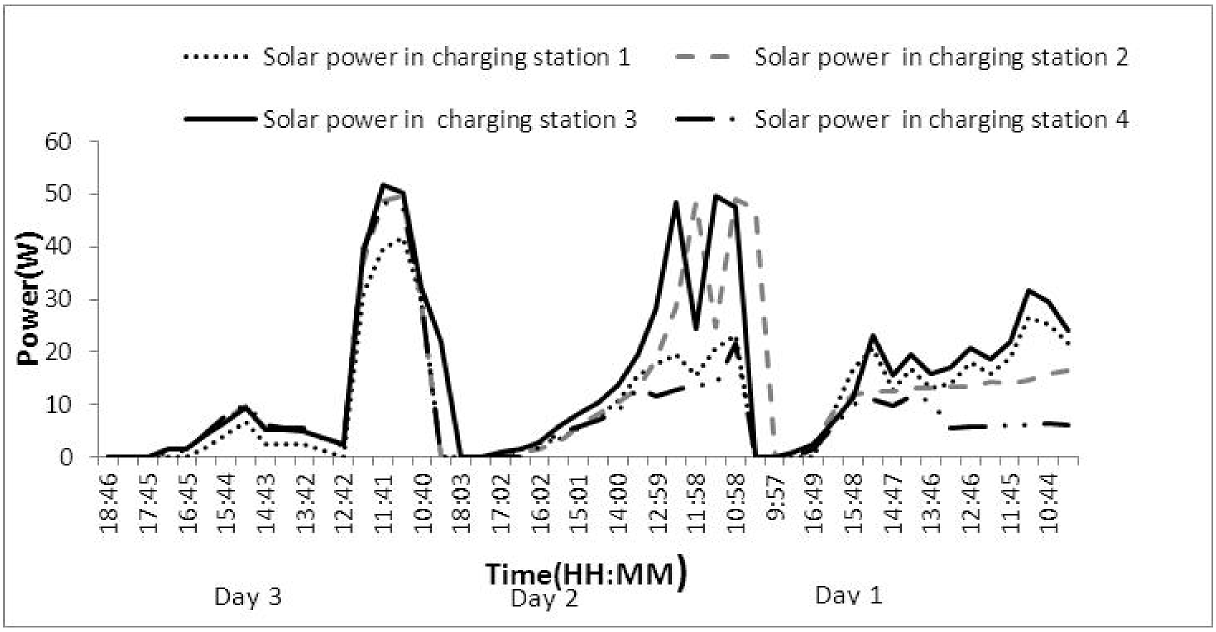

Figure 8. Solar power utilization by the solar lantern charging stations as a part of the SMU

4. Conclusion

The concept of SMU has been described. The fully operational c-Si SPV based stand-alone SMU designed, developed and installed at a remote site in Assam has been described as a case study of this concept that proves to be beneficial to the rural communities living in remote areas without access to electricity. Facilities such as spice grinding, bamboo splitting, battery charging, water purification and solar lantern charging are provided by the SMU that is designed for optimal utilization through the year. The SMU also provides stable income to the operators apart from improving the livelihood of the beneficiaries. System design, customization of components and appliances, technical specifications, Remote Monitoring System and performance monitoring has been described.

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