Solar Equipment Based Micro Grid in Hilly Terrains of Rural India - A Broad Perspective

Archan Bhanja, Anil Kumar, Anshuman Gupta

Abstract— Rural electrification is an essential requirement for improving the lives of people residing in rural areas and improving their image among the international community. To install Photo Voltaic (PV) panels in isolated regions as per government plans and regulations, solar-based micro grids are needed for Efficiency in the Energy Sector. There are many components required for installing and operating a micro grid. In addition, the location of the micro grid also plays a vital role in the installation. To analyze the difficulties and challenges, especially in hilly terrains, a detailed review of the factors involved in installation of solar-based micro grid is carried out. The general challenges involving the technical difficulties such as the stability, reliability, power imbalance, control and operation are presented in this paper. Stand-alone models of micro grids are described along with its advantages. The government initiatives like subsidies and funding for rural electrification is discussed. As a case study, two micro grids in India, one at Ladakh and one at west Bengal are presented. These case studies bring out the problems and issues faced during the rural electrification and recommendations were given for the future scope.

Keywords- Rural electrification, Solar Power, Microgrid, Efficiency, Hilly Terrain, stand-alone model.

I. INTRODUCTION

India has a large population without access to electricity within the rural regions [1]. Even though 88% of the population, have access to electricity, the remaining 12% which constitutes 157 million people, does not have access to electricity grid. The process of electrification particularly for rural belt takes place in three stages. Stage starts with building of electricity infrastructure, followed by the connection of households in the infrastructure. The final stage is of high significance and challenging one. It is to ascertain on safe, reliable, affordable and sustained electricity [2]. Electrification in the plain terrain and urban regions are relatively easy, but there are many obstacles and challenges in electrification of the rural region of India especially for remote locations. Rural regions are normally situated in isolated remote terrains which includes hill or mountain side, deep forests, deserts and islands.

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It is difficult to lay live power cables in such terrains due to their topography and distance from the major electricity grid [3]. The lack of basic facilities and approachability makes the terrain sparsely populated.

Providing electricity, with a new grid infrastructure or by extending the existing grid is highly expensive. Most of the electricity load in rural belt are used for basic household lighting and agriculture activities. Hence the power demand is low. The power load curve is also highly variable. Thus, transmission of such low demand and variable power over long distances from the grid will incur high losses including technical and commercial. The return on investment would become unviable in most cases and would not be affordable for the rural terrain population [4]. Stand-alone model of micro grid would be a promising solution for providing affordable and reliable electricity to the inhabitants of remote rural hilly terrains [5]. This paves the way for distributed generation, which can be integrated in both standalone and interactive grid structures [6].

There are many distributed electric energy producing sources. The source should be sustainable and reliable for fulfilling rural electricity demand. One such prominent source, especially for tropical regions is solar energy. Fossil fuels for energy are not only depleting in nature, but also presents an environmental challenge. Hence, it is high time to move to renewable energy sources. Solar energy has high capacity to provide electricity which we are not been utilized to its complete potential. Hence, solar energy based micro grids are found to be a promising solution to rural terrain electrification. Also, solar power emerges as one of the best solutions for sustainable and non-pollutant environment friendly way of producing energy [7].

It is suggested that the post electrification of villages there will be increase in the valued capabilities [8]. In a nutshell, the significance of providing electricity in rural areas had been accentuated through the Electricity Act (2003) and through other national policies like National Electrification Policy [9] and Rural Electrification Policy [10]. A detailed study pertaining to rural electrification is presented in the further sections of the paper. General details about the micro grid and distributed generation is given in section 2, and also historical overview. Solar grid working principle and the key challenges of implementing micro grid are also discussed. Different types of site analysis, design analysis, and economic analysis performed during the microgrid installation is explained also. For this paper a case of rural electrification through distributed energy source in two villages of India is elaborated. Finally, the entire paper is summarized, and recommendations were given for future scope.

II. LITERATURE REVIEW

A. *Rural Electrification in India*

Rural electrification is the way of providing electricity to rural/village and remote/distant/inaccessible ranges [11]. Electricity is a crucial service for financial activities in rural regions. For rural inhabitants electricity is mainly used for pumping water for drinking and irrigation, street lighting and house lighting. Lighting in houses will enable students to study during the evening and night hours. Small scale industries can be started here with the presence of quality and reliable electricityand which will provide job opportunities to the local population. Condensed labour time for getting electrically pumped and disinfected drinking water might possibly reduce the time and that could be effectively used for revenue creating events by women, which might in turn be assisted by electric power inputs [12]. In the early seventies, when linking the towns with grid, few villages near that grid would have been benefited, i.e. rural electrification was just the by-product of town electrification in those days. The major economic activity in India being agriculture, which comprises of irrigating the fields for which pump sets are being used. So electricity was needed and we can conclude that rural electrification need is mainly driven by irrigation pump sets. Household electrification came to the forefrunt only through the Rural Electricity Supply Technology Mission (2002).

The scope of rural electrification needed certain basic agenda to be followed, which includes:

- The construction of substations and blocks of transmission lines in places, where they are absent;
- Electrification of possible villages with grid enabling facilities and habitations with a populace of 100 and more, by providing distribution transformers in newly electrified villages/habitations;
- Situating small generators and distribution net in villages where grid extensions are very costly as well as not enclosed by the remote village electrification program offered by the Ministry of New and Renewable Energy (MNRE); and
- Those households Below Poverty Line (BPL) are to be equipped with free connection while the households Above Poverty Line (APL) are to be given provision for approaching distribution companies for connection [6].

There is always shortage in quantity and quality of electricity supply in India specially in the rural terrain. The grid outages are high along with the transmission and distribution (T&D) losses, which strongly calls for an enlarged and enhanced infrastructure even for non-rural electrification. A substantial amount of the generated power is wasted due to the inefficient nature of transmission and distribution and also due to power theft. Hence, India requires better infrastructure to improve its power transmission and reduce power leakage. In addition, India is a country of farmers who are spreaded accross all terrains and hence electrifying the rural villages is a prime duty. It stands with the basic amenity like food, water and shelter in the present era. Hence, government decided on providing electricity to all villages, initially, aiming to give electricity for farming and then extending to household connection also. In recent past, Indian Govt. has introduced a major programme of grid expansion and strengthening of the infrastructure for rural electricity under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) [13].

The Indian Government has. sketched a striving plan for electrification through solar energy to 400 million people who do not have access to it. In 2015, the Government of India, started a dedicated rural electrification programme called Deen Dayal Upadhyaya Gram Jyothi Yojana (DDUGJY) for electrifying the villages which are still in darkness and allocated a budget of about 11 billion US dollars. By the end of April 2018, the villages were given electricity, but only the public places like schools, health centres, panchayat buildings, medical dispensaries and 10% of the households have been electrified, leaving 90% of households with no electric connection Wouters, C. (2015). To address this and to ensure electrification to all (100%) households in the villages, the government introduced another scheme called Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya) with a budget of 2.5 billion US dollars in 2017. This scheme would cover around 4 crore households in rural as well as urban areas just by paying INR 500 to distribution companies, as easy monthly instalments over a 10 month period in total, costing INR 50 every month. Till date, about 50% of the targeted households got electric connection and still work is in progress. The key challenges/difficulties faced during the implementation of these kinds of schemes are summarized as:

1. There are many logical issues in constructing/situating power transmission network/infrastructure, due to big topographical extent. Also, these areas are mostly uneven terrains. Hence, the grid structure with transmission lines may not be similar to that in the cases of urban and metro regions. This require intricate calculation, design and manpower.
2. Seamless implementation of government scheme with huge crores involved, requires a strong and deep coordination between various levels of government, which is not so easy.

100% electrification is essential for economic growth of the country. Transportation of electric power from the central grid to villages involves heavy loss and huge money because of the distance (remoteness) involved and the prevalent topology. Since new grid connections and expansion of the available grid are not cost-effective with regard to rural electrification, the concept of Distributed Generation (DG) can be utilized for village electrification. On-site generation/DG based on non-conventional alternate energy sources will be an economic choice to allow rural electrification at a faster pace [6].

B. *Micro Grid and Distributed Generation (DG)*

The DG can be designed as grid-interactive (Grid connected/on-Grid) or decentralized (Off-Grid/Stand-alone) types. The type of DG is mainly dependent on the type of consumer profile and the locality. The DG is frequently used as a backup source of electricity. It is used as a means of delayed investment in constructing of new transmission and distribution infrastructure.

The network charges are thus avoided, line losses are decreased, facilities for huge generators are adjourned with the use of DG. In addition, an alternative source of electric power is available in the electricity market that replaces the conventional and costlier grid power supply. This also helps in reducing environmental pollution because of the clean sources of energy associated with DG [14]. There are typically two models available for DGs. Generating electricity by the use of localized sources of energy at a local level, establishing a micro grid. It serve restricted number of consumers in the form of grouped generators. This can either be interconnected with main grid at one point or it may be a totally independent unit. In the second model, same machineries with minor scales are used and they are installed for individual power consumers, which is then referred as Distributed Generation. They can be linked to the grid individually and they can supply grid power as and when required, thus, every consumer can be a potential power producer, with a new terminology prosumer [15]. The structural differences among the centralized and distributed generation is depicted in Figure 1.

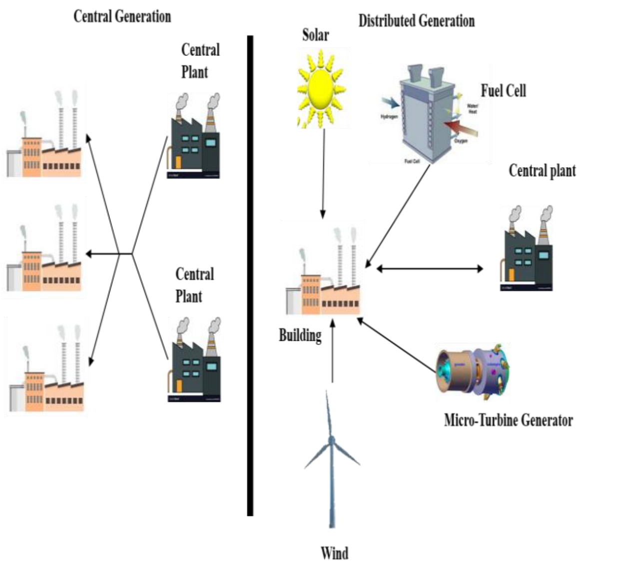

Fig 1. Structure of Distributed Generation (Source: India Smart Grid Knowledge Portal)

The microgrid can detach from the normal grid and can function independently. This grid can disconnect and operate on its own by means of local power generation during power crisis or outages. It is powered by Diesel generators, batteries, and/or renewable sources like solar panels [16].

Many renewable sources of power are appended with DGs like small hydro, micro hydro, wind turbine, geo-thermal, bio-mass etc. Apart from those mentioned, currently, solar photovoltaic (PV) plants are mainly emphasized. The similarity between all the quoted plants including PV is that they are supplying the local loads as isolated sources of power. During the year 2017, solar PVs were used to illuminate a famous monastery that is around 2,500-year-old, situated at the Ladakh region of Himalayas. This was achieved by a team of global Himalayans, to fulfil the needs of about 150 monks, who had never experienced night lighting so far [17].

The USA's very first electric commercial power plant was erected by Thomas Edison, in the Manhattan Pearl Street Station, in the year 1882 and it was basically a microgrid. It was a coal-based station, serving about 82 customers by electrifying 400 lamps. After two years, the customers grew to 508 and the lighting loads were 10,164 in number. In 1886, the firm of Edison, installed 58 microgrids with direct current. The first industrial microgrid equipped with modern technologies was constructed in Whitling refinery in Indiana with 64 MW capacity, which was constructed by USA, in 1955 [18].

The microgrid covers a variety of services, starting from lighting for residences to entertaining, refrigerating and other productive trading uses. The capacity of installation of microgrids is dependent on the amount of load to be served, type of renewable sources used, and the category of service to be provided, and ranging from a single kW to few hundred kW. Solar PV systems with microgrid is gaining significance for its reduced market price globally in recent period, and its less cost. Still, the prerequisite for solar PV cells is the battery system for storage.

The microgrid has a varied capital cost and generally spans through tens of thousands to hundreds of thousands of US dollars. The factors governing the billing charges are capital, operational and maintenance cost, government subsidies, the degree at which manufacturer recovers these expenditures. Almost in all cases, the bill paid for microgrid power is lesser than that of candles and kerosene (Energy Sector Management Assistance Program [19].

The main demerit of distributed power generation is that, there is no broad improvement in rural economy due to minimal power loads but still the energy poverty and the expenditure for the traditional method of lighting are reduced [20]. The stand-alone microgrid structure with a provision of connection to main grid is depicted in Figure 2 [21].

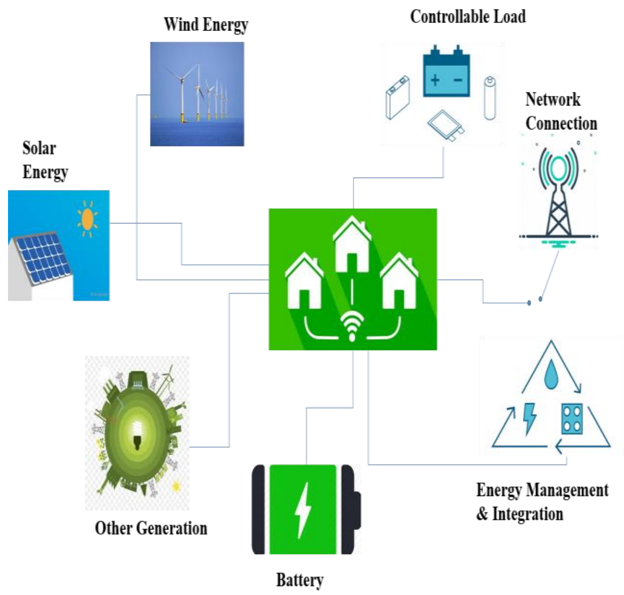

Fig 2: Micro grid system (Source: India Smart Grid Portal)

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The foremost discriminating aspect between off-grid/stand-alone and grid connected models is that the load demand and solar energy output is matched, in off-grid models. When a PV microgrid is linked with the central grid, it may transport surplus power to the grid or utilize the main grid as a system for backup, in case of inadequate generation from PV. Stand-alone systems are generally used in the cases of rural electrification [22].

The microgrids are broadly classified as DC, AC and Hybrid microgrids.

The DC microgrid incorporates a DC bus and hence avoids many conversion stages as opposed to AC microgrid. Thus, the energy efficiency is enhanced along with healthier economic operation. One of the main sources that offers DC output is the solar energy.

Solar PV cells integrated with DC microgrid is otherwise referred as Solar microgrid. The following merits can be observed with DC microgrid.

1. Many distributed PV units can be employed
2. Energy dissipation is reduced and facility cost (cost involved in AC/DC conversion) is lessened.

Even at the time of blackout of central grids, power is continued to load through normal lines of distribution.

C. The status quo of Renewable energy and microgrid in India

Decentralized stand-alone/off-grid Solar Home Systems (SHS) is majorly utilized in almost all PV projects for the purpose of rural electrification in India.

The specification of these systems ranges from 35 to 100 Wp (Watt Peak Capacity).

As per MNRE report, July 2009, about 450,000 solar home systems had been installed.

Even, 1500 KwP off-grid PV plants with self-governing distribution capability (micro-grid) had been well thought-out for electrifying the villages in India.

Based on the report of MNRE, 2009, around 5 MWp of collective micro-grid volumes are available in India, most of these being situated in Sundarbans section of West Bengal. The domestic consumers, who majorly use lighting are supplied with DC, that is obtained from SHS and in fact, the household consumers are the owners.

The Energy Service Company (ESCO), who generally setup microgrids, supply electricity in AC mode to various load points through a distribution network of low voltage capacity and it is a paid service; the power users pay for the consumed electricity [23].

SHS are premeditated and deployed for usage within individual establishment/household.

The setup for SHS comprises of PV modules, which charge a bank of batteries, that store power as DC electricity and then this stored power is used to supply the consumers, those use DC appliances like fan, TV and Compact Fluorescent Lightbulbs (CFL).

The energy flow from the battery bank and to the bank is governed/panelled by the charge controller, which is an essential fragment of SHS.

The traditional power sources such as candle, torch, kerosene, recycled battery for operating TV are replaced with SHS and are being utilized to serve the basic household facilities which are not associated to central grid.

Small power applications and home lighting are best served through SHS but the scope of generating income and the development of entire community is very much limited with SHS.

The community development here refers to the establishment of harmless drinking water, road light provision and refrigerating the essential vaccine [24].

Microgrids are meant for central electricity production and the generated power is supplied to the applications spanned inside a nominated geographical zone.

It is generally produced either as three phase or single phase as with 220 V and 50 Hz capacity.

The power being dispersed through a low voltage distribution network for domestic, commercial and community applications.

The commercial events here include the electrification of shops, video centres, small wet grinders and communicating kiosks that are operated through computers.

The major sections of a microgrid encompasses a PV array for electricity generation, a bank of battery for storing the electricity, a Power Conditioning Unit (PCU) entailing charge controllers, distribution boards, junction boxes, inverters and necessary cables /wires (all are placed within a suitably constructed building), Power Distribution Network (PDN) containing conductors, poles, insulators, cables and wires, internal wiring, service lines and appliances to separate households.

A well-designed PV/Solar based microgrid could supply sufficient power to all for 24 hours effectively when combined with other power sources viz. wind electric generator, genset operated with diesel as fuel, biomass gasifier [24].

The Indian renewable energy sector is administered by the Ministry of New and Renewable Energy (MNRE). It is focused to develop innovative and non-traditional sources, especially, wind and solar energy at an extremely faster leap and these determined goals will enhance the pride of India and the country will be placed in one among the top-most nations.

Being, the forerunners of alternate energy use, India will be put at the mid of the Global Solar Alliance plan promoting solar power expansion in almost 120 nations, worldwide.

India was the very first country across the globe, that compiled a renewable energy sources ministry, MNRE, in 1980s and this ministry intended to monitor the alternate energy resources.

As on 14 June 2017, the full installed capacity of India has touched 329.4 GW, a major of 57.472 GW is being contributed by the renewable sources of energy.

A greater share of 61% is contributed by wind energy and a considerable share of 19% is by solar energy out of the entire renewable energy [26].

The total installed capacity of grid connected renewable energy sources in India up to March 2017 is shown in Figure 3.

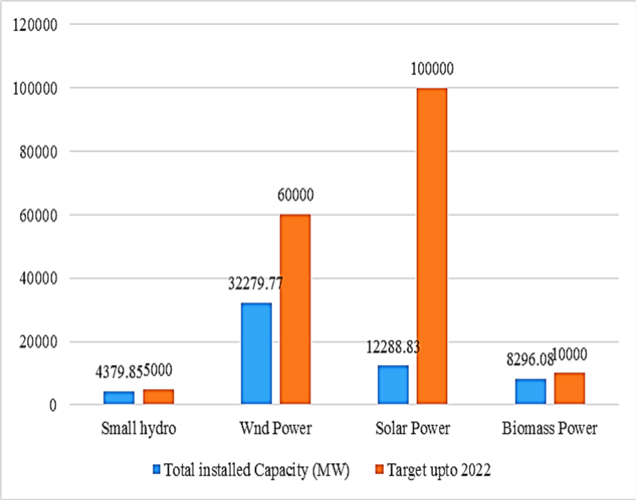

Fig 3: Total Installed capacity of grid connected renewable energy sources in India up to March 2017 (Source: Ministry of New & Renewable Energy.)

India is gifted with a massive solar energy capacity. The land area of India receives around 5x103 trillion-kilowatt hour every day and most of the parts get 4-7 kilowatt-hour per m2 each day. So, solar irradiance can effectively be transformed into both heat and electricity leading to solar thermal and solar photovoltaic technologies. These powers can be effectually harnessed and thus offering a vast scalability in India for solar power. The major advantages associated with solar power are that it is capable of generating power on distributed mode and it is possible within a short span of time to add further capacities very quickly. Applications with stand-alone, decentralized, and low temperature are beneficial from a rural electrification viewpoint and serving additional energy requirements for power, heating and cooling in rural as well as urban zones. From secured energy standpoint, solar is the utmost protected of all sources, because it is plentily available Wouters, C. (2015). Supposedly, a minor fraction of the whole incident solar energy (if captured successfully) can meet the energy requirements of the entire country. It is further understood that provided the massive percentage of underprivileged and electric power un-served inhabitants in the country, all efforts need to be done to exploit the comparatively ample sources of energy available, to the nation (MNRE).

III. WORKING OF SOLAR MICROGRID

A system based on renewable energy (RE) with dimensions lesser than 10 kW, can supply clean electric power to a bunch of households in a remote zone [27]. DC power usually produced via solar power is generally chosen, in which there are only low voltage or low power loads, viz. lighting, fans, radio, etc., and when it is closely located. The relevant voltage for the given specification of load or demand is given as under.

DC micro grids:

(i) 24 V DC -- up to 1 KwP

(ii) 72 V DC -- above 1 KwP to 10 KwP

The solar radiation impinging on the array of PV panels is transformed to electrical energy. It is then transferred to a central controller, which is referred as Power Conditioning Unit (PCU). The job of PCU includes controlling, regulating and directing the electric power received through the PV array and supplying the same to residents, streetlights, offices and shops. If the generated power is not utilized during the day or additional power is produced, the PCU channels this power to the battery bank to store the power. After sunset or during night, this saved power can be used. Both, the microgrid and the battery bank are coupled to a computer for monitoring the usage of local power. With the help of a modem, this data can be accessed from a distant/remote location, abolishing the requirement for local manpower for monitoring the system.

A. Key Challenges

There are quite a few challenges/issues with microgrid. They generally depend on the location/site, technical, policy, economic and social aspects [28][29]. In addition, the storage of energy in batteries is yet another problem that is to be effectively managed [30]. Only a few important challenges are exhibited in this section.

I. *Technical Challenges:* The microgrid must be able to function securely either coupled to the main grid or in an 'islanded/decentralized' manner [31]. In case of decentralized, stand-alone mode, it requires to dynamically manage power production and electricity utilization [32]. The crucial technical challenges on microgrid would be the frequency and voltage control, islanding/disconnecting from the main grid, and the protection of microgrid in terms of guaranteeing the distributed generations, loads and the lines [33]. In addition, a noteworthy participation by loads is mandatory and it is necessary to have durable interaction between real and reactive power. The control/ regulatory and marketplace consequences, new technologies, assessment of the microgrid boundaries are the other technical factors that influence the operation of microgrid [34].

II. *Regulatory Challenges:* The microgrid, majorly coexists with the central grid. Hence, the consumers/customers of microgrid are supposed to share some of the charges allied with the central grid's operation [35]. As well, there should be an ownership liability while offering safe operation and security of electric power supply; responsibilities that are presently accepted by the utility in the prevailing arrangement [36]. It is concentrated on distributed renewable energy (DRE) specifically, as renewables are motivating the development in distributed power generation [37]. A set of data containing the variables describing four important issues namely, present electrification condition, idea and strategies for enhancing the rate or degree of rural domestic electrification, the role of distributed renewable energy at present and policies of country for using distributed renewable energy as electrification approach are considered to comprehend the role of DG in national electrification plans [38].

The concerns and vital variables are shown in Table 1

Sl. No.	Concern	Vital Variables
1	Current Condition of Electrification	i. Rate of National, urban, and rural electrification (People, in %) ii. Non-electrified populace of National, urban, and rural (in million)
2	Electrification Plan for National and Rural Areas	i. Document title of national and rural electrification plan ii. Short-term and long-term energy access target (in %)
3	Current State of Distributed Renewable Energy (DRE) Production	i. DRE generation capacity (in MW) ii. DRE electricity consumption (in GWh/yr) iii. National and rural population electrified by DRE technologies (in million)
4	DRE's Role: Plan/ Policy for National Electrification	i. Document title of national DRE plan ii. Responsible institution iii. Short-term and long-term DRE generation target (in %) iv. Investment plan (in million USD) v. DRE technologies vi. Policy instrument

Table I: The concerns and vital variables considered to comprehend the role of DG in national electrification plans (Source: Author Source)

I. *Economic Challenges:* At least at commencement, and particularly in areas where the resources for utility is fully depreciated, the energy cost will be more from the distributed resources/companies. As costs for important microgrid components like renewable energy sources (e.g., solar), storage of electrical energy (e.g., batteries, supercapacitors), cutting-edge load generation controls, and intelligent switches continue to reduce, the finances for microgrids for explicit applications may become inexpensive in comparison with the regular power sources [39].

II. *Energy Storage System:* One of the decisive components that aids in proper functioning of microgrid is the storage device, for instance, the battery bank. The Energy Storage System (ESS) actually matches the energy demand of the consumer with the generated energy of power producer. From the prevailing techniques for ESS, batteries and super capacitors are found to be the better choices for micro grid functioning [40].

IV. MICRO GRID ANALYSIS

A detailed analysis is needed for effectively implementing the system. The analysis is done on site, design and economy with regard to the microgrid.

A. Proposed Site Analysis

Lots of aspects comprising the topography of the land, nearness to load demand, reachability/approachability, the kind of land use, distance between the available and planned electrical transmission lines decide the process of PV plant siting [41]. The temperature and dust, which are referred as negative environmental elements had a great influence over the efficiency of the plant which in turn affect the economic profits in case of PV farms and they were also accounted for the site analysis [42]. Research on siting focus of solar system and assessment of solar energy reveal that it is very tough to get flat terrains in urban zones and it is not cost-effective. As per the studies by Gastli and Charabi [43], the utmost appropriate area for PV plant is the flat area and for successful operation, it must face south or north direction (as per equator direction) with an angle of slope lesser than 10 degrees. The apt terrains for PV plant setting up was abstracted using multi-criteria evaluation model, which combines the Digital Evaluation Model (DEM) in GIS platform and other spatial information [44]. Huge terrains are essential for execution and expansion of PV farms. A master design for deploying solar energy and for planning the optimization of electric transmission grid to ascertain the future solar energy market lies on identifying the appropriate land. Almost in all developed/urbanized nations, a highest percentage of residents live in urban environment, leading to difficulty in getting lands near the city areas and getting even a minimum land area is very costly. This pushes the location of PV plants in remote/distant areas, which are far away from the core loads. The assessment of solar irradiance necessitates a denser network of PV plants in case of composite terrains as opposed to flat terrain [45]. The surface elevation, gradient, alignment and positioning, surface position of adjacent terrains are the deciding factors of solar irradiance in mixed terrains. The larger usage of solar energy is affected by climatic and geographic elements that influence the spatial and temporal variations. To eliminate the lengthy lines for transmitting the energy produced to the power consumption areas through solar PV, an inclined terrain will be a very good option. The unexploited inclined nearby lands were used to evaluate the capacity of solar PV [46][47][48].

B. Design Analysis

The isolated/stand-alone power systems should be modelled on the basis of constraints related to technical and economic aspects, to satisfy the location specific demands [49]. Also, the design should accommodate the effect of fluctuating PV resources. The design of battery size is decided by considering the number of self-sufficient days and the days during which sun is not available (cloudy days). But sometimes it is solely dependent on the end use [50]. The assessment by these kinds of methods is not accurate and complete. The design space method is useful because the entire viable configurations of the system are mapped [51]. The sizing of PV system is not only meant for design of PV array but also includes the design storage battery capacity.
CA, the capacity of PV array, is defined as the ratio of mean values of produced energy of PV array and the load demand. CS, the capacity of storage battery is the ratio of capacity of battery to load demand. There are 3 types of sizing methods, namely, intuitive or empirical, analytical and simulation methods [52]. The requirements of battery storage capacity and rating of islanded PV generator were linked for the given pattern of electric power demand and the efficiency of power conversion from solar irradiance to electricity. In this method, a sizing curve is framed to find the rating of PV generator and associated least capacity of storage batteries.

The maximum and minimum values of ratings of generator as well as batteries could be found. This method was demonstrated on DG-battery and PV-battery Systems [53]. The effect of projected load factor of the village that has to be solar powered, on the microgrid design was tested and the energy cost had been investigated [54]. In addition, there are many technical studies available in the literature for resolving the technical issues related to microgrid [55][56].

There exists a disparity while the microgrid shifts from on-grid to off-grid mode, especially when the disconnect takes place during supplying or absorbing power by the microgrid. Few micro resources may be with less inertia and the dynamic response of these sources would be slow. Hence, to maintain the balance of power, energy storage units are used. When the microgrid is about to restore to grid connected mode, it may be synchronized after verifying the voltage, frequency and phase angle. This issue may be resolved by the use of an automated sensitive static switch of high-speed capacity before the disconnection [57].

C. Economic Analysis

Most of the studies related to the analysis of energy cost in microgrids omitted the grid infrastructure cost because of the minor contribution by the main grids which are just less than 10% of the total cost [58]. Rural electrification with microgrid needs to encompass industrial, commercial and residential loads at the preparation stage itself to improve the electrification of the intended village. These are encouraged by the government, microgrid investors and NGOs [59]. Currently solar panels are offered at subsidized costs by the government of India, which would help in developing the microgrid. Even though the grids are not available directly for purchase in single module, individual components can be purchased. Most of the microgrids installed in rural regions have been done with financial assistance from NGOs [60].

In fact, any technical challenges are resolved by placing any new tool/gadget. The energy storage system may increase the cost of the microgrid. Any other challenges considered as key challenges will include the economic aspect also [61].

V. CASE STUDIES

The benefits and intricacies involved in microgrid pertaining to rural electrification is well perceived by analysing the case studies. A few case studies have been discussed in this section.

A. 1MW Solar Microgrids – Ladakh, India

Ladakh village, famous for “kargil war of year 1999”, is in Union Territory of Ladakh, India. It is "the land of high passes" and lies between the Himalayas and the Kunlun mountain range at an elevation of more than 3,000 meters. From December to February, the temperature may go up to -20°Cand the average temperature being 2°C. During March and April, the night temperature floats between 6°C to -5°C and the average day temperature is 12°C. From May to August, the temperature shifts from 16°C to 3°C between day and night respectively. September to November, this region receives high sunlight and the average temperature in day is 21°C and 7°C at night [61]. The entire inhabitants of this region are equally fragmented in Leh and Kargil districts. The total population in Leh is 1,17,637 and in Kargil is 1,15, 287. The public of stunning Leh valley have struggled for epochs to have complete access to energy for their rudimentary needs, for example, light, hot water or electricity. The home-grown renewable energy agencies and MNRE recognized the villages of Ladakh that were lacking any supportable source of energy and united with Tata Power Solar to design solar power ventures that solar-powered more than 100 villages where grid connectivity was not possible [62].

Challenges: Transportation of components: Mules and yaks carried solar panels across the high passes of the mountains (where in which motor power units are not possible) through altitudes be close to at 18,000 ft. and the average temperatures at -20°C during winter. To counter these issues, Tata Power Solar customized the components of the solar power plant in such a way that they are compact and easy to transport. For sample, dimensions/size of the battery was reduced to permit its transportation via mules and yaks on the uneven, and bumpy terrain and the number of batteries had been increased for getting the required power output.

Very cold climate for 6 months: As the climatic situations of the Leh and Kargil region is such that there is no access to these regions at least for 6 months in a year, maintenance of the projects was a big challenge. This unruly weather was taken into consideration and an adequate stock of standbys were maintained at the site.

Impact: More than 3.5 Mn units of power has been created in the past 2 years that has illuminated about 35 villages (including schools and institutions) with lights in addition to offsetting approximately 3000 tons of carbon di oxide every year. Uninterrupted power supply for more than 8 hours is offered to public of this region.

B. 110 kW Solar Microgrid – Sundarbans, West Bengal, India

The village Indrapur is situated in Patharpratima Tehsil of South Twenty-Four Parganas district in West Bengal, India. It is located 22 km away from sub-district headquarter Ramganga and 117km away from district headquarter Alipore. The whole geographical measurement of this village covers about 7.69 square kilometres [63]. It has a total inhabitant of 2,00,000 people. There are about 2000 families in this village.

The nearest town for this village is Diamond Harbour, which is roughly 100km away. From Howrah to Patharpratima, the distance is 81 km and it takes close to one and half an hour to reach this village through a ferry boat. Tata S olar Power custom-built 110 kW solar plant and it was commissioned in March 2011. The village climate is such that it alternately gets a bright and cloudy day [62].

I. Challenges: Accessibility to site location: The only way to access the project location was through a 90-minute commuter boat ride from Patharpratima, the nearby ferry dock, that is 81 kms away from the adjacent railway station.

The shipping of components and the process of work should be well planned and organized. If not, the overall project would be affected.

II. Absence of continuous sunlight: Due to nonexistence of incessant exposure to sun, there was a problem of getting consistent electricity powered by solar. An exclusive solar power scheme was premeditated on a two-day autonomy (self-sufficiency) mechanism, where, the battery bank was changed to release/ discharge only 25 – 30% of stored power per day irrespective of a cloudy or sunny day. Thus, the battery can store up to 70-75% of energy so that it can be used on the subsequent day.

III. Impact: The designed microgrid was well matched to the fragile ecosystem, that may include small islands, deserts, mountains, semi-arid lands, wetlands and few coastal areas of the region (ENVIS Centre on Floral Diversity, West Bengal, India). The fishing community of 10,000 people got accessibility to electric power and hygienic water. About 2000 families had received electricity and children were privileged to get good quality of light for doing their homework after dark. The rate of literacy had been improved, and the economy of island had been enhanced by stretched working hours, in particular, the periodically held village markets in India.

VI. DISCUSSION

Rural electrification decides the economy of the nation and for the welfare of the population, community and nation as a whole. Microgrid is the best choice of electrifying the villages. Out of the available resources, solar PV suits the rural climate. However, the placing of microgrid depending on the terrain and designing of microgrid with respect to rural loads. Maintaining and controlling the microgrid is really require careful planning and execution. The Government of India has a clear vision of improving electrification in all the villages across the nation and provides subsidies in various forms for various schemes. The awareness about these schemes should be created amongst the rural population to achieve real success. The contribution of this work lies in the fact that the work has covered the Indian perspective of rural electrification. There are very few studies on rural microgrids on the Indian perspective. The rural mountainous regions of India have very less population density, hence the government do not find it feasible to electrify these isolated pockets of villages.

VII. CONCLUSION AND FUTURE SCOPE

Electricity has wide range of applications viz. domestic, industrial, commercial, irrigation etc., The country's entire population is segregated in cities, towns and villages. Though people in cities and towns enjoy the full benefits of electricity, the rural community is deprived of it. It is because of various reasons.

Electricity is a commodity, which requires strong infrastructure, starting from power stations, substations, transmission and distribution network, central grid etc., transporting electricity involves line losses also and this would increase with larger distances. According to the topology, the rural populations reside in remote areas from power producing centres and substations. The grid structure involves construction of poles and towers. The terrain where rural people live are generally complicated and involves more planning and design. Moreover, the load demand or electricity usage in urbanized areas is more and hence the energy cost can be recovered easily. In contrast, the demand for load is less in rural villages and mostly the load is for lighting. The cost of power infrastructure is not justified with regard to grid connected electricity supply for the rural populace. As an alternative and cost-effective method, SHS and microgrid came into place. In microgrid, excess power if generated or the power that was not used during day time can be supplied to grid if the microgrid designed is interactive to main grid. Microgrid can be islanded whenever required and it can supply loads even during blackout. This paves way for "prosumers" which enhances the livelihood of village dwellers [36].

Though a method is devised for electrifying villages, there are many complications involved in actually creating a microgrid at their places. A rigorous literature survey was made to understand the challenges involved in solar microgrid including, site analysis, technical difficulties, storage of power, number of batteries, cost optimization and regulatory issues. The probable solution to a particular challenge was discussed in the previous section. Few case studies were discussed to analyze the problems, which are location specific. The reliability of the solar microgrid is mainly based on the intensity of sunlight and availability of sunlight. Also, to extract maximum power, proper power tracking technology should be used. So, in future to fully harvest the benefits of electricity in rural areas, a hybrid system involving many renewable sources will evolve. These systems are already in place but in rural community, solar and wind are used as sources of hybrid energy. In future, many sources which have potential in that particular region can be examined. When combined with proper algorithm and technology, the quality of microgrid would improve and in future, the design and control of microgrid should be integrated with economy optimization. It is concluded that more challenges are faced while placing the microgrid in hilly terrain and entirely different approach is needed for transportation of components, improving the sustainability of the grid and the economy.

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