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TECHNO-ECONOMIC CHALLENGES IN IMPLEMENTATION OF SOLAR EQUIPMENT BASED ON A STAND-ALONE MICROGRID IN HILLY TERRAINS OF RURAL INDIA

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Abstract: Rural electrification is an essential requirement for improving the lives of people and improving their image among the international community. To install photovoltaic (PV) panels in isolated regions according to the government plans and regulations, solar-based microgrids are the best solution. However, there are several components required for installing and operating the microgrid, including its location of the microgrid. The present paper made an effort to explore the challenges encountered in installing solar-based microgrids, especially in hilly terrains of rural India. The review highlighted the varied technical difficulties including the stability, reliability, power imbalance, control and operation. Besides, the discussion on the stand-alone models of a microgrid along with its advantages, also been highlighted. Further, government initiatives like subsidies and funding for rural electrification also been presented. As a case study, two microgrids in India, one at Ladakh and one at west Bengal are presented. These case studies bring out the challenges faced during the rural electrification, and strategies adopted to overcome are given for the future scope.

Keywords: rural electrification, solar power, microgrid, hilly terrain, Indian solar power scenario, stand-alone model of microgrid

INTRODUCTION

India has a large population and with third-largest electricity producer in the world. Nonetheless, about 300 million people remain un-electrified especially in the rural regions (Ritchie & Roser. 2019). On the other hand, there is an exorbitant gap between electricity production and the demand for electricity. The use of coal and fossil fuels for electric energy is not only depleting them but also keeps a challenge on environmental concern. Therefore, the use of renewable energy is the only solution to make pollution free(The World Bank. 2019). Although there are several electric energy producing sources, the heart of rural electrification is having the sustainable, non-pollutant environment-friendly and reliable energy. One such prominent and viable sources, especially in the tropical region is the solar energy (Verma et al. 2014).

Solar energy, which is produced by using the techniques of concentrated solar power (CSP) or solar photovoltaic (SPV). The solar energy has the highest capacity to provide electricity, but it has not been utilized to the highest potential. Solar energy-based microgrids are found to be a promising solution to terrain electrification particularly in rural, remote villages and for poor communities. In remote villages of India, there are many constraints in electrifying as these isolated regions are presented with deep forest, deserts, islands, hills and therefore there is a lack of clear approachability and less populated. Besides, laying live conductors in such terrains is challenging due to their topography and distance from the grid (Diesendorf & Elliston. 2018). Providing electricity, with a new grid structure, or through the expansion of existing grid is highly expensive, especially considering the quantity of consumption. Most of the loads would be used for lighting; hence the power demand would be low and transmitting such low power over long distances from the grid will incur high losses for power transaction and distribution. The return on investment would become non-existent and might be negative in most cases, and hence would not be affordable (Sastry. 2003). Rather than expanding the central grid, using a stand-alone model of microgrid would be a promising solution for isolated hilly terrains (Hubble & Ustun. 2018). This paves the way for distributed generation or for the concept of a microgrid which is suitable for both stand-alone and interactive structures (Mothilal Bhagavathy & Pillai. 2018). Although the government has initiated several rural electrification programs at village levels (e.g., Deendayal Upadhyay Gram Jyoti Yojana (DDUGJY), the Rajiv Gandhi Grameen Vidyutikaran Yojana) [9], but these programs have largely created impact [4] and still, the aspiration for rural electrification is self-limited.

The paper is structured as follows: First section of the paper overviews the rural electrification in India while section 2 details about the microgrid and distributed generation, and gives a historical overview, solar grid working, and the key challenges of implementing microgrid. The next section describes the different types of site analysis, design analysis, and economic analysis performed during the microgrid installation. Two case studies are discussed in terms of challenges faced during the rural electrification, and strategies adopted to overcome. Finally, the summary and recommendations were given for future scope.

RURAL ELECTRIFICATION IN INDIA: AN OVERVIEW

Rural electrification involves transmitting electric power to rural and inaccessible regions (Alliance for Rural Electrification. 2019). Electricity is an important service for financial operations in rural areas. For rural communities, the beneficial and optimistic results of supplying energy for essential needs such as drinking and irrigation pumping, street lighting, house lighting are significant. House illumination would enable students to learn during night and night hours. Small-scale factories can be started here with energy to create livelihood prospects for the local community. Condensed operating periods for electrically pumped and disinfected drinking water could reduce time and could be used efficiently to raise income for women, who could, in turn, be supported by electrical power inputs. (Cecelski. 2003).

A few decades earlier, when linking the towns with grid was the primary priority, few villages near that grid were benefited, i.e. rural electrification was just the by-product of urban electrification. The main occupation in India was its agricultural sector, hence electrical pumping systems were used to irrigate the fields of a larger region, for which electricity was required. Therefore, rural electrification was mainly powered by agricultural electrification. Household electrification was only brought to the fore by the Rural Electricity Supply Technology Mission (2002). The scope of rural electrification needed specific basic agenda to be followed, which includes:

- The construction of substations and transmission lines, wherever required.
- Electrification of possible villages with grid enabling facilities and habitations with a population 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
- The households of Below Poverty Line (BPL) are to be equipped with free connection while the households of the Above Poverty Line (APL) are to be given provision for approaching distribution companies for connection (Mothilal Bhagavathy & Pillai. 2018).

Electricity is a crucial input to make people's choices and opportunities very clear. It is suggested that the qualitative approach towards the electrification of villages should improve the settings for politics and society in terms of valued capabilities (Malakar. 2018). There is a strong mandate for the State Electricity Boards (SEBs) to supply electricity to all regions, including urban and non-urban areas. In a nutshell, the significance of providing electricity in rural areas had been accentuated through the Electricity Act (2003) and the other policies of a nation like National Electrification Policy (The Gazette of India. 2005) and Rural Electrification Policy (Authority & Power. 2006). Therefore, at the household level, in October 2017, the government launched the Saubhagya Programmes alongside DDUGJY [12]. Implementation of these programs had reached 30 million households with some degree of electrification [13]

There is still a significant shortage in the quantity and standard of electricity supply in India. Grid outages are common along with transmission and distribution (T&D) losses, which clearly call for an expanded and improved system and for non-rural electrification. Owing to the unreliable existence of transmission and distribution and power theft, a considerable amount of produced power is lost. India also wants improved facilities to boost its power transmission and reduce its waste of electricity. Moreover, India is a land of farmers who have spread through all fields, and hence electrifying rural villages is a primary task, and in the present era it is considered a necessity along with food, water, and shelter. Thus, the government agreed to provide electricity to all villages, initially to provide power for cultivation, and then also to add power to household connections. Recently, the Indian Government. has introduced a major program of grid expansion and strengthening of the infrastructure for rural electricity under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)(Data.gov. 2020)

The Indian government has sketched a striving plan for electrification through solar energy to 400 million people who do not have access to the grid. In 2015, India's Government started a dedicated Rural electrification programme called Deen Dayal Upadhyaya Gram Jyothi Yojana (DDUGJY) for electrifying the villages that 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 public places like schools, health centers, 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 ensure electrification to 100% households in the villages, the government introduced another scheme called Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya) budget of 2.5 billion US dollars in 2017. This scheme would cover around four crore households in rural and urban areas just by paying INR 500 to distribution companies, as easy monthly installments for ten months' period in total, costing INR 50 every month. To date, about 50% of the targeted households got an electric connection and still work is in place. The Key challenges/difficulties faced during the implementation of these kinds of schemes are summarized as:

There are many logical issues in constructing/situating power transmission network/infrastructure due to a 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 requires intricate calculation, design and manpower. Seamlessly, implementing a government scheme with huge cores involved requires strong and deep coordination between various levels of government, which is not so easy. 100% electrification is essential for the economic growth of the country. Carrying electric power from the central grid to villages involves massive loss because of the distance (remoteness) involved and the topology existing. Since new grid connections and expansion of the available grid are not cost-effective concerning 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 is an economical choice to allow village electrification faster (Mothilal Bhagavathy & Pillai. 2018).

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 consumers and locality. The DG is frequently used as a backup source of electricity. It is used as a means of delayed investment in the building 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 associated with DG (S. Singh et al. 2009).

There are typically two models available for decentralized generation. Generating electricity by the use of location-specific sources of energy at a local level, establishes a Microgrid, serving a restricted number of consumers in the form of generators grouped. This can either be interconnected with the main grid at one point, or it may be a totally independent unit. In the second model, the same machinery with minor scales are used, and they are installed by the individual consumer of power, which is then referred to 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 (India Smart Grid Knowledge Portal. 2019). The structural differences between the centralized and distributed generation is depicted in Figure 1.

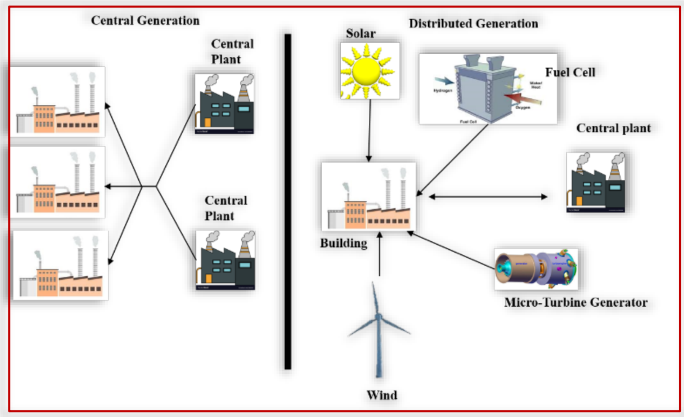

Figure 1. Structure of Distributed Generation (2019)

The microgrid can detach from the normal grid and can function autonomously. The microgrid has control capacities and is a local energy/power grid. This grid can disconnect and operate on its own by means of local power generation during the power crisis or outages. It is powered by Diesel generators, batteries, and/or renewable sources like solar panels (Hirsch et al. 2018).

Many renewable sources of power can be compatible with generators including small hydro, micro-hydro, wind turbine, geothermal, and biomass. 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 without a link to the central grid. During the year 2017, solar PVs were used to illuminate a famous monastery of 2,500-year-old, situated in the Ladakh region of Himalayas. This was achieved by a team of global Himalayan to fulfill the needs of about 150 monks, who had never experienced night lighting so far (Suryad et al. 2017).

— Historical overview

The USA's first electric commercial power plant was erected by Thomas Edison in the Manhattan Pearl Street Station, in the year 1882. It was a coal-based station, serving about 82 customers for 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, in 1955 (Pike Resarch. 2009)

The microgrid encompasses a range of services, from the illumination of homes to entertainment, refrigeration, and other efficient industrial uses. Microgrids' operation depends on the volume of load to be handled, the type of renewable source used, and the type of service to be offered. This can vary from a single kW to a few hundred kW. Microgrid solar PV systems have been highly important owing to their decreased retail rates worldwide in the recent timeframe and their lower costs. Even the storage battery solution is a requirement for solar PV cells.

The microgrid has a varied capital cost and generally spans 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 the 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, (ESMAP. 2000).

The main demerit of distributed power generation is that there is no broad improvement in the rural economy due to minimal power loads. However, expenditure for the traditional method of lighting are reduced (Aklin et al. 2017).

The stand-alone microgrid structure with a connection to the main grid is depicted in Figure 2 (Energy Networks. 2019).

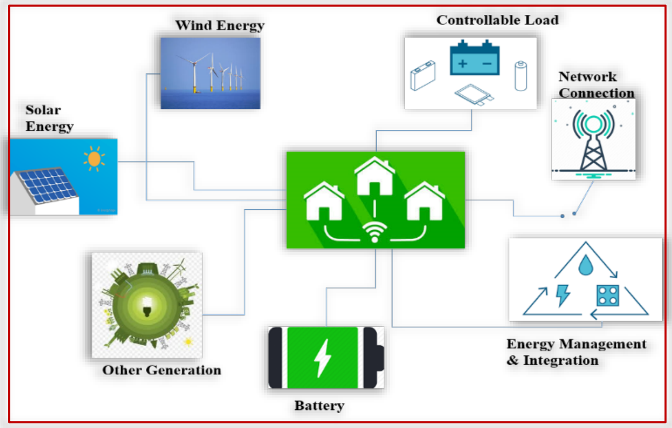

Figure 2. Microgrid system

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 backup system, in case of inadequate generation from PV. Stand-alone systems are generally used in the cases of rural electrification (Saulo & Omondi. 2015).

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, energy efficiency is enhanced along with healthier economic operation. One of the main sources that offer DC output is solar energy. Solar PV cells integrated with DC microgrid is otherwise referred to as Solar microgrid. The following merits can be observed with DC microgrid.

≡ Many distributed PV units can be employed
≡ 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 distribution lines.

— 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 India's villages. 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 the 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 micrograds, supplies the electricity in AC mode to various load points through a distribution network of low voltage capacity. It is a paid service; the power users pay for the consumed electricity (Arun et al. 2007).

SHS are premeditated and deployed for usage through individual establishment/household. The setup for SHS comprises PV modules, which charge a bank of batteries, that store power as DC electricity. This stored power is used to supply the consumers that use DC appliances like fan, TV, and Compact Fluorescent Lightbulbs (CFL). The battery bank's energy flow and the bank are governed/paneled by the charge controller, an essential SHS fragment. The traditional power sources such as candle, torch, kerosene, recycled battery for operating TV are replaced with SHS. They are being utilized to serve the necessary household facilities which are not associated with the central grid. Small power applications and home lighting are best suited through SHS, but the scope of generating income and the entire community's development 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 (Kamalapur & Udaykumar. 2011).

Micrograds are meant for central electricity production, and the generated power is supplied to the applications spanned inside a nominated geographical zone. It usually is generated as 3-phase and 1-phase power with a power capacity of 220 V and 50 Hz. The electricity is distributed through a low voltage distribution network for residential, commercial, and community purposes. The commercial activities here include shops and offices. The major sections of a microgrid contain a PV array for electricity generation, battery banks for storing the electricity, a Power Conditioning Unit (PCU) distribution boards, junction boxes, inverters, and necessary cables /wires. The Distribution Network contains various materials like conductors, poles, insulators, cables, and wires, to individual households. A well-designed PV/Solar based microgrid could supply sufficient power for at least 24 hours effectively when combined with other power sources like wind, electric generator, diesel generator, or biomass gasifier (Alzola et al. 2009).

Indian renewable energy is administered by the Ministry of New and Renewable Energy (MNRE). It is focused on developing innovative and non-traditional sources, especially wind and solar energy, at a significantly faster leap. Being the forerunners of alternate energy use, India would be among the Global Solar Alliance plan promoting solar power expansion amongst 120 nations. India was the first country to have a dedicated ministry for renewable energy sources. This ministry was started in the 1980s and is intended to monitor alternate energy resources. As of 14 June 2017, India's full installed capacity has touched 329.4 GW, the renewable sources of energy are contributing a major of 57.472 GW. A more significant share of 61% is contributed by wind energy, and a considerable share of 19% is by solar energy out of the entire renewable energy (Government Of India Ministry of Power Central Electricity Authority. 2018). The total installed capacity of grid-connected renewable energy sources in India up to March 2017 is shown in Figure 3.

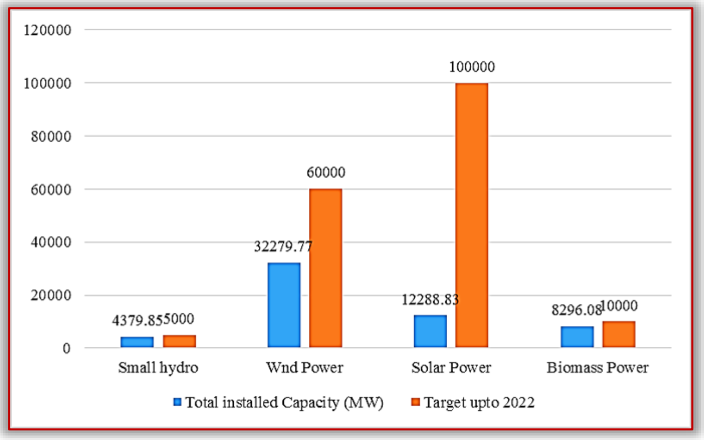

Figure 3. The total installed capacity of grid-connected renewable energy sources in India up to March 2017 (Ministry of New & Renewable Energy. 2019).

India is gifted with a massive solar energy capacity. India's land area 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 vast scalability in India for solar power. The major advantages associated with solar power are that it can generate power on distributed mode, and it is possible within a short period to add additional capacities very quickly. Applications with Stand-alone, decentralized, and low temperatures are beneficial from a rural electrification viewpoint and serve additional energy requirements for power, heating, and cooling in rural and urban zones. From a 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 entire country's energy requirements. It is further understood that provided the massive percentage of underprivileged and electric power un-served inhabitants. All efforts must be made to exploit the comparatively ample energy sources existing to the nation (MNRE).

— Key Challenges

There are quite a few challenges/issues with a microgrid. They generally depend on the location/site, technical, policy, economic and social aspects (Chauhan. 2016; Sabzehgar. 2017). In addition, the storage of energy in batteries is yet another problem that is to be effectively managed (Faisal et al. 2018). A few of these challenges are discussed in this section.

Technical Challenges: The microgrid must function securely either coupled to the main grid or in an 'islanded/decentralized' manner (Sandhu & Thakur. 2014). In the case of decentralized, stand-alone mode, it must dynamically manage power production and electricity utilization (Hossain et al. 2018). The crucial technical challenges on microgrid would be the frequency and voltage control, islanding/disconnecting from the primary grid, and microgrid protectionmicrogrid protection in terms of guaranteeing the distributed generations, loads, and the lines (Salam et al. 2008). In addition, 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 (Hatziargyriou. 2004)

Regulatory Challenges: The microgrid majorly coexists with the central grid. Hence, the microgrid consumers/customers are supposed to share some of the charges allied with the central grid's operation (Kharul. 2013). There should also be an ownership and liability while offering safe operation and security of electric power supply; responsibilities that are presently accepted by the utility in the prevailing arrangement (Wouters. 2015). It is concentrated on distributed renewable energy (DRE) specifically, as renewables motivate the development of distributed power generation (Williams et al. 2015). A set of data containing the variables describing the country's important issues and policies is considered to comprehend the role of DG in national electrification plans (Ma & Urpelainen. 2018). The concerns and vital variables are shown in Table 1.

Table 1. The concerns and vital variables considered to comprehend the role of DG in national electrification plans (Ma & Urpelainen. 2018).

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

— Economic Challenges: The installation cost would be higher for the utility companies. As costs for important microgrid components like renewable energy sources, Energy storage, 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 (Carey & Miller. 2012).

— Energy Storage System: One of the decisive components that aids in the proper functioning of a microgrid is the storage device, for instance, the battery bank. The Energy Storage System (ESS) matches the consumer's energy demand with the generated energy of the power producer. From the prevailing techniques for ESS, batteries, and supercapacitors are better choices for microgrid functioning (R. Singh et al. 2018).

MICRO-GRID ANALYSIS

A detailed analysis is needed for effectively implementing the system. This will lead to a proper feedback and corrective measure. The design analysis and economic analysis is done on the site.

— Proposed Site Analysis

Several aspects are necessary to decide the location of the site. The primary factors are the land's topography, nearness to load demand, approachability, and the type of land use (Charabi & Gastli. 2011). The temperature and dust, which are referred to as negative environmental elements, had a great influence over the plant's efficiency, which in turn affect the economic profits in the case of PV farms and were also accounted for the site analysis (Mani & Pillai. 2010). Research on location identification focuses on the illumination of the region. It is identified 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 (2010), the utmost appropriate area for PV plant is the flat area, and for successful operation, it must face south direction with an angle of slope lesser than 10 degrees. The apt terrains for PV plant setting up were abstracted using a multi-criteria evaluation model, which combines the Digital Evaluation Model (DEM) in GIS platform and other spatial information (Arangarajan et al. 2015). Large terrains are essential for the execution and expansion of PV farms. A master design for deploying solar energy and planning the optimization of the electric transmission grid to ascertain the future solar energy market lies in identifying the appropriate land. Almost in all developed/urbanized nations, the highest percentage of residents live in an urban atmosphere, 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 the case of composite terrains as opposed to flat terrain (Chrysoulakis et al. 2004). The surface elevation, gradient, alignment, and positioning, the surface position of adjacent terrains are the deciding factors of solar irradiance in mixed terrains. The larger usage of solar energy is affected by the climatic and geographic elements that influence the spatial and temporal variations. An inclined terrain will be a very good option to eliminate the power consumption areas through solar PV. The unexploited inclined nearby lands were used to evaluate solar PV's capacity (Charabi et al. 2016; Chimtavee & Ketjoy. 2012; Hamza et al. 2017).

— Design Analysis

The Isolated/stand-alone power systems should be modeled based on constraints related to technical and economic aspects and probable consistency to satisfy the location-specific demands (Markvart et al. 2006). Also, the design should accommodate the effect of fluctuating PV resources. The design of the battery's size is decided by the number of self-sufficient days in case of simple methodologies (Khatib et al. 2016). These kinds of methods are not accurate and complete, while the design space method is useful because the entire viable configurations of the system are mapped (Hontoria et al. 2005). The sizing of a PV system is meant for the design of a PV array and 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 storage battery capacity, is the ratio of the capacity of battery to load demand. There are 3 types of sizing methods, namely, intuitive or empirical, analytical and simulation methods (Egido & Lorenzo. 1992). 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 was created to find the rating of PV generator and associated least capacity of storage batteries. The maximum and minimum values of ratings of the generator as well as batteries, could be found. This method was demonstrated on DG-battery and PV-battery Systems (Arun. 2018). The effect of the village's projected load factor that has to be solar-powered on the microgrid design was tested, and the energy cost had been investigated by Mellit (Mellit. 2010). In addition, there are many technical studies available in the literature for resolving the technical issues related to microgrid (Balijepalli et al. 1967; Del Carpio Huayllas et al. 2010).

A disparity in the microgrid shits from on-grid to off-grid mode, primarily when disconnect occurs while supplying or absorbing power by the microgrid. Few micro resources, maybe 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 magnitude and phase angle. This issue may be resolved by using an automated, sensitive static switch of high-speed capacity before the disconnection (Xiao et al. 2010).

— Economic Analysis

Most of the studies related to the analysis of energy cost in microgrids omitted the grid cost because of the main grids' minor contribution, which are just less than 10% (Moreno et al. 2012). Rural electrification with designed microgrid needs to encompass industrial, commercial and residential loads at the preparation stage itself to improve the intended village and are to be encouraged by the government, microgrid investors and NGOs (Robert et al. 2017). 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, individual components can be purchased. Most of the microgrids installed in rural regions have been done with financial assistance from NGOs (Fowlie et al. 2018). Any technical challenges, resolved by placing any new tool/gadget and the energy storage system, would increase the microgrid cost. Any other challenges considered as critical challenges will include the economic aspect also (Mao et al. 2014)

CASE STUDIES

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

≡ **1MW Solar Microgrids – Ladakh, India**

Ladakh village, famous for "Kargil war of the year 1999", is in Jammu and Kashmir, India. It is "the land of high passes" and lies between the Himalayas and the Kunlun mountain range at more than 3,000 meters above sea level. The temperature may go up to -20°C from December to February and 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 the day is 21°C and 7°C at night (Climate Data website. 2019). The entire inhabitants of this region are equally split 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 has 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, united with Tata Power Solar to design solar power venture that solar-powered more than 100 villages where grid connectivity was not possible (TATA Power Solar Website. 2019).

≡ **Challenges:**

- Transportation of components: Mules and yaks carried solar panels across the mountains' high passes through altitudes close to 18,000 ft. and the average temperatures at -20°C during winter. To counter these issues, Tata Power Solar customized the solar power plant components so that they are compact and easy to transport. For instance, the battery dimensions were reduced to permit transportation via mules and yaks on the uneven and bumpy terrain. The number of batteries had been increased to get the required power output.
- Temperature: The climatic situations in Leh and Kargil region are such that there is no access to these regions for 6 months in a year. Hence maintenance of the projects was a big challenge. This unruly weather was taken into consideration, and an adequate stock of standbys was maintained at the site.

≡ **Impact:**

More than 3.5 million units of power have been created in the past 2 years, which has illuminated about 35 villages with lights and offsetting approximately 3000 tons of carbon dioxide every year. The uninterrupted power supply for more than 8 hours is offered to the public of this region.

≡ **110 kW Solar Microgrid – Sundarbans, West Bengal, India**

The village Indrapur is situated in Patharpratima Tehsil in West Bengal, India. It is located 22km away from sub-district headquarter Ramganga and 117km away from district headquarter Alipore (Indian Village Directory. 2019). It has a total population of 200,000 people and 2000 families. The nearest town is Diamond Harbour, which is roughly 100 km 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 Solar 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 (TATA Power Solar Website. 2019).

≡ Challenges: Accessibility to site location: The only way to get to the project site was via a 90-minute boat trip from Patharpratima, the nearby ferry port, 81 km from the adjacent railway station. The shipment of parts and the work process should be fully prepared and well-coordinated. If not, the total project may have been impacted.

≡ Absence of continuous sunlight: Due to the nonexistence of continuous exposure to the 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 to be used on subsequent days.

≡ Impact: The designed microgrid was well matched to the fragile ecosystem, including 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 a good light quality for doing their homework after dark. The literacy rate had been improved, and the island's economy had been enhanced by stretched working hours, particularly the periodically held village markets in India.

FUTURE RECOMMENDATIONS AND LESSONS FOR TRANSITION

Rural electrification decides the nation's economy and the welfare of the people. The microgrid is the best choice for electrifying the villages. Out of the available resources, solar PV aptly suits the rural climate. However, the microgrid placing depending on the terrain and designing microgrid concerning rural loads and maintaining and controlling the microgrid requires careful planning and execution. The Government of India has a clear vision of improving electrification in all the villages across the nation and provides subsidy in various forms under various schemes. Awareness about these schemes should be created amongst the rural population to achieve real success. This work's contribution lies in the fact that the Indian perspective of rural electrification is covered. There are very few studies on rural microgrids from the Indian perspective. India's rural mountainous regions have very less population density; hence, the government does not find it feasible to electrify these isolated pockets of villages.

CONCLUDING REMARKS

Electricity has a large variety of uses like domestic, agricultural, commercial, and irrigation. While people in cities and towns enjoy the fullest benefits of electricity, the rural population still does not have wide access to it, and there are many reasons for it. Electricity is a resource that needs a strong infrastructure, starting from power plants, substations, transmission and distribution networks, central grids, e, etc. Transporting electricity often includes lines which will increase over longer distances. According to the topology, the rural population living in remote areas is from power-producing centres and substations. The grid system consists of the building of poles and towers. The terrain in which rural people live is usually complicated and requires more planning and design.

Moreover, there is more demand for loads or power in urban areas and thus the cost of energy can be easily recovered. On the other hand, there is less demand for load in rural villages, and most of them use lighting loads. The energy system's cost is not justified in comparison to the grid-connected electricity supply of the rural population. Hence, microgrid have come into place as an alternative and cost-effective system. In a microgrid, excess power is generated or the power that was not used during day time can be supplied to the grid, if the microgrid designed is interactive to the main grid. A microgrid can be islanded whenever required, and it can supply loads even during a blackout. This paves the way for "prosumers" which enhances the livelihood of village dwellers (Wouters. 2015). Though, methods have been devised for electrifying villages, there are many complications in creating a microgrid. A detailed literature survey was made to understand the challenges involved in a 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 solar microgrid is mainly based on the intensity of sunlight and the availability of sunlight. Also, to extract maximum power, proper power tracking technology should be used. So, in the 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 solar and wind would be used as hybrid energy sources in a rural community. In the future, many sources that are potential in that particular region can be examined. When combined with proper algorithm and technology, the quality of microgrid would improve, and in the 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 an entirely different approach is needed for transportation of components, improving the sustainability of the grid and the economy.

References

[1] Aklin, M. Bayer, P. Harish, S. P. & Urpelainen, J.,Does basic energy access generate socioeconomic benefits? A field experiment with off-grid solar power in India,*Science Advances*, *3*(5), pp. e1602153. 2017
[2] Alliance for Rural Electrification*Rural Electrification*, https://www.ruralelec.org/rural-electrification
[3] Alzola, J. A. Vechiu, I. Camblong, H. Santos, M. Sall, M. & Sow, G.,Microgrids project, Part 2: Design of an electrification kit with high content of renewable energy sources in Senegal,*Renewable Energy*, *34*(10), pp. 2151–2159. 2009
[4] Arangarajan, V. KSV, S. M T O, A. Arif, M. Shafiullah, G. & Stojcevski, A.*Impact Analysis study in a Typical Solar PV Microgrid Power system*
[5] Arun, P.,Sizing Curve for Isolated Photovoltaic-Battery Systems using Artificial Neural Networks,*2018 2nd International Conference on Green Energy and Applications (ICGEA)*, pp. 147–151. 2018
[6] Arun, P. Banerjee, R. & Bandyopadhyay, S.,Sizing curve for design of isolated power systems,*Energy for Sustainable Development*, *11*(4), pp. 21–28. 2007
[7] Authority & Power, M. of*The Gazette of India Extradinary PART-I - Section-1*,
[8] Balijepalli, V. S. K. M. Khaparde, S. A. & Dobariya, C. V.,Deployment of MicroGrids in India,*The Journal of Bone and Joint Surgery. British Volume*, *49*(2), pp. 333–341. 1967
[9] Carey, B. & Miller, A.,The Future of Micrograds: their promise and challenges,*PriceWaterHouseCoopers*, *June*. 2012, https://www.pwc.com/us/en/technology/publications/cleantech-perspectives/pdfs/pwc-cleantech-the-future-of-microgrids.pdf
[10] Cecelski, E.,The International Bank for Reconstruction and Development / The World Bank, In *The International Bank for Reconstruction and Development / THE WORLD BANK*, http://documents.worldbank.org/curated/en
[11] Charabi, Y. & Gastli, A.,PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation, *Renewable Energy*, *36*(9), pp. 2554–2561. 2011
[12] Charabi, Y. Rhouma, M. B. H. & Gastli, A.,Siting of PV power plants on inclined terrains,*International Journal of Sustainable Energy*, *35*(9), pp. 834–843. 2016
[13] Chauhan, R.*Challenges and Opportunities for DC Micro Grid*
[14] Chimtavee, A. & Ketjoy, N.,PV Generator Performance Evaluation and Load Analysis of the PV Microgrid System in Thailand,*Procedia Engineering*, *32*, pp. 384–391. 2012
[15] Chrysoulakis, N. Diamandakis, M. & Prastacos, P.,GIS based estimation and mapping of local level daily irradiation on inclined surfaces,*7th AGILE Conference*, pp.

587–597. 2004,

[16] Climate Data website*Climate Leh*, https://en.climate-data.org/asia/india/jammu-and-kashmir/leh-24802/

[17] Data.gov*Rajiv Gandhi Grameen Vidyutikaran Yojana Demographic characteristics of Sample Beneficiaries under RGGVY Scheme*,

[18] Del Carpio Huayllas, T. E. Ramos, D. S. & Vasquez-Arnez, R. L.,Microgrid systems: Current status and challenges,*2010 IEEE/PES Transmission and Distribution Conference and Exposition: Latin America (T&D-LA)*, pp. 7–12. 2010

[19] Diesendorf, M. & Elliston, B.,The feasibility of 100% renewable electricity systems: A response to critics,*Renewable and Sustainable Energy Reviews*, *93*, pp. 318–330. 2018

[20] Distributed Generation*India Smart Grid Knowledge Portal*, http://www.indiasmartgrid.org/Distributed-Generation.php#

[21] Egido, M. & Lorenzo, E.,The sizing of stand alone PV-system: A review and a proposed new method,*Solar Energy Materials and Solar Cells*, *26*(1–2), pp. 51–69. 1992

[22] Energy Networks, *What could customers save with standalone systems & microgrids?*, https://www.energynetworks.com.au

[23] ESMAP*Impact of power sector reform on the poor - a review of issues and the literature*pp. 14. 2000,

[24] Faisal, M. Hannan, M. A. Ker, P. J. Hussain, A. Mansor, M. Bin & Blaabjerg, F.,Review of Energy Storage System Technologies in Microgrid Applications: Issues and Challenges,*IEEE Access*, 6, pp. 35143–35164. 2018

[25] Fowlie, M. Khaitan, Y. Wolfram, C. & Wolfson, D.*Solar microgrids and remote energy access: How weak incentives can undermine smart technology*Energy Institute at Haas, WP 295, University of California Berkeley,

[26] Gastli, A. & Charabi, Y.,Solar electricity prospects in Oman using GIS-based solar radiation maps,*Renewable and Sustainable Energy Reviews*, *14*(2), pp. 790–797. 2010, doi: 10.1016/j.rser.2009.08.018.

[27] Government Of India Ministry of Power Central Electricity Authority*Government Of India Ministry of Power Central Electricity Authority*, http://www.cea.nic.in/reports/

[28] Hamza, M. Shehroz, M. Fazal, S. Nasir, M. & Khan, H. A.,Design and analysis of solar PV based low-power low-voltage DC microgrid architectures for rural electrification,*2017 IEEE Power & Energy Society General Meeting*, pp. 1–5. 2017, doi: 10.1109/PESGM.2017.8274134.

[29] Hatziargyriou, N.,Overview of Micrograds, Problems and Solutions,*Distribted Generation, Grid and Micro Grid Problems, Bilbao, October*. 2004,

[30] Hirsch, A. Parag, Y. & Guerrero, J.,Microgrids: A review of technologies, key drivers, and outstanding issues,*Renewable and Sustainable Energy Reviews*, *90*, pp. 402–411. 2018

[31] Hontoria, L. Aguilera, J. & Zufiria, P.,A new approach for sizing stand alone photovoltaic systems based in neural networks,*Solar Energy*, *78*(2), pp. 313–319. 2005

[32] Hossain, M. A. Pota, H. Hossain, M. J. & Blaabjerg, F.*Evolution of Microgrids with Converter-Interfaced Generations: Challenges and Opportunities*

[33] Hubble, A. H. & Ustun, T. S.,Composition, placement, and economics of rural microgrids for ensuring sustainable development,*Sustainable Energy, Grids and Networks*, *13*, pp. 1–18. 2018

[34] India Smart Grid Knowledge Portal*Distributed Generation*, http://www.indiasmartgrid.org

[35] Indian Village Directory*Indian Village Directory*, https://villageinfo.in/west-bengal/south-twenty-four-parganas

[36] Kamalapur, G. & Udaykumar, R.,Rural electrification in India and feasibility of photovoltaic solar home systems,*International Journal of Electrical Power & Energy Systems*, *33*(3), pp. 594–599. 2011, https://scholar.google.co.in/

[37] Kharul, R. V.,Effective Policy And Regulation For Energy Access In India And Regulation For Energy Access In India,*RE Feature*, 6(4), pp. 36–40. 2013, https://mnre.gov.in/file-manager/akshay-urja/january-february-2013/EN/36-40.pdf

[38] Khatib, T. Ibrahim, I. & Mohamed, A.,A review on sizing methodologies of photovoltaic array and storage battery in a standalone photovoltaic system [BOOK]In *Energy Conversion and Management* (Vol. 120)

[39] Ma, S. & Urpelainen, J.,Distributed power generation in national rural electrification plans: An international and comparative evaluation,*Energy Research & Social Science*, *44*, pp. 1–5. 2018

[40] Malakar, Y.,Evaluating the role of rural electrification in expanding people's capabilities in India,*Energy Policy*, *114*, pp. 492–498. 2018

[41] Mani, M. & Pillai, R.,Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations,*Renewable and Sustainable Energy Reviews*, *14*(9), pp. 3124–3131. 2010

[42] Mao, M. Jin, P. Chang, L. & Xu, H.,Economic Analysis and Optimal Design on Microgrids With SS-PVs for Industries,*IEEE Transactions on Sustainable Energy*, 5(4), pp. 1328–1336. 2014

[43] Markvart, T. Fragaki, A. & Ross, J. N.,PV system sizing using observed time series of solar radiation,*Solar Energy*, *80*(1), pp. 46–50. 2006

[44] Mellit, A.,ANN-based GA for generating the sizing curve of stand-alone photovoltaic systems,*Advances in Engineering Software*, *41*(5), pp. 687–693. 2010

[45] Ministry of New & Renewable Energy*Ministry of New & Renewable Energy*, https://mnre.gov.in/physical-progress-achievements

[46] Moreno, S. G. Novielli, N. & Cooper, N. J.,Cost-effectiveness of the implantable HeartMate II left ventricular assist device for patients awaiting heart transplantation,*The Journal of Heart and Lung Transplantation*, *31*(5), pp. 450–458. 2012

[47] Mothilal Bhagavathy, S. & Pillai, G.,PV Microgrid Design for Rural Electrification,*Designs*, *2*(3), pp. 33. 2018

[48] Pike Resarch*Microgrids Islanded Power Grids and Distributed Generation for Community, Commercial, and Institutional Applications*, https://www.missioncriticalmagazine.com/ext/resources/MC/Home/Files/PDFs/WP-MICROPike_Research-

ExecutiveSummary.pdf
[49] Ritchie, H. & Roser, M.*Access to Energy*Ourworldindata,
[50] Robert, F. C. Sisodia, G. S. & Gopalan, S.,The critical role of anchor customers in rural microgrids: Impact of load factor on energy cost,*2017 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)*, pp. 398–403. 2017
[51] Sabzehgar, R.,Overview of Technical Challenges, Available Technologies and Ongoing Developments of AC/DC MicrogridsIn *Development and Integration of Microgrids*InTech, doi: 10.5772/intechopen.69400.
[52] Salam, a a Mohamed, A. & Hannan, M. a,Technical Challenges on Microgrids,*Network*, *3*(6), pp. 64–69. 2008, doi: 10.1364/OE.20.021702.
[53] Sandhu, M. & Thakur, T.,Issues, Challenges, Causes, Impacts and Utilization of Renewable Energy Sources - Grid Integration,*Journal of Engineering Research and Applications*, *4*(3), pp. 636–643. 2014,
[54] Sastry, E. V. R.,Village electrification programme in India [CONF], *3rd World Conference onPhotovoltaic Energy Conversion, 2003. Proceedings of*, *3*, pp. 2125–2128 Vol.3. 2003
[55] Saulo, M. J. & Omondi, V. O.,Design and Analysis of Solar Energy Mini-Grid for Rural Electrification,*OALib*, *2*(9), pp. 1–10. 2015
[56] Singh, R. Ansari, D. R. Shukla, S. P. & Thakura, P. R.*Microgrid and its current status in India : a review7*(1), pp. 11–15. 2018,
[57] Singh, S. Østergaard, J. & Jain, N.*Distributed Generation in Power Systems: An Overview and Key Issues*,
[58] Suryad, V. A. Doolla, S. & Chandorkar, M.,Microgrids in India: Possibilities and Challenges,*IEEE Electrification Magazine*, *5*(2), pp. 47–55. 2017
[59] TATA Power Solar Website*MW Solar Microgrids – Ladakh, India*, https://www.tatapowersolar.com/project/1-mw-solar-microgrids-ladakh-india/
[60] The Gazette of India*National Electricity Policy*,
[61] The World Bank*Access to electricity (% of population)*, https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS
[62] Verma, N. Dua, I. & Kumari, N.,Scenario of Rural Electrification in India- Challenges and Impact,*Journal of Engineering Research and Applications*, *4*(12), pp. 39–43. 2014,
[63] Williams, N. J. Jaramillo, P. Taneja, J. & Ustun, T. S.,Enabling private sector investment in microgrid-based rural electrification in developing countries: A review,*Renewable and Sustainable Energy Reviews*, *52*, pp. 1268–1281. 2015.
[64] Wouters, C., Towards a regulatory framework for microgrids—The Singapore experience,*Sustainable Cities and Society*, *15*, pp. 22–32. 2015
[65] Xiao, Z. Wu, J. & Jenkins, N.,An Overview Of Microgrid Control, *Intelligent Automation & Soft Computing*, *16*(2), pp. 199–212. 2010

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