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Design and Evaluation of Renewable Energy in Rugga Community in Balle Local Government Area of Sokoto State

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Abstract

One of the major challenges facing developing countries is the provision of adequate power to the citizens. Nigeria, one of such countries is operating a centralized grid system of electrification that is difficult and expensive to expand and would take decades to reach majority of rural areas. There are high numbers of remote villages that need electrification in these countries. Consequently, industrial and economic activities are seriously affected. Harnessing the abundant renewable energy sources would provide an alternative means of electrifying these rural communities. Solar power is one of the best renewable energy technology which is not only cost effective but environment friendly as well. An off-grid photovoltaic system is designed for a rural community located in Balle Local Government Area of Sokoto State, Nigeria. The solar power plant's site is located at longitude 5°27′, north latitude 13°03′. The energy requirement of the community was found to be about 93.5 kWh/day. The meteorological data of the location was gotten from NASA. PVSYST V6.47 simulation software was used to obtain the simulation result.

Keywords–Centralized grid system, Renewable energy, Solar power, Off-grid, Photovoltaic system, PVSYST software

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I. INTRODUCTION

1.1 Background of the Study

According to International Energy Agency (IEA) report of 2015, Nigeria is one of the countries with the least energy access; it has an utterly weak electricity sector which was ranked 187 of 189 countries by the World Bank in terms of access.[1]

Over 50% of the population lives in rural areas and more than 60% of this depends on fuel wood for energy needs [2,3]. The livelihood of over 65% of rural people, and overall national development is highly impeded due to a lack of access to electricity [4]. Electricity is required for effective delivery of basic services such as potable water, health care, telecommunication and education, as well as agro-industrial processes [5].
Energy sources are divided into conventional energy which is crude oil, natural gas and coal while non-conventional energy or renewable energy is solar, wind, hydro and biomass energy [6]. Conventional energy contains mostly carbon which is the leading cause of global warming when released from crude oil products, gas and coal to the atmosphere [7].
With the increasing population, pressures on the infrastructures for the supply of conventional energy resources continue to increase, knowing that conventional energy is deflectable with extinction risk. In order to enhance the energy security of the country and establish a sustainable energy supply system, it is necessary to promote the policy of diversifying the energy supply as to include alternative or renewable resources and technologies into the nation's energy supply mix.[8]
Since Nigeria is blessed with abundant renewable energy resources such as hydroelectric, solar, wind, tidal, and biomass, there is a need to harness these resources and chart a new energy future for Nigeria.[9]

Nigeria has the potential to generate 12,522 megawatts (MW) of electric power from existing plants, but most days is only able to generate around 4,000 MW, which is insufficient.[9] The Federal Government with the backing of Section 88 of Electric Power Sector Reform Act 2005 established the Rural Electrification Agency on March 16, 2006.[10]

1.2 Problem Statement

This study will consider the integration of micro-grid or off-grid system to address electricity challenges by creating a unique combination of locally suitable power generation and distribution network.

1.3 Aim of Study

The aim of this study is to conduct an evaluation and analysis of an off grid hybrid renewable energy system that can generate and provide electricity to the study case in the rural area.

1.4 Objectives of Study

To collect numerical data from existing household/physical structure in the rural setting.
To formulate mathematical equations to access the viability of the load demand requirements to match intended generation capacity.
To implement the numerical data collected into formulated mathematical equation for purpose of evaluation and estimation, in order to meet-up power generation requirement.
To conduct a comparison analysis, in terms of the various options including Diesel-Generation (D-G) and PV – solar power system for purpose of efficient optimization of power system management and cost.

1.5 Scope of Study

The supply of electricity using mini grid or off-grid solutions, to a rural community of about 50 household capacities which are mostly mud structures (huts).

1.6 Significance of Study

This study will strongly propose and recommend the optimal mix combination that is economically feasible to serve the rural community concerned.

II. LITERATURE REVIEW

2.1 Review of Past Works

In order to gather reasonable information about renewable energy resource potentials of the country, hybrid energy systems, rural electrification techniques applying combined resources a detailed study of all this was needed. Different research efforts for the application of renewable energy options have been conducted for the access of renewable energy resource potentials and stand-alone hybrid systems. The following different authors were conducted for a range of hybrid systems at different times, sites and different countries; however, the methodology applied for the simulation was HOMER.
[11] According to Yusuf, (2017) the study has demonstrated that in setting up a micro-grid power system, where cost is a factor and there is no government subsidy as it happens in developed countries of the world, it is very economical to use only PV as the renewable energy source, over only diesel, as the Cost of Energy (COE) for PV is #18.64 whereas that of diesel generator is #20.12.
The initial cost of setting up the Micro-grid generation dramatically falls when an appropriate capacity of Diesel generator is brought to the mix. However, the KWh cost of energy gotten from the software is higher because a number of the inputs are wrong.

[12] A study carried out by Bhata (2013) has been devoted to the design of an off-grid renewable hybrid power system for a community of 1100 households in the rural village of Haressaw, Atsbi. Wind speed and horizontal global radiation potentials of Haressaw village were obtained from Mechanical Engineering department, Mekelle University, Ethiopia. The average monthly profiles and hourly data for both sources were analyzed using HOMER, and the result displays wind and solar energy potentials are undisputable to exploit for the provision of electricity. The two year mean wind speed measured at 30m wind mast and the mean global horizontal solar radiation was 4.407m/s and 5.638kWh/m2/day respectively.
During the design of the off-grid system set-up it was done using an optimization process based on the electricity load, climatic data sources, and economics of the power components in which the NPC has to be minimized to select an economic feasible power system. HOMER simulation result displayed the most economical feasible system sorted by NPC from top to down, the prime system ranked first has renewable fraction of 76% containing 6 unit
wind turbines with 50kW each rating power, 100kW photovoltaic panel, 100kW diesel generator, 300 unit batteries, and 150kW converter, where the diesel generator runs in load flowing (LF) strategy. However two additional comparison approaches were also used beyond the NPC to select a techno-economic system design by considering two comparison parameters like renewable fractions greater than 77% and low cost of energy less than $0.385/kWh. Thus different configurations were obtained, however the selection could be performed by giving due attention to both comparison parameters separately. The results showed that various feasible hybrid system setups with different contributions made by renewable fractions.
Sensitivity analysis was also performed for the system, 12 sensitivity cases were used such as; 2 values of primary loads, 4 cases of diesel prices, 2 cases of minimum renewable fractions and 4 cases of capacity shortages. The sensitivity analysis showed that almost the same configuration was obtained except in some cases there are quantity and size change of the components. The different setups resulted in this paper could be appropriate in areas that have the same climatic resources.
[13] Also, according to Uwibambe (2017), the aim of the thesis was to analyze the use of PV system to convert solar energy into electric power to supply the electricity need in rural areas. The preliminary design step was based on the comparison of different solar home systems for a typical single house in Kanazi village, Nyamata sector of Bugesera district. This village is located at a far distance from national grid lines and most of the populations do not have access to electricity from the grid. The Bugesera district receives a large amount of sunlight with an annual average solar radiation of 5.28 kWh/m2/day. In addition, Bugesera is one of the driest site among other districts of the eastern province of Rwanda since its average temperature is high, with values above 21°C and the precipitation amount in this area is the lowest in the whole country, with values below 900 millimeters per year. A fixed daily load profile has been assumed throughout the year because Rwanda is located closer to the equator, therefore Bugesera district is not affected by seasonal variations and the day length does not change in a significant way. The average daily load demand for the single house in Kanazi village is 200Wh/day and the peak load is 71W, thus the system size has been chosen to be above that peak of load.
The used overall system consists of a PV panel with a rated power of 200W and a storage battery which consist of Vision 6FM55D with a nominal capacity of 55 Ah, 12V. For this system, the maximum annual capacity shortage calculated by homer is 50% and the minimum renewable faction is 10%. Further analysis was performed based on different PV sizes used in Rwanda for existing solar home system (SHS) in the range of 30 W to 200W, to identify which system is more efficient and compare it with a 10kW PV village system. If we compare in terms of total cost for the village with only SHS to a village system of 10kW, it is evident that the village system becomes more economical. For example, considering a village of 300 homes having each a SHS of 200W that costs $1478 including additional cost of operation and maintenance means that the total is 300×$1478 which equals $443400 yet for the village system of 10kW that can supply a minimum of 50 houses the cost is $55970 which means that it is required to have 6 systems of 10kW each to supply 300 houses and the total cost for those systems is $55970×6 which equals $335820. Therefore, there is a difference of $107580 that can be saved by taking an option of using a much bigger solar PV system for the rural community with a suitable operation and maintenance scheme which can ensure the sustainable operation of the system.
Moreover, the obtained solar home system solution and village system can only be implemented in other rural locations if the environment's conditions such as solar radiation, sun hours and temperature requirement are similar. Furthermore, the PV system performance and efficiency should also remain unchanged but there is a possibility of moving to the design of bigger off-grid system in case of high load demand. Therefore, an increase in the total energy storage capacity could solve this problem for a better management of energy flow. Instead of waiting for the grid power in case of increase in demand, the best option is the design of higher capacity stand-alone PV system of 10kW with a big battery storage capacity that can supply the entire village community. This is proposed as the best option because the cost of extending the grid to rural villages is extremely high, around 21.000 $ per km of one power distribution line and the current national grid electric power price for the

domestic consumers in Rwanda lies in the range of 0.2 – 2.4 $/kWh. Therefore, it is confirmed that the cost of the energy consumption is high compared to the alternative use of photovoltaic system.

III. MATERIALS AND METHOD

3.1 Materials for the Research Work

Considering the fact that the location of the study case does not have direct electricity supply at all presently, this research work will propose and determine the load/energy requirement by every household and the design for the needed solar radiation that will be imping on the solar panel which will be converted into electrical form of energy for daily consumption. The structures includes 5 block buildings (1-shop, 1-health center. 1-mosque, 2-schools) while 45 smaller structures are huts.

3.2 Analysis of the Method used for Micro-grid System Components

Photovoltaic Panel (PV): The total peak power of the PV generator required to supply certain load depends on load, solar radiation, ambient temperature, power temperature coefficient, efficiencies of solar charge, regulator and inverter in addition to the safety factor taken into account to compensate for losses and temperature effort. This total energy generated and its power obtained as:

$$E = A \times r \times h \times PR \qquad (3.1)$$

Where;E: Energy (kWh),A: Total Solar Panel Area (m^2),r: solar panel yield or efficiency (%),H: Annual average solar radiation on tilted panels (Shadings not included),PR: Performance ratio, (range between 0.5 and 0.9, default value = 0.75).

3.3 Battery Bank (BB)

Batteries are used to supply load requirements, if renewable generated energy is not enough and to store the energy that exceeds load requirements. The battery capacity for a certain period may be defined as:

$$C_{wh} = (E_L \times AD)/(\eta_V \times \eta_{wh} \times D_oD) \qquad (3.2)$$

Where: AD: Daily autonomy E_L: Load requirement at certain the time interval ,η_V and η_{wh}: Efficiency of inverter and battery bank respectively
Battery depth of discharge is specified and not to be exceeded. So that;

$$E_{min} = EBN \times (1 - DoD) \qquad (3.3)$$

Where:E_{min}: Minimum allowable capacity of the battery bank, EBN: nominal capacity of battery bank,DoD: Depth of discharge

3.4 Converter for Energy System

Converter (Bio-directorial converter) is crucial in case of integrated energy systems. Inverter can be modeled.
P_{di}: Inverter charging power output
P_{Gen}: Generator power output
η_{edi}: Efficiency of inverter in charging.
Efficiency of DC/AC conversion is more than 90%.

3.5 Diesel Generator (DG)

DG genetrator is used for generating electricity in the remote area. However, in the case of off-grid system, DG is used as back-up if the renewable sources are insufficient to supply power to the estimated load demand. Similarly, the DG is also used to charge the batteries to increase its state of charge (SOC) to an adequate state. DG rated power supply should be enough to support the load power whenever needed. Energy output and fuel consumption equations are given as:

$$E(kwh) = p \times h \times d \qquad (3.4)$$

$$C_{(L)} = E \times C_{kwh} \qquad (3.5)$$

Where:E: Active electric energy in output of the diesel engine in kwh,P: Active electric power output of the diesel engine in kw,h: Number of hours per day the generator runs, d: Number of days the power generator runs ,Ckwh: Fuel consumption of per kwh,C: Fuel consumption in liter

3.6 Battery Sizing and Cost

The choices of the batteries are taken into consideration using the capacity, the load time and the depth of discharge. They are designed to be discharged and recharged hundreds or thousands of times. The batteries are rated in amp hours (Ah). Like solar panels, batteries were wired in series and parallel to increase voltage to the desired level and increase amp hours.

3.7 Determining the Safe Energy Storage (E_{safe})

The safe energy storage (E_{safe}) is equal to E_{rough} divided by the maximum allowable level of discharge (MDOD), as given in equation 3.6.

$$E_{safe} = \frac{energy\ storage\ required}{maximum\ depth\ of\ discharge} = \frac{E_{rough}}{MDOD} \qquad (3.6)$$

Where:E_{safe}: Is the storage energy, MDOD is the maximum allowable level of discharge and E_{rough} is the rough energy storage.

3.8 Capacity of the Battery Bank Needed (C) in Ampere Hours

The capacity of the battery bank needed (C) in ampere hours is equal to the safe energy storage (E_{safe}) divided by the rated voltage of each battery V_b to be used in the battery bank. V_b is DC voltage. C was calculated using equation 3.7.

$$C = \frac{E_{safe}}{V_b} \quad (3.7)$$

Where C is the Capacity of battery bank; V_b is the battery voltage; E_{safe} is the safe energy storage.

3.9 The Total Number of Batteries

The total number(s) of batteries are obtained by dividing the capacity of the battery bank needed (C) in ampere hours by the capacity of one of the battery C_b selected in ampere hours. Since the battery bank is composed of batteries, $TN_{batteries}$, was deduced using equation 3.7.

$$TN_{batteries} = \frac{C}{C_b} \quad (3.8)$$

Where C is the capacity of battery bank; C_b is the battery capacity in Ah and $N_{Lbatteries}$ is the total number of batteries needed.

From the above equation, the connection of the battery bank can then be easily figure out. The number of batteries in series is equal to the DC voltage of the system divided by the voltage rating of one of the batteries selected, is presented in equation 3.9.

$$TN_s = \frac{V_{dc}}{V_b} \quad (3.9)$$

Where TNs is the number of batteries in series, V_{dc} is the input voltage of the charge controller and V_b is the battery terminal voltage.

The number of batteries in parallel TNp is obtained by dividing the total number of batteries by the number of batteries connected in series, using equation 3.10.

$$TN_p = \frac{TN_{batteries}}{TN_s} \quad (3.10)$$

Since the system is a 300volt system, the batteries in multiple of 180 are used.

Hence, the total number of battery $TN_p = TN_p \times TN_s$ (3.11)

The total battery area $A_b - TN_b \times dimension\ (m)$ (3.12)

3.10 Load Estimate for Rugga Community, Balle L.G.A Sokoto State

In a remote rural village, the demand for electricity is not high compared to urban area. Electricity is demanded for domestic use (for appliances like radio, ceiling fans, bulbs), agricultural activities (such as water pump) and community activities (such as in community mosque, schools and health centers)

Table 3.1: Projected Load Estimate for Balle Community

Appliances	Wattage (W)	No of Appliances for all consumers	Total power consumed	Estimated hours of usage	Project 24 hour load in KWHr
Bulbs	13	150	1950	12	23.4
Fans	60	30	1800	15	27
Fridge	400	2	800	12	9.6
TV	150	3	450	10	4.5
DVD	50	2	100	10	1
Radio	9	100	900	10	9
Phone Charger	4	120	480	15	7.2
Computer	100	1	100	8	0.8
Iron	1000	2	2000	4	8
Water Pump	500	1	500	6	3
Totals	2,286		9,080		93,500

Source: Research desk

Determine power consumption demands

Total watts of appliances = 9.08KW

For a 30% increase for future expansion = 11804 = 11.84kW

*11804 * 24 = 283296Wh/day*

103403kWh/year

PV panel Sizing

Panel generating factor = 3.43

Total Wp of PV panel capacity = 283296 / 3.43
= 82593.59Wp

Number of PV panels needed = 82593.59/ 325
= 254

Actual requirement = 254 modules

This system should be powered by at least 254 modules of 325watts PV module.

Inverter Sizing

Total Watt of all appliances = 11804W

For safety, the inverter should be considered 25-30% bigger size.

The inverter size should be about 15345W or greater.

Battery sizing

Total appliances use = 283296Wh/day

Nominal battery voltage = 120V

Days of autonomy = 1 day

*Battery capacity = 283296 * 1 / 0.85*0.6*120* (8)

Total Ampere-hours required 4629Ah

So, the battery should be rated 120 V 4629Ah for 1-day autonomy.

IV. RESULTS AND DISCUSSIONS

PVsyst V6.47 software package along with internal tools was used to calculate energy loss factors for the proposed stand-alone PV systems [11]. The solar power plant's site is located at longitude 5°27', north latitude 13°03'; it is rich in solar energy resources based on simulation results. The best angle for bracket installation is 30°. The main simulation results of the system production are produced energy 103718MWh/year and specific prod. 103403kWh/year as well as performance ratio PR 72.4% is found.

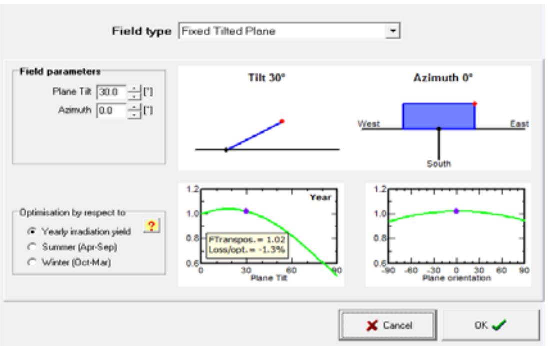

Plate 3.9: Monthly Meteo

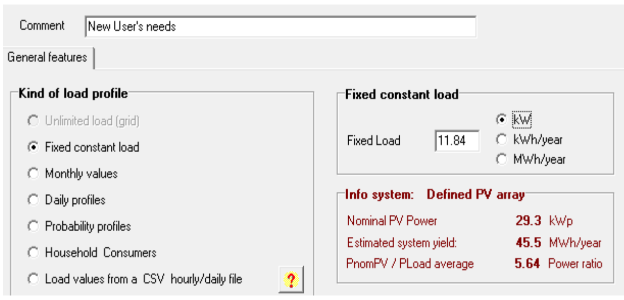

Plate 3.11: Users Need

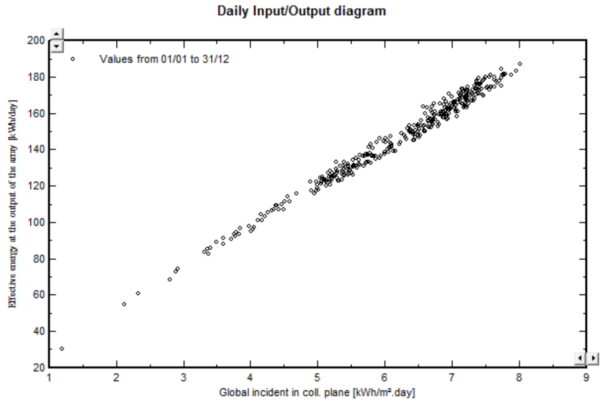

Figure 4.1: Daily input/Out Diagram

RuggaFile
Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E User MWh	E Load MWh	SolFrac
January	171.3	209.0	4.761	0.000	8.812	8.809	0.529
February	178.9	201.1	4.451	0.000	7.959	7.956	0.548
March	202.8	202.4	4.479	0.000	8.811	8.809	0.490
April	201.9	178.0	3.933	0.000	8.527	8.525	0.447
May	198.1	158.5	3.573	0.000	8.811	8.809	0.398
June	189.5	144.1	3.332	0.000	8.527	8.525	0.386
July	180.7	140.7	3.312	0.000	8.812	8.809	0.370
August	172.6	147.4	3.464	0.000	8.811	8.809	0.385
September	179.3	170.3	3.896	0.000	8.528	8.525	0.442
October	190.8	204.8	4.538	0.000	8.812	8.809	0.488
November	178.3	216.7	4.800	0.000	8.527	8.525	0.527
December	168.9	216.0	4.876	0.000	8.812	8.809	0.519
Year	2213.0	2189.1	49.416	0.001	103.750	103.718	0.460

Table 4.1: Balance and main results

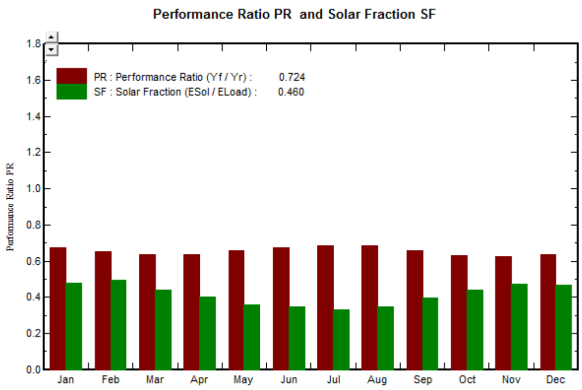

Figure 4.2: Performance Ratio and Solar Fraction

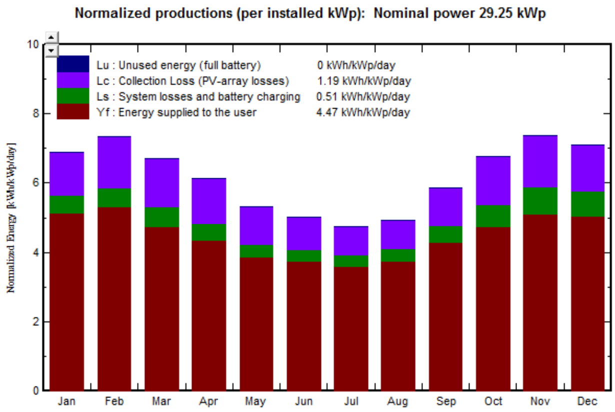

Figure 4.3: Normallized productions 29.25 KWp

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This dissertation is devoted to the design of an off-grid renewable hybrid power system for a community of 50 households in Rugga Community in Balle L.G.A. of Sokoto State. Each household is given three lighting points and two power points

Electrifying rural areas has been a challenging assignment for developing countries like Nigeria. An 11.8 kWp stand-alone solar power system for a rural village in Balle l.G.A in Sokoto State has been discussed in this dissertation. The goal was achieved by considering the global horizontal radiation at the selected site and by considering the primary load obtained during the survey conducted for single house analysis in daily hours In addition, an evaluation of the climate data as well as the potential of renewable energy resources available in that area has been done for finding feasible solutions for the entire population.

As shown by the research, Rugga Community is a region with high intensity of solar radiation and low rain-fed. Therefore, the use of photovoltaic technologies for electricity production and supply will be a sustainable solution for the population in the rural village which is far from the national electric grid. Photovoltaic systems are not capable of ensuring a continuous electric power supply unless if they are connected to an additional storage system. Since this can become a serious challenge during rainy days, it would be impossible for the PV panels to provide the needed electrical power. Hence batteries have been associated with off-grid PV systems and other solar based technologies. To meet the energy requirement of the nation, hybridizing renewable energy technologies can cater for this deficiency and provide sustainable solutions. If due-merit is given to the electricity deficiency of the country, it would play a major role in the improvement of the quality of life of the people living in the rural areas and at the same time improve the quality of education, reduce firewood cultivation and in-house pollutions. Thus, the implementation of other renewable energy sources like solar and wind energy power systems can elevate the country's electric shortage. The simulation results have shown that it is more advantageous to use a 11.8kW off-grid system for rural electrification, although the initial capital investment is higher, it is much more economical throughout the lifetime compared to the grid connection which is not yet available in the community and would cost a fortune to bring to the community. Solar PV is indeed a good alternative for electricity generation because it is both cheaper and beneficial towards energy independence, in addition to being one of the most abundant renewable energy resources that is available in Sokoto State.

Finally, this project work provides a basis and framework for the evaluation of this solution not only in Rugga Community but also in other parts of the country where the sun shine is relatively intensive and based on the results from simulation, the Diesel Generator (DG) backup especially during the rainy season has also been put into consideration.

5.2 Recommendation

Across different corners of the country there are renewable energy resources which varies from site to site, thus can be used for electricity generation either in grid or off-grid system. Electricity generation using off-grid systems from local renewables alleviates the country's electricity shortage. However, there are different challenges facing the implementation of such systems which includes

i. Finance of the community,
ii. Infrastructures,
iii. Lack of awareness on how to use renewable resources
iv. Risk taking decisions by investors and other related issues.

To improve the energy deficiency at national and state level, grid and off-grid renewable energy technology systems has to be promoted using different mechanisms including subsidy. Empowering the rural communities' income to grow renewable generated electricity purchasing power is also fundamental.

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