Solar PV System Utilization in Nigeria: Failures and Possible Solutions.

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ABSTRACT

The abundance of solar energy resources shows that solar energy is a promising solution to meet demand for decentralized lightening systems and electricity services in urban and remote locations in Nigeria. However, the incessant failures of installed solar PV systems cast doubts on the effectiveness and suitability of solar PV systems to serve this purpose. After a thorough analysis of some failed systems, we present a brief review of the possible causes of these failures and practical ways to circumventing them. This is intended to serve as a precursor to intending solar energy investors, as we continue to make case for improved solar energy investments in Nigeria.

(Keywords: photovoltaic, renewable energy, PV system, PV failures, possible solutions, Nigeria)

INTRODUCTION

Nwofor et al. [1] singled out energy optimization by criteria ranking method as a sure way of boosting energy generation in Nigeria. This is imperative as energy diversification choices are synonymous with energy resources availability, Nigeria is endowed with enormous and diverse energy resources.

Undoubtedly, energy is one of the major determinants of economic development as the quantity of energy consumed by a nation has been greatly linked with the level of industrialization and economic activity going on in the society [2]. The growth in the world energy consumptions is known to have increased exponentially owing to increased demand of energy by the growing populations. In Nigeria, exponential growth has been observed in population and energy need, this is evident in the high importation of gasoline fuel generators by the helpless populate who can no longer depend on the erratic power supply from the national grid. This is due to the fact that the national electricity generating capacity cannot keep pace with development and the growing energy demand.

Nigeria with a present population estimated at 180 million, generated ~5,500 MW of electricity in 2015. The Federal Government has continued to show determination to tackle this energy poverty through her numerous energy policies which are yet to deliver the expected results. All these policies are expected to scale up this generation capacity to 40,000 MW by 2020, which will help to drive our growing industrial economy, in addition to linking a good number of rural communities to the national grid.

The country had been solely dependent on electricity production through hydro-electric power plants and gas power stations Integrated Power Projects (IPPs), which seek to utilize the abundant gas reserves flared in the country [3]. It was quiet clear that there is need to enhance the energy sector with renewable sources like solar and wind energy options as it is captured in the Renewable Energy Master Plan (REMP) [4] and the new Roadmap for Power Sector Reforms (RPSR), to alleviate the growing energy problems of the citizenry. This will be an addition to the traditional power sources and the current consideration of nuclear energy in power production and other forms of renewable energy.

Chineke and Jagtap [5]; Chineke et al. [6]; Fadare [7]; Chineke et al. [8]; Chineke et al. [9]; Dike et al. [10]; Dike et al. [11]; Ohunakin et al. [12], and many other researchers estimated average exploitable daily solar radiation of about 5.25kWh/m/day varying between 3.5kWh/m/day at the coastal area and 7.0 kWh/m/day at the Northern boundary in Nigeria and designed practical optimization methods for pointing, sizing and inclining solar PV devices.

These reports sparked up quantum solar energy investment across Nigeria which is estimated at about $150 million in 2014 alone and the investments are projected to grow by ~200% in 2016 following Government policies and other concerted efforts on off-grid solar energy mix.

Many solar energy systems installed in the rural areas have proven to be beneficial to the rural dwellers, providing not only water but also a microenterprise center, powering health care and educational services and providing new economic opportunity. Juxtaposed against these notable successes are incessant failures of some small and high profile solar energy projects (mini-grids) in Nigeria. This portends huge economic loss and leaves so much to be desired. Efforts have been made to understand the root causes of these problems, a conclusive solution have not been read on any literature and hence this research paper.

In an attempt to solve these problems, Dike et al. [11] reported Optimal Inclination Angles (OIA) for mounting solar PV modules in some selected African cities, a scholarly published technical note intended to enhance efficient utilization of solar PV modules which is the mainstay of solar energy systems. The report took care of the technical error encountered in the mounting and orientation of the solar PV modules by deriving (OIA) for each city base on their coordinate.

On a similar note, Bhatnager and Nema [13] proposed "bang-bang" (hysteresis) control strategy algorithm for Maximum Power Point Tracking (MPPT) for photovoltaic based generation systems while Seyedmahmoudian et al. [14] employed "swarm optimization" and evolutionary algorithm technique for MPPT. These publications are expected to provide technical guidance.

Additional, Ikejemba and Schuur [15] designed a multi-step approach for locating solar parks and/or solar and wind energy parks for mini-grid application. The authors considered solar and wind energy resources in the cite, as well as geography and demographical characteristics of the location before designing a suitable energy mix to meet energy demand of the populates, this is in line with solar-wind-tide technique [3] proposed, considering the intermittency of each of the energy sources.

However, many pointers suggest that the influx of substandard products into the Nigerian solar energy market and/or lack of technological know-how on the part of technicians may perhaps be responsible for the failure of these installations, only a thorough analysis will certify. In addition, the components of the solar PV system, namely, the charge controller, battery, inverters and pumps system need to be evaluated. Consequently, a thorough investigation into the cause of incessant failures of this equipment will be a step in the right direction to prevent future occurrence. Therefore, we will focus on the verification of these pointers that suggest causes of incessant failure of some installed Solar Energy Systems in Nigeria using some defunct systems in Owerri-Nigeria as a case study.

The remaining part of this paper will be contained in four sections. An assessment of Solar Energy Potential in some Northern Nigeria cities in line with [10] and evaluation of failed Solar PV Systems is presented, along with the solar energy potentials in some stations, what went wrong with the failed systems, and helpful tips to effective solar energy systems are described.

EVALUATION OF FAILED SOLAR ENERGY CONVERSION SYSTEMS

Evaluation of failed solar systems such as solar street lights, solar home systems and solar water pumps was done through two distinct methods:

a. A thorough assessment of defunct systems to gain insight into the possible cause of their failure.

b. Through a detailed questionnaire issued to solar energy systems dealers and technicians in the field (Solar Energy Practitioners).

In all, one hundred and three (103) observations representing (deductions from thirty (30) defunct Solar Energy Systems were evaluated and seventy three (73) questionnaires respondents returned) were analyzed to draw out key factors responsible for the observed failures.

Evaluation Solar Radiation Potentials

In any solar energy conversion system, the knowledge of global solar radiation is extremely important for the optimal design and the prediction of the system performance. Therefore, Renewable energy development or utilization vis-à-vis solar energy program should start with assessment of energy potential at the site or region of interest. It is, therefore, necessary to approximate radiation from commonly available climate parameters such as sunshine hours, relative humidity, maximum and minimum temperatures, cloud cover and geographic location [16-18].

Different methods can be used to estimate the global solar radiation (GSR) from climate data. However, in this study, we will explore Hargreaves' equation to model Global Solar Radiation as described below and compare our results with NASA solar radiation satellite estimates, in our attempt to check the accuracy of the estimated data a similar method as adopted by [10]. This part is expected to recap the abundance of solar energy resources in the study site and Nigeria at large.

Hargreaves Global Solar Radiation Equation

Hargreaves and Samani [19] presented equation (1) for the evaluation of global solar radiation and this equation has been tested and found suitable for tropical Africa [20-21]. It requires temperature value to compute solar radiation estimate and is found to be favorable or gives better results in the tropical regions [22-23]. The equation needs as input data the daily temperature range (*Td*) (maximum temperature-minimum temperature and the extraterrestrial solar radiation (*Ra),* which depends on the latitude of the location [21].

The equation for computing the daily GSR is:

$$\text{GSR HAR} = 0.16\, Ra \sqrt{Td} \qquad \textbf{(1)}$$

The average monthly solar radiation = $\sum(\text{GSR})/n$, where n is the number of days in the particular month, see [10,19].

Where Ra is the extraterrestrial solar radiation which was computed with the routine developed by [21], when the latitude is supplied in degree radian. We chose our unit for global solar radiation as Kilowatt hours (KWh) which is convenient for evaluating the solar power potential especially for solar photovoltaic applications. It is the power output (kW) and the number of hours of sunshine (hrs) that comes into play in any solar home system or related photovoltaic application.

NASA Surface and Solar Energy Data

The U.S. National Aeronautics and Space Administration (NASA), through its science mission directorate, has long supported satellite systems and research, providing data important to the study of climate and climatic processes. Such data include long-term estimates of meteorological quantities of solar energy fluxes [10]. The satellite and modeled data have been shown to be accurate in providing reliable solar and meteorological resource data over regions where surface measurements are sparse or nonexistent.

NASA continues to support the development of surface meteorology and solar energy (SSE) data set, which has been formulated specifically for photovoltaic and renewable energy system design [10]. In this paper, a solar radiation data of 22 years average from 1983-2005 has been obtained from NASA online data store (http://eosweb.larc.nasa.gov/sse/). The estimate of the NASA horizontal insolation level of accuracy as compared with most ground-based measurements for latitudes below 60° equator ward is 8.71% or approximately 9% (http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?s05#s05) which we assumed for this work.

ANALYSIS AND DISCUSSIONS

Solar Radiation Estimates

Figure 1 shows a comparative analysis between Hargreaves estimates and NASA estimates of solar radiation measured in kWh/m^2/day for Owerri, 0.95 correlation coefficient shows that the dataset agrees at 95% confidence level as described by [10] and therefore the NASA estimates can be assumed to represent the true scenario at different locations in Nigeria (*cf* Table 2 of Dike et al. [10]).

In Figure 2(a) is shown the distribution of average monthly solar radiation incident on the horizontal surface in six states in the North Eastern Nigeria.

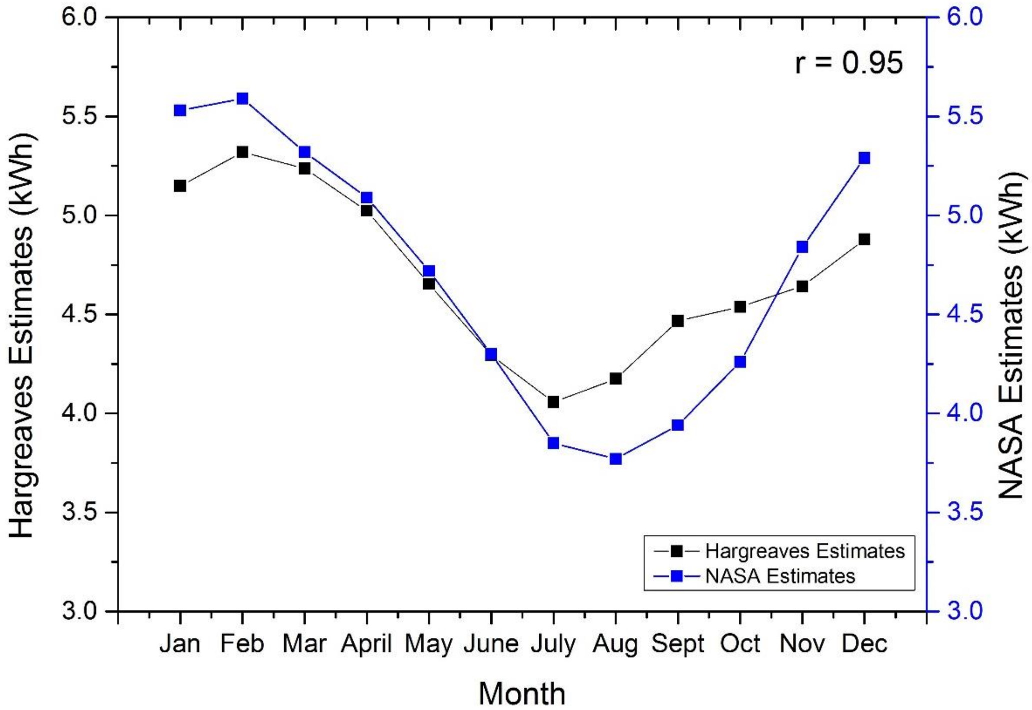

Figure 1: Comparative Analysis between Hargreaves and NASA Solar Radiation Estimates.

The cities received the highest levels of solar radiation in the month of March (Maiduguri 6.7kWh, Gombe 6.45 kWh, Bauchi 6.4 kWh, Yola 6.41 kWh while Damaturu 6.98 kWh and Jalingo 6.47 kWh in the months of March and February respectively. However, the cities considers as black-days the days in the month of August when the solar radiation received is low due to cloud cover (see Figure 3(a)) the normalized clear sky index for the North East Nigeria.

Despite the cloud cover mostly in the month of August, Maiduguri 5.14 kWh, Gombe 5.0 kWh, Bauchi 5.08 kWh, Yola 4.79 kWh, Jalingo 4.43 kWh while Damaturu recorded 5.27 kWh least solar radiation in December at the peak of winter, when dust plume from the Sahara Desert contributes immensely to cloud cover.

Figure 2(b) shows the distribution of solar radiation in the North West Nigeria cities, they cities recorded the highest level of solar radiation in the month of April. Hence, Kano 6.96 kWh, Kastina 6.82 kWh, Sokoto 7.15 kWh, Bernin-Kebbi 6.76 kWh, Dutse 6.67 kWh, Gusau 6.84 kWh and Kaduna 6.72 kWh in the month of March. The least amount of solar radiation is received in the month of December, thus Kano 5.32 kWh, Kastina 5.19 kWh, Sokoto 5.25 kWh, Bernin-Kebbi 5.25 kWh, Dutse 5.25 kWh and 5.24 in Gusau while Kaduna recorded the least amount of solar radiation in the month of September.

Clear Sky Indices shows that the situation could be associated with Sahara desert dust plume see Figure 3(b). Listed in figure 2(c) is the features of monthly solar radiation incident on the horizontal surface in seven major North Central cities of Nigeria.

It is apparent that the cities receives the highest levels of solar radiation in the months of March, Minna 6.26 kWh, Jos 6.35 kWh, Lafia 6.15 kWh, Abuja 6.27 kWh and Ilorin 6.02 kWh while Lokoja and Makurdi recorded 5.84 kWh and 6.01 kWh, respectively, in the month of February. The cities records the least amount of solar radiation all in the month of August, Lokoja 4.13 kWh, Minna 4.36 kWh, Jos 4.21 kWh, Lafia 4.28 kWh, Abuja 4.19 kWh and Ilorin 3.95 kWh.

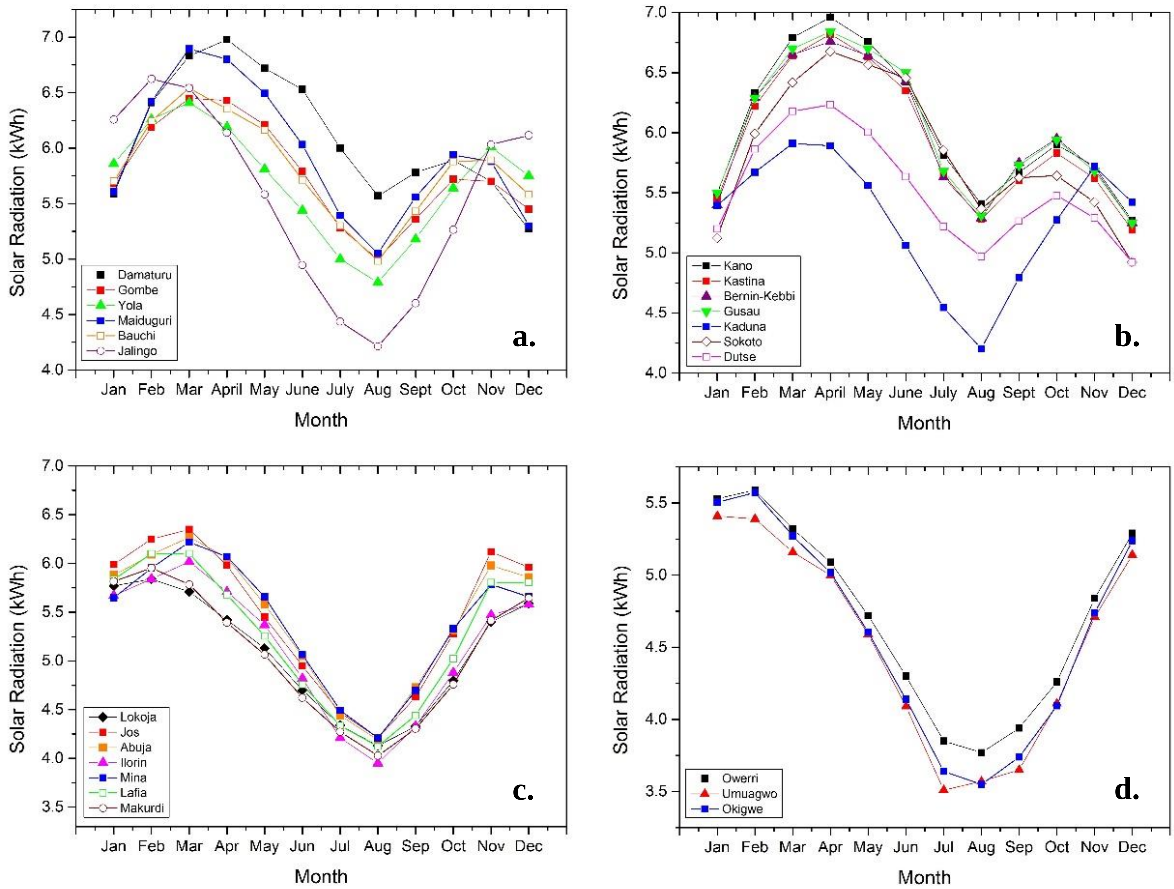

Figure 2: The Distribution of Average Monthly Solar Radiation Incident on the Horizontal Surface in Some Selected Locations in Nigeria.

In Figure 2(d) and Figure 3(d) is listed the solar radiation estimate incident on the horizontal surface and the normalized clear sky index respectively for the three locations in Imo State Nigeria where the defunct solar energy installations are located. It is evident that the locations receive the highest levels of solar radiation in the month of February, Owerri 5.59 kWh/m^2/day, Okigwe 5.59 kWh/m^2/day and Imo State Polytechnic 5.39 kWh/m^2/day.

The locations records least values in August Owerri 3.77kWh/m^2/day and Okigwe 3.77 kWh/m^2/day when the clear sky index is nearly at its peak, Imo State Polytechnic receives the least values in the month of July 3.51 kWh/m^2/day, a period seen as black days in this location.

Figure 4 shows the yearly average of daily sums of global horizontal radiation estimate for Nigeria between 1985 and 2005 as evaluated by [24], the figure clearly shows the spatial variation of global horizontal solar radiation in Nigeria. 4kWh/m^2/day in the southern location and 6.5 kWh/m^2/day in the northernmost location, these goes further to validate our results and shows that at 5.6-6.5kWh/m^2/day northeastern Nigeria is enormously endowed with solar radiation resources. The northeast and north central regions receives 5-5.6 kWh/m^2/day and the southern locations 4-5 kWh/m^2/day.

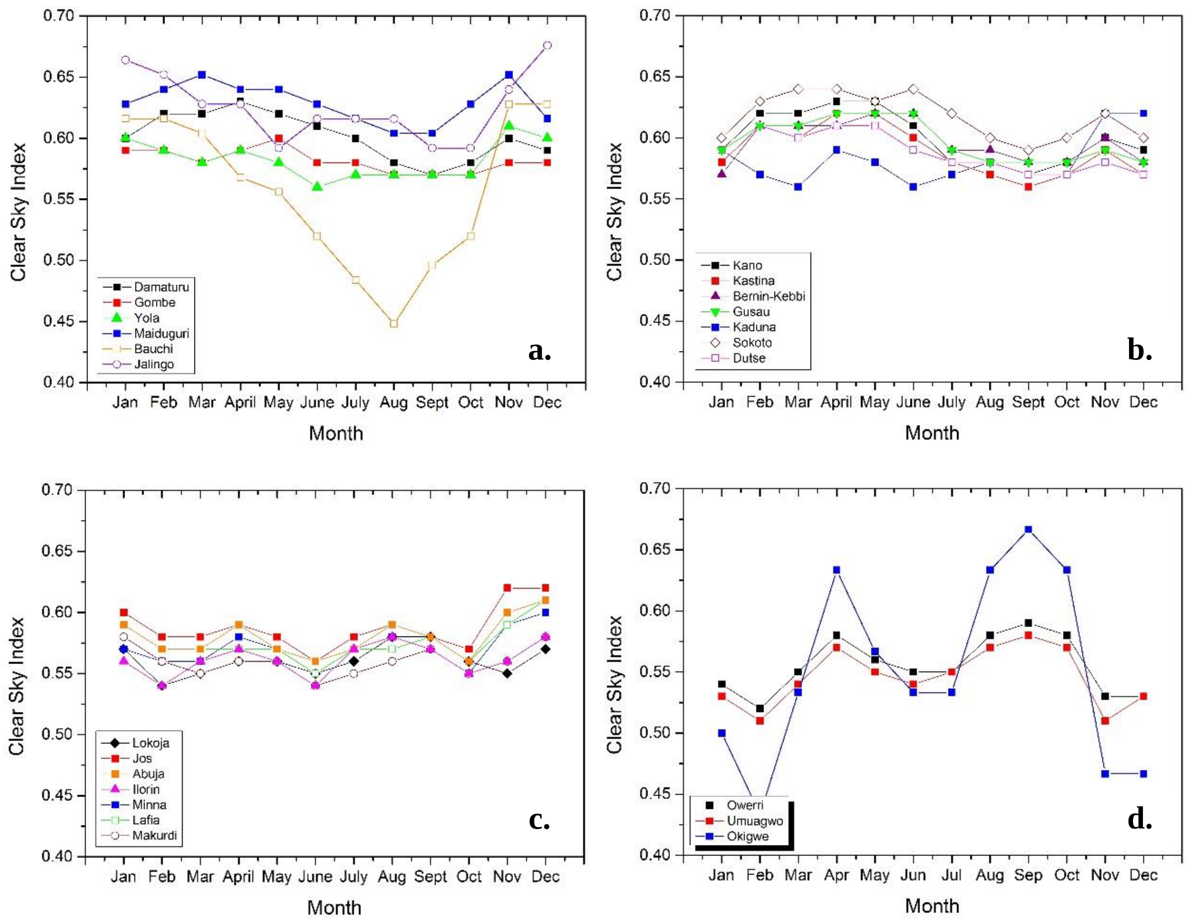

Figure 3: The Distribution of the Normalized Clear Sky Index in Some Selected Locations in Nigeria.

It is therefore evident from the above analysis that solar radiation resource remains abundant and it is not responsible for the failure of the installed systems. Sambo [25] inferred that if solar energy collectors or modules were used to cover 1% of Nigeria's 923,773km^2 land area, it is possible to generate 1850×10^{3}GWh of solar electricity per year.

What Went Wrong with the Failed Systems?

In fair quantitative terms, we report the inferences drawn from the evaluation of the failed systems and the questionnaires "the possible causes of incessant failure of some installed Solar Energy Systems in Nigeria" as follows; Our detailed evaluation of 10 failed systems each, of Solar Home Systems, Solar Street Light and Solar Water Pumps and the inference drawn from 73 questionnaires suggests that five key factors summarized in Figure 5 contributed to the failure of the solar energy systems.

The contribution of these factors to the failure of these energy systems is perhaps a subject for further analysis. However, analysis suggest that some of the charge controllers failed due to moisture percolation issues, percolation of moisture in the charge controller results to bridging of the circuitry which bothers on the design. Mismatch and wrong sizing of the charge controller results in overloading (burning out) of the charge controllers and or damage to the batteries. It also identified that Pulse-Width Modulation (PWM) charge controllers were mostly used in the failed systems evaluated.

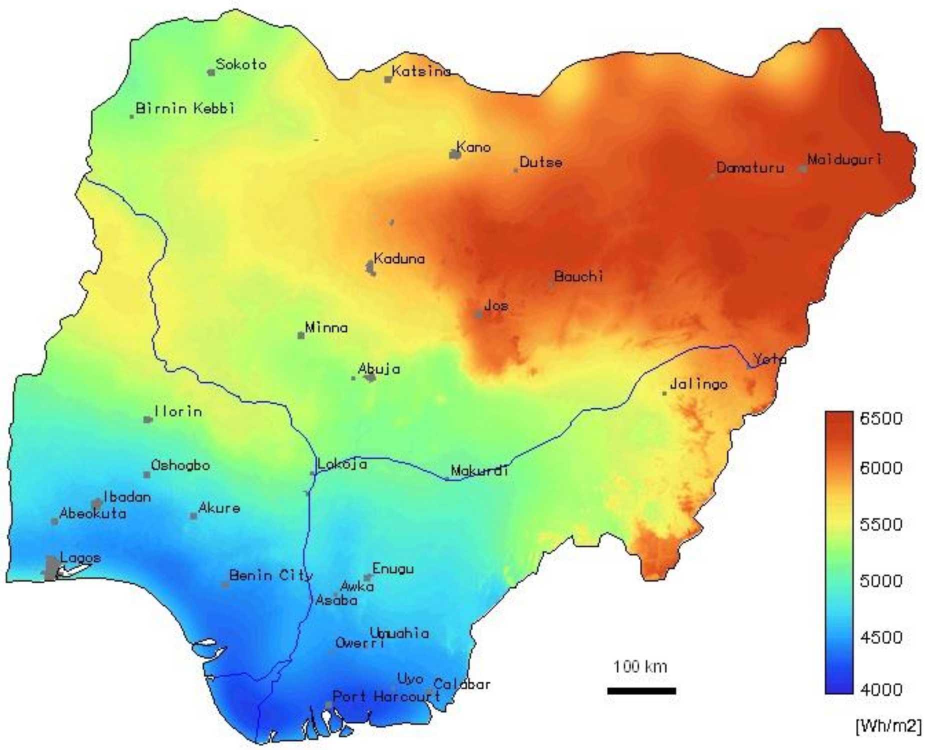

Figure 4: Yearly Average of Daily Sums of Global Horizontal Radiation Estimate for Nigeria.

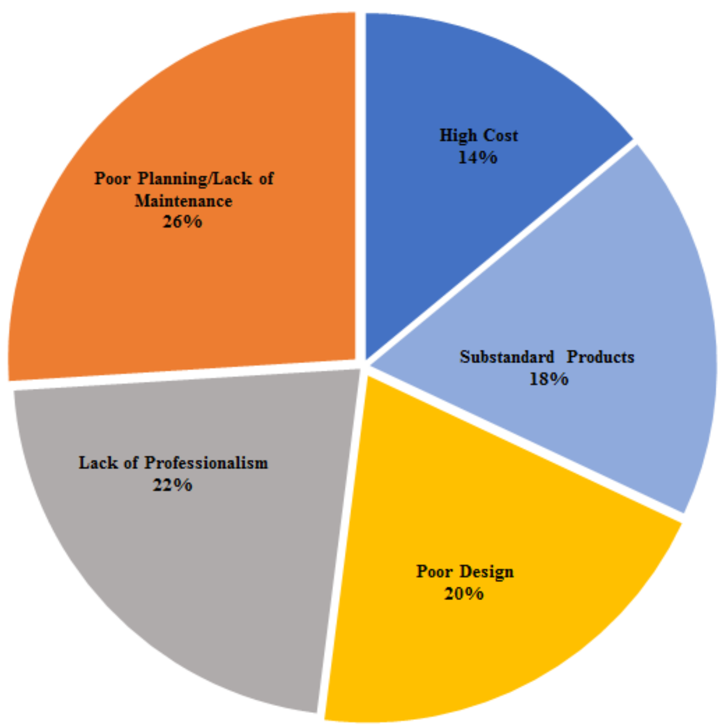

Figure 5: Identified Causes of Incessant Failure of Installed Solar PV Systems in Nigeria.

In PWM controllers up to 60% of power can be lost but there low price makes them a viable option than the Maximum Power Point Tracking (MPPT) controllers which are 93-97% efficient in power conversion. It was observed that flooded and Gel deep cycle batteries are commonly used in the systems evaluated. Apart from environmental factors like high temperature, the Depth of Discharge (DoD) and State of Charge (SoC) has tremendous effect on the lifespan. Our evaluations suggest that most batteries fail less than two years after installation due to DoD which bothers on the sizing of the system and undercharging of the batteries. Undersized solar PV array, dust cover and other obstructions reduce solar power output from PVs to adequately charge batteries which will result into low States-of-Charge. However, excessive charge voltage may have caused out-gassing and a permanent loss of water as seen in some batteries.

Using the inverters beyond their operating limit, can contribute to circuit bridge and inverter failure. In addition, some of the inverters was identified to be lacking capacity to protect itself from excessive heat generated by spikes in current or voltage. High temperature perhaps induced by high current, may have shortened the lifecycle of the component. As capacitors in the inverters are extremely sensitive to temperature variations. This is due to poor design and influx of substandard products in the market.

More so, some solar panels failed to generate electricity when tested, analysis suggests that spike from lightning and thunder storms may have caused this damage. Following that fact that there are common failure amongst solar PV panels mounted on metal roof top, it is also inferred that heat feedbacks from the metal roofs contribute to their damage.

Figure 5 clearly explains the contribution of five dominant factors to the failure of the energy systems. Lack of proper planning, long-term maintenance plans and usage of the equipment is another factor, our experience in this study shows that some of the projects are not well planned and cited. Although, there is relatively high abundance of solar energy resources in Nigeria, it is important to consider environment and solar radiation exploitable in a place before citing a project, especially large-scale projects which require adequate information on sizing and pointing. It is our observation that some of these projects did not meet these requirements, and thus they are not producing the required results. Poor maintenance culture results in dead-bulbs on street lightening systems where not replaced. In some cases, most solar PV panels are covered by dusts, over-grown by trees, and blocked by buildings. Overload of the energy systems is another factor that contributes to their failure, 26% of the respondents inferred. Indeed, lack of professionalism represents 22% of the respondents' opinion. Most of the solar energy system practitioners/installers are not well trained, they have little or no knowledge of the system components, and this have resulted into poor sizing and pointing of the system components. It is however, important to train and retrain the technicians to equip them with the necessary skills and emerging technologies (see, [26]).

Our investigations suggest that some of the designs did not take some prevailing environmental factors into consideration. For instance, the location of system components on solar street lightening pole without considering moisture issues in a humid location. It is observed that most users are not solely dependent on solar PV system, they however use it as a back-up system to compliment erratic power supply from the national energy grid. The design did not take into account peculiar needs of the users when designing those systems. However, this has encouraged local fabrication of inverters which are hybridized to meet specific needs.

In addition, parts of some packed up inverter and charge controller components are not readily accessible for replacement. In flux of substandard products in solar energy market due lack of government control, this have brought bad experience to solar energy users. 18% of the respondents suggest that this is the major cause of incessant failure of the solar PV systems. It underscores the need to regulate the market and impose stringent quality standards on solar PV system importation and development in Nigeria.

Following the high cost of solar energy systems, especially the solar PV panels, many users do not buy adequate solar PV panels required to effective run their systems. This has attendant effects on the state of charge of the batteries and the system in general. Although, it represents only 14% of the respondents opinion, it is important to introduce financial incentives to assist users acquire adequate and complete systems to serve their needs. A number of publications [26-27] suggest that high cost of solar energy systems is a major constrain to the growth of solar energy investment in Nigeria.

It is however imperative to suggest that these incessant failures are mainly due to poor maintenance, wrong sizing, and mismatch of the solar PVs, charge controller, and batteries. Therefore, the following subsections will feature helpful tips to correct sizing, the prediction of battery life based on the state of charge and depth of discharge and the need to promote home grown technology and development of renewable energy standards in Nigeria.

Possible Solutions to Solar PV System Failure in Nigeria

Adequate Planning and Correct Sizing of Solar Energy Systems: Adequate planning and correct sizing of solar energy systems are critical issues that must be considered before citing solar energy systems in Nigeria, the foregoing suggest that poor planning and design are primarily the causes of incessant failures of renewable energy systems. It is there important for renewable energy investors to pay close attention to the availability of solar radiation in the choice cite, the power need and the correct size of the solar energy systems to generate more than the energy need, this will undoubtedly forestall future failures. More so, the ability to predict the lifetime of a battery in target applications is helpful in selecting the most economical battery type and size for a given renewable power system application. The actual working depth of discharge (DoD) is one of the critical factors that contribute to the useful cycle life of a battery in a given application [28]. This suggests that increasing depth of discharge causes battery [29]. Therefore, the corresponding actual DoD can be calculated by the mean actual working state of charge (SoC) of a battery in a given application (see, [28], for more details).

Promoting Home Grown Technology: In the course of the work, we oberved the prolification of locally made power inverters and charge controllers. While we do not have up-to-date estimate about the number of locally fabricated power inverters and charge controllers in the Nigerian market, we infer that the importance of local manufacturing of solar PV systems considering the need to fill the energy demand and supply gap. There have been a quantum surge in local production of inverters. Although sine wave and not perfectly built to entice, these inverter have shown to be durable, efficient and serving the purpose. Little wander it is more expensive than some of the imported ones, they maker designed the systems to meet specfic needs and they provide service support to the users. This is an encourageable venture, we argue that providing the necessary financial incentives and advanced technical training to these brilliant inventors (local manufactures) will grow their businesses and in turn provide the needed energy access to the people [30]. Indeed, this production frontiers can be enhanced by efficient diffusion of technologies that are more advanced. Consolidating on the gains technological diffusion is crucial as we strive to find a long lasting solution to energy poverty in Nigeria and Africa at large.

Development of Renewable Energy Standards in Nigeria: As shown in Figure 5, 18% of the respondants attibuted incessant failure of Solar PV system to the influx of substandard products into the Nigeria renewable energy market. This is so because Nigeria lack adequate regulatory measures and standards on renewable energy to check these inlux. Emodi et al. [30] focused on the need for the development of standards for renewable energy technologies in order to prevent the importation of substandard renewable energy technologies in Nigeria. The authors underscored the fast growing renewable energy market and the implications of lack standards. The standards organization of Nigeria, the standards regulatory body in Nigeria should stand up to it responsibilities and introduce the right standards for these products to check impeding huge economic loss and to encourage clean development mechanism as well as improved energy access to the people.

CONCLUSION

In fair quantitative terms, critical analysis of the emerging challenges of solar PV utilization is Nigeria which have been verified with the following conclusions and associated implications:

1. Solar Energy potentials in Nigeria remains abundant. It is evident that Northern Nigeria has enormous solar energy resources. Our investigation shows that the least values of solar radiation incident on horizontal surface

in these cities are greater or equal to highest levels received some locations in Southern Nigeria. This strengthens the case we make for decentralized renewable energy investments in Nigeria [30].

2. This study identified the factors and the root causes of the observed incessant failure of solar PV systems in Nigeria. In resolving these factors that have adversely affected solar PV system reliability and investments in Nigeria, it is important to isolate the root causes of failures and implement practical countermeasures to circumventing them. This is imperative as solar energy system users are savvy on the reliability and lifespan costs of these products. A durable system must endure a wide range of inputs and outputs, overloads, including potential short-circuit conditions, and normal operation must resume once the faults have been cleared.

3. Keeping consistent maintenance regime and regularly replacement of damaged out parts may take care most problems caused by wear and tear.

4. Solar PV systems fail in less than a year after installation due to failures induced by poor design and/or wrong sizing/matching of the solar energy system.

5. Influx of imported substandard products into the Nigeria solar energy market leaves so much to be desired and strengthens the case we make for standardization of these products. It is in our belief that the standardization of the energy systems in Nigeria and beyond will reverse the ugly trend.

6. There is a need to fill the technological gap by training and retraining of our technicians with the requisite technical know-how to enable them confront the challenges of installations and repairs of these systems with precision. In addition, the promotion locally designed and production of the solar PV systems will be a step in the right direction. Advanced technological diffusion in Nigeria and African at large will yield measurable successes and improve energy access to the people.

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