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A 20kWh Off-grid Solar System to Power Help of Christian Hospital and Maternity, Okpatu in Udi LGA of Enugu State Nigeria

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Abstract – In this study, the potentials of solar energy utilization as an off-grid energy option for powering a hospital in Okpatu, a typical Nigerian rural community in Udi local government area of Enugu state were considered. Photovoltaic off-grid system is an effective solution to the shortage in power supply for isolated and remote areas undersupplied from the national grid connections. The work here presents a model of Photovoltaic system for powering a hospital in Okpatu. The correct size of the photovoltaic system was determined for all the appliances and equipments available in the hospital and their energy demand profile. Based on the electricity demand profiles and current costs, the analysis shows an improvement in average downtime, improved efficiency and service delivery. Furthermore, with the costs of photovoltaic technology predicted to decline in the next few years and the continuously increasing costs of diesel, the photovoltaic system tends to become economically viable.

Keywords – Renewable Energy, Hybrid, Off-Grid Power, Photovoltaic Systems, Energy Demands In Rural Areas.

1.0 Introduction

In a developing country such as Nigeria, with more than 60% of the population lacking access to electricity, social, economic, health and educational development is stunted (Yamegueu et al., 2010).

The major effects of lack of access to stable and affordable power supply in Nigeria are felt most in the rural areas. It impacts household utilities, small scale industries and health facilities alike, negatively. In the health sector in particular, it results in underinvestment in the sector, thereby, limiting the ability of hospitals expand capacity when need arises.

Nigeria and other countries in the West African region are strongly dependent upon fossil fuels. Studies have shown that while fossil fuels in this region are being exhausted, interests and research in clean and renewable energy is on the increase globally. This is further fuelled with the threat of global warming worldwide

Solar energy has a significant potential ranging from 4 to 6 kWh/m2/day and a range of different applications from single energy production, stand-alone to grid-connected systems or a combination with other forms of energy generations to produce a hybrid system (Joyashree and Soma,1999).

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In this work, the motivations for adopting solar energy system as a choice off-grid alternative for meeting the electricity demands in a Christian hospital in Okpatu village were considered. The Hospital before now used a diesel generator (DG) as a back-up supply in the event of loss of power from the grid This has not been economical for the hospital and as such it is deemed necessary to provide the hospital with a more stable and cost effective power system.

The different applications to which solar energy have been put generally and the extent of utilization were also investigated and discussed. The load analysis and operational efficiency of the hospital was analysed and presented.

Over the years, crude oil, natural gas and dams have been the predominant sources of energy in the country for electricity generation and other applications. With maximum electricity generation at 4500 mW, and a population of about 180 million people, Nigeria has been unable to provide power to more than 80 million of its people (Chineme Okafor, 2018).

The country is currently at a risk of impending energy crises in view of the fast diminishing fossil reserves, inadequate refining capacity to meet domestic consumption and serious cases of energy insecurity in restive regions where exploitations exist.

Even those connected to the national grid are mostly undersupplied, necessitating their recourse to alternative means, which include expensive fossil fuel generating sets (Chineme Okafor, 2018).

1.1 The Potentials of the solar energy in Nigeria

Solar energy is a clean source of energy which results from the conversion of energy from sunlight into electricity. This could be achieved directly using photovoltaic (PV) cells or indirectly using concentrated solar power (CSP) (Energy Resources, 2011). The photovoltaic module converts sunlight to electric current by photovoltaic effect while concentrated solar power systems focus large area of sunlight into a small beam by use of lenses or mirrors and tracking systems (Panapakidis, 2009).

The Sun, if harnessed maximally can bring solution to our current and future energy needs (Crabtree, 2013),) It is capable of delivering more energy per hour than the earth uses in one year, It is free from pollutants, greenhouse gases and very secure from geo-political constraints and conflicts. The amount of solar energy reaching the Earth's surface is about 100,000TW (Yeramilli & Tuluri., 2012)

Nigeria with her location on the equator is within a high sunshine belt where solar radiation is fairly well distributed (Bala et al, 2014). It was estimated that the annual daily average of total solar radiation varies from about 12.6MJ/m2/day (3.5kWh/m2/day) in the coastal region to about 25.2MJ/m2/day (7.0kWh/m2/day) in the far north. thus making her to have an estimated 17,459,215.2 million MJ/day(17.439TJ/day) of solar energy falling on its923,768km2 land area.

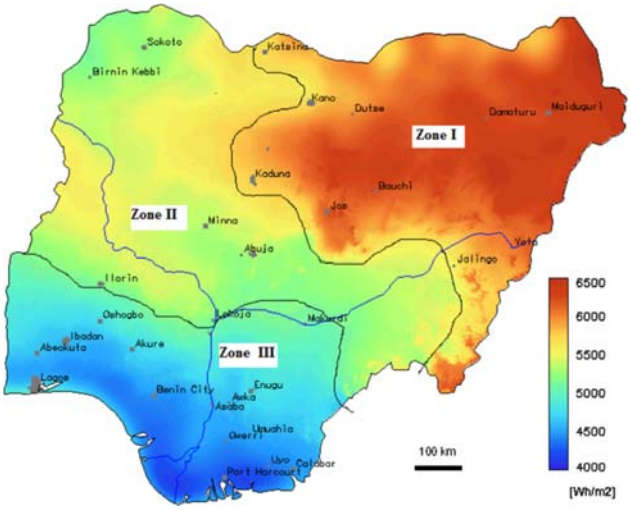

Fig. 1.1: Solar radiation map of Nigeria (Olayinka et al, 2014)

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In spite of this potential, Nigeria as a country is still slow in the adoption and use of solar energy to meet her increasing energy demands.

However, despite huge installation cost and other economic barriers to its adoption, a greater number of Individual electricity consumers are fast embracing it to overcome the poor supply from the national electricity grid.

Judging by the rate of developments in photovoltaic (PV) systems and the dwindling power generation capacity of the national grid, solar power systems may become the most preferred alternative source of electricity.

1.2 A review of photovoltaic systems development

For decades, Nigerian rural dwellers have mainly used solar energy directly in their agricultural processing for purposes such as drying of grains, cassava (tubers or marsh),yam flakes, meat, fish, fruits, kernels, drying of manure, hides and skins, cooking and frying of agricultural products which are not preserved or sold raw.

Other areas of solar energy utilizations include heating and lighting of animal pens, pumping of water and irrigation, food and vaccine storage (Yohanna & Umogbai, 2010). In addition to these, solar energy has also found wide usage in Nigeria viz: solar street lightings, solar refrigerators, solar cookers, solar-powered water pumps, etc; different applications exist in the form of solar thermal and solar PV (Rilwan & Sigalo, 2017),

According to (Sambo, 2010), solar PV installations are growing in Nigeria. A survey in (Bala et al., 2000) on PV installations in over ten Northern states of Nigeria, showed that the distribution in application by type includes: water pumping (57%), rural-clinic (for refrigeration and lighting (24%)), communications (television and radio (10%)), village and domestic lighting/TV viewing (8%) and experimental room air conditioning occupying 1%. All these have increased in recent years due to the poor electricity supply in the country. In addition, low-powered solar appliances in kWp (solar lanterns, solar battery chargers and other solar-powered home appliances) can be seen on retails across the country.

1.3 Drivers and barriers to solar application and development

Apart from the abundant availability of sunshine and solar radiation across Nigeria, several other drivers propelling solar energy development in Nigeria are as discussed below.

- Power sector reforms law

The enactment of the Electric Power Sector Reform Act (EPSRA) Cap E7 LFN 2004 in March 2005, made it legal for an individual to construct, own or operate an undertaking for generating electricity not exceeding 1000 kW in aggregate at a site without a license and/or own or operate an undertaking for distribution of electricity with a capacity not exceeding 100 kW in aggregate at a site without a license (Ohunakin, 2011). This exemption to holding a license favours energy generation from renewable resources.

This law empower individual or group of individuals to invest in off-grid power generating systems to augment the short falls from the grid supply (Ohunakin, 2011). The legislation also made way for the establishment of the REA whose major objectives are to: (i) extend the national grid (ii) facilitate independent off-grid systems (iii) generate renewable energy power and (iv) coordinate renewable electricity activities among the state and federal agencies (Olayinka, 2014)

Solar energy will thus play a major role in achieving these objectives in both the grid-connected and independent off-grid systems because of the abundance of solar radiation in this country.

- Meeting Local Energy demand

The population of Nigeria is projected to grow from 115.22 million in 2000 to 268.81 million by 2030 at an average annual rate of 3.86% between 2000 and 2030 (Olayinka, 2014). Population growth is a major driver of energy demand while its most important determinant is the level of economic activity measured by the total GDP alongside its shares by the various sectors and sub-sectors of the economy (Ohunakin, 2010).

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The rapidly growing demand for energy will create opportunities for solar energy development because conventional energy sources will not be enough to meet the need of the ever increasing population in a flexible manner. This is particularly true for rural areas which suffer the most from the poor electricity situation in the country.

Furthermore, the expanding economic opportunities in the rural areas will also demand an aggressive deployment of renewable energy options (most especially the vast solar resources) due to grid non-availability needed to evacuate generated conventional power to the respective primitive locations (ECN- UNDP, 2005)

- The Need for Energy Security and Improved Access for Rural Electrification

The estimate on the population of rural dwellers in Nigeria with access to electricity has been put at 10% (ECN- UNDP, 2005). Even in semi-urban and urban areas, there is also an 80% demand-supply gap in electricity in the country making diesel or gasoline generators the prime choice for running most businesses in the country.

In addition, the transmission network is overloaded resulting in a poor voltage profile on most parts of the network. There are occurrences of frequent system collapse and exceedingly high transmission losses [15], often in the range of 30–35% (Ohunakin et al, 2011). However, the official transmission losses are reported as less than10% (Ohunakin, 2010).

Particular issues identified include stagnated power generation capacity growth, lack of proper maintenance procedures for power generation and transmission equipments, and a lack of human capacity development. Currently, power mix in the country is dominated by fossil fuel based generating plants.

Since Nigeria is faced with a huge need for off-grid power sources, stand- alone PV and solar thermal systems thus constitute a safe, reliable and somewhat affordable alternative to the predominant diesel or fuel-powered generator sets. Every part of the country (as shown in Fig. 2) is very relevant for modern off-grid solar products, even in grid-urban areas that are characterized by a highly unreliable network. Solar energy is thus a stabilizing factor for the energy supply system in Nigeria.

Therefore, energy generation through various solar energy developments will be a high potential source for diversifying energy sources and increasing the share of domestic energy supply in the country, thereby meeting the objective of security of supply.

- Solar energy is a Conflict-neutral energy source

One of the major problems of fossil-fuel plants in Nigeria is the lack of/or irregular supply of gas for the gas-powered plants. In most cases, the problem is due to sabotage and destruction by the restive youth and oil pipeline vandalism in the Niger Delta region of Nigeria (Okoli & Orinya 2013).

Solar technologies are built off the sun, which is abundant in supply and inexhaustible. It cannot give rise to conflicts about usage and ownership of rights to such usage. This may serve as an important pushing factor for solar technologies since it addresses the same market segment in the country as other conflict prone energy sources like fossil fuels.

- Increasing demand for Local added value and job creation

Only about 30% of the entire Nigeria population is connected to the national grid and the majority (mostly rural dwellers) are left to the use of biomass and fuel wood for their energy needs (Olayinka, 2014).

Promotion of solar technologies across the country will contribute immensely to poverty reduction through local communities benefiting from employment opportunities, skills development, investment opportunities and technology transfer.

Many renewable energy pilot projects in developing countries give credence to the important role renewable energy projects can play in creating jobs for dwellers in energy-poor communities (Nnaji B).

Increased investment in solar applications will lead to the development of indigenous expertise in repairs, installations and manufacture of the various solar devices across the country and in particular the rural, off-grid communities thus leading to vast job creation.

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ISSN: 2509-0119.

https://ijpsat.org/
Vol. 48 No. 1 December 2024, pp. 471-480

Solar energy though seems to be the most popular choice for renewable energy systems, they have their drawbacks. Due to the unpredictable nature of the energy from the sun in some cases, the energy produced by the photovoltaic systems and the electricity demand time distributions do not match. This usually leads to extensive use of independent solar systems which results in over-sizing in terms of system reliability and overall over-cost (Post and Thomas, 1992).

1.4 Overview of research works on off-grid solar energy system.

Here a number of research and studies in the applications of solar energy as an off-grid power system were reviewed. Studies on the potential of solar systems working in combination with other sources of off grid power were also considered.

An assessment was made by (Offiong, 2003) on the economic prospects of stand-by powered systems in Nigeria such as solar powered or diesel generators, and he concluded that solar systems are economically viable compared to diesel generators, but that diesel-powered plants should be completely substituted for solar power systems

Two different hybrid systems in four regions in Greece with different solar and aeolic capacities were evaluated by (Ioannis, 2009). The first one involves a Photovoltaic system and a Diesel generator while the other one considers a wind turbine (WT) together with a Fuel cell (FC). The results showed high initial capital cost of the FC units, the WT/FC hybrid system has higher total cost compared with the PV/DG hybrid (Vosen and Keller, 2001).

2.0 Design methodology

To design the photovoltaic system, the load analysis of the hospital was done first to determine the right size of the system components to be assembled. The software PVSyst was used to simulate the system and determine the optimal system configuration for the location while PVGIS was used to get the solar irradiation of the region as the solar irradiance is also an important parameter to consider. The system diagram is shown in figure 2.1

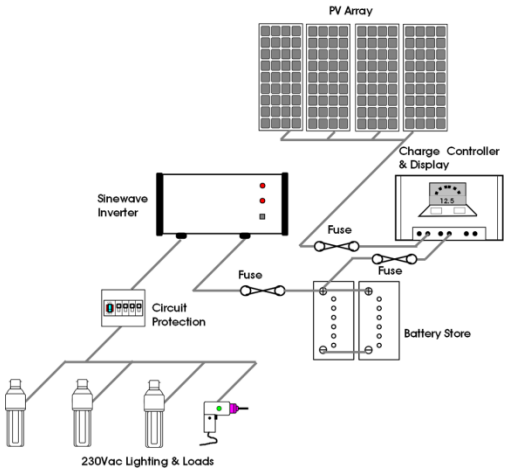

Fig 2.1: Photovoltaic system diagram (Source : windandsun.co.uk)

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https://ijpsat.org/
Vol. 48 No. 1 December 2024, pp. 471-480

Fig 2.2: a cross section the hospital with the PV panels on the roof

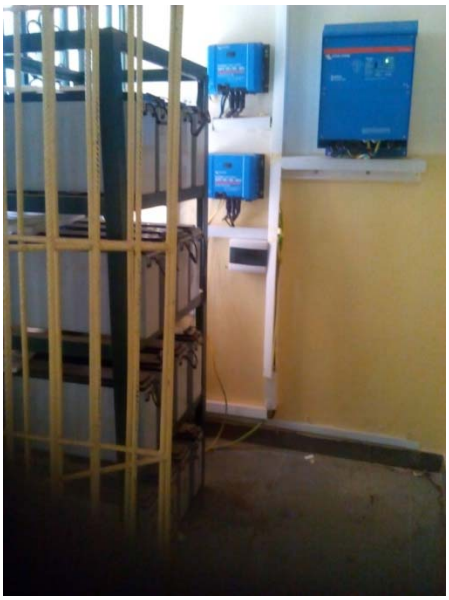

Fig 2.3: the battery bank powering the system

3.0 Results and analysis

From the analysis of the system design and its configuration, it was possible to identify the system performance parameters, load requirement, optimal performance conditions, and the size of equipment required to set up an optimal off-grid photovoltaic system for the hospital.

The lifetimes of the solar system units are considerably the same except the deep cycle batteries which need to be replaced at some points.

This cost of the system depends on the following:

- The cost of purchasing PV panels, batteries and inverter.
- The cost of replacing units throughout the lifetime of the system.

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 48 No. 1 December 2024, pp. 471-480

3.1 Power Design Criteria

The system should reduce the rate at which diesel is purchased, the operational time of the diesel generator (or be able to eliminate its use entirely) thereby reducing operation and maintenance cost providing long term cost savings (Ahmed and Ramesh, 2011)

The system should be able to provide stable and uninterrupted power to the hospital for a period of 24hrs

So that some critical loads in the hospital would not go off even when there is grid failure.

The system should be robust to withstand various weather conditions and be able to cope with much of the daily fluctuations in power demand and supply.

The system should guarantee ideal battery recharge schedules (maximize battery life) as well improve the system efficiency.

Reliability of the system is another important factor to consider. This ensures that the system operates in such a way that loss of load probability would be low.

Provision was also made in the design to allow the system incorporate load growth of a fixed amount beyond the current load profile of the hospital.

3.3 The Hospital Load Profile

A hospital can have a simple or complex emergency power supply system (EPSS) but the technique and ability to ensure that the equipment continues contributing to safe and effective patient care with today's challenges is quite difficult. In a standard Hospital, different departments are equipped with different appliances, machines and devices. For the hospital at Okpatu village, the available appliances and their estimated power consumption is shown in table below table 1.

Table 1: Hospital energy consumption measurement

Appliances	Quantity	Power (wats)	Total watts	Watt hours/day
Fan	1	50	50	6 - 8
Decoder	2	18	36	12
Standing fridge	2	200	400	6 - 12
Lighting bulbs	6	26	156	12
TV set	2	70	140	6
Desktop computer	3	270	810	1 – 2
Laser printer	1	50	50	1 - 2
Ceiling fan	15	75	1125	5 -6
Split unit AC	1	1125	1125	5
Theatre light	1	70	70	3 - 4
Ultrasound	1	180	180	
Incubator	1	300	300	2 - 12
Microscope	2	600	1200	5
Vaccine refrigerator	1	60	60	6 - 12

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Vol. 48 No. 1 December 2024, pp. 471-480

Centrifuge	2	600	1200	3
Electrophoresis Machine	1	200	200	1 - 2
ECG Machine	1	60	60	1 - 2
Deep freezer	1	400	400	6 - 10
TOTAL			**7562**	

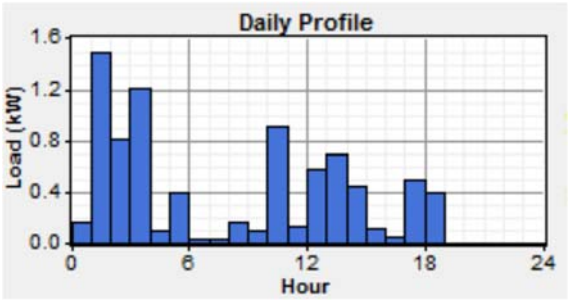

Fig 2.2: The daily load profile

All loads, including the air conditioner, theatre light, ultra-sound, incubator, elecrophoroetic machine, E.C.G, fridge and freezer are connected to the solar system. A 9.0kWp solar array is connected to the powerful Victron Energy 150V/100A x2 MPPT solar charge controller, which charges the 48V/720Ah deep cycle battery bank. The total energy storage for the hospital is 40kWh. The average electricity generated and stored is forecast to be 24-48kWh per day. This is enough to keep the batteries charged and to cover the daily loads, even when the weather conditions are not optimal. A Victron 48V/10000VA Quattro inverter/charger supplies electricity for the hospital. The AC 1 line is connected to the grid. At the moment the system is using a virtual switch with the dedicated ignore AC input option, but when grid metering becomes available, the system can be upgraded to a HUB1 system and the excess electricity can then be fed back to the grid.

3.2 System Configuration

The performance of PV modules depends on the temperature and solar irradiance on a particular day, starting from sunrise to sun set. The array of solar panels is mounted on the roof at an angle that allows it receive maximum sunlight within the day.

The system consists of PV panels mounted on the roof of the hospital building and positioned at an angle which receives maximum sunlight and traps solar radiations for conversion to electric energy. There are also batteries for energy storage, inverters for the conversion of direct current to alternating current to enable powering of the AC loads.

The system also consists of a battery charge controller which is used to control battery charging by both the PV array and the power from the grid. There is also circuit protection device to protect the appliances connected to the power system. The system starts operation automatically whenever there is an unstable supply or total failure in supply from the grid.

The PV panels are connected in a combination of both series and parallel connection to achieve the desired power output. The PV power output characteristics are peak power, voltage at peak power, current at peak power, short circuit current and open circuit voltage (PVGIS, 2011). The PV array could be modelled based on the following equations:

$PPV(t) = \eta . Ap . NPV . Ins(t)$ ……(1)

Where;

ŋ : Energy conversion efficiency (%)

A*p* : Area of single PV panels (m2)

NPV : Number of PV panel

Ins(*t*) : Insulation data (W/m2)

4.0 Conclusion

The main goal of this paper is to design, implement and analyze the performance of a PV solar energy system as a standalone source of power to a hospital in a rural community

The hospital relied on the renewable energy source (PV) more than the power from the grid. From this paper, it was evident that a solar powered off-grid electric generation systems is more suitable for the supply of electricity in such areas where the grid power is not reliable.

The PV array was adjusted to face the south direction with an angle from horizontal that maximises the incident solar radiation. The sizing of the PV modules is based on the module characteristic, system voltage, and the daily energy balance between the PV array and the hospital load. The system batteries were sized in such a way it could supply the load with both the daily and seasonal energy deficits.

The solar system has low maintenance cost, running cost and is environmentally friendly. It reduced the operational downtimes experienced in the hospital.

The results from the study clearly illustrate the potentials of solar energy in Nigeria to replace fossil fuels which pose great negative environmental impact on the environment and economy.

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