Design of a Stand-Alone Photovoltaic (PV) System for a Three-Bedroom Apartment in Mubi, Adamawa State, Nigeria.

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ORIGINAL RESEARCH

Abstract- In the world today, electricity is also among the essential basic amenities of every human being because it drives the socio-economic activities of any country. More than 1.3 billion of the populations across the globe are living with low or no source of electricity. The lack of accessibility to electric power to this population brought an existence of a wide gap in current energy sources and this affected the growth of such population mostly residing in remote settlements of developing nations. Electrical energy is a significant feature for the economic and developmental advancement in every nation. Even with the abundance of many sources of energy (conventional and non-conventional sources) around the world and in Nigeria, there are still problems in accessing electricity which could be attributed to its generation, transmission, or distribution. These challenges hinder the socio-economic advancement of a country. About 95 million (55 % of Nigeria's population) Nigerians are living with no supply of electricity and the total power/electricity produced, there is about 30-35 % loss in the generated energy from transmission and distribution. This research studied the possibility of electrifying a three-bedroom apartment in Mubi's high residential layout using a solar photovoltaic system through the adoption of HOMER Software. The parameters/data used in this research work were obtained from the basic appliances usually found in an average household and from works of literature on studies performed on energy utilization in some residential areas in Nigeria, taking into consideration their power ratings, quantity, and solar component prices. These and some design considerations like system fixed capital operation and maintenance cost of ₦4,000 per year, project lifetime of 20 years, system fixed capital cost, discount rate of 9 %, average solar radiation data, coordinate of Mubi, among other parameters were applied in the HOMER software for the design, simulation and optimized results obtained. The optimized results indicate that a solar PV array of 5 kW comprising 25 solar panels of 200 W each, 10 sets of 12 V / 220 Ah batteries, and a 5000 VA inverter with charger are sufficient to accommodate the load of 16.086 kWh/day. The cost of energy (COE) with a 100 % renewable fraction is ₦410.94 / kWh.

Keywords- Accessibility, Electricity, HOMER, Mubi, Photovoltaic.

1 INTRODUCTION

Energy (electricity) is of great importance for the betterment of man's daily accomplishments. More than 1.3 billion of the population across the world are living with low or no source of electricity (Francesco Fuso Nerini et al., 2016). The lack of accessibility to electric power to this population brought a wide gap to current energy sources, affecting the harnessing and growth of such populations mostly residing in remote settlements of developing nations. Electrical energy is a vital element for the economic and developmental progress/advancement in every nation.

Even with the abundant blessings of many sources of energy (conventional and non-conventional sources) around the world and in Nigeria, there are still problems with electricity access due to issues concern with energy generation, its transmission, and its distribution. These challenges hinder the socio-economic advancement of a country (Muyiwa S. Adaramola & Samuel S. Paul, 2017). About 95 million (55 % of Nigeria's population) Nigerians are living with no supply of electricity and the total power/electricity produced, there is about 30-35 % loss in the generated energy owing from transmission and distribution (Muyiwa S. Adaramola & Samuel S. Paul, 2017). The accessibility of some important infrastructure and other services in the suburban and urban areas of man's needs such as cooking, water supply, communication, and health amenities involves the supply of energy (Ajala, A.O et al, 2023). According to the Food and Agriculture Organization of the United Nations (FAO), those living or residing in rural areas need electricity for agricultural activities such as land preparation, irrigation, fertilization, and agro-processing etc. to better their lives (FAO, 2016). Energy through solar sources is a good choice when compared with many other renewable

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energies because sunlight is free, surplus, and noiseless (Fang and Song, 2018).

Nigeria, a country in sub-Saharan Africa is located at latitudes 4.32 °N and 14 °N of the equator and between longitude 2.72 °E and 14.64 °E of the Greenwich meridian with a land area totaling approximately 924,000 square kilometers covering almost 3.1 % of the land area of Africa (Aliyu, A.B et al., 2021; Sambo, 2010). The non-stop reduction in the conventional sources of energy, the high and unstable cost of oil/fuel in Nigeria, and the need by the emerging world and industrialized nations to reduce carbon footprints necessitated other forms of energy to be considered and harnessed which will in the future reduce over-dependence on the petroleum energy resources (Aliyu et al., 2015a).

Too much dependence on petroleum for energy supply has hampered the awareness, progress, and utilization of other sources of energy, there is a need to explore other alternative energy sources into the energy mix of the country (Aliyu et al., 2015b; Kennedy-Darling, J. et al., 2008). The development/exploration of renewable energies like solar energy systems, wind power systems, biomass, etc. helps to ameliorate the well-being of the population living without electricity and even the environment that we live in (Aliyu et al., 2015a; Dada, J.O., 2014). A study conducted by (Diemuodeke, O. et al., 2021) on the PV electrification system in Nigeria considering the six geo-political zones got the cost of energy (COE) ranging from $ 0.387 / kWh - $ 0.475 / kWh.

This study used the Hybrid Optimization Model for Electric Renewables (HOMER) software to design the cost and capacity implications of solar PV components in providing electricity to a 3-bedroom apartment in Mubi-Nigeria.

Table 1. Electrical Appliances with their Power Ratings

S/No.	Electrical Appliances	Quantity (Q)	Power Rating (W)
1	Lighting Bulbs (energy saving)	14	10
2	Ceiling fan	6	55
3	Radio	1	15
4	Shaver	2	15
5	Television 15″ LCD	1	50
6	DVD Player	1	35
7	Lenovo Laptop	1	65
8	Cellphone Charger	3	08
9	Fridge 12 cu. ft	1	280
10	Desktop fan 12″ blades	1	50
11	Security Lights	8	40

2 Materials And Method

2.1 Parameters/Data Considered

The data considered for this study include the commonly used appliances found in residential areas (average income earner). The power rating on each appliance was used in estimating the load needed in a three-bedroom apartment that is connected to the national grid as shown in Table 1. Prices for each of the solar components were considered taking the average market price of solar components obtained from suppliers here in Mubi

2.2 Gps Coordinate Of Mubi (Study Area)

The study area (Mubi) is located on latitude 10.2667 °N 10.27 °N) and longitude 13.2667 °E (13.27 °E) (Ngala, G.M et al., 2013; Ogbaka D.T et al., 2021). Mubi is among the commercial areas and the leading cattle market in Adamawa State-Nigeria, due to its size and population, it is also among the towns that consumes much energy when compared to many towns around the state and possesses an average temperature of 28.83 °C (Abubakar S. U., 2023) with six months (November - April) in the dry season and the other six months (May – October) in the rainy season (Abubakar S. U., 2023).

2.3 Source(s) Of Data

Solar Radiation data was obtained from the National Aeronautics and Space Administration (NASA), database using the geographical coordinates of the Mubi area (NASA Surface Meteorology and Solar Energy: RETScreen Data, n.d.) and also from work conducted by (Medugu D. W. et al., 2013).

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2.4 Required Loads That Are Estimated For The Three-Bedroom Apartment

The estimated hourly loads and the daily load profile needed for this study as required for the HOMER input were evaluated and presented in Figure 1.

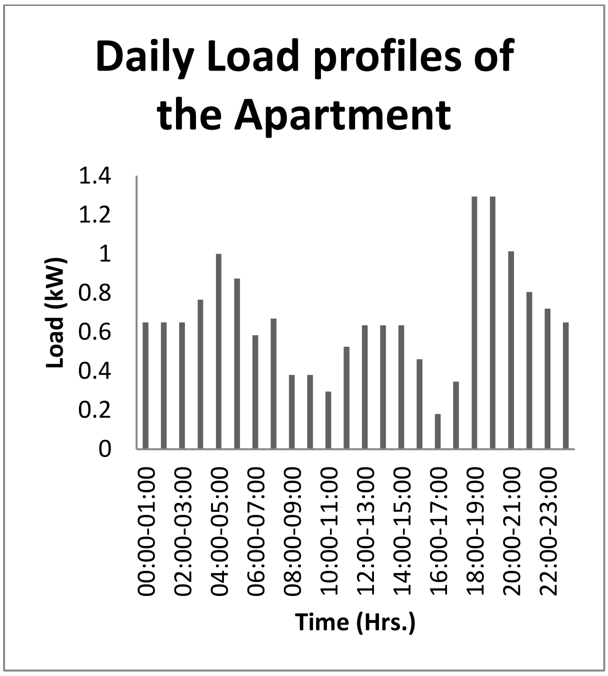

Fig. 1. Daily Load Profile of the Apartment

2.5 Average Clearness Index, Air & Earth Temperatures, And Average Solar Radiation

The average solar radiation and other input data for the study area (Mubi) are shown in Table 2 and the graph of the average solar radiation versus the clearness index is shown in Figure 2.

Table 2. Clearness Index, Average Solar Radiation and Temperatures

S/ No.	Months	Clearness Index	Average Solar Radiation (kWh/m²/day)	Air Temp. (°C)	Earth Temp. (°C)
1	January	0.671	5.94	23.3	24.4
2	February	0.666	6.36	25.9	27.2
3	March	0.545	6.55	29.3	30.8
4	April	0.593	6.24	31.0	32.8
5	May	0.562	5.87	30.2	32.0
6	June	0.527	5.42	28.2	29.5
7	July	0.483	4.98	25.6	26.2
8	August	0.475	4.75	24.4	24.6
9	September	0.509	5.23	25.0	25.0
10	October	0.584	5.71	26.2	26.4
11	November	0.678	6.09	25.3	25.5
12	December	0.677	5.82	23.3	24.1
	Average	**0.581**	**5.75**	**26.5**	**27.4**

Measured at 10 m

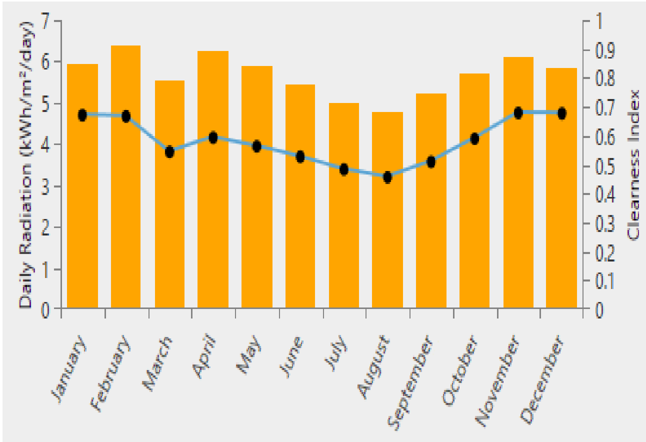

Fig. 1. Profiles of Average Solar Radiation and Clearness Index

2.6 Choice Of Photovoltaic Panels And The Input Values For The Model

Solar panels of 200 W costing ₦ 63,500 per one were chosen as one of the input data that will be given to the software, HOMER software has an inbuilt equation that will be used to calculate and optimize the capacity and number of panels that will be used to power the residential loads comfortably. The monocrystalline solar panel was chosen because of some qualities it possesses such as good efficiency, longer lifespan, and greater heat resistance among others. Some design values used in the simulation were obtained from the panel specification and are shown in Table 3.

Table 3. Design Values on Solar Module

Items	Capacity	Unit

Panel Capacity	200	W
Capital cost	1,921,000	₦
Replacement cost	0	₦
Cost of operation & Maintenance	4,000	₦
Temp. effects on power	-0.47	%/⁰C
Derating factor	80	%
Panel lifetime	25	yr.
Ground reflectance	20	%
Slope	10.27	Degree
Azimuth	0	Degree
Nominal Voltage	24	V
Nominal operating cell temperature	45	⁰C
Efficiency at standard test condition	17	%

Capital cost comprises cost of solar panels, 5 mm conductor wires, Binding wire, nails, change over, circuit breaker, clips, Panel Connectors, Fishers, Bolts and nuts, and fuses. 2 % of the installation cost was used for the operation and maintenance costs (Akinyele et al., 2015).

2.7 Design Parameters

HOMER uses some parameters like system fixed capital operation and maintenance cost (₦ 4,000), project lifetime (20 yrs.) system fixed capital cost, and discount rate (9 %) among other parameters in its economic window to aid in providing an optimized result.

2.8 Choice And Sizing Of Solar Battery

The battery or battery bank is required in the solar system to provide electricity backup where there is poor/low power generated due to bad weather or during peak load (Ugirimbabazi, 2015). The model calculates battery bank capacity (number of batteries required) and the life of the battery bank based on the inputs such as nominal voltage, cost of a battery, capacity, minimum state of charge, minimum storage of life, etc. given to it (Lambert et al., 2004). A 12 V and 220 Ah tubular battery costing ₦ 230,000 was chosen for this design.

2.9 Choice And Sizing Of Solar Inverter

A 5 KVA, 24 V inverter with an inbuilt charger (G-POWER PLUS) costing ₦ 530,000 was chosen for this study. The lifetime, efficiency, cost, etc. are among the data needed for the necessary inputs in the HOMER software.

2.10 Solar Charge Regulator Sizing And Selection

MPPT charge controller of 12 V / 24 V / 36 V 48 V / 120 A costing ₦ 253,000 was chosen for this study to ensure that all loads receive the maximum current, disallow overcharging of the batteries and prevent return current (by opening the circuit to halt the charging when the batteries are fully charged).

3.0 Results And Discussion

3.1 Simulation/Optimized Results

The solar system schematic is in Figure 3 while the optimized results for the system are shown in Table 4.

the power ratings of the appliances and usage is 5 kW, that is about 25 pieces/sets of the 200 W solar panels are required for that.
Moreover, ten (10) sets of 12 V / 220 Ah tubular batteries and an inverter with a charger of 5000 VA will be needed to support the load. The cost of energy stood at ₦ 410.94 / kWh **with $ 1 = ₦ 995**. An MPPT charge controller of 12 V / 24 V / 36 V and 48 V / 120 A was considered in the design and costing. No emission was recorded as the source of energy is clean and environmentally friendly

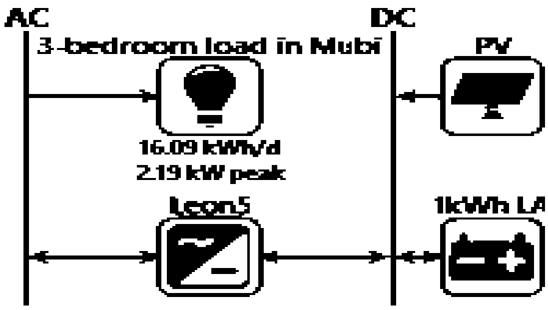

Fig. 2. Schematic of the System

Table 4. Optimized System Results

From the system results above, the PV array capacity required to serve the load of 16.086

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Architecture				Cost			PV	
PV (kW)	Batt.	Inverter (kW)	Dispatch	COE (N/kWh)	NPC (₦)	Initial Cost (₦)	Operating Cost (₦/yr.)	Ren. Frac. (%)
5	10	5	LF	410.94	37,569	5,505,000	4,000	100

kW/day, an average of 0.67 kW/day and 2.19 kW peak load for the 3-bedroom apartment based on the power ratings of the appliances and usage is 5 kW, that is about 25 pieces/sets of the 200 W solar panels are required for that.

Moreover, ten (10) sets of 12 V / 220 Ah tubular batteries and an inverter with a charger of 5000 VA will be needed to support the load. The cost of energy stood at ₦ 410.94 / kWh **with $ 1 = ₦ 995**. An MPPT charge controller of 12 V / 24 V / 36 V and 48 V / 120 A was considered in the design and costing. No emission was recorded as the source of energy is clean and environmentally friendly

4 CONCLUSIONS

A study and simulation run on the generation of electrical power to a 3-bedroom apartment in Mubi area show that source of electricity access through solar photovoltaic (PV) technology is viable and affordable as the cost of energy simulated is ₦ 410.94 / kWh which agrees with the result of the work conducted by (Diemuodeke, O. et al., 2021) that arrived at the cost of energy ranging between $ 0.387 / kWh - $ 0.475 / kWh (i.e ₦ 385.07-₦ 472.63), although the cost is on the high side as compared with the cost of energy supplied to the area (Mubi) by the Yola Electricity Distribution Company (YEDC) which is at ₦ 52.51 / kWh for tariff class C-NMD, but the supply is epileptic and of low voltage in many cases. A solar PV array of 5 kW (comprising 25 pieces of 200 W solar panels) with about 10 sets of 12 V / 220 Ah tubular batteries and a 5000 VA inverter with charger will be adequate to cater for a load of 16.086 kW / day. The total initial capital cost stood at ₦ 5,505,000 with an annual operation and maintenance cost of ₦ 4,000 /yr.

5 RECOMMENDATIONS

The HOMER simulation/study conducted centered on how electricity can be provided to a 3-bedroom apartment in an area of Mubi-Nigeria using solar PV technology only, it is therefore recommended that some of the renewable sources of energy be developed and harnessed in that area to reduce the over-dependence on the conventional source of electricity provided by the government, and that sensitivity(uncertainty) analysis be conducted for this energy source and other energy sources to be adopted for similar work.

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