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DESIGN, INSTALLATION AND TESTING OF SOLAR POWER BASED MICRO OFF-GRID SYSTEM FOR HOUSEHOLD ENERGY NEED DURING RAINY SEASON

[1]LATEEF OLASHILE AFOLABI, [2*]FREDERICK OJIEMHENDE EHIAGWINA, [3]OLUFEMI OLUSEYE KEHINDE, [4]IKEOLA SUHURAT OLATINWO,

[1,2,3]Electrical/Electronic Engineering Department, Federal Polytechnic Offa, Kwara State, Nigeria [4]Department of Computer Science, the Federal Polytechnic Offa, Offa, Kwara State, Nigeria

Abstract

Due to unstable power within Nigeria, there is a need to provide alternative but renewable means of energy supply. Among all the renewable sources, solar power has proven to be more sufficient and renewable for Offa, Kwara State, Nigeria (lat, 8.1393° and long, 4.7174°), even during the rainy season. We designed and installed a 500 W solar power system consisting of a battery, solar panel with charger controller and an inverter. The step in the design of the solar power system includes determining the household type and the daily energy demand, selection of PV modules and selection of an inverter. The number of the solar panel is determined by the battery size, solar radiation and sunshine hours of the site. The inverter rating was estimated at 500W, solar panel size was 350 W, monochromic panel and the battery size was two 200 AH. Due to cost constrain, a 100 W PV module was used to test the performance using one 100AH 12V Gel battery with 100% and 25% full load rating. Given the rainy season, there was insufficient radiation resulting in the PV voltage output being <10V. When the system was loaded 100% the system lasted for 4hours and when the load was 25%, it lasted for the whole night from 6:00 PM to 8:00 AM when the battery is fully charged.

Keyword: *Inverter, battery, PV modules, solar panel, solar radiation*

Background of the Study

A major factor militating against African development is inadequate electrical power supply. Many have resorted to the use of fossil fuels in the generation of electricity with unsatisfactory results. Besides, fossil fuels have caused a lot of havoc to the ecosystem with Africa not being able to tap into the advantages of using fossil fuels to generate electricity. Therefore, the need for an alternative source of generating electricity arises. The alternative source must be cheap, reliable and efficient.

Solar energy is considered the most significant source of renewable energy (Kabir et al., 2018 & Timilsina et al., 2014). The earth receives solar power at a rate of 120 Peta-Watts, meaning that all the energy obtained from the sun in a single day could satisfy the world's energy needs for twenty years (Rashad et al., 2015). The energy from the sun can be directly converted into electricity by using photovoltaics (PV) or indirectly by using concentrated solar power (CSP) technology which changes solar energy to heat energy so it can be used in thermal power stations to produce electrical energy (Rashad et al., 2015).

One of the discouragement in the installation of solar power systems is the short life span and large cost of the initial installation which is determined by the efficiency of design, installation methods and the environmental factors considered during the design. This study aims to design, install and test a solar power system for a maximum load of 500W in a simple two-bedrooms flat at a minimal cost. The testing will be done during the rainy season where the amount of solar radiation is expectedly low. To realise the goal of this study, the following will be done:

- Performance of a load audit for a typical two-bedroom flat with some selected loads
- Select an inverter with maximum performance and efficiency as the criteria
- design and select a better battery for maximal working hours of at least 4 hours when there is no sun for the installed location.
- determine suitable conductor sizes for the installation at a minimal cost
- design for a solar PV module to fully charge the battery with or without main grid supply
- Install and test the system

Review of Related Work

Introduction to Solar Power System

The electricity demand in the world is increasing rapidly.it is a great matter to meet this demand with no effect on the environment. Renewable systems have a high chance to have a new means of power generation to reduce gas emission from the conventional electrical power generation (Jena *et al*, 2011 & Liu *et al*, 2013). The lack of conventional energy resources like fuel encourages the widely spread of renewable resources, also the initial fixed cost of renewable resources is still high. Environmental changes like the weather and climate changes give another weak point to the renewable resources, so an energy management system should be implemented to transfer the supply feeding from one resource to another according to the resource adaptation to the change of the ambient environment. The best advantage of renewable resources is to generate different resources intelligently that satisfy the demand and to keep batteries charged. one of the main sources of renewable energies is the wind and solar energy are the primary renewable resources that depend on uncontrollable parameters like wind speed and sun irradiance, therefore this resources must be supported with the energy storage device. The key issues in the design and management of hybrid sources are found in Karthick and Manoharan (2017).

The elevated cost of solar energy compared to traditional sources of electric power is a result of the high manufacturing costs and expense of solar panels in spallation which resulted in limited solar energy employment and lead to the restriction of this type of energy in small applications only. However, solar energy costs have been dropping due to technological developments, resulting in steep cost reductions in the past 30 years (Timilsina et al., 2014; Rashad et al., 2015; & Ali et al., 2019).

Examples of some works in connection with the off-grid study are highlighted next. Ho, Lomi, Okoroigwe and Urrego (2019) investigated the current state, obstacles, recent initiatives, and prospects of solar energy in nations such as Malaysia, Indonesia (Asia), Nigeria (Africa), and Colombia (South America).

Hassan (2021) constructed a renewable energy system with a low energy cost, a high renewable energy fraction, and low CO2 emissions that can supply the specified electrical load of houses. Simulation and optimization were utilized to examine photovoltaic solar power systems used to electrify ordinary Iraqi dwellings. The performance and net present cost of two photovoltaic power system configurations, namely I off-grid and (ii) on-grid solar photovoltaic power systems, were determined using one-minute resolution simulations and optimizations. The results reveal that both systems operate well, however, the on-grid photovoltaic power system is less expensive than the off-grid solar power system. The total energy generated by an off-grid photovoltaic power system meets the desired electrical load of households and recharges the batteries, whereas excess electricity generated by an on-grid photovoltaic power system feeds the grid. Both technologies are both ecologically benign and economically viable.

Using ten distinct sites in Pakistan, the thermal, economic, and environmental feasibility of a 5 MW solar photovoltaic power system as an alternative to fossil fuel-operated power plants was investigated by Rafique and Bahaidarah (2019). Long-term metrological data was used to assess the viability of the planned plant's energy production, financial, and emission analyses. The results show that all of the sites are profitable, but Quetta is the most feasible location for solar PV plant installation. For all sites under investigation, the average values of internal rate of return equity, payback period, net present value, benefit-cost ratio, and capacity factor are 21.75 per cent, 10.58 years, 3,704,588 US$, 1.99, and 24.13 per cent, respectively.

Materials and Method

Component of Solar Power System

A solar power system contains a battery group, a battery charge regulator, inverter and auxiliary electronic circuits. These components may vary depending on the application. The number of solar panels is determined according to the amount of energy needed. Since the sun is not out at all hours of the day, the battery group is included in the system to provide the system with continuous energy. Therefore, it is necessary to use a battery charge regulator to prevent the battery from being damaged due to overcharge or discharge. Another duty of the charge regulator is to disrupt the current coming from the solar cells or the current drawn by the load depending on the state of the battery. If loads will be fed by alternating current in the system which will be fed by the solar panel, then one needs to use an inverter. Given that many loads are fed by alternating current, it is inevitable to use an inverter to convert the direct current obtained from the panel into alternating current. It will be more appropriate to add a maximum PowerPoint tracker to the system to increase its efficiency of the system.

The Steps in the Design of the Solar Power System

It is possible to summarize the steps in producing electricity using solar panels as follows:

- Determination of the annual need of the user
- Determination of solar radiation in the area of application
- Selection of PV modules
- Selection of the inverter
- Harmony of the maximum DC voltage and current belonging to the load with PV panels
- Checking the compatibility of the Voc and Isc values of the module group with the values of the inverter.
- Determination of the battery capacity in the battery fed systems taking into account the period of autonomy and the battery charge discharge yields
- Determination of the charge control device in the battery fed systems
- Checking the harmony of the maximum power monitoring window with PV panels

Panel Calculation

Equation (1) can be used to determine the number of parallel panels required for the PV system.

$$P_n = \frac{L_a . I_{dc}}{I_p . t_e} \quad (1)$$

P_n expresses the number of panels, *La* loss of activity, I_{dc} daily current capacity, *Ip* panel current, and effective solar time. Loss of activity is the loss that occurs as a result of the loss of time while charging/discharging an unleaded acid battery. This loss can be taken as 20 % on average. Since it was going to be taken as 20 % in this study, too, the loss of activity coefficient was used as 1.2. The daily current capacity is the current value that is needed for the whole system to operate for one day. Panel current is the active current value of the PV appropriate for the input voltage of the charging unit. Effective solar time expresses the time that can be used to generate electric energy from solar energy. Effective solar time may vary depending on days and months. The average annual effective solar time during the day in Nigeria is 5.2 hours. Determination of the effective solar time taking into account the city for which the system will be designed will increase the accuracy of the calculation.

Battery Calculation

Batteries in PV systems should have such a capacity that they should be able to meet the energy need of the system when electric energy cannot be obtained from PV panels. Capacities of batteries vary depending on temperature. Therefore, values of temperature should also be taken into account in calculations. The temperature coefficient value of the battery is shown in Table 1

Table 1: Temperature coefficients of the lead-acid battery

Temperature(c)	coefficient
26.7	1.00
21.2	1.04
15.6	1.11
10.0	1.19
4.4	1.30
-1.1	1.40
6.7	1.59

The total battery capacity of the PV system can be calculated using equation (2).

$$B_c = D_b . DD_. B_{cd} \qquad (2)$$

B_c in (2) expresses the total battery capacity needed, *Db* the number of days when energy will be obtained from the battery, *DD* discharge depth, *Ct* the temperature coefficient of the battery, and $B_c d$ the daily battery capacity needs. The average temperature in Offa, Kwara State, Nigeria is greater than 26.7°C. Therefore, the temperature coefficient of the battery was taken as 1 in this study. Charge depth can be defined as the change in the charge percentage of the battery during charging and discharging. As the charge depth increases, the lifespan of the battery decreases, so battery manufacturers recommend not taking the charge depth value above 50 %. Therefore, the charge depth was taken as 50 % in this study. After the battery capacity is determined, an appropriate battery is chosen from among the standard batteries produced by battery firms.

Installation, Testing and Performance Evaluation

Determination of the daily need of the user.

The project was installed in a two-bedroom flat which has the following load and daily time of operation as shown in Table 2. The average hour of sunshine in Offa is shown in Table 3.

Table 2: Table of Load and **Household Energy Consumption**

S/N	Load Description	units	Power rating/unit	Operating time, Hrs	Energy consumed, WH
1	A set of 24" plasma TV	1	100W	4	400
2	Ceiling fan	2	70W	3	420
3	LED 3W bulb	10	3W	3	90
4	LED 10W bulbs	3	10W	3	90
5	satellite decoder	1	30W	10	300
6	Home theatre	1	80W	3	240
	Total				1540

Total household power = 410W

Table 3: Determination of solar radiation hours in Offa, Kwara State

Mont	**Cleaner index**	**Daily radiation (kWh/m^2 /day)**	**Average sunshine hour (h)**
J	0.57	6.55	5.22
F	0.59	6.06	5.31

M	0.58	7.08	5.13
A	0.59	7.12	5.45
M	0.53	7.47	5.66
J	0.54	6.93	5.11
J	0.55	6.51	4.82
A	0.52	6.57	4.63
S	0.51	6.56	4.61
O	0.53	6.26	4.74
N	0.56	6.280	5.12
D	0.57	6.56	5.36

Average daily solar sunshine hour $=\frac{\sum h_i}{12}=\frac{61.8}{12}$

$= 5.15$ hours

Total Load 415 W

Total Energy 1540

The tolerance for inverter should be between 20-30%

20% of 415= 83 W

Total inverter rating = 415+83 = 498

Therefore, Inverter size = 500 W

Solar panel sizing unit factor = 80% = 0.8

The minimum voltage the cable loss = 0.85

The total power $= \frac{Energy}{0.3\times 5.23} = \frac{1540}{0.85\times 5.23}$

=346.379

Inverter = 350 W

Two 200 AH battery needed

Minimum voltage limit factor for battery = 80% = 0.8

The battery size = Total energy × 1.3 × 1.6

$=\frac{3203.2}{0.8} = 4004$

Designing for a day without solar energy = 4004

The battery size = 12v

Total energy rating = $\frac{4004}{12} = 333.67$

$= \frac{333.67}{200} = 1.7$

= 2

PV Panel = 350

Voltage rating = 37.6

Current I = $\frac{p}{V} = \frac{350}{37.6} = 9.31$

The resistance of the conduct

R = $\frac{V}{I} = \frac{37.6}{9.31} = 4.04$

A = $\frac{Sl}{R} = \frac{1.72*50}{4.04} = \frac{8.6}{4.04} = 2.13$

The conductor size = 2.13

R = $\frac{37.6}{4.04} = 9.31$

R = $\frac{Si}{A}$

The Change-Over Switch

This section is used to switch ON the inverter when the AC mains supply is OFF and to switch OFF the inverter when the AC mains supply returns (ON). During the changeover, when the inverter receives AC mains supply, it stops drawing the battery supply and the AC mains supply at the inverter input is directly sent to the inverter output socket. This is done using a one, two-pole relay.

Inverter AC Output

The AC output gives a 220V AC, 50Hz either directly from the input when the AC mains supply is available or from the inverter circuit action on the battery when the AC mains supply is not available. Computers and other household appliances are connected to this output.

Protections

The AC input to this device was fused with a 5Amp fuse to protect the transformer as well as the rectifying circuit in case of over-voltage, and high current which could flow into the transformer. It is also protected against overloading above 500W load will automatically switch off the inverter.

Indicators

Three indicators are connected to the front of the inverter; a digital display meter that shows the level of battery voltage when in use or during charging.

Switch

A switch is connected to the front of the inverter to turn On and Off the inverter and another switch is at the rear side to the automatic switch of the inverter against any fault.

Testing of the solar power system

On assembling the proposed system, the following test results shown in Table 4 were observed. The test load switching On and Off times are shown in Table 5:

Table 4: Battery Charge Condition Table for 12V battery.

Battery condition	12v
Battery near fully charge while charging	14.4 – 15.0
Battery near full discharge while charging	12.3 – 13.2
Battery fully charged with a light load	12.4 – 12.7
Battery fully charged with a heavy load	11.5 – 12.5
Battery near full discharge while discharging	10.2 – 11.2

Table 5: 25% loading Switching On and Off Test result

Test day	Switch on time	Switch off time
1	5.55 PM	7.52 AM
2	6.01 PM	7.54 AM
3	5.59 PM	7.55 AM
3	5.58 PM	7.52 AM
4	5.55 PM	7.55 AM
5	6.00 PM	7.52 AM
6	5.59 PM	8.00 AM
7	5.45 PM	7.58 AM
8	5.45 PM	7.58 AM

From the tests carried out, it can be deduced that the solar irradiance at 6:00 AM will not give sufficient voltage output (> 10V). Test Days 7 and 8 had cloudy evenings as it rained those evenings. The test also confirmed that switching on and off of the lights is possible.

Conclusion and Recommendation

The project involves the design and installation of a solar power system which was used to power two 24 plasma television, 2 fans, 1 satellite decoder, 13 LED bulb and 1 home theatre the design was based on the solar climate of Offa, north Centre of Nigeria, on the average sunshine hour of 5.15 hour located on (lot, log). After the design the inverter rating was estimated to be 500W, solar panel size in one 350W monochromic panel, the battery size was designed to power the load for the day without sunshine and was estimated to be two 200AH and so on due to the cost constrain a 100W panel was used to test the performance using one 100AH 12V GZL battery with a load rating, it was deduced that some irradiant 6.00 pm in raining season will not give sufficient voltage output >10V for the panel then 6.00 AM have when the system way loaded 100%, the system lasted for 4hours with the stimulated and when it was loaded 25%, it lasted the whole night before switched off. From 6:00 PM to 8:00 AM for seven days

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