

# Design of a Standalone Photovoltaic System for the Department of Physics, Faculty of Science Complex, Gombe State University, Nigeria.

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## Abstract

Energy is generally essential to economic and social development and improves quality of life globally. Most of the residences derive their electricity from utility companies but due to their inefficient services some people have resort to diesel and gasoline powered generators among others. These machines are usually associated with noise pollution and also with the disadvantage of increasing the greenhouse gas emission which has a negative impact on the environment. It is therefore necessary to look for an alternative and reliable source of energy to obtain steady power in the Department of Physics, Faculty of Science complex in Gombe State University for effective learning condition. In this work, a standalone photovoltaic (PV) system was designed for the Department of physics to overcome some of the challenges mentioned earlier. The aim was achieved through energy audit, battery sizing, charge controller sizing, inverter sizing, and photovoltaic system sizing were carried out. In this research design analysis of PV system were carried out based on the load assessment of the Department of physics, faculty of science. The system was planned to have a 3 days of autonomy and has a total power of 13185W and total energy requirement 80897.857 Wh/day which would require 25280.580 AH; 141 photovoltaic panels of 280W each; 50 KVA rated inverter; 11 charge controller rated 60A each; panel covers area of 17.2 m<sup>2</sup>.

**Keywords:** PV System, Standalone, Load assessment, Sizing, Modules.

## INTRODUCTION

The energy that is usually sustainable in our solar system is provided by the sun. In our daily activities, energy plays an important role. The country will consider has development and civilization, if the amount of utilization of energy in a country is one of the measure. The economy of any country is enhanced by the sustainability and availability of electrical power of the nation (Ikeme and Ebohon, 2005).

Due to declining electricity generation from domestic power plants, Nigeria faces serious energy crisis which are basically dilapidated, obsolete, and unreliable and in appalling state of disrepair, reflecting the poor maintenance culture in the country and gross inefficiency of

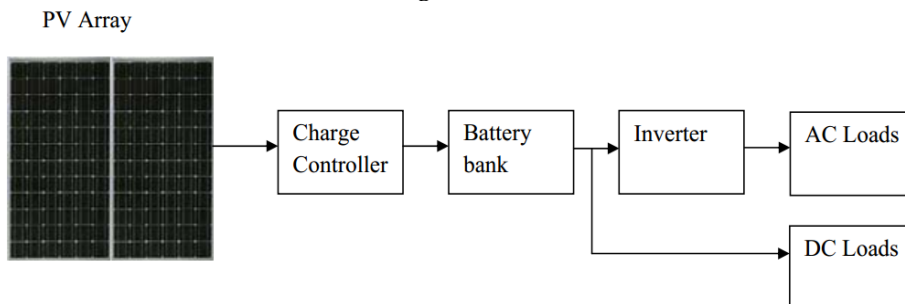
the public utility provider (Ikeme and Ebohon, 2005). According to the Nigerian energy policy report, it is estimated that the population connected to the grid system is short of power supply over 60% of the time (Okoye, 2007).

Energy is generally essential to economic and social development and improves quality of life globally. It is very important for the developing society like Nigeria. In Nigeria, most residential homes are connected to the electric grid (utility company). However, there still exist several or remote locations, which, for financial or environmental reasons related to their distance from an existing power line, are not connected to the utility grid (jovanovic, 2008). Most of these residences derive their electricity from gasoline or diesel powered generators, which can be noisy and have the disadvantage of increasing the greenhouse gas emission which has a negative impact on the environment (Ani, 2015).

Gombe State University was established in 2004, the study area was Department of Physics in new faculty of science complex building of Gombe State University in Gombe town, Nigeria. It lies between the geographical coordinates of 10°18'16.1"N and 10.3045° (Latitude) 11°10'32"E and 11.1756° (Longitude). Faculty of science complex of Gombe state university and in particular the Department of Physics suffers from epileptic power supply. The result from this study will therefore provide useful information to government and Gombe state university in the design standalone photovoltaic system in the new faculty of science complex in Gombe state university so that to improve staff output in terms of teaching and research. The photovoltaic system option is environmentally clean and friendly, noiseless and required less maintenance.

### **PV System Configuration**

In a stand-alone system depicted in figure 1, the system is designed to operate independent of the electric utility grid, and is generally designed and sized to supply certain DC- and/or AC electrical loads as shown in figure 1.



**Figure 1:** Stand-Alone PV System (Jayakumar, 2009).

### **PV Equipment / Components.**

Photovoltaic (PV) energy generating systems (or PV systems) convert the solar energy directly into electric current using state-of-the-art suitable semiconductor materials. PV systems produce clean and reliable energy used in a variety of applications. Some are called a “stand-alone or off-grid” system, which means they are the sole source of power to a home, water pump or other load (King, 1996). The photovoltaic effect phenomenon was first discovered by a French scientist Edmund Becquerel in 1839 (Klaus *et al.*, 2014).

**PV Power System Components:** The components required for Solar Photovoltaic system are selected according to your system type, site location and applications.

### Photovoltaic module:

A photovoltaic module is a group of cells, wired in series. The electrical output from a single cell is small; so multiple cells are connected in series and encapsulated (using glass) to form a module as shown in figure 2. PV modules are part of the basic building blocks of a PV system, and any number of modules can be connected either in series or parallel to give the desired electrical output in a PV array as shown in figure 2. This modular structure is a considerable advantage of PV systems, because new panels can be added to an existing system as and when required (King, 1996).

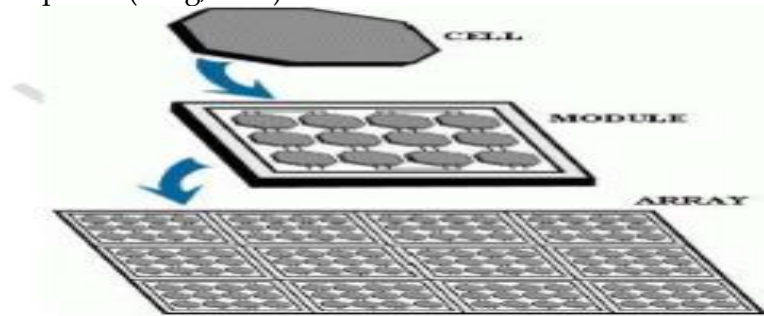


Figure 2: Solar module and array (Ammar, 2017)

### Batteries

Batteries are very crucial component in stand-alone PV systems. The main function of a battery is to store the electrical energy generated by PV modules during sunny days to be consumed during night or rainy days. The most common types of batteries currently used are lithium-ion and nickel-metal hybrid and, nickel cadmium batteries for cold climates (Jayakumar, 2009). A bank of batteries connected in series (wired positive to negative) is done to build voltage. The batteries are supposed to be housed in a vented enclosure as shown in figure 3.



Figure 3: Battery bank (Franklin, 2017).

### Inverters

The main function of an Inverter is to convert DC output of PV panels or wind turbine into a clean AC current for AC appliances or it can be fed back into grid line. It is one of the

important solar energy system's main component, as the solar panels generate DC voltage. Inverters are differentiated base on the output wave format, output power and installation type as shown in figure 4. It is also called power conditioner because it changes the form of the electrical power. The efficiency of all inverters reaches their nominal efficiency (around 90 percent) when the load demand is greater than about 50 percent of rated load (Ibrahim *et al.*, 2013).



Figure 4: Examples of inverters (Franklin, 2017).

### Charge Controllers

Charge controllers are necessarily included in most photovoltaic systems to protect the batteries from overcharge or over discharge. Overcharging can boil the electrolyte from the battery and cause failure. The charge controller has connections to the solar module, the battery, and the load. This model has a “low voltage disconnect” (LVD) option and automatically deenergizes the load until the battery is re-charged by the solar module as shown in figure 5. (Franklin, 2017).



(a) SunSaver-10L

(b) ProStar-15

(b) Figure 5: Charge controllers. (a). SunSaver-10L and (b) ProStar-15 (Franklin, 2017).

**Load** - is electrical appliances that is connected to solar PV system such as lights bulbs, radio, TV, computer, refrigerator, etc

### PV SYSTEM DESIGN

PV system design is the process of determining the capacity (in terms of voltage and current) for each component of the stand-alone photovoltaic power system with the view to meeting the load profile of the Department.



### Residence Device

Firstly the electrical devices available at Department are itemized with their power ratings and time of operation during the day to obtain the average energy demand in Watt-hour per day as shown in Table 1. The total average energy consumption is used to determine the sizes and ratings of the equipment, starting with the solar array and ending with system wiring.

### Sizing of the PV Array

To avoid under sizing, the total average energy demand per day divide by the efficiencies of the system components to obtain the daily energy requirement from the solar array (Aithal *et al.*, 2008).

$$E_r = \frac{\text{daily average energy consumption}}{\text{product of component efficiencies}} = \frac{E}{\eta_b \eta_i \eta_c} \quad (1)$$

where,

$\eta_b$  = battery efficiency

$\eta_i$  = inverter efficiency and

$\eta_c$  = charge controller efficiency

The previous result is divided by the average sun hours per day for the geographical location  $T_{min}$  to obtain the peak power. (Aithal *et al.*, 2008).

$$p_p = \frac{\text{daily energy requirement}}{\text{minimum peak sun hours per day}} = \frac{E_r}{T_{min}} \quad (2)$$

The total dc current of the system ( $I_{DC}$ ) is then obtained by dividing the average peak power by the dc voltage of the system (Aithal *et al.*, 2008).

$$I_{DC} = \frac{\text{peak power}}{\text{system DC voltage}} = \frac{p_p}{V_{DC}} \quad (3)$$

The number of parallel modules which equals the whole modules current divided by the rated current of one module  $I_r$  (Aithal *et al.*, 2008).

$$N_p = \frac{\text{Whole module current}}{\text{rated current of one module}} = \frac{I_{DC}}{I_r} \quad (4)$$

The number of series modules which equals the DC voltage of the system divided by the rated voltage of each module  $V_r$  (Aithal *et al.*, 2008).

$$N_s = \frac{\text{System DC voltage}}{\text{rated voltage of one module}} = \frac{V_{DC}}{V_r} \quad (5)$$

The total number of modules ( $N_m$ ) that form the array is then finally determined by multiplying the number of modules in series by the number of parallel modules which gives the required array size:

$$N_m = N_s \times N_p \quad (6)$$

The total area of coverage of the panels would be;

$$A = L \times W \times N_p \quad (7)$$

where, L is length of a panel,

W is width of a panel, and

$N_p$  is total number of panel (Aithal *et al.*, 2008).

### 2.3.3: Sizing of the Battery Bank

$$E_{rough} = E \times D \quad (8)$$

where,  $E_{rough}$  is amount of rough energy storage,

$E$  is total power demand and

$D$  is the number of autonomy days.

$$E_{safe} = \frac{\text{energy storage required}}{\text{maximum depth of discharge}} = \frac{E_{rough}}{MDOD} \quad (9)$$

where,  $E_{safe}$  is safe energy storage,

MDOD is maximum allowable depth of discharge and

$E_{rough}$  is amount of rough energy storage required.

$$C = \frac{E_{safe}}{Vb} \quad (10)$$

where  $E_{safe}$  is safe energy storage,

$C$  is the capacity of the battery bank needed in ampere-hours and

$Vb$  is DC voltage of one of the batteries selected.

$$N_{batteries} = \frac{C}{Cb} \quad (11)$$

where,

$N_{batteries}$  is total number of batteries,

$C$  is the capacity of the battery bank needed in ampere-hours and

$C_b$  is capacity of one of the battery selected in ampere-hours.

$$N_s = \frac{V_{DC}}{Vb} \quad (12)$$

where  $N_s$  is the number of batteries in series,

$V_{DC}$  is DC voltage of the system and

$Vb$  is voltage rating of one of the batteries selected.

$$N_p = \frac{N_{batteries}}{N_s} \quad (13)$$

where,  $N_p$  is number of parallel paths,

$N_s$  is the number of batteries in series and

$N_{batteries}$  is total number of batteries. (Aithal *et al.*, 2008).

### 2.3.4: Sizing of the Charge Controller

To obtain the rated current of the voltage regulator I: (Aithal *et al.*, 2008).

$$I = I_{SC} \times N_p \times F_{safe} \quad (14)$$

where I is rated current of the voltage regulator,

$F_{safe}$  is the safety factor and

$I_{SC}$  is short circuit current of the modules connected in parallel.

To obtain the number of controller, we divide the Array short current Amps by current rating of one controller (Aithal *et al.*, 2008).

$$N_{controller} = \frac{I}{\text{current of one controller}} \quad (15)$$

### 2.3.5: Sizing of the Inverter:

The size of the inverter required can be obtained using general power equation.

$$S = \frac{WHT}{Pf} + 25\% WHT \quad (16)$$

where; S = Inverter power rating,

$WHT$  = Total power rating and

$Pf$  = Power factor.

The 25% of  $WHT$  accounts for factor safety (Theraja and theraja, 2012).

### Sizing of the System Wiring

Due to lose through cables, it is very important to consider the types of the cables that will be used.

## RESULT AND DISCUSSION

The computed results obtained from the appliances of different lecture rooms, offices and laboratories in the department of Physics were presented in Table 1.

### Energy Requirement for the Department of physics.

The energy audit of department of physics in Faculty of science was carried out, and the power required for each of the appliances were obtained. Also, the data obtained was analyzed consequently considering time of operation as presented in Table 1.

**Table 1: Energy Requirements analysis for Physics Department.**

S/N	Appliance	Qty.	Power(w)	Total power (Pr)(w)	Time of operation (Hours)	Usage days/week	Days/ week	Total energy required /day(wh/day)
01	Light bulbs	149	15	2235	10	7	7/7	22350.000
02	Fans	68	70	4760	9	6	6/7	36720.000
03	P.C	13	65	845	4	6	6/7	2897.143
04	Stabilizer	1	1000	1000	9	5	5/7	6428.571
05	Extractor	6	70	420	7	6	6/7	2520.000
06	Desktop	2	250	500	4	6	6/7	1714.286
07	Printer	5	50	250	4	5	5/7	714.286
08	Photocopier	2	1500	3000	3	5	5/7	6428.571
09	Fridge	1	175	175	9	5	5/7	1125.000
Total				13185				80897.857

### Components Data Sheet

Technical characteristics of the components are vital for sizing the components, they are usually found from the data sheets of the components obtained from the manufacturers, the components include: Electrical load, Inverter; Solar module, Storage battery and Charge controller.

### Selection of System Components According to the Innovation Companies of Photovoltaic System

The mono - crystalline silicon module was selected due to its high efficiency and durability.

### Selected PV module specification.

Module (Mitsubishi - MLE208HD2, 280-W, VDC=24, IR=8.68-A)

Manufacturer: MITSUBISHI ELECTRIC

Model Name: PVMLE280HD2

Cell Type: Mono-crystalline silicon, 78mmx1566mm

Number of Cell: 120 cells

Maximum power rating ( $P_{max}$ ): 280W  
Open circuit voltage ( $V_{oc}$ ): 38.6V  
Short circuit current ( $I_{sc}$ ): 9.37A  
Maximum power voltage ( $V_{mp}$ ): 32.4V  
Maximum power current ( $I_{mp}$ ): 8.68A  
Bus bars per cell: 4 bus bars  
System voltage DC ( $V_{dc}$ ): 24V

#### Selected battery specification.

Battery (Toyan – SPRE/2225) MDOD = 80%  
Manufacturer: Trojan Battery Company  
Model Name: SPRE/2225  
Voltage of battery: 12V  
Capacity of the battery: 225Ah@100Hr  
Material used in the battery: polypropylene  
Type of battery: Deep – cycle flooded /advanced lead acid battery.  
Watering: Single-point watering kit (Optional)  
Production Highlights of the battery life: 8 years battery life based on IEC 61427  
MDOD (Maximum Depth of Discharge) = 80%  
Autonomy Days: 3 days  
Efficiency of the battery: 85%

#### Selected charge controller specification

Charge controller: (xantrex C-60, 24-V, 60-A)  
Rated charged current of charge controller: 60A  
Input voltage of charge controller: 24V  
Efficiency: 90%

#### Selected Inverter

The selected inverter was a pure sine wave inverter system which operate a wider variety of appliances and has an efficiency of 90%.

#### Sizing of the solar Array.

Daily average energy demand (E) from table 4.1 = 80897.857 Wh/day

Using equation (1), the daily energy requirement from the solar array can be determined as:

$$Er = 117498.703 \text{ Wh/day}$$

Using equation (2), the peak power of the PV can be obtained as:

$$p_p = 29374.676 \text{ W}$$

Using equation (3), the total current can be obtained as:

$$I_{DC} = 1223.945 \text{ A}$$

Using equation (4), the number of parallel modules required can be calculated as:

$$N_p = 141.007 \approx 141 \text{ panels}$$

Using equation (5), the number of series modules required can be calculated as:

$$N_s = 1 \text{ panel}$$

Using equation (6); we have,  $N_m = 141 \text{ panels}$

The Photovoltaic array of the system consists of 141 panels in parallel.

Using equation (7), the total area covers of the panels would be,

$$A = 17.2 \text{ m}^2$$



### Sizing of the battery bank

Using equation (8), the amount of energy storage required can be calculated as:

$$E_{\text{rough}} = 242693.571 \text{ Wh}$$

Using equation (9), we have;  $E_{\text{safe}} = 303366.964 \text{ Wh}$

Using equation (10), the capacity of the battery bank can be evaluated as:  $C = 25280.580 \text{ Ah}$

Using equation (11), the total number of batteries can be obtained as:

$$N_{\text{batteries}} = 112.358 \approx 112 \text{ batteries}$$

Using equation (12), the number of batteries in series can be obtained as:  $N_s = 2$

Using equation (13), the number of batteries in parallel was obtained as:  $N_p = 56 \text{ batteries}$

### Sizing of the Charge Controller:

Using equation (14), the rated current of the voltage controller can be obtained as:  $I = 655.900 \text{ A}$

Using equation (15), we have;  $N_{\text{controller}} = 10.932 \approx 11$

### Sizing of the inverter

Using equation (16), the size of the inverter was obtained as;  $S = 16.481 \text{ KVA}$

Hence, an inverter 50 KVA was selected, considering surge Photocopier and the inverter capacity that is available in the market.

## CONCLUSION

The design of a standalone photovoltaic system for the Department of physics was successfully carried out, a total energy requirement per day 80897.857 Wh /day was obtained; with the following components requirement: a 25280.580 AH of battery; 141 photovoltaic panels of 280W each; 50 KVA rated inverter; 11 charge controller rated 60A each; panel covers area of 17.2. m<sup>2</sup>.

## REFERENCES

- Ani, V. A. (2015). Energy optimization at GSM base station sites located in rural areas [Ph.D. thesis], <http://www.unn.edu.ng/publications/files/17774> Energy Optimization at GSM Base Station Sites Located in Rural Areas.
- Ammar A., (2017). Design of an Off-Grid Solar PV System for a Rural Shelter. German Jordanian University School of Natural Resources Engineering and Management Department of Energy Engineering. 2017.
- Aithal, R. S., Ravishankar, K. H., Singh, P. K., Ashis, K. S. and Danak, A. R. "Modelling of Photovoltaic Array and Maximum Power Point Tracker using ANN". JES Regular paper, 2008.
- Franklin, E.d. (2017). Types of solar Photovoltaic System. College of Agriculture, University of Arizona. <http://hdl.handle.net/10150/625568>.
- Ibrahim, U.H., D.A. Aremu, Unwaha, J.I. (2013) Design of Stand-Alone Solar Photovoltaic System for Residential Buildings. *International journal of scientific & technology research* Volume 2, ISSUE 12, December 2013 ISSN 2277-8616.
- Ikeme, J. and Ebohon, J.O. (2005). Nigeria's Electric Power Sector Reform: what should be the key objectives? *Energy Policy* 33: 1213-1221.
- Jayakumar, P., for APCCT, "Solar Energy Resource Assessment Handbook," APCCT, 2009.
- Jovanovic, M., (2008) "An analytical method for the measurement of energy systems sustainability in urban areas," *FME Transactions*, vol. 36, no. 4, pp. 157-166,.

- King, D.: "Photovoltaic Module and Array Performance Characterisation Methods for All System Operating Conditions", Proceeding of NREL/SNL Photovoltaics Program Review Meeting, 1996, Lakewood, CO, USA.
- Klaus J., Olindo I., Arno H.M., R. van Swaai., Miro Z.(2014) . Solar Energy Fundamentals, Technology, and Systems. Copyright © 2014, Delft University of Technology.
- Okoye, J.K. (2007). "Background Study on Water and Energy Issues in Nigeria". The National Consultative Conference on Dams and Development.
- Theraja, A. K. & Theraja (2012), ABC of Electrical Technology. S. Chand publishing. ISBN: 9788121939096