Design of a 1 kva PV System for Electrical Laboratory in Faculty of Engineering, University of Uyo, Nigeria

Ye-Obong N. Udoakah, Ekpenyong E. Nta, Iyakkenseme E. Okon, Unyime E. Akpabio
Department of Electrical/Electronics Engineering, University of Uyo,
Uyo, Nigeria
yeobongudoakah@yahoo.co.uk

***ABSTRACT* - One of the most challenging issues in most developing countries of the world today remains access to electricity. In areas where there is access to electricity, the epileptic nature of the supply and the inconsistency of the generated voltage and over loading pose a serious threat to the safety of electricity consumers equipment. In Nigeria, just like most developing countries, the situation is not different, hence the need for this study. In this work, a 1 KVA Photovoltaic (PV) system was designed and implemented for use in the electrical engineering laboratory of University of Uyo, Nigeria. A 12 V 100 Ah storage system was integrated into the design to support laboratory emergency load of up to 6.5 hours off peak and 1.5 hours peak loads. The designed PV system was used during laboratory sessions and was seen to be effective and provided the needed solution to sudden power failure which is a predominant occurrence experienced during laboratory sessions.**

Keywords: Sustainable Energy, Solar Photovoltaic System, University of Uyo, Nigeria.

I. INTRODUCTION

One of the most challenging issues in most developing countries of the world today remains access to clean and sustainable energy. Statistics given by The International Energy Agency (IEA) 2011 [1], shows that about 1.3 billion people in the world do not have access to electricity of which 585 million were in Sub-Saharan Africa (SSA). Nigeria which falls in this category is situated in the tropics in West Africa and is said to be Africa's most populous country, with a population of over 160 million people. It coast lies on the gulf of Guinea in the South and it borders Lake Chad to the North-East. It has been observed in [2] that in spite of her extremely rich renewable energy resources, Nigeria has continued to be deprived of constant electricity supply with her current power generation capacity being about 4,500 MW which obviously is far from being enough to support the national population. Over the years, most part of the country continues to experience extreme electricity shortage and prolonged periods of power outages especially those in the rural and remote areas. This severe sustained electricity deficiency and the quest to reduce the risk and spending associated with unsafe alternatives as noted in a recent study conducted in [2] have attracted the World Bank and International Finance Corporation (IFC) attention to Nigeria, thus identifying her as an important market for off-grid lighting solutions.

In this study, which seeks to integrate the off grid technology in providing lighting solutions, a 1 KVA PV system was designed to provide backup electricity for electrical engineering laboratory in University of Uyo, Nigeria. It is envisaged that with the successful implementation of the first phase of this design, the project would be upgraded with time to accommodate the power need of the faculty at large. The next section captures the method adopted in the study while the subsequent section features the discussion of results and conclusion respectively.

II. METHODOLOGY

A. Study Location

The study was conducted in University of Uyo, Uyo, Akwa Ibom State, Nigeria. Akwa Ibom State is one of the 36 states in Nigeria located in the Niger Delta region of the country and sharing boundary to its south with the Atlantic Ocean. The state falls within the tropical rain forest agro-ecological zone and has two climatic seasons – the rainy season which lasts from late April to October and the dry season which lasts from November to mid April. Uyo, which is the state capital where the University is located is situated at a latitude of 5^{0} 18' 53.7''N.

TABLE 1. LABORATORY LOAD SPECIFICATION FORECAST

Electrical Equipment	Quantity	Hours of use per day	Power rating (W)	Overall power rating (W)	Daily energy use (Wh)
Energy saving bulbs	10	1	36	360	360
Trainer panels	6	2	35	210	420
System unit	2	2	80	160	320
Monitor	2	2	36	72	144
Total	20	7	187	802	1244

B. Laboratory Load Specification

In PV system design, the first requirement is to determine the required power. Research on the power consumption of each device in the laboratory and estimation of the approximate number of hours each device would utilize power in a day is captured in table 1. From the forecast, the total load demand at full load is 802 W which is approximately equal to 1 KVA while the daily energy use is 1,244 Wh.

C. Panel sizing

PV module output is basically a function of irradiance solar energy. To ensure that sufficient solar radiation is captured and enough energy is generated, selection of a sufficiently sized panel is essential. Also for the effectiveness of the project, the sizing took into consideration the periods of least sunlight per day which in Nigeria occurs during the rainy seasons usually from late April to October. To aid in these calculations, peak sunlight hours were determined, and are defined as the number of hours of peak insolation (such as, at solar noon) that would produce the same amount of energy as the variable insolation dispersed throughout an entire day. A study on global solar radiation estimated from sunshine hours for Uyo, Nigeria conducted by [3] indicates that the greatest and least amount of solar radiation is received in the months of April and July respectively.

On the whole, as was observed in [4], solar radiation throughout the country is fairly well distributed recording on the average a daily sunshine of about 6 hrs and solar radiation of about 19.8 MJm^{-2} day^{-1} respectively.

Inferring from this, and adopting the criteria used in a similar study, with a minimum of peak sunlight hours, averaging about 5 peak sunlight hours per day, it was assumed that the solar panel used in this project can collect an equal amount of energy in 5 hours of peak sunlight as it could throughout the day with varying sunlight.

Taking into consideration all the variables highlighted above, the system was designed for minimum insolation months (May through October) in order to meet the requirement of 1244 Wh being the daily energy use assuming full load. Equation 1 gives the relationship needed to calculate necessary panel output power.

$$Ppanel * PSH = Daily\ Energy \qquad (1)$$

Where:
Ppanel is the nominal panel output
PSH is the peak sun hours for the design month (5 hours)
Daily Energy is the required 1244 Wh.

Determining the panel output from equation 1 showed that a 249 W panel would be appropriate. Thus, two solar panels rated 150 W, 17.4 V, and 10 A each was used in this work. The excess allowance was to allow for some variance in output due to varying cloud cover, and also due to the fact that the panel may not operate at the maximum power point on its I-V characteristic curve. Table 2 shows the panel specifications and other requirements. The system specifications and other design parameters as given in the tables below was obtained from data sheets and by manual calculation using appropriate mathematical relations and taking into consideration the laboratory load forecast.

TABLE 2. PANEL SPECIFICATION

Irradiance & cell temperature	1000 W/m^2 Am 1.5 **@ 25'C**
Power	150 W
Voltage	17.4 V
Current	10.0 A
V_{oc}	21.7 V
I_{oc}	9.8 A
Length	117 cm
Breath	54 cm
Width	3 cm
Area	618 m^2

D. Battery Requirements

Loading and Sizing Calculations: A battery with a nominal voltage of 12 V was used in this project which is capable of supporting laboratory emergency load of up to 6.5 hours off peak. The total energy demand on the battery is a maximum of 1244 Wh per day, with a peak load of 802 W. Dividing 1244 Wh by 12 V gives a daily discharge of 103.6 Amp-hours (Ah). The battery must be able to power the laboratory load for this period without recharging while remaining above 20% charge capacity. To accomplish this, the battery must have a minimum capacity of 100 Ah, it must be allowed to discharge to 20% charge capacity, and it must have a round trip efficiency of 80%. Since the system is rated 1KVA and the power factor is 0.8, it means that the true power of the system is 1KVA*0.8 which is 800 W. This means that the appropriate battery to be selected is 12V/100 Ah battery, since the power of this battery is 12*100 = 1200 Wh.

E. Charger Controller Requirements

The charge controller design was implemented such that it detects and disconnects the battery either from the load or the panel when the battery voltage drops below 12 V or exceeds 14.5 V. The aim of this is to lengthen the life of the battery by preventing overcharging or over-discharging.

F. Inverter Requirements

A 0.8 KW inverter was used for this project. The inverter design was such that, it would be capable of providing an AC voltage of 220 V at a frequency of 50 Hz, with an allowed input voltage ranging at least from 12 V to 15 V DC with 90% efficiency. Obtaining a high efficiency is important because an inefficient inverter draws significantly more power from the battery than is used by the load, thus limiting the required time of usage without recharging. The battery and inverter specifications are shown in table 3.

TABLE 3. BATTERY & INVERTER SPECIFICATIONS

Specification	Rating
Battery nominal rated voltage	12 V
Type	Deep cycle
Maximum voltage	13.62 V
Current capacity	100 Ah
Charge rate	6.4 Hours
Inverter nominal power	0.8 KW
Operating voltage	220 V - 240 V A.C
Operating frequency	50 Hz +/- 0.5 %
Output waveform	Modified sine wave
Power factor	0.8

G. Battery Back-Up Time Analysis

One of the factors that determine the effectiveness of an inverter is its back-up time, hence analyzing the back-up time of our designed system was pertinent. From the laboratory load analysis, the anticipated load was projected to be 802 W. The back-up time at full load for the designed system was calculated as follows;

Battery Power = 12 V x 100 Ah = 1200 Wh

Anticipated Load = 802 W

Back-up time (hr.) = 1200/802 = 1.5 hrs.

From the above analysis, the system can provide a back-up time of 1.5 hours at full load. However, it is anticipated that since the design is basically for laboratory sessions, the load will sometimes vary within the design range from no-load to full-load. The table below shows the back-up time at different loads.

TABLE 4. BACK-UP TIME AT DIFFERENT LOADS

Load (W)	Back-Up Time (H)
200	6
300	4
400	3
500	2.4
600	2
700	1.7
800	1.5

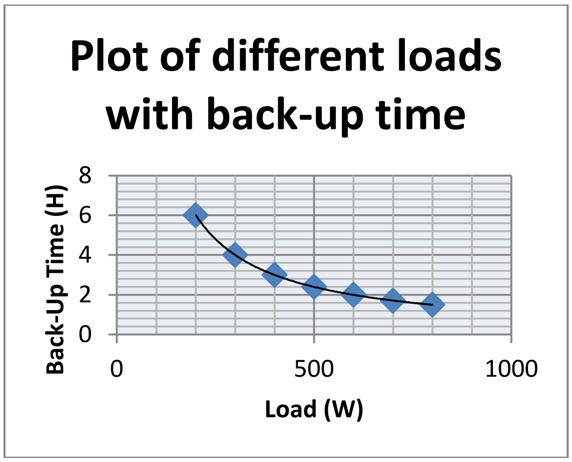

Fig. 1: A graph showing the load variation with time

H. System Output

The proposed design for the first phase of this project assumes that provision of electricity to electrical laboratories would primarily be for the running of practical during laboratory sessions. The study also assumes that all items use AC current and energy saving appliances; therefore, with the near constant level of irradiance in this region, it is expected that a PV module should produce 1000 W/m^2. However, for our design, it is envisaged that under ideal conditions, the system would produce about 3 KWh each day. The block diagram of the designed system is shown in figure 2.

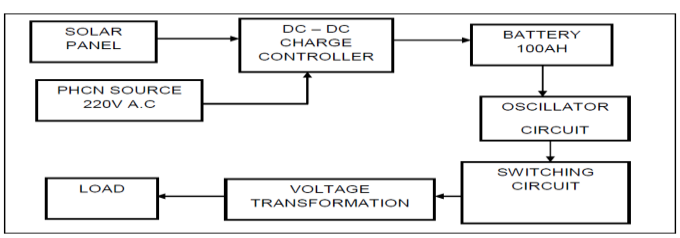

Fig. 2: Block diagram of the designed system

I. Project Testing

Testing on this project was performed on each of the subsystems namely: the panel, the battery, the inverter, and the charge control circuit. First, the solar panel's voltage-current characteristic curve was taken by varying the load on the panel, giving a smooth curve showing the voltage as current varies from no load to full load. As noted previously, the design of the charge control circuit was such that it disconnects the battery from either the panel or the load when the terminal voltage exceeds 14.5 V or drops below 12 V respectively. This was achieved by using a comparator to compare the battery voltage to two reference voltages of 14.5 V and 12 V. The comparator outputs control the gate signals of two MOSFET transistors connecting the battery to the panel and to the inverter. The MOSFET gate signals were measured against the battery voltage to ensure the circuit was turning each MOSFET on at the correct voltage. The MOSFET drain source resistances were measured at various loading conditions to show these characteristics relate to each other. The voltage and current output waveforms of the MOSFET driver circuit is shown in figure 3 and 4 respectively. The battery voltage versus state of charge was measured by discharging the battery at full load current from full charge until the terminal voltage dropped below 12 V. This 12 V threshold according to the manufacturer's datasheet occurs at about 20 % charge. The voltage was measured at 10 amp-hour intervals. Since the battery capacity is nominally 100 Ah, each interval represents one-tenth of the total capacity.

Testing on the inverter consisted of measuring the minimum & maximum input voltages and the output voltage. The maximum AC current was also measured. As earlier mentioned, the inverter is designed to automatically shut off if the DC voltage or AC current varies outside of the preset limits. Finally, the efficiency of the inverter was measured with respect to load current. This was done by measuring both DC input voltage and current and AC output voltage and current to obtain the input and output power for different load current.

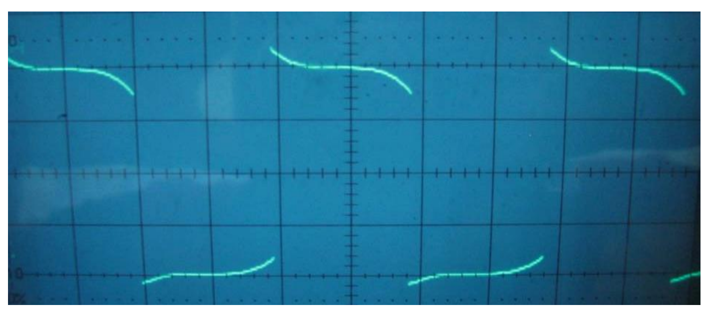

Fig. 3: Voltage output waveforms of the MOSFET driver circuit

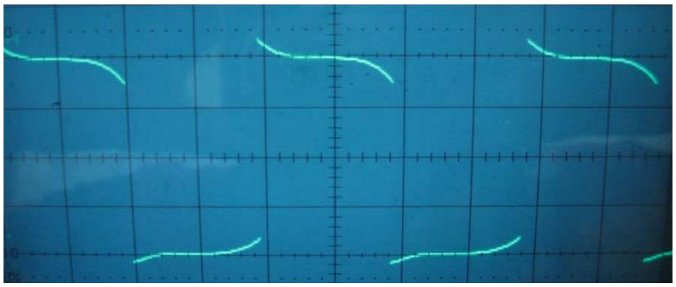

Fig. 4: Current output waveforms of the MOSFET driver circuit

III. DISCUSSION OF RESULTS

In this project, the design and construction of 1KVA solar powered inverter was successfully carried out and implemented. The system has the following major units: the PV module unit, the battery & charge controller unit, the inverter unit and the control unit. Two 150 Watt solar panels were used in parallel. One 12V, 100 AH battery was used. The solar PV module was mounted on a steel frame in front of the electrical laboratory while the other units were mounted on a special chassis designed and fixed inside the laboratory as part of the project. Due to the sudden power failure which is a predominant occurrence often experienced during laboratory sessions, the project incorporated control features such as automatically changing over from the inverter to the public power supply when it is on and vice versa when it is out. It also regulates the battery charging from either of the sources (PV & Public Power) by connecting or disconnecting if it voltage falls below or rises above the preset levels. The automatic control algorithm that was implemented is shown in figure 5 below.

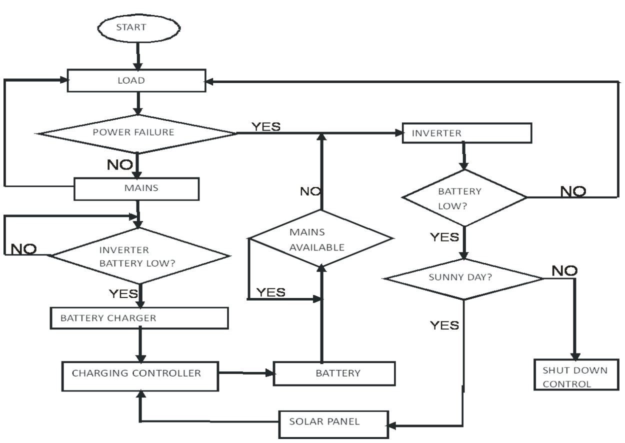

Fig. 5. Automatic control algorithm

IV. CONCLUSION

The design and implementation of a 1 KVA PV system for electrical laboratories in faculty of engineering, University of Uyo was successfully carried out. With the successful implementation of the first phase of this project which was conceived as a result of the dwindling power situation in the country which often times affected laboratory practical sessions, it is obvious that the deployment of solar technologies for energy production for the University at a large scale was possible. By so doing, the University Community would not only be sure of a near constant power supply, but would also have contributed significantly to the global fight of securing a sustainable environment for both the present and future generation.

ACKNOWLEDGMENTS

The authors are very grateful for the great support provided by the laboratory technologist. The initiative of providing a power bank for the department was proposed by Dr. Simeon Ozumba & supported by the head of department Dr. Umana Itaketo. We wish to thankfully acknowledge the inputs made by other members of staff. We appreciate everyone who contributed in one way or the other to the success of this project.

REFERENCES

[1] IEA, "Global status of modern energy access," 2011. [Online].Available:http://www.worldenergyoutlook.org/resources/energydevelopment/globalstatusofmodernenergyaccess/#d.en.8609. [Accessed 2 October 2013].

[2] Y. Udoakah and M. Umoh, Sustainably Meeting the Energy Needs of Nigeria: The Renewable Options. (A paper presented at the Institute of Electrical and Electronics Engineers (IEEE) Energycon Conference in Croatia, May, 2014).

[3] A study on global solar radiation estimated from sunshine hours for Uyo, Nigeria conducted by [3]

[4] U. Akpan, S. Isihak and Y. Udoakah, Electricity Access in Nigeria: Viability of Off-grid Photovoltaic System. (A paper presented at the Institute of Electrical and Electronics Engineers (IEEE) Africon Conference in Mauritius, Sept., 2013)

[5] Keyhani. Design of smart power grid renewable energy systems. New Jersey: Wiley & Sons, Inc; 2011.