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MODELLING, SIMULATION AND PERFORMANCE EVALUATION OF A GRID CONNECTED PHOTOVOLTAIC SYSTEM FOR SCHOOL OF ENGINEERING GOMBE STATE POLYTECHNIC, BAJOGA.

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ABSTRACT
Electrification of school of Engineering (SOE), Gombe State Polytechnic Bajoga is often realized through distribution network from Jos Electricity Distribution Plc (JED PLC), Jos business unit. SOE buildings, each consists of academic staff offices, administrative rooms and public facilities. Huge sum of money is spent daily to run generators and noise pollution has come to stay with us. Nigeria however has immense exposure to solar radiation all through the year. It has highest daily solar radiation of 7.0KWh/m2/day and lowest of 3.5KWh/m2/day. Load profile for SOE has been carried out by determining the number of solar panels and inverter rating. Monthly average radiation was equally obtained from Nigeria meteorological agency between January 2020 and December 2024. The designed PV system plant capacity is estimated at 150kW based on estimated load profile. Various tools such as system yield factor, capacity utilization factor, performance ratio is used in carrying out performance of 196kW PV system. Plots of I-V characteristics at constant irradiance, P-V characteristics at constant temperature and irradiance and efficiency curve of P-V panels is obtained. The PV is expected to meet 71,540 kWh annual load demand for SOE, using MATLAB's sympower systems software. This supply period of electricity is between official hours of 8am to 4pm daily.

INTRODUCTION
USAID linked several challenges besieging Nigeria to poor power supply. It was also found that of the 45% total population of Nigeria that is connected to the grid, 36% population are rural dwellers and 64% are urban settlers (www.usaid.gov.powerafrica/nigeria, accessed April 13, 2019). Aremu (2019) presented lack of stable power supply as the root cause of high rate of unemployment and inflation in Nigeria. This in reality has resulted to close down of many businesses. Gupta and Shukla (2016) has attributed the deplorable state of Nigeria's power sector to structural inefficiency. The report further revealed that an average Nigerian enjoys significant portion of their electricity from private generators at higher cost (NGN 62-94/kWh) compared to supply from distribution companies of Nigeria. Over 95 million Nigerians are not connected to the grid, and even those that do have access experience very regular power outages. However, civilization and socio-economic development depend largely on constant power supply to meet daily growing demand. Poor attitude towards maintenance and sustenance of various sources of power supply is another factor besieging Nigeria power sector. Federal Ministry of Power and Housing presented poor generation capacity of power to the deplorable state of the power network. More so, it is worthy of note that not all citizens are connected to the grid. (Odunowo, 2018).

Lack of constant and sufficient power supply is a major challenge in present-day Nigeria, especially in Jos community which is a sub-hub of Gombe state where Gombe State Polytechnic Bajoga is Located. Presently, high cost of running generators in the faculty and noise pollution as a result of running such generators is another problem besieging Engineering Faculty. SOE buildings, each consists of academic staff offices, administrative rooms and public facilities. Huge sum of money is spent daily to run generators and noise pollution has come to live with us. However, at the end of this research work, noise pollution as a result of running power generating machines for hours will be eliminated as these machines will no longer be needed. Also, cost of running the school of engineering, Gombe State Polytechnic Bajoga will be reduced as there will be no need to run generators.

The aim of this research is to model, simulate and carry out performance evaluation of a grid connected photovoltaic system for school of engineering, Gombe State Polytechnic Bajoga.

Feng et al (2022), in trying to address the issue of energy scarcity by using photovoltaic energy as a renewable source, designed a three-phase grid-connected photovoltaic inverter system and investigated uncertain system model parameters. They also proposed an enhance back stepping approach to explore the control strategy of three-phase grid-connected inverter which includes adaptive control, dissipative theory, sliding mode control, and rapid terminal sliding. They further subjected the system to external interference during simulation and discovered that the adaptive control technic suppressed the interference to a greater extent and possesses strong robustness to the external interference. In general, their research yielded promising results. However their research work was carried out, specifically for their nation, China that has different weather conditions when compared to the northern part of Nigeria.

Johnson and Ogunseye (2017) designed and simulated a grid connected 148.5 kWp photovoltaic system using the PV*SOL software. In their design they evaluated the system performance and to know if it is capable of feeding the selected local government. They also investigated the amount of electrical energy that their design can generate for every day of the year. In their result, they discovered that their design could produce 13, 802 kWh on average and an energy of 20, 053 kWh, as the highest in the month of November. This far exceeds the energy demand for the building in the local government they were investigating. This research yielded promising results however, their research work was carried out, specifically for their region that has different weather conditions when compared to the northern part of Nigeria, specifically, Jos Local government.
Samir et al (2015) in their paper overviewed existing PV energy conversion systems, addressing the system configuration of different PV plants and PV converter topologies that have found practical applications for grid-connected systems taking note of their possible advantage with respect to existing technologies. The concluded in their paper that out of all the PV converter topologies, the most important appearance has been the multilevel converter, mainly the NPC, the T-type and the H-bridge which serves for high power application and, also, for residential applications.

Nouha et al (2022) in their research explained how the complex-vector-filter method can help in minimizing the current harmonic of a grid-tied photovoltaic system. This technic produces smooth sinusoidal current, thereby, feeding clean active power to the grid. The MATLAB Simulink software was used and a PI controller designed in the MTTP stage of the DC-DC boost conversion. This research yielded promising results however, their research work was carried out, specifically for their region that has different weather conditions when compared to the northern part of Nigeria, specifically, Jos Local government.

Abdul et al (2022) looked at benefits, challenges and mitigations of grid-connected photovoltaic and photovoltaic/thermal systems. In achieving this, they evaluated two solar PVs, traditional PV and PV/T plants. They applied innovative approaches and found that intelligent strategies optimally ensure the overall efficiency of grid tied PVs using real time control and measurement under innovative applications and technologies.

MATERIALS AND METHODS

Materials

The materials needed to actualize this research work includes data of power consumption or load profile of the school of engineering building. Also the Matlab and simulinks software, release 2016b will be used to model the PV-connected grid system. Lastly, a Hewlett Packard computer, third generation processor running at 2.16 GHz with at least 4GB of ram and at least 512 GB of ROM.

Table 1. Load demand for school of engineering

S/N	Department	Time	Demand (kW)
1	Electrical Engineering	8am to 2 pm	10
		2pm to 4pm	1
2	Science Laboratory Tech.	8am to 10am	5
		10am to 12pm	10
		12pm to 4pm	8
3	Computer Engineering	8 am to 11am	6
		11am to 4pm	5
4	Computer Science Tech.	8am to 9am	2
		9am to 12pm	5
		12pm to 4pm	3

Methods

The method used is based on itemization of appliances with their corresponding power ratings and time of operation during the day to obtain total energy demand in kilowatt-hour per day by the faculty. Total consumption will then be used to determine the proposed grid connected solar PV system components sizes.

Load Profile

Due to variations in load demand during different times of the day, there is need to take accurate load profile of the faculty and also to determine the number of solar panels and inverter to be used. The load profile for the SOE is presented in figure 1. This profile is generated using table 1

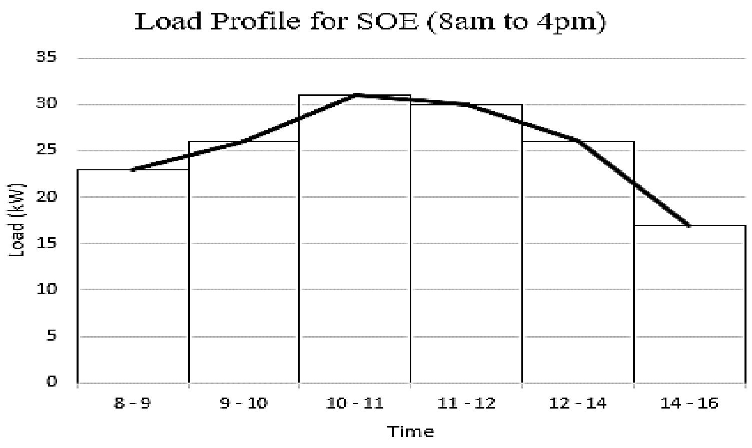

Figure 1. Load profile of SOE

Load demand per 24 hours =

23 x (9-8) + 26 x (10-9) + 31 x (11-10) + 30 x (12-11) + 26 x (14-12) + 17 x (16-14)

= 196 kW

= 196 x 365 = 71, 540 kW yearly

PV System Layout

The proposed plant capacity is 196kW daily which will be designed to meet the estimated daily load demand of SOE. In order to satisfy the optimal system operation, different system parameters will be considered such as the number of PV modules to be connected in series and in parallel in other to meet up the power demand.

With the data available in table 1, the PV plant will be designed with an intended capacity to supply a total of 196 kW of electricity.

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In designing the PV plant or array, there would be a series-parallel connection of PV modules. There are three arrays in this design; each consists of Sun power SPR-415E-WHT-D PV modules for each of the three-phase power system (see figure 2). Modules are first connected in series (string) to produce the required voltage. The strings are then combined in parallel to increase the current.

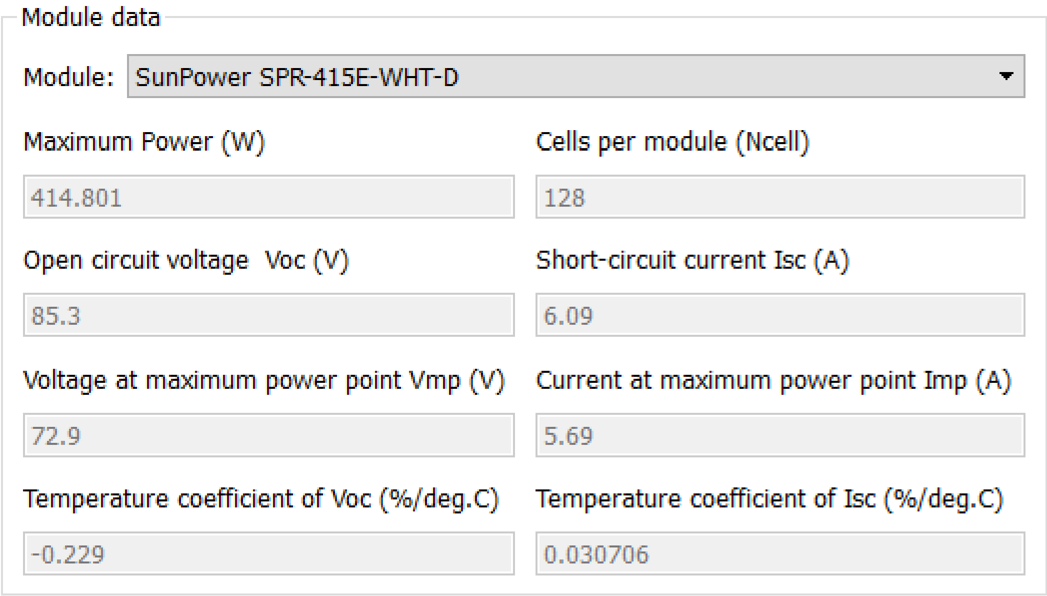

Figure 2 PV module parameters

The required AC voltage will determine the DC voltage needed from a PV module string. In Nigeria power system, a single phase is around 240V/phase, 415V L-L AC. So the equivalent DC phase voltage is given by:

$$V_{dc} = \sqrt{2}V_{ac} = \sqrt{2} \text{ x } 240 = 339.41 \text{ V} \quad (1)$$

10% of V_{dc} in equation (1) is added to account for the ripples of the specified voltage in the design.

$$V_{dc} = \sqrt{2}V_{ac} = \sqrt{2} \text{ x } 240 + 10\% = 373.35 \quad (2)$$

The open circuit voltage Voc of the module is 85.3V (figure 2). Therefore the number of modules in string is calculated as:

$$V_{dc} \div V_{oc} = \frac{373.35}{85.3} \approx 4.38$$

Therefore 5 modules are selected in this design. This string of 5 modules gives the maximum power point voltage at Standard Test Condition (STC) to be:

5 x V_{mp} = 5 x 72.9 = 364.5 V (see figure 2 for value of V_{mp})

The open circuit voltage of the string at STC equals

5 x V_{OC} = 5 x 85.3 = 426.5 V (see figure 2 for value of V_{0C})

This is up to 364.5V of V_{dc} actually required. The excess will take care of losses along the cable and voltage variation from the PV generator due to temperature increase above 25^{0}C and other variations in environmental condition (irradiance). In addition, the number of modules in string can

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only be a whole number, more so that modules of similar electrical characteristics is used. Also, the output of the PV array will never be constant, although MPPT will cause it to operate at maximum power point irrespective of changing weather; yet provision still need to be made for voltage variation. This is design for worst-case scenario. Therefore, whatever voltage that is coming from PV array or the battery bank, the buck-boost DC-DC section regulate it to 375V and feeds the inverter input. The inverter is capable of accepting voltage between 250 to 500V. Since the 5 modules are in series, the short circuit current remain the same at 6.09A (figure 2).

Also, since it is intended to achieve a maximum power of 196 kW then the following calculations will suffice:

Total amount of current required

$$I_{Total} = \frac{196\ 000}{426.5} = 459.55\ A$$

Since I_{SC} = 6.09 A then

The number of strings to be connected in parallel to give 459.55 A will be

$$\frac{459.55}{6.09} = 75 \text{ strings connected in parallel}$$

The short circuit current (I_{SC}) and maximum power point current rating (I_{MP}) of the chosen solar panel is 6.09A and 5.69A respectively (see figure 2 form I_{MP}).

Irradiance and Temperature

Irradiance or solar irradiance is the radiant energy of the sun's beam measured on a plane perpendicular to the beam. Irradiance is expressed in WM^{-2}. Solar irradiance forms part of the energy converted by the PV cells to electricity. Temperature is also a factor that contributes to how PV cells generate electricity. As a result these two parameter will be fed to the PV plant designed. Both irradiance and temperature are simulated in this research work in simulinks using the signal builder block. The signal used to simulate these two parameters is shown in figure 3.

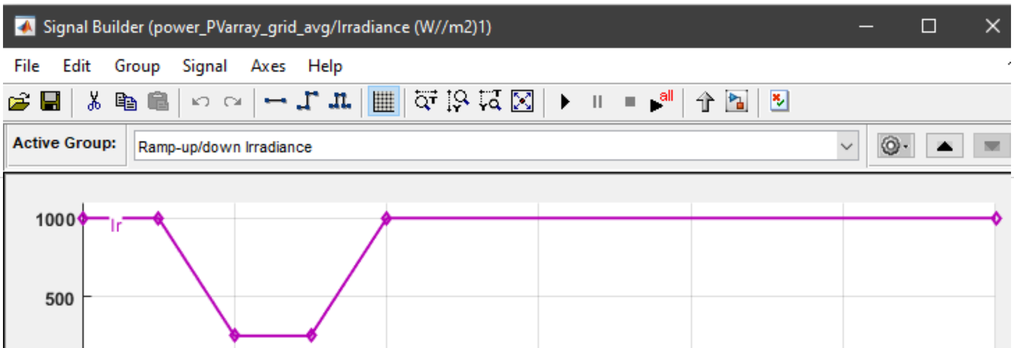

Figure 3 Irradiance and temperature signals

In the first graph of figure 3, the deep indicates evening periods when the sun's energy or irradiance is low. While in the temperature graph, the shape simulates varying temperatures.

Inverter Design

A 196 kW PV array is connected to a grid network via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC). Maximum Power Point Tracking (MPPT) is implemented in the boost converter by means of a Simulink model using the 'Perturb & Observe' technique.

Simulation Overview

The entire system is modelled using MATLAB's sympower systems software. The model of the designed system is shown in figure 4

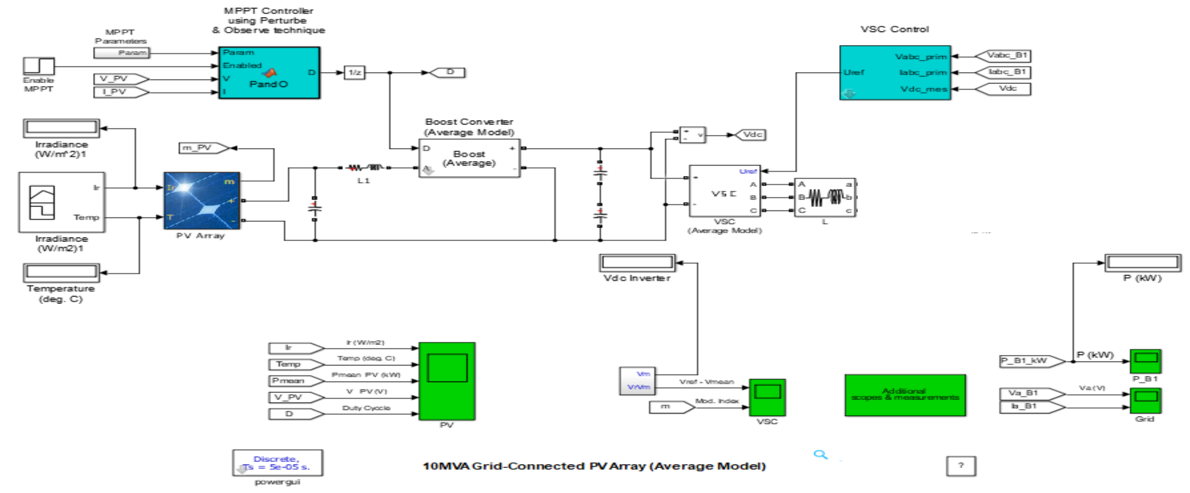

Figure 4 system model

In the above figure, the PV array block consist of 5 modules in a string and 75 parallel connection of string. The PV module has a general characteristics shown in figure 5 and figure 6. In figure 5, the first graph indicates the current voltage characteristics of the PV cell used when temperature is constant at 25^0C and irradiance varies as shown in the graph.

The second graph indicates the relationship between power and voltage when temperature is constant at 25^0C and irradiance varies as shown in the graph.

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In figure 6, the first graph indicates the current voltage characteristics of the PV cell used when temperature is varied and irradiance is constant at $1000Wm^{-2}$.
The second graph indicates the relationship between power and voltage when temperature is varied as shown in the graph and irradiance is constant at the same $1000Wm^{-2}$.

RESULT AND DISCUSSION

In figure 5, the first graph indicates the current voltage characteristics of the PV cell used when temperature is constant at 25^0C and irradiance varies as shown in the graph.
The second graph indicates the relationship between power and voltage when temperature is constant at 25^0C and irradiance varies as shown in the graph.
In figure 6, the first graph indicates the current voltage characteristics of the PV cell used when temperature is varied and irradiance is constant at $1000Wm^{-2}$.
The second graph indicates the relationship between power and voltage when temperature is varied as shown in the graph and irradiance is constant at the same $1000Wm^{-2}$.

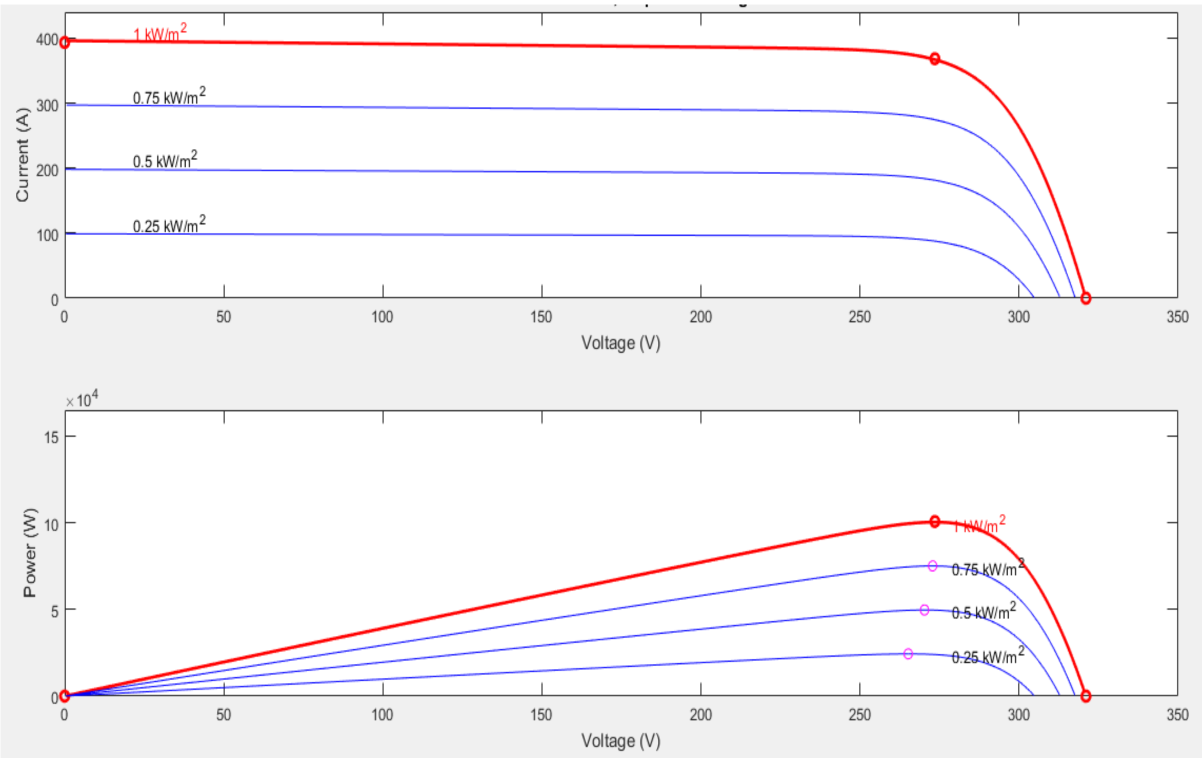
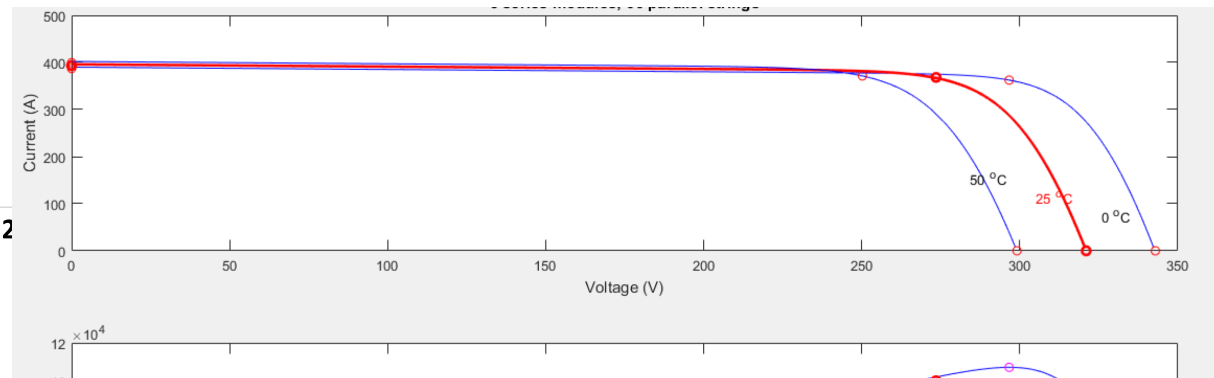


Figure 5 IV and PV characteristic of PV cell at constant temperature and varying irradiance



It is seen from each of figure 5 and 6 that the PV design is able to produce approximately 120 kW of energy. This is normal (even though it is not up to the 196 kW) since temperature and irradiance vary in ideal situations.

CONCLUSION

This work has explicitly how PV modules can be interconnected as strings and modules to meet the power demands of ay facility. Results reveal that the system was able to produce approximately 65 percent of the energy demanded for. This is due to temperature and irradiance parameters as simulated to match an ideal situation.

RECOMMENDATION

The strong recommendation that this work is presenting is the fact that I PV designs it is highly recommended to oversize the panels so as to make the most out of situations where temperature and irradiance are low.

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