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# EVALUATION OF THE PERFORMANCE OF PROPOSED GRID-TIED SOLAR PHOTOVOLTAIC SYSTEM FOR SCHOOL OF ENGINEERING, NATIONAL INSTITUTE OF CONSTRUCTION TECHNOLOGY AND MANAGEMENT.

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## ABSTRACT

*Electrification of Scchool of Engineering Technology (SET) located in Amedoshian Campus in the Institute of Construction Technology and Management (NICTM) is realized through distribution network from Benin Electricity Distribution Company (BEDC). SET building blocks consist of 2 nos*

## Introduction

The age-long fundamental problem that has almost engulfed the entire country is poor power supply. It may be said 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) [1]. It may also be said that, lack of stable power supply is probably the root cause of high rate of unemployment

*of each three floors building structure with basement, academic staff offices, administrative rooms, lecture/classrooms and public facilities. Huge sum of money is spent daily to run generators and noise pollution has come to live with us. Meanwhile, Nigeria 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. The Uromi community where the institute is situated has an average radiation of 4.55kWh/m²/day and temperature of 27.23⁰C. Uromi is at latitude 4⁰49'27" North and longitude 7⁰2'1" East and altitude (elevation) of 20m (64ft). Load profile for SET was carried out to determine the number of solar panels and inverter rating. Monthly average radiation was obtained from Nigeria meteorological agency between January 2016 to December 2020.The proposed PV system plant capacity is estimated at 100kW based on estimated load profile. Various tools such as system yield factor, capacity utilization factor, performance ratio were used in carrying out performance of 100kW 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 were obtained. The PV is expected to meet 123,228.38kWh annual load demand for SET, using PVsyst software. This supply period of electricity is between official hours of 8am to 4pm daily and estimated that annual DC energy generated from the system is 126619kWh/year, whereas available energy exported is 121914kWh/year.*

**Key words:** *Solar irradiance, power system, Photovoltaic system, Nigerian Grid, Load Demand, Generated Power. Load*

and inflation in Nigeria [2]. This in reality has resulted to close down of many businesses [3] and this deplorable state of Nigeria's power sector may be attributed to structural inefficiency [3]. Energy 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 [1]. Over 95 million Nigerians are not connected to the grid [1], and even those that do have access experience very regular power outages. Meanwhile, 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. Lack of constant and sufficient power supply is a major challenge in present-day Nigeria, especially in Amedoshian community which is a remote rural community where the Institute 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 the School of Engineering Technology. The aim of this paper is to evaluate the performance of grid connected solar photovoltaic (PV) system for School of Engineering Technology (SET), at the National Institute of Construction technology and Management (NICTM), Uromi, Edo State.

The following objectives shall be done:

i. Assessment of electrical load demand of SET, NICTM.
ii. Collection of meteorological data from Nigeria Meteorological Agency (NImet) between January 2016-December 2020.
iii. Determination of maximum electrical power that can be generated from the PV system.
iv. Determination of amount of electrical energy that the system can produce in a year.


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## Review of Related Works

Energy is of utmost significance for development and economic improvement. Among various types of energy, electricity has the most tremendous impact in the way of lives in the society. Hence, it is the duty of the government, among other things, to provide electricity to meet the growing demands of its citizens. Sadly, the present generation capacity in Nigeria is unable to meet the growing daily demand of electricity. It has been reported that majority of the global population is not connected to the grid [5] and between 2000 and 2015, abouth 8TWh of energy had been consumed. It has also been reported that 60% of the entire population in Nigeria is without light [6]. Even those having access are experiencing epileptic power supply. All these reports pointed out that the poor state of the economy may be attributed to the deplorable state of power sector.

With this consumption rate, it is now understandable why the climate is in a deplorable state, given that electricity is generated through conventional process. As a result of inadequate supply of power in most developed and underdeveloped nations, especially Nigeria, renewable sources are gradually getting attention as an alternative means of generating cleaner power supply. Globally there is an increasing interest in renewable energy giving rise to annual increase in renewable capacity.

Research has shown that, Nigeria has enough natural resources that can produce more electricity than is demanded if properly harnessed [7]. But due to selfishness and the intention to amass unnecessary wealth, the nation's power sector has suffered serious setbacks. Other issues such as technical and socio-economic are also part of the reasons Nigeria power sector is dwindling over the years. Recently the Nigerian Government through the Federal Ministry of Power has turned to renewable energy sources in order to augment total energy mix as over 55% of Nigeria population is currently unconnected to the grid [8]. Globally, there is huge concern over conventional carbon-based energy production which includes increasing atmospheric carbon dioxide concentration from greenhouse gas emission, environmental safety of energy production techniques, fluctuation of energy prices and depleting carbon-based fuel reserve to name a few [9]. Nigeria, whose most of its electricity is generated either by thermal power station or hydro power station, is not exempted from environmental challenges. This concern has prompted most countries to develop sustainable and clean energy system to provide growth and development and researchers have identified indigenous sources as panacea for lingering energy crisis and further suggested that more effort be concentrated towards tapping of solar energy sources [10,11]. In addition, the researcher further stated that solar energy could solve both present and future energy consumption demand if dedicated attention is given to it. Rooftop solar plant has been described as the most efficient solar technology available which receives higher insolation compared to ground mounted system [12].

## Design Methodology

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 watt-hour per day by the faculty. Total load was then used to determine the proposed grid connected solar PV system components sizes. Meteorological data was also obtained from Nigeria meteorological Agency to determine how its effect on the overall output of the proposed plant. Finally, performance ratio was used to estimate performance of the proposed solar PV plant.

## Site Characteristics

Nigeria has immense exposure to solar radiation all through the year. It has highest daily solar radiation of 7.0KWh/m$^2$/day and lowest of 3.5KWh/m$^2$/day. The University is located in Choba community, which is within the city of Port Harcourt in Rivers State of Nigeria. It was established in 1975 as a University College, Port Harcourt and was later given University status in 1977. Engineering faculty was established in 1983. The faculty is located in Choba and it consists of two buildings. Choba is located at 4$^0$49'27" North latitude and 7$^0$2'1" East longitude and altitude (elevation) of 20m (64ft). The faculty buildings, each consists of two floors with basement, academic staff offices, administrative rooms and public facilities. Electrification of the faculty is often realized through an electric distribution network. The university campus is an ideal topography for solar energy deployment. As at 2016, Port Harcourt urban area had an estimated population of 1,865,000 inhabitants, up from 1,382,592 as of 2006. The proposed PV power plant, which will cover electricity demand of the faculty, will be installed on the rooftops of the faculty buildings. 100kW grid-connected PV system is to be installed on the rooftop of the two buildings of the Faculty, University of Port Harcourt.

## Climate Information

Before selecting site for PV system installation, meteorological data should be given primary consideration, especially solar irradiation and ambient temperature over a period of time. Table 2 shows monthly average radiation on the horizontal surface obtained from Nigeria Meteorological Agency. The data obtained span between January 2014 and December 2018.



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From the data as shown in Table 2, the peak load which happens to reflect the appliance size of 100KW and daily load consumption is 338KWh/day.

## Components Assessment

In the grid-connected solar PV system, energy is generated, converted and delivered to meet load demand. Excess of the generated power is fed into the local grid. In this study, solar PV is a module which directly converts solar energy to electricity. The grid-connected inverter converts DC voltage source to AC as required. The cost and performance of the system components are major factor in the design and costing.

## PV System Layout

The proposed plant capacity is 100KW which is designed to meet the estimated daily load demand of FOE as presented in Table 1 and the total daily solar energy (G) in kWh/m$^2$/day. In order to satisfy the optimal system operation, different system parameters were considered.

### (a) PV Module

CS6X-315P-FG Canadian Inc solar panel model is chosen from the list of modules in the database of PV modules. Figure 1 shows system orientation of tilt angle of PV array. The module has peak power of 315Wp as shown in Figure 2. It is seen that 320 modules are required to design the proposed PV plant. The modules are connected in 40 parallel strings, with 8 modules in each. These 320 mono-crystalline silicon PV modules (panels) will generate 100KW power that will be fed into 100KW inverter. The PV system will be mounted on 625m$^2$ area of the building roof where it will receive



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best solar radiation; hence derives maximum amount of electricity from solar PV panels.

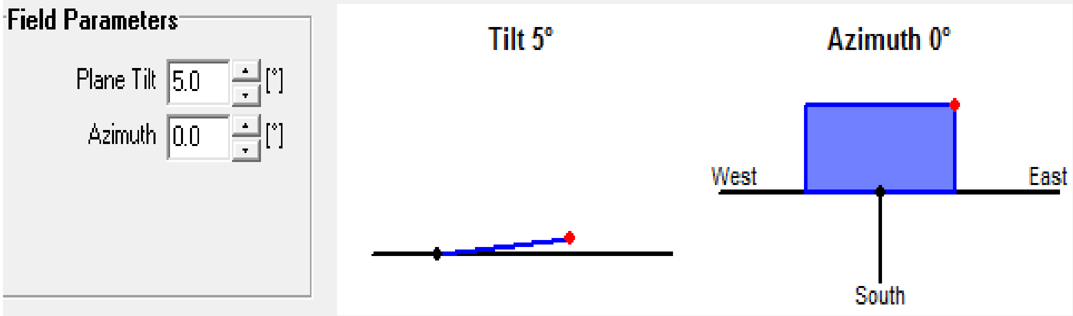


Figure 1: Tilt angle of PV array (source; PVsyst Software)

Figure 1 describes the tilt angle of solar PV array for Choba site. In order to absorb maximum solar irradiance, the tilt angle must be inclined approximately equal to the latitude of the corresponding location. Since latitude of location is 4.8$^{0}$, it is then imperative to use tilt angle at 5$^{0}$ with Azimuth 0$^{0}$, meaning facing toward south.

### (b) Grid Tie Inverter

10 units of PV-10-1-OUTD-S1-US-480 grid-tie inverter are chosen from grid-tie inverter database of PVsyst programming software. Each of the inverter has a capacity of 10KWac with 120-470V operating system and maximum output voltage of 480V. Grid-tie inverter is an electrical device that converts the dc output voltage of the solar array into its ac equivalent. It can supply power at the same time with the electric utility grid when the inverter output synchronizes with those of the grid. In this grid-connected system, the inverter ought to be high enough to take care of total amount of watts needed at a time. The inverter capacity is 100KVA, which is connected to handle power from PV arrays of 100kWp rated output.

Table 1 shows the values and simulation parameters used to carry out the simulation for the grid connected system. These include the geographical site location, inverter ratings and size, PV array characteristics, cell area as well as cell to area with all their empirical values. This is as shown in the table.

**Table 1.** Grid connected simulation parameter.

| Grid connected system | Simulation parameter | Grid connected system | Simulation parameter |
|---|---|---|---|
| **Geographical site location** | Latitude: 4.8$^0$N, Longitude: 7.0$^0$E | PV array characteristics | PV module model= CS6X-315P- FG |
| **Collector orientation** | Tilt=5$^0$ | | Manufacturer: Canadian Solar Inc |
| | Azimuth=0$^0$ | | Total no of PV modules:320 |
| | Model used: Transposition perez | | Series connection :8 Parallel string= 40 |

| | | | |
|---|---|---|---|
| | Horizontal=Free horizon | | Unit of nominal power=315Wp |
| **Inverter** | Model= PV1-10-1-OUTD-S1-US-480 | | Array Global Power (STC)=101 kWp |
| | Manufacturer= ABB | | Operating condition=90.4 |
| | Operating voltage=120-470V | | Impp=346A, Vmpp=261V |
| | Unit of nominal power =10kW ac | Cell area Total area | S561m2, 652m2 |
| | No of Inverter=10 | | |
| | Total power=100kW ac | | |

**Source:** PV syst software.

**(c) Amount of Actual Energy Generation**

Although 100kW is the proposed net installed capacity of the plant, this should not be seen as the actual output, reason being that energy produced by solar power plant depends so much on certain variables such as solar irradiance, daily temperature, number of sunny days and air mass, which are beyond the control of solar design engineers, as well as plant location, module efficiency, roof orientation, quality of equipment used and operation and maintenance culture which happen to be within the control of solar developer. Several losses occur in the system as presented by Habert [13] energy generated by the plant will be fluctuating and much lower than the nominal energy at the array. The identified low energy output to losses in the system. Saeed, et al. [14] described temperature, voltage drop, dirt and soil, shading, mismatch and inverter as major contributor to over 30% losses associated with grid connected solar PV system. In determination of number of solar PV module, Mevin, et al. [15] applied 30% losses in equipment sizing which ultimately increased number of modules required for the proposed plant.

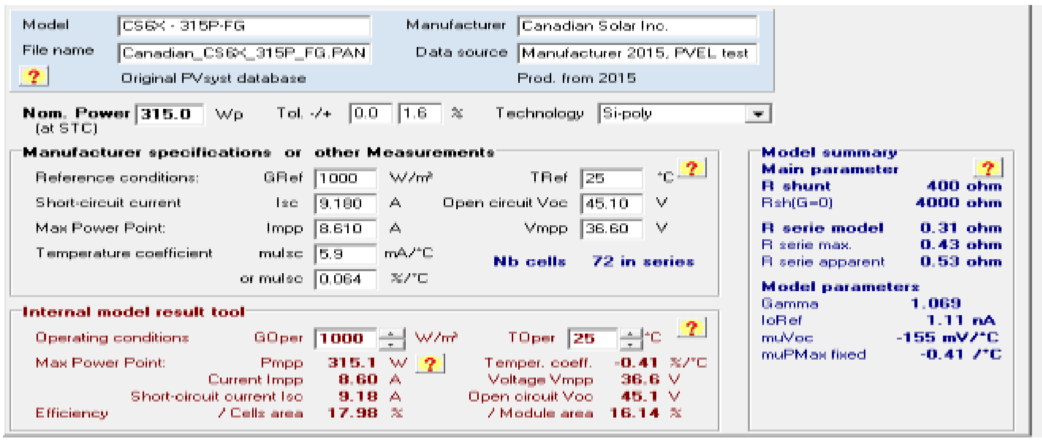


figure 2: Module specification.

Figure 2 describes parameters of the module used in the design. Solar module model number is CS6X-315P-FG Canadian Inc solar panel model was chosen from the list of modules in the database of PV modules. The module has peak power of 315Wp. It has short



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circuit current Isc of 9.160A; open circuit voltage is 45.10V; maximum power point voltage (Vmpp) 36.60V and maximum power point (Impp) of 6.610A.

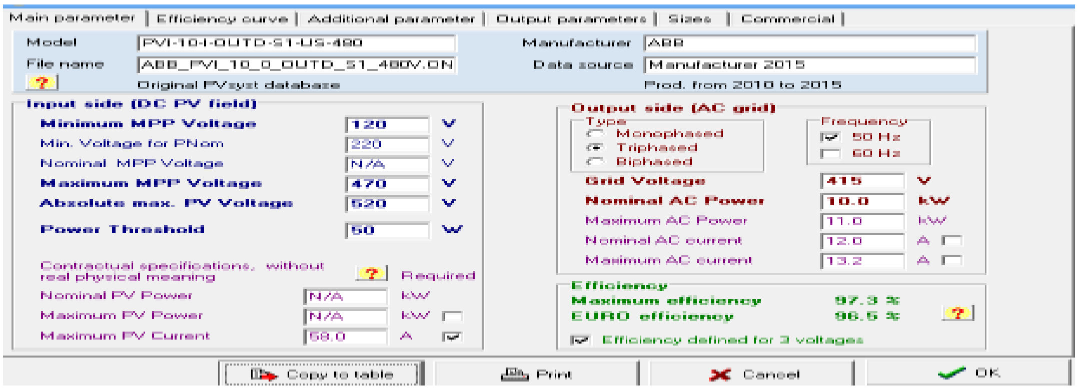


Figure 3: Inverter specification.

Figure 3 gives specification of grid tie inverter used in the design. PV-10-1-OUTD-S1-US-480 grid-tie inverter was chosen from grid-tie inverter database of PVSyst programming software. The capacity of inverter is 10KWac with 120-470V operating system and maximum output voltage of 480V. Maximum power point voltage is 1200V. It has minimum and maximum power points of 120V and 470V respectively. It is grid tie and as such is to be connected to 415V utility grid as specified in the parameter.

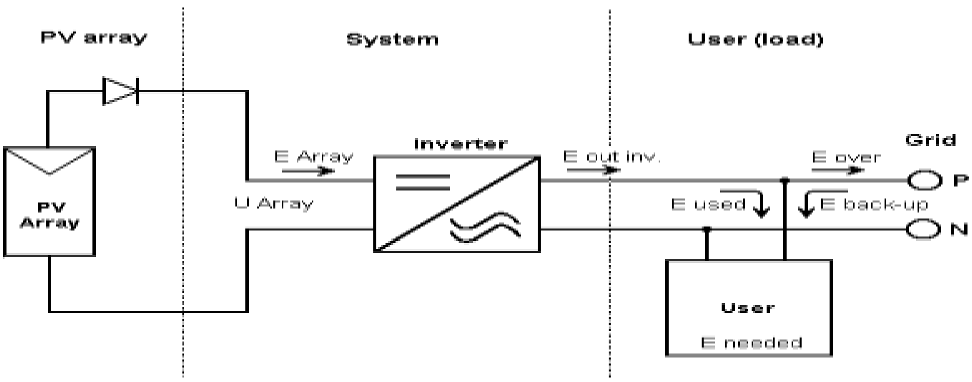




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figure 4:. Model of grid connected solar PV system (**Source:** PVsyst software.)

Figure 4 shows proposed model of grid connected PV system as designed by PVsyst software. The model comprises three significant components, which are: PV array, grid-tie inverter system and load. The principal function of PV array is to convert solar energy into DC energy. The inverter converts DC energy into AC energy, which is then used by the load. During high irradiance, it is expected that solar PV system generated more energy than is needed by the user load so that excess would be exported to the grid. But at times of low irradiance, solar PV system generates less energy than is needed and the deficit is then supplied by the grid.

**(d) Tool for Performance Evaluation of Solar Power Plant**

Several tools exist for performance evaluation of solar power plants. In this research work, performance ratio is employed to evaluate the performance of the proposed 100KW power plant for FOE, university of Port Harcourt in order to ascertain the viability of the project.

**(e) System Yield Factor (YF)**

This refers to the ratio of the final energy at the output of inverter and the nominal power at the PV array. It describes the ratio of net energy that is produced over the lifespan of the plant It is expressed mathematically as:

$$Yf = \frac{EA}{Pmax\ STC} \quad [1]$$

Where:

EA = amount of electrical energy generated by the PV power plant. Pmax STC = total installed power of the solar module.

Yf unit is (kWh/kWp/day).

**(f) Capacity Utilization Factor (CUF)**

This refers to the ratio of actual output energy from a solar plant over the year to the maximum possible output from it for a year under ideal condition. Usually, it is expressed in percentage as shown in Equation 2.

$$CUF = \frac{Actual\ Energy\ from\ the\ Plant\ (kWh)}{Plant\ Capacity\ (kWp) \times 24 \times 365} \quad [2]$$

2

$$\mathbf{CUF} = \frac{121914}{100 \times 24 \times 365} = 13.9\%$$

**(g) Performance Ratio (PR)**

According to Nayana, et al. [11] performance ratio can be expressed as the ratio of the actual energy generated to the theoretical possible power output of the solar PV plant. It is expressed as percentage. Several other factors such as losses are also considered. Performance ratio defines the quantity of energy that is actually exported to the grid. It is the most important parameter of PV plant which describes it performance and behavior to determine whether plant is in good shape or not. This parameter depends hugely on system losses.

Mathematically, it is expressed as shown in Equation 3.

$$PR = \frac{Actual\ Energy\ Generated\ (kWh)}{Theoretical\ Power\ Output\ of\ Plant\ at\ STC\ (kWh)} \quad [3]$$

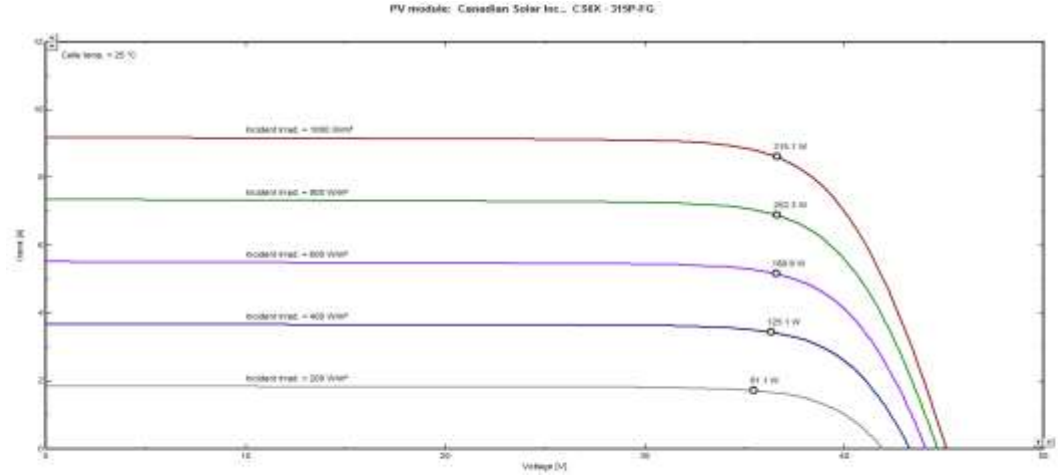


Figure 5: I-V Characteristics of solar panel used at constant temperature.

Figure 5 is a graph that illustrates I-V characteristics of the panel used for the study (CS6X-315P-FG) when subjected to constant temperature and variable irradiance condition. The figure clearly illustrates variation in voltage and current with changing irradiance when temperature is kept constant. It is observed that current increases slightly while voltage increases drastically when irradiance increases, and ultimately there is a corresponding increase in power. The graph also shows various levels of irradiances and their corresponding maximum power. It is also observed that the voltage at which maximum power is located is almost the same. At 200W/m$^2$, maximum power point is 61.6W; at 400W/m$^2$, maximum power point is 125.1W; at 600W/m$^2$, maximum power output is 188.9W; at 800W/m$^2$, maximum power point is 3252.3W; and finally, at 1000W/m$^2$, maximum power point is 315.1W. Each of the power output describes maximum power points at their corresponding irradiances.


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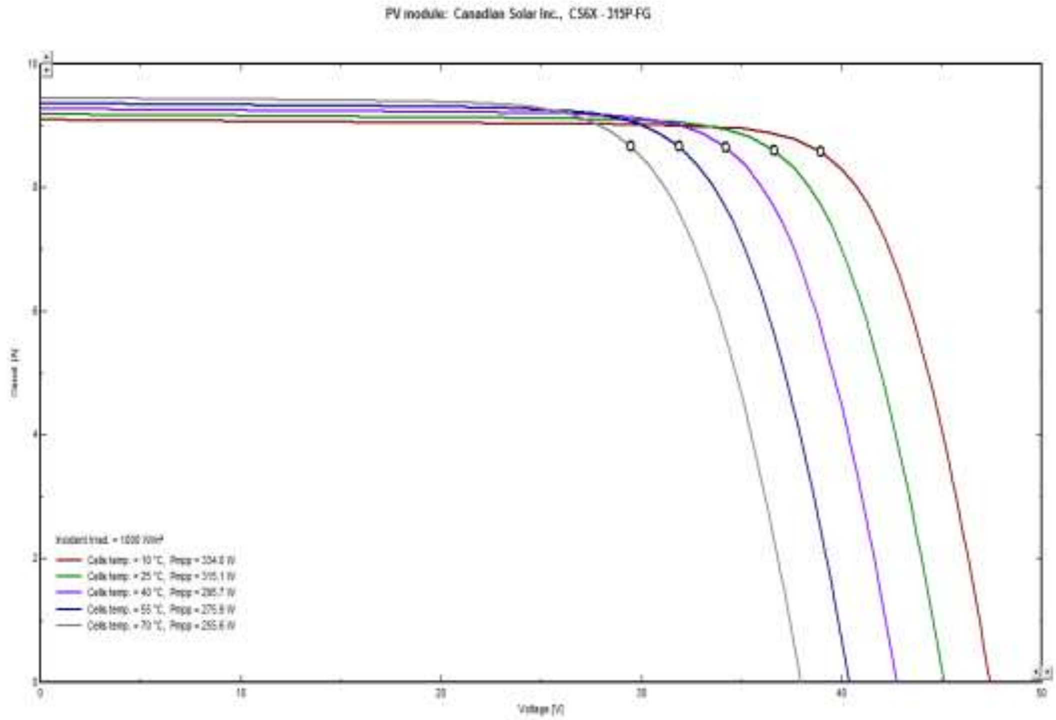


figure 6: I-V Characteristics at constant irradiance. (Source: )

Figure 6 is a graph that describes the effect of changing temperature on the output of solar panel when irradiance is kept constant. It is observed that increase in temperature causes a slight increase in short circuit current and a drastic decrease in open circuit voltage; hence, there is overall decrease in output power. Each curve has a point at a particular voltage where the PV module produces maximum power output. This point is known as maximum power point. It is the nodes on the diagram. This maximum power point varies as irradiance and temperature vary. It is also observed that under influence of changing temperature, maximum power points are located at various points of operating voltages, which are far from each other. At 10⁰C, maximum power point is 334W; at 25⁰C, maximum power point is 315.1W; at 40⁰C, maximum power point is 295.7W; at 55⁰C, maximum power point is 275.9W; at 70⁰C, maximum power point is 255.5W.


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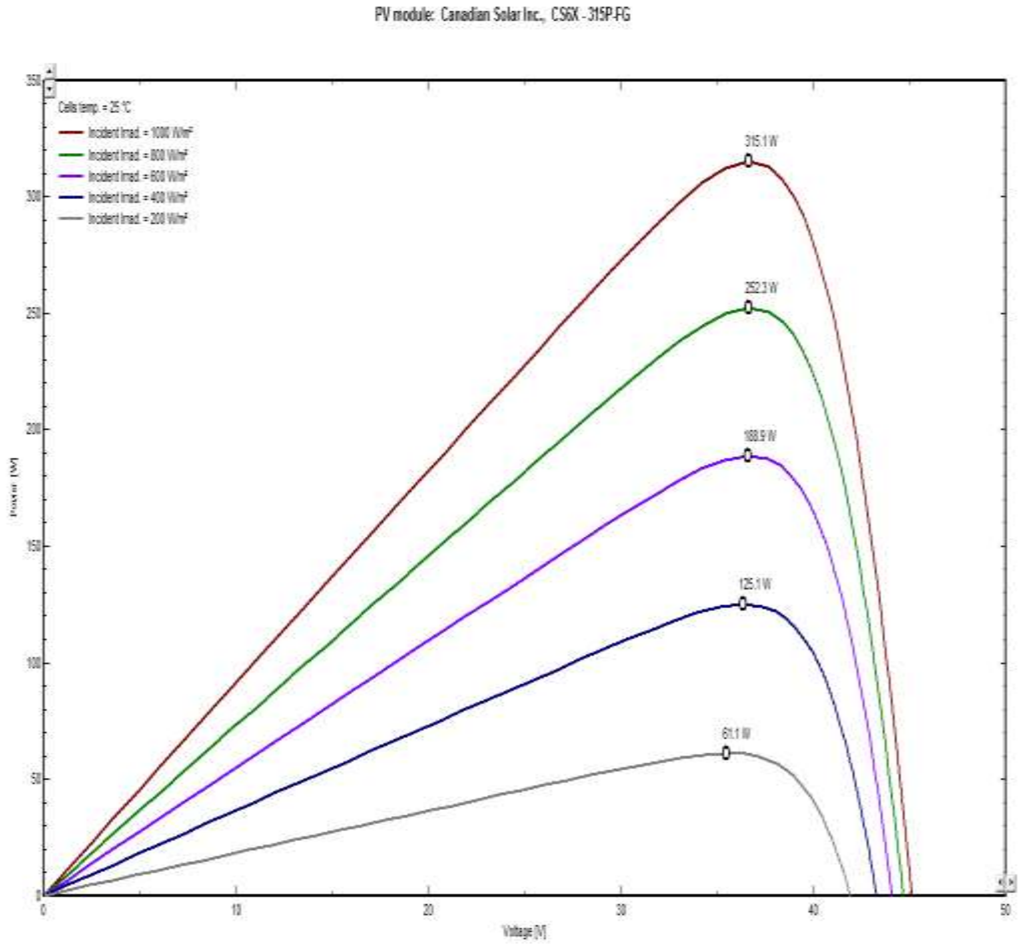


Figure 7**:** P-V characteristics at constant temperature.

Figure 7 is a graph that describes relationship between various levels of irradiance and their corresponding maximum power points. It is observed that when irradiance increases at constant temperature, there is corresponding increase in maximum power point and vice versa. At 200W/m$^2$, maximum power point is at 61.1W; at 400W/m$^2$, maximum power point is at 125.1W; at 600W/m$^2$, maximum power point is at 188.9W; at 800W/m$^2$, maximum power point is at 252.3W; at 1000W/m$^2$, maximum power point is at 315.1W. Increase in irradiance results in more power generated from the PV system.



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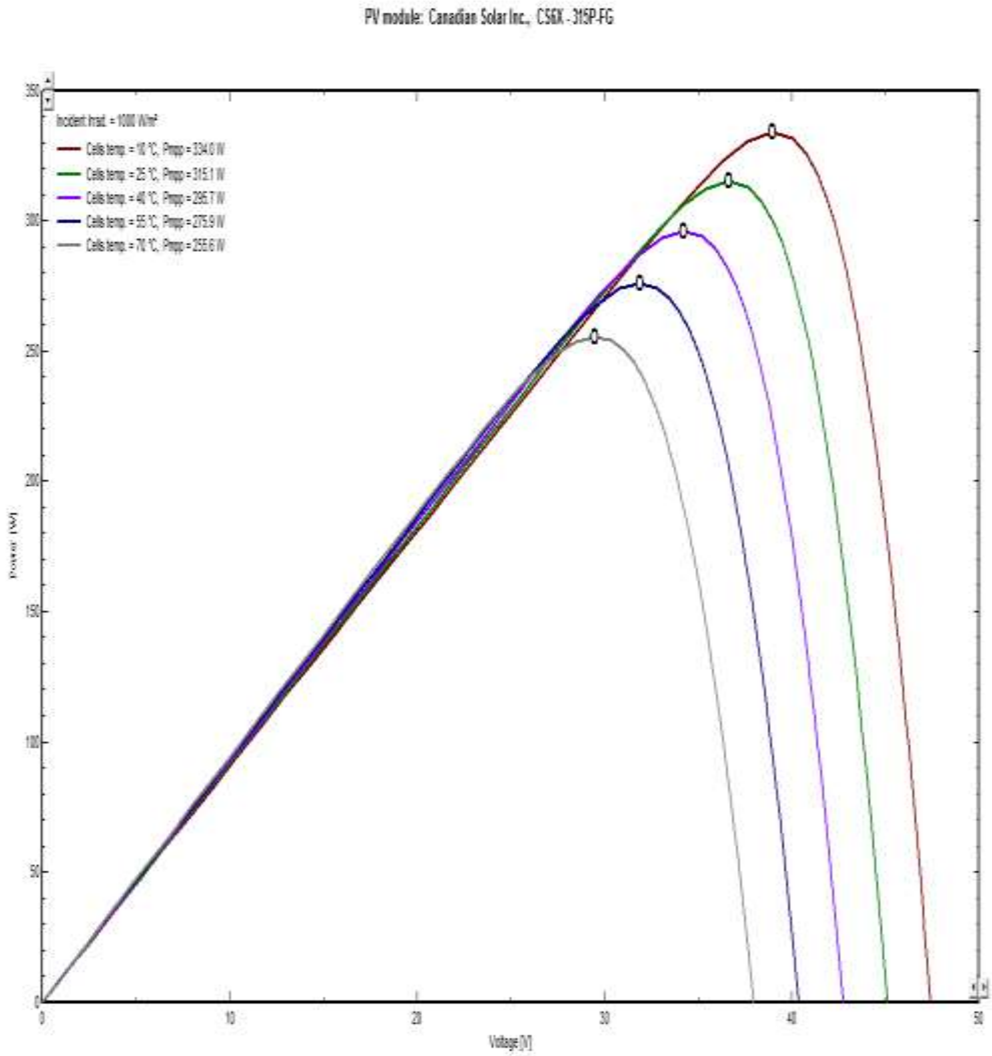


figure 8**:** P-V Characteristics at constant irradiance

Figure 8 also illustrates the impact of changing temperature on power output of solar module. Temperature is inversely proportional to output power of the module as shown in the graph. When temperature is 100C, power produced was observed to be 334W; as temperature increased to 250C, power output dropped to 315.1W; further increased in temperature to 400C led to further decrease in power output to 295.7W; at550C, power produced became 275.9W; and finally, at 700C, maximum power output was 255.6W.


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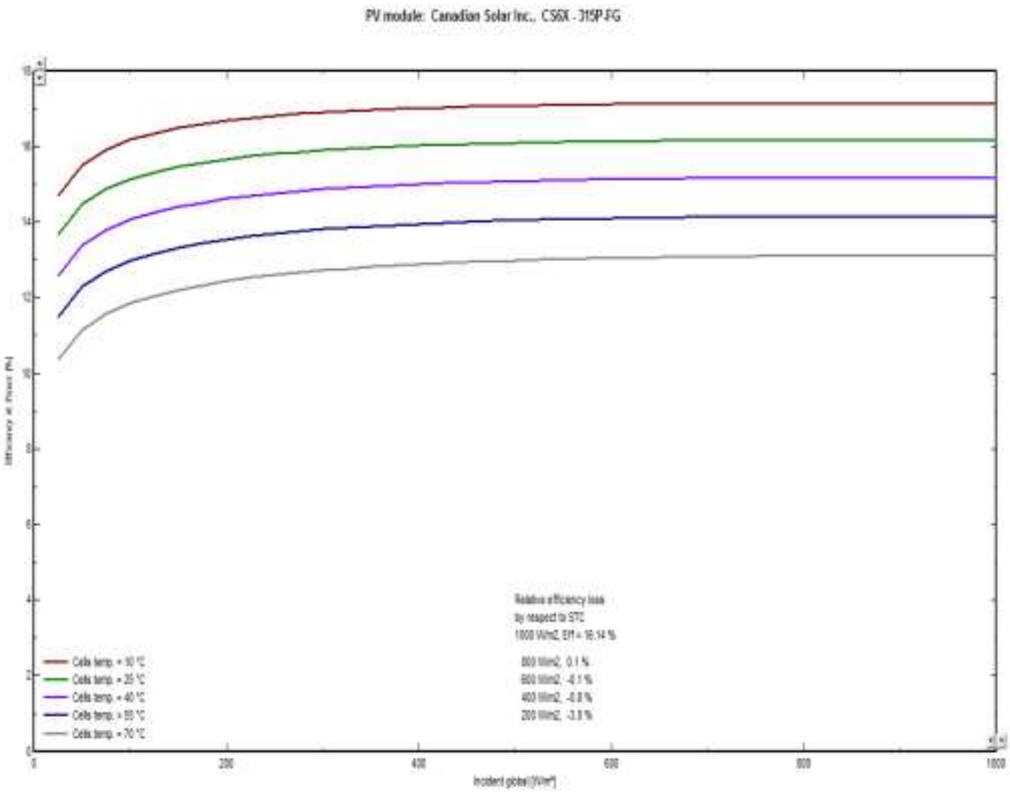


Figure 9**:** Efficiency curve of PV panel.

Figure 9 is efficiency curve of PV panel that illustrates relationship between temperature and panel efficiency. Temperature is inversely proportional to efficiency. As temperature increases, efficiency of panel decreases as shown in the graph.

**Discussion of Findings**

The site for the proposed grid connected PV system receives annual average energy of 1474kWh/m$^2$/year. The annual performance ratio of the system is 81.1% and capacity utilization factor of 13.9%. With nominal energy of 144.6MWh and useful energy of 121.9MWh, it is estimated that over 80% of total energy is exported to point of utilisation. These useful findings indicate that the PV system will be operated with good performance ratio and capacity utilization factor. It is also indicative of the fact that it will feed enough power at maximum available percentage.

Factors such as irradiance and temperature have tremendous impact on the power output of the system. PV system should be sited where appreciably high irradiance and temperature close to standard test condition of the panel, as temperature adversely affects efficiency of panel. Subsystems of the PV system contribute to various levels of losses as power travels from one point to another and during conversion process. This also affects efficiency of the entire system. In order to absorb maximum solar irradiation, solar PV array should be tilted at angle approximately close to the latitude of the location. This will help in effective utilization of incident radiation on the array.

## CONCLUSION

This work focused more on performance evaluation of grid-connected solar PV system for FOE, University of Port Harcourt. FOE represents an ideal site for installation of solar PV system as the location records high insolation because the present generation capacity and use of private generators to provide electricity in FOE faces enormous logistical challenges making it less cost effective with very high operating cost. This work evaluated the performance of proposed grid connected PV system with a view to providing reliable, cost effective and clean solution for power supply deficiency in FOE. The present power supply from the Power Holding Company of Nigeria (PHCN) is very unstable and unreliable as huge sum of money is spent on running generators on daily basis.

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