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Design And Simulation Of 500kw Grid Connected PV System for Faculty of Engineering, Rivers State University Using Pvsyst Software

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Abstract- ***This work is based on the design and simulation of a proposed 500kW grid connected PV system using Pvsyst which is desired to take care of 995,161 MWh annual load demand of the Faculty of Engineering, Rivers State University (FOERSU) between the official hours of 8am to 4pm daily using Pvsyst 7.2.6 programming software and the excess energy is sold to the Power Holding Company of Nigeria (PHCN) through the grid network. The University community has a mean solar radiation of 4.55kWh/m²/day as obtained from Nigerian Meteorological Agency (NIMET) and an average temperature of 26.61⁰C. The method used is enumeration of electrical load of the Faculty of Engineering alongside their hour of operation to obtain the energy required per day in Watt hour (1523.768kWh) but 2726.48kWh is used for the purpose of selling the excess and also due to load forecast. The energy (2726.48kWh) is divided by an average sun hour of 4.5 hours and the result is again divided by a threshold frequency of 0.77 to get the peak power of the PV module (787kWp). This peak power, tilt angle of 5⁰, grid voltage (415V) are entered into the Pvsyst programming software to chose the number of PV panels in series and parallel and the inverter. The simulation result shows that the annual DC energy the proposed plant generates per year is 1,140,796kWh while the actual AC energy exported to the grid network is 1,114,502kWh/year with a loss of approximately 20%. The effects of weather conditions on the overall performance were looked at. The proposed PV plant is viable and will address the lingering energy crisis in the faculty. A total of 1962 panels are required for this work with 18 panels in series and 109 panels in parallel. Multilevel inverter is used to track the maximum power from the PV array.***

Indexed Terms- ***Design, Grid, PV, Simulation, System, Network.***

I. INTRODUCTION

One of the most basic need of life is energy. It is critical for the development and improvement of a society. Electrical energy among the various types of energy, has a significant impact on how a society operates. As a result, it is crucial for a government to provide among other things, power to meet the growing demand of its inhabitants.

The Nigerian Electricity Regulatory Commission (NERC) has enacted a common law that allows power Plants (including renewable energy) to connect and operate directly through a distribution system. It Provides a window for businesses, communities, local, and state governments to generate, sell or use energy without going through transmission network. This also provides an opportunity for distribution companies to increase energy sales capacity by removing transmission cost of the tariff. NERC has pledged to support investment in renewable energy in Nigeria. In line with the National Renewable Energy and Energy Efficiency, the commission approved three windows for grid-connected replaceable energy projects as follows:

Net-metering for very small capacities (typically below 1MW)

1. Feed-in tariff for capacities up to:

i. 5MW of solar
ii. 10MW of wind
iii. 10MW of Biomass and
iv. 30MW of small hydropower (SHP)

Competitive tender for capacities above these thresholds to be procured through Nigerian Bulk Trading Company (NBET).

(https://NERC.gov.ng/index.php/operator/renewable-energy).

A grid-connected PV system is a system in which the Photovoltaic panels or assemblies are connected to the grid by a power inverter that allows them to operate in parallel with the grid. Grid-connected PV systems are solar panels that produce part or most of their energy needs during the day while being connected to the local grid at night to get supply. It sometimes produces more electricity than is needed or used especially during the long summer months. The extra or surplus energy is stored in the battery or as is usually the case with PV systems linked to the grid, is fed directly to the grid for profit making. Battery for storage is eliminated since the extra energy is fed directly to the grid. A bidirectional kWh meter is used to record the flow of energy to and fro the system.

The objectives of the study are:

i. To determine the electrical load demand of the Faculty of Engineering per day by enumeration.
ii. To determine the amount of electrical energy the proposed system will yield over a year.
iii. Use of Pvsyst programming software for simulation.

This research will solve the problem of power supply in Nigeria and Faculty of Engineering, Rivers State University in particular that is currently facing power outages. It will reduce high expense of running generators on daily basis, which has a negative impact on the environment, creates noise pollution and contribute to global warming. This initiative will also address employment issues employment issues a reliable power supply will lead to job creation as more business or factories that depend on electrical energy will spring up. The environment will be spared if the proposed grid-connected PV plant is installed in the faculty since it eliminates pollutants caused by gasoline generators. It will also enhance productivity and reduce lose of man-hours.

II. LITERATURE REVIEW

2.1 Extent of Past Work

Hydropower and gas-fired plants are the major sources of power in Nigeria. United Nations in 2019 estimated the population of Nigeria to be over 200 millions (www.worldpopulation.com). With this growing population index, the present installed capacity is unable to meet the ever-growing demand of electricity of the citizen. Akinyele et. al. (2017) describes the current power of the country with a generating capacity of 4000MW and with electrification capacity of up to 55% which is mainly used by users in urban communities whereas rural people have poor or no connection at all. Shaaban and Petinrin (2014) finds show that Nigeria has much sun to use PV energy in all parts of the country. The results show that renewable energy resources are yet to be utilized.

2.2 Related Work

Ramoliya (2015) investigates the efficiency of a 1MW Photovoltaic station connected to the grid using a PV system. The study discusses the feasibility of linking a 1MW PV plant to an electrical network, taking into account different power losses and efficiency ratios. Ravi and Sandeep (2016) designed and Modeled Photovoltaic cells with MPPT using Matlab/Simulink. Mathematical equations are used to model the PV characteristics. TheI-V and P-V characteristics are determined using the Matlab/Simulink tool.

Akikur et al. (2013) look at renewable energy resources as a cost-effective alternative for energy production. Renewable energy sources can be found all over the place. They are self-replenishing, green, emission-free and inexhaustible. According to Brimmo et al. (2017) the sun, wind, Tide's, falling water, biomass and geothermal renewable resources are always available. Presently, there has been a major boost towards generating electricity using solar Photovoltaic system. This is partly due to instability in power, unfriendly nature of burning fossil fuel, fear of fossil depletion and resource diversification.

According to Bhushan et al. (2016) solar photovoltaic materials use electrical properties of a conductor to generate electricity. A PV cell is a diode whose p-n junction is open to light. When the solar cell is hit by sunlight, then generation of free electrons and holes occurs and the charge when short circuited, delivers current. To achieve high output voltage, PV modules are connected in series while high current is achieved by connecting PV cells in parallel. A grid-connected PV system is a decentralized form of solar-powered photovoltaic system that is connected to the grid.

According to Atkomstdatum(2014) the annual energy generated by the grid is considered as the sum of the production per hour and year in kWh. According to Perez-Gallardo et al. (2014) the size and structure of grid-connected PV system play an important role in assessing the environmental benefits and performance of the network.

Byregowda (2014) evaluates the activity of a 5MW PV power linked to an electrical network using two Methods : manual and Pvsyst. The parameters of manually generated energy with SCADA system are compared with those of the Pvsyst. The parameters of manually generated energy with SCADA system compared with those of the Pvsyst. The studies show a small difference between the two methods and the results are within acceptable limits. According to Himanshu et al. (2015) sunlight is an important and sustainable source of power everywhere. Despite its fluctuating nature, it is an abundant and sustainable source of energy. Nayana et al. (2017) highly grade the performance of a 10MWp grid-connected solar power plant based on a system already installed at Karnasaki Shiva Samudram. The researcher identifies several losses associated with PV power plants and suggested ways to improve the plant's efficiency.

The study shows that the project used 35,840 polycrystalline panels with a power of 285Wp.Olusola et al. (2017) describe the distribution of solar radiation as unequal across Nigeria, with an average of 19.8MJ/m2. Venkate et al. (2018) look at design and simulation of 100kWgrid-connected solar systemusing Matlab/simulink. Pertube and Observe (P&O) is used as MPPT protocol to monitor the maximumenergy of the solar arraydue to changes in solar radiation and temperature. Karunakar et al. (2019)develop and simulate a 100kW Hybrid Grid-connected PV system using Matlab/Simulink. MPPT algorithm is used to track the most extreme energy of the solar array.Vikrant and Chandel (2013) test theefficiency of a 190kWp interactive solar power plant linked to the grid in India. Grid-tie inverter with MPPT is used to harness maximum power and a performance ratio of 74% was achieved.

a. Wind Energy

It is a renewable energy source that can also be used to generate electricity through a wind turbine. It isClean and unbreakable. Shaaban and Petinrin (2014) report an average wind speed of 2-4m/s in Nigeria. Aliyu et al. (2015) note that the wind speed should be around 7m/s for commercial use. According to data from the Nigerian Meteorological Agency for the proposed site, the average wind speed is 2.4m/s whichis not enough for use. Wind energy is caused by the uneven heating of the soil by solar energy that causes different air densities in different places, hence wind is considered as moving air. Different part ofthe earth absorb different solar radiation when exposed to sun.

b. Biomass

According to Gonzales et al. (2015) biomass is one of the most widely used energy sources which hasreceived unprecedented attention as a renewable energy technology for electricity generation. Studies have shown that the integration of photosynthetic organisms is responsible for the growth and development of biomass for the production of electricity. Mirza et al. (2017)show that if serious attention is paidto use of such renewable resources, a large amount of energy can be generated from waste to improve the entire energy source. According to research, this is possible due to the integration of photosynthetic organisms, in which organic waste is converted into useful electricity.

c. Hydropower

Water power can be described as energy from falling water. Anyaka (2013) explores the real purpose of generating electricity in an energy exchange system, when the body of water at a certain height converts to a moving body of water flowing into the water. Small hydropower (SHP) is seen worldwide as a renewable energy source and has the potential to reduce global warming and provides electricity to remote people. Adejumobi (2013) describes water as a source of electricity when it is used efficiently.

III. MATERIALS AND METHOD

This study presents the design and simulation of a proposed 500kW PV system linked to the grid using Pvsyst software for Rivers State University, Faculty of Engineering. It is based on a site survey of theNkpolu-Oroworukwo community. Meteorological Data in Nkpolu-Oroworukwo municipality is collectedbetween 2017 and 2020 to determine solar radiationand analyzed accordingly. Past works on design and simulation of grid connected solar photovoltaic system have been studied. Other scientific papers have been looked at to evaluate equations.

3.1 Materials

PV array, grid-connected inverter, net metering (kWh meter), isolator (switch), cables and circuit breakerare used in the project. The decision to use grid-connected arise from the fact that a standard grid system is close to the Rivers State University.

3.2 Method

The method used is enumeration of electrical appliances alongside their corresponding power ratings and time of operation during the day to get the total energy required in Watt-hour per day by the faculty. This energy (2726.47kWh) is divided by an average sun hour of 4.5 hour and the result is again divided by a threshold frequencyof 0.77 to get the peak power (787kW). The peak power, average sun hour, grid voltage, the latitude, longitude and the tilt angle are entered into the Pvsyst software to determine the sizes of the components of the photovoltaic system and the required electrical energy that will be evacuated to the grid network. The energy yield of the system is calculated as:

$$E_{sys} = P_{array\_STC} \times f_{man} \times f_{dirt} \times f_{temp} \times H_{tilt} \times \eta_{pv\_inv} \times \eta_{inv} \times \eta_{inv\_sb} = 1{,}114{,}502kWh \quad (3.1)$$

Where:

E_{sys} = Average yearly energy output of the PV array, in watt-hours

$P_{array\ at\ STC}$ = Rated output power of the array under standard test conditions (785Wp)

f_{man} = de-rating factor for manufacturing tolerance, dimensionless

f_{dirt} = de-rating factor for dirt, dimensionless

f_{temp} = temperature de-rating factor, dimensionless

H_{tilt} = Yearly (monthly) irradiation value (kWh/m^2) for the selected site (allowing for tilt, orientation)

η_{pv_inv} = efficiency of the subsystem (cables) between the PV array and the inverter

η_{inv} = efficiency of the inverter dimensionless

η_{inv_sb} = efficiency of the subsystem (cables) between the inverter and the Switchboard

The system yield factor which is a ratio of the output of the inverter to the nominal power at PV array inkWh/kWp/day is given by :

$$Yf = \frac{E_{sys}}{P_{\max at\ STC}} = \frac{1{,}114{,}502}{785\ x\ 365} = 3.89 \quad (3.2)$$

The performance ratio (P.R) of the system is given by:

$$PR = \frac{Y_f}{Y_r}\ \% = \frac{3.89}{4.675}\ x\ 100\% = 83.2\% \quad (3.3)$$

Where:

Y_r = Reference incident energy on collector plane

Y_f = Produced useful energy (inverter output)

According to Nayana et al. (2017) performance ratio is the ratio of the actual energy generated to the solar PV plant's theoretical possible power production. It is used to assess the installation quality.

IV. RESULTS AND DISCUSSION

The efficiency of the system has a great impact on power generation and as well as on the overall performance of power plants. Subsystem losses play a significant role in lowering system efficiency, resulting in low energy output.

4.1 Summary of Loads

Table 4.1 Summary of Loads in the Faculty of Engineering

Appliances	Quantity	Total Wattage (W)	Energy Req. per day (Wh/day)
Desktop computers	76	7600	60800
Air conditioner	125	186500	932500
Photocopier	12	5700	17100
Plasma TV	108	10800	43600
Ceiling fans	197	15760	126080
Refrigerator	100	12000	96000
Laptops	217	21700	90100
Printers	105	3150	25200
Projectors	13	3900	15900
Lighting points	837	12329	116488
Total		279.439kW	1523768

From Table 4.1 above, the total loads of the faculty of engineering is 279.439kW and the required energy is 1523.768kWh/day. As a result of load forecast and for the purpose of selling the excess energy, 500kW load and its required energy of 2726.476kWh/day is used for this work. This helps in determining the PV plant's component sizes.

4.2 Nkpolu-Oroworukwo Meteorological Data

Before deciding on a location for a PV system installation, meteorological data particularly solar irradiance and ambient temperature over time, should be taken into account. According to World Energy Council Trend and Prospects (2016), the acceptable range for solar radiation is 3.5-7.0 kWh/m^2/day. From Table 4.2 below, the average solar irradiance is 4.55kWh/m^2/day which makes it suitable to cite the project at Nkpolu-Oroworukwo.

Table 4.2: Meteorological Data from NIMET

NIGERIAN METEOROLOGICAL DATA FOR (NKPOLU-OROWORUKWO) PORT HARCOURT

Month	2016			2017			2018			2019			2020			Monthly Average		
	Wind	Solar	Temp	Wind	Solar	Temp	Wind	Solar	Temp	Wind	Solar	Temp	Wind	Solar	Temp			
Jan	2.4	4.383	27.9	2.4	4.795	27.3	3	4.709	26.1	2.4	5.026	27.9	2.1	4.867	28	2.46	4.647	27.44
Feb	2.5	4.824	28.4	3.2	4.838	28.2	3.1	4.853	28.3	3.2	5.242	30	2.4	5.155	29.4	2.88	4.782	28.86
March	2.5	4.766	28.3	2.7	4.666	27.7	2.4	4.68	27.9	2.7	4.766	28.8	2.7	4.701	28.2	2.6	4.71	28.18
April	2.5	4.752	28.1	2.7	4.68	27.8	2.4	4.738	28.1	2.7	4.234	26.8	3	4.694	28.1	2.62	4.26	27.78
May	2.4	4.594	27.6	2.7	4.709	28	2.6	4.608	27.7	2.7	4.234	26.6	2.1	4.536	27.5	2.5	4.536	27.48
June	2.3	4.277	26.2	2.8	4.781	28.2	2.9	4.219	26.3	2.7	4.5	27	2.3	4.349	26.9	2.6	4.425	26.92
July	2.5	4.147	25.6	2.5	4.162	25.8	2.4	4.118	2.6	2.4	4.176	26.1	2.6	4.19	25.9	2.48	4.159	25.88
August	2.7	4.19	25.9	2.7	4.118	26	2.5	4.104	25.8	2.7	4.234	26.2	2.1	4.133	25.8	2.6	4.152	25.94
Sept	2.7	4.248	26.3	2.8	4.5	26.9	2.7	4.291	26.6	2.6	4.406	26.9	2.8	4.291	26.4	2.72	4.347	26.62
Oct	2.3	4.421	26.6	2.1	4.55	27.1	2	4.421	26.9	2.2	4.651	27.7	2	4.486	26.9	2.12	4.506	27.04
Nov	1.9	4.493	26.8	1.9	4.493	27.6	1.9	4.666	27.8	2	4.752	28.1	2	4.579	27.4	1.94	4.597	27.54
Dec	2.1	4.594	26.4	1.8	4.594	27.3	2.6	4.882	26.3	1.8	4.766	27.7	2	4.538	27.8	2.06	4.675	27.1
Annual Average																2.465	4.55	27.23

Annual Average: 4.55kWh/m^2/day

Source: NIMET

4.3 System Energy Yield

The energy generated by the PV system as shown in table 4.3 below is 1,140,796kWh and this is called DC energy. The output of the inverter is 1,114,502kWh an is called the system yield. It is an alternating current energy that is fed to the grid. From this system yield, it is evident that the proposed plant can power the faculty of Engineering, Rivers State University which has annual energy requirement of 556,175.32kWh and the excess energy which is 558,326.68kWh, is fed to the grid for profit making.

Table 4.3 Balances and Main Result

New simulation variant

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	KWh/m²	KWh/m²	°C	KWh/m²	KWh/m²	KWh	KWh	ratio
January	149.3	94.27	27.58	153.6	149.2	102079	99805	0.828
February	126.0	87.77	28.29	127.9	124.5	84804	82830	0.825
March	148.4	97.25	28.01	149.1	145.2	98885	96629	0.826
April	156.9	91.26	27.10	155.3	151.1	103313	101043	0.829
May	151.9	84.78	27.17	148.5	143.9	98817	96529	0.829
June	122.2	76.84	25.71	119.1	115.1	80284	78264	0.838
July	132.7	84.36	25.51	129.6	125.4	87751	85620	0.842
August	136.3	87.01	24.95	134.3	130.2	91007	88830	0.843
September	139.1	72.90	25.07	138.8	134.8	92847	90692	0.832
October	151.9	81.89	26.06	154.3	149.9	102913	100570	0.831
November	140.1	80.75	26.43	144.0	139.8	96175	93990	0.832
December	147.8	94.37	27.49	152.6	148.0	101920	99701	0.832
Year	1702.7	1033.44	26.61	1707.1	1657.2	1140796	1114502	0.832

4.4 Pvsyst Programming Software

The Pvsyst programming software is more suited for Photovoltaic work for it is designed specifically for PV works. It is designed by Energy Institute of Geneva. From Figure 4.1 below, it shows that 18 PV panels in series and 109 panels in parallel are required for the proposed project and total area of 3936m^2.

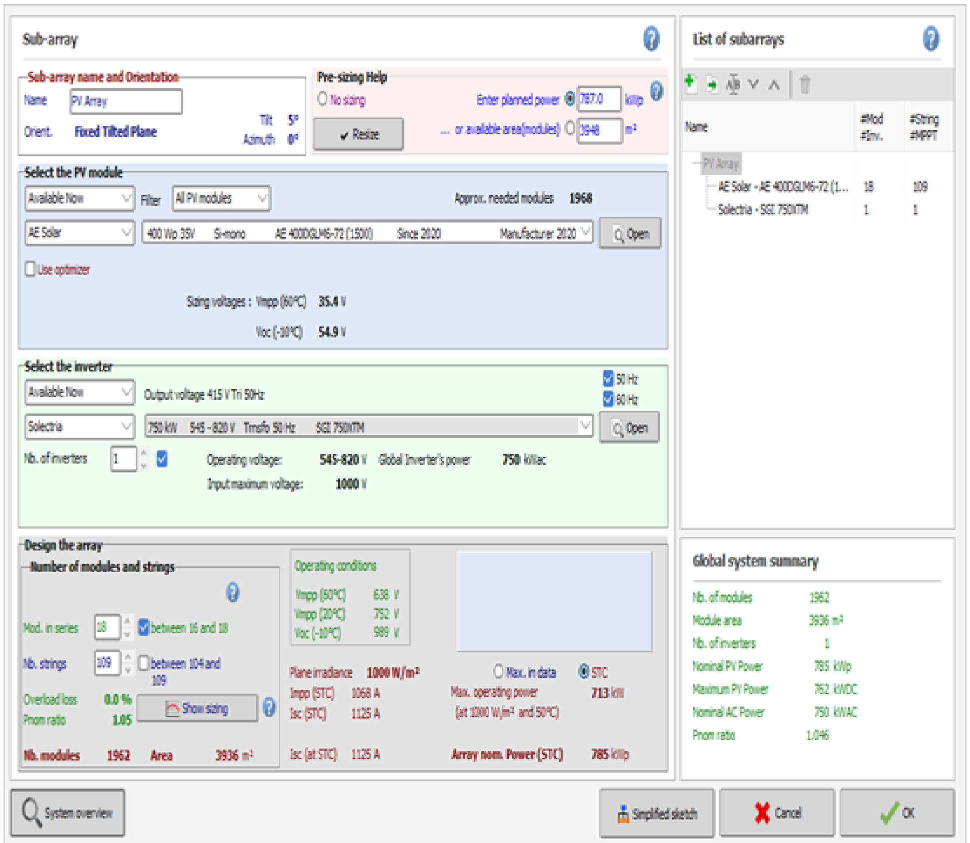

Figure 4.1: Pvsyst 7.2.6 Programming Software Environment

Figure 4.2 is a bar chart describing electricity production in kWh/kWp. It gives the ratio of the mean daily electricity production in kWh to the rated power in kWp. The average energy loss is compared to the rated power. The figure presents that the collector losses (Lc) of the PV is 0.69 kWh/kWp/day, the systemic loss of the inverter (Ls) is 0.09 kWh/kWp/day. Finally, the mean daily capacity is 3.89 kWh/kWp/day.

4.5 Normalized Production

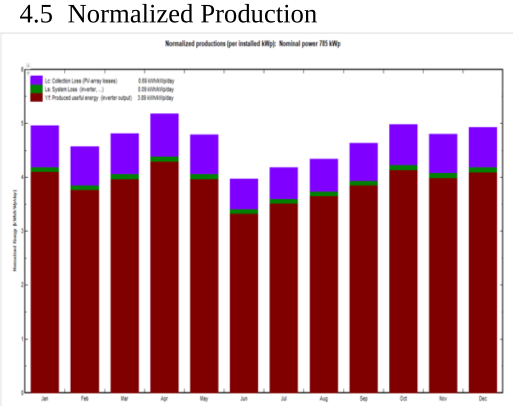

Figure 4.2: Normalized Production (Per kWp)

4.6 Performance Ratio

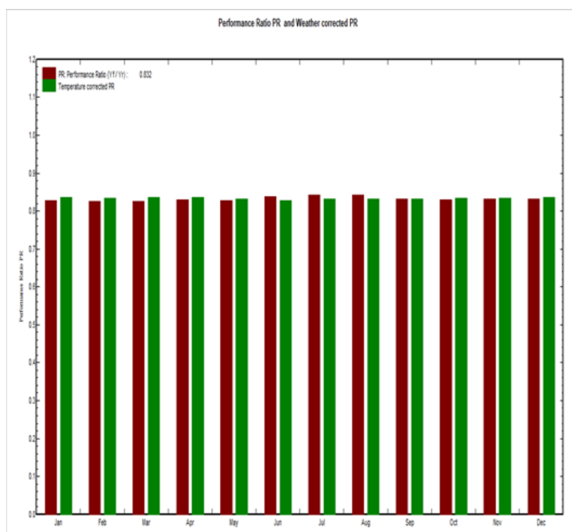

Figure 4.3: Performance Ratio

Figure 4.3 shows the performance ratio for the Nkpolo-Oroworukwo solar grid connection at Rivers State University in Port-Harcourt. This measure is important and determines theplant's profitability. The performance ratio is 83.2%. This ratio shows that the loss is not up to 20% in the network.

4.7 Current Voltage Characteristics

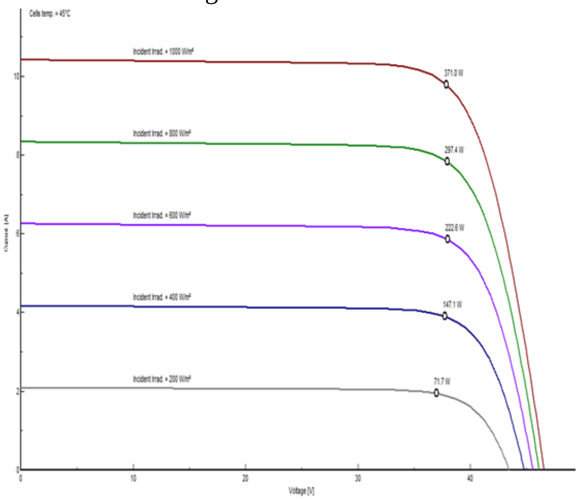

Figure 4.4: I-V Characteristics of the Solar Panel Used at Constant Temperature

Figure 4.4 shows the properties of AE solar energy, AE 400DGLM6-72 (1500) I-V for varying irradiance at fixed temperature. From the figure, current increases slightly while the voltage increases drastically. The current and of course the voltage increases as the irradiance and thus, the output power of the PV module. At 200W/m^2, MPP is 71.7W, at 400W/m^2, MPP is 147.1W, at 600W/m^2 , MPP is 222.6W, at 800W/m^2 , MPP is 297.4W and at 1000W/m^2, MPP is 371W. This relationship is further explained in Figure 4.5 below.

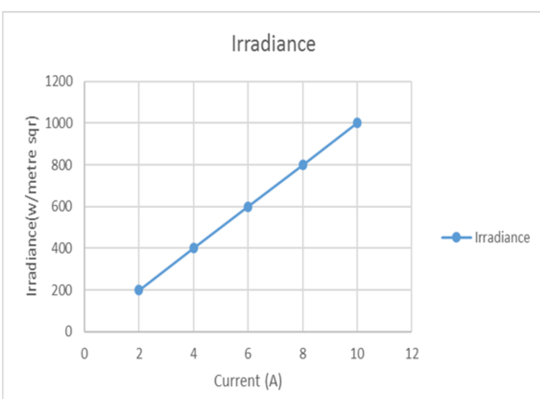

Figure 4.5: Graph of Irradiance against Current

From figure, current is directly proportional to the solar irradiance at fixed temperature (I G). Therefore, irradiance and current are related mathematically as G = IT where G is irradiance, I is current and T is the constant of proportionality (temperature).

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The current generation capacity and use of private generators to deliver energy in the FOERSU faces huge logistical obstacles, making it less cost efficient and requiring high operational cost. The goal of this project is to design and simulate a propose 500kW grid-connected PV system in order to provide a dependable, cost-effective, and clean solution for power supply shortfall at Rivers State University's Faculty of Engineering and sell the excess energy for profit making. The current grid power supply is extremely unstable and unreliable. On a daily basis, huge amount of money is spent on running generators.

The PV plant is simulated using PVsyst 7.2.6 programming software and the results obtained are in line with the objectives. The electrical load demand of the faculty is rated at 279.439kW and the average irradiance of Nkpolu-Oroworukwo is estimated at 4.55kWh/m^2/day. Maximum electrical power of the PV array is 785kW/day and thus the electrical energy that the PV plant generates per year is 1,114,502kWh. The system is monitored for a year to check for performance and is found to have a total loss of 262,294kWh/year and 97.7% efficient with a performance ratio of 83.2%.In conclusion, the project is viable and can produce the required energy. It is found from the research that :

- Multilevel grid-tie inverter with independent voltage control for each PV module tracks more solar power from the PV array with efficiency of 97.7% than MPPT technique with efficiency of 85%.
- The solar panels tilted at an angle approximately equal to the latitude of the site (5^0) receive maximum solar irradiance of 1657kWh/m^2 as against 30^0 with solar irradiance of 1367kWh/m^2
- Irradiance is directly proportional to current at fixed temperature.
- Temperature is inversely proportional to the output power of the PV module at constant irradiance.

5.2 Recommendations

To help improve on grid connected PV systems, the following should be considered:

i. Renewable energy regulations as found in developed countries, should be used in Nigeria.
ii. Emphasy on renewable energy for electricity production in order to optimize the existing energy potential in Nigeria should be adopted.
iii. More attention should be given to renewable energy strategies from educational institutions, policy makers, private sectors, and implementation agencies.
iv. Finally, further work on this research should focus on designing a suitable transmission line that will evacuate the energy generated from this PV plant to the grid network.

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