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Original Article

Design and Simulation of 500KW On-Grid Photovoltaic Power System using PV*SOL

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Abstract - *The intractable and susceptibility of existing fossil fuel-dominated sources of power generation in Nigeria have prompted echelons of studies on renewable energy resources to provide reliable, clean and affordable alternatives to assuage the energy crisis bedeviling the nation. This paper focuses on designing and simulating a 500 kW on-grid photovoltaic power system using PV*SOL "case study of pacesetter FM Umuahia". The configuration is made up of 38 x PVS300-TL-3300W-2 hybrid inverters, 532x345 W sun power monocrystalline PV modules covering a total surface area of 867.5 m² and KACO new battery energy of 64.44kWh capacity. The system was simulated using PV*SOL, which displayed quite promising results of a specific annual yield of 1,177.03kWh/kWp, a performance ratio of 80.3 % with minimal shading losses of 8.3%/year. It prevented the emission of 129,337 kg of CO_2 per year. Additionally, P-V and I-V curves were plotted to provide information on the operating performance of the panels, while aspects of economic analysis, which consist of 18.72 % return on assets and 5.6 years amortization period were equally realized up the implementation of this design in line with the sustainable energy target.*

Keywords - *Cementation, Degradation, Cash flow hot-spot, Amortization period.*

1. Introduction

Electricity demand relies on different socio-economic aspects like Industrialization, urbanization, and new technological improvements that influence lifestyles and governmental policies [1]. Presently, the Nigerian power industry is witnessing an intractable age-long energy crisis. Because of erratic power supply, load shading has now become a norm. This is not only attributed to the obsolete grid equipment; rather, the energy consumption surpasses the generation [2]. The quest for reliable, clean and cheap alternative energy has ignited echelons of research on renewable energy, more especially photovoltaic technology. The on-grid photovoltaic power system will provide the much-needed energy satisfaction to consumers.

Fortunately, studies have confirmed that Nigeria is inundated with abundant renewable resources. The mean amount of the nation's sunlight is estimated at 5.25 kWh/m^2/day, stretching between 3.5 kW/m^2/day from the south to 7.0 kWh/m^2/day to the north [3]. This alternative energy technology is expected to boost the country's gross domestic product when fully incorporated into the grid [4-6].

Presently, power generation in Nigeria is highly dominated by conventional fossil fuel, which accounts for a substantial amount of environmental pollution and greenhouse gas emissions. Worrisomely, it has been predicted that fossil fuels in the country will be exhausted to an uneconomical stage by the year 2050 [7-8].

The functionality of solar energy depends on the solar irradiance. The output is adversely affected by various factors such as temperature, degradation, mismatch losses, soiling, cementation and shading from nearby objects. Soiling can be explained as gathering dirt elements in a solar panel; its impact equally reduces the output efficiency. This phenomenon usually occurs during the harmattan period. When early morning dew touches a soiled panel, it results in a process called cementation. This is the suspension and following precipitation of objects, which robustly rely on the remains of dust particles on the photovoltaic module [9-10]. Photovoltaic shading is analogous to a blockage in a pipe of water, which prevents the free flow of water via the pipe [11-13]. In the same way, when a current passes through shaded solar cells, it results in a hot spot.

The hot spot phenomenon happens when the operating current of a photovoltaic panel surpasses the short-circuit current (I_{sc}) of the shaded areas or portions of panels [14].

2. Overview

Pacesetter FM Umuahia is among Nigeria's federal government-owned radio broadcasting stations. The station is located at radio house, km 5, New Umuahia - Aba Express road (Ururuka Road), Amakama Olokoro Umuahia inside National Cereals Research Institute (NCRI) premises, Amakama Olokoro Umuahia, Abia State, Nigeria. It is located on a latitude of 5.46° and longitude of 7.44° with an annual sum of global irradiation of 438kWh/m^2 and an average temperature of 26.5^{o}c. The broadcasting house is fed via the existing 33kv Alaoji-Olokoro Umuahia feeder. Pacesetter FM has 17.5 hours scheduled daily transmission time, but the electricity supply has been inconsistent. The daily electricity supply at the station is mostly less than 3 hours. Thus, the station runs almost 16 hours on 2x100kVA Milkano diesel-powered generating sets. Over one million is being expended monthly in buying diesel to run the generators, which is counter-productive. The enormous losses, high cost, and environmental effects associated with the existing fossil source of power generation is a huge gap that needs to be filled by this research; this is why it is urgent to advance to the photovoltaic energy system. The introduction of energy-saving devices is highly recommended to make prudent and adequate utilization of energy to increase profit and improve competence.

This photovoltaic energy transition will provide reliable, clean and affordable alternative power to augment the inadequacies of the existing utility grid. The simulation of the system design will be performed using PV*SOL software. The excess power generated will be exported to the network. The price of energy transaction between the exported and imported electricity from the grid is reconciled with the energy meter. The process is called "Net Metering" [15, 16]. The current market price for electric energy determines the cost of energy transactions. 64.44kWh battery storage was also incorporated into the design to provide standby power in the event of adverse weather conditions or utility grid collapse.

3. Materials and System Design

This research adopted a procedural simulation approach. These design and sizing steps include estimating daily energy consumption, inverter, battery, charge controller, cables calculations and solar PV module calculations. After that, PV*SOL software was employed to simulate the system to ascertain the general performance and behavior of the configuration. PV*SOL is a 3-dimensional simulation software with a series of inbuilt solar PV facilities. The block diagram of the methodology is shown in Figure 1.

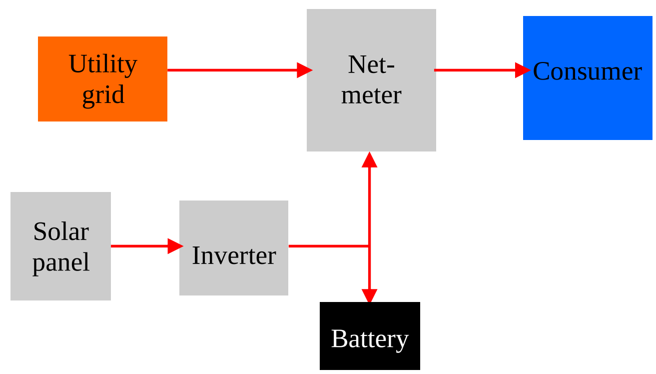

Fig. 1 Block diagram of design steps

3.1. Load Profile Examination

Pacesetter FM Broadcasting station is made up of ten departments, namely, Engineering, Programmes, News and current affairs, Audit, Administration, Finance and Accounts, Procurement, Marketing, Information technology and Security. The power consumption of various appliances is tabulated below.

Table 1. Energy consumption of transmitter and studio halls

Description	Ratings(W)	Qty	Run hrs	Total load(W)	Daily energy(W)
Lightening points	60	30	12	1800	21,600
AC (1Hp) AC(1.5Hp)	746 1119	10 20	10 10	7460 22380	74600 22380
Laptop	80	15	10	1200	12000
Radio	40	10	10	4000	40,000
Desktop Computer	100	20	10	2000	20000
Vacuum cleaner	500	2	1	10,000	10,000
Printer	50	10	5	500	2500
Radio Modem	20	2	24	400	9600

Stabline Dehydrator	500	2	2	1000	2000
Transmitter BE FM20S	2000	1	24	48000	48000
Aviation light	40	4	12	160	1920
alarm indicator	10	2	10	20	200
D 75 Audio Console	100	2	12	200	2400
VCD/DVD players	50	2	12	100	1200
Tape decks	50	2	12	100	1200
Microphone processor	20	2	12	40	480
Turn table player	50	2	5	10	50
Audio Amplifier	50	2	12	10	120
Distribution amplifiers	200	2	12	400	4800
VSAT	100	1	24	100	2400
				99,880	**277,450**

Table 2. Energy consumption in various offices

Description	**Rating(W)**	**Qty**	**Hours in use**	**Estimated load(W)**	**Daily energy(W)**
Lightening points a. Internal b. External 1	 5 10	 50 20	 10 10	 250 200	 2,500 2000
Fans	80	10	10	800	8,000
Refrigerators	80	10	10	800	8,000
Water dispensers	500	2	2	1000	2000
Air Conditioners (1Hp)	746	15	10	11,190	111,900
TV	60	10	10	600	6,000
Photocopiers /Printers	1000	2	2	1000	2,000
Laptop	50	5	10	250	2500
CCTV Cameras	5	10	10	50	500
Internet router	5	10	10	50	500
Desktop Computer	100	10	10	1000	10,000
Printer/Scanners	50	2	10	100	1000
Bore Holes (1Hp)	746	10	2	7460	14,920
				24,750	**171,820**

Table 3. System setup

Climate Data:	Umuahia South
Type of System	3D, Grid-connected PV System with Electrical Appliances and Battery System - Net Metering
Consumption	
Total Consumption	300000 kWh
Load Peak	75.8 kW
PV Generator Module Area	
Name	Area South
PV Modules*	364 x SPR-X21-345
Manufacturer	SunPower
Inclination	38 °
Orientation	South (180 °)
Installation Type	Mounted - Open Space
PV Generator Surface	593.6 m²
Inverter	
Module Area	Area South
Inverter 1*	16 x PVS300-TL-8000W-2
Manufacturer	ABB
Configuration	MPP 1: 2 x 11
Inverter 2*	1 x auroPOWER VPI 5501/1
Manufacturer	Vaillant
Configuration	MPP 1: 4 x 3
Cable	
Total Loss	Total Loss
Battery System	
Manufacturer	Tesvolt
Battery System	Li 10
Power Rating	4.6 kW
Maximum Charging Power (30 mins)	4.6 kW
Maximum Discharge Power (30 mins)	4.6 kW
Batteries*	Tesvolt - 3 x Li 120 - 3xSI8.0H-11 Set
Capacity	2,680.0 Ah
DC Battery System Voltage	153.6 V

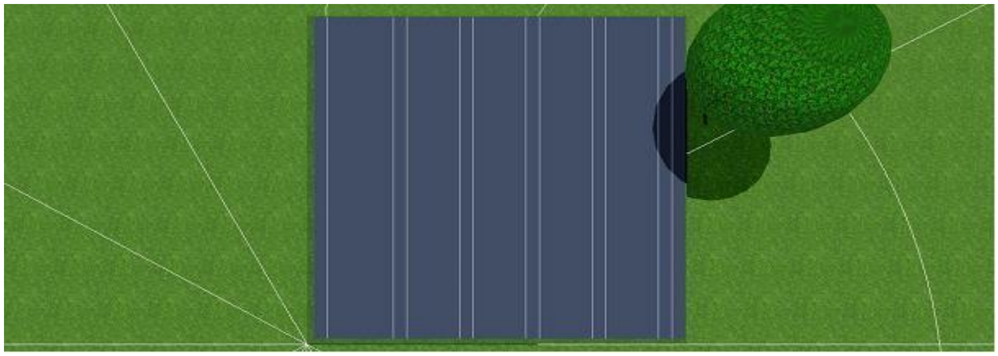

Fig. 2 3-Dimensional design for the area south

Figure 2 is a 3-dimensional illustration of the automatic arrangement of PV modules mounted in an open space inside the broadcasting house and simulated using PV*SOL.

4. Program Simulation

The system design and simulation were performed using PV*SOL Software. The software automatically supplied solar irradiance data of the site area with a 345 W_p sun power monocrystalline PV module with 96 PV cells connected in series with 3 bypass diodes. Other photovoltaic parameters applied in the simulation include Inverters, charge controllers, batteries, etc., upon the simulation process's completion.

4.1. Simulation Results and Discussion

PV*SOL software was utilized for the simulation. This software has features of 3D visualization and detailed financial and PV sizing computations. The simulation results are presented and discussed in the sections with figures and tables:-

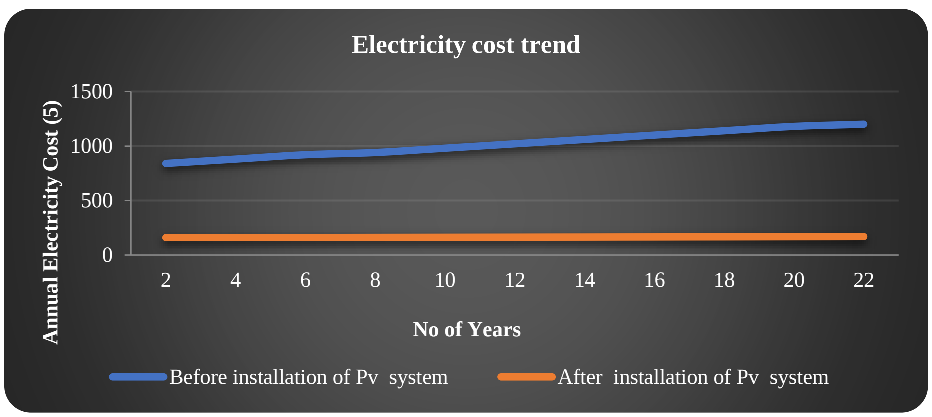

Fig. 3 Electrical cost tends to price increase rate of 2%

Figure 3 shows the movement of electricity costs with a 2% growth rate. The blue represents the trend before the PV installation, showing the cost's linearity, while the red shows the trend after the PV system was installed.

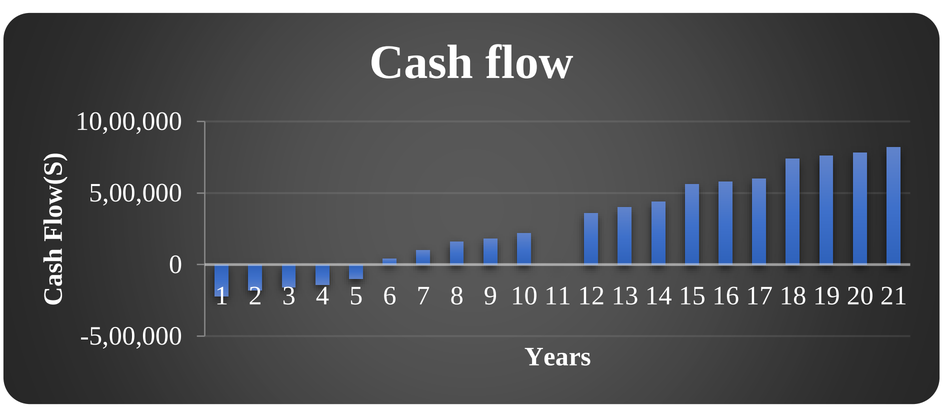

Fig. 4 Accrued cash flow

Figure 4 represents a bar chart of accumulated cash flow (cash balance) within the period. – $200 signifies the total sum of money expended during the accounting time, while the positive bar charts represent the account.

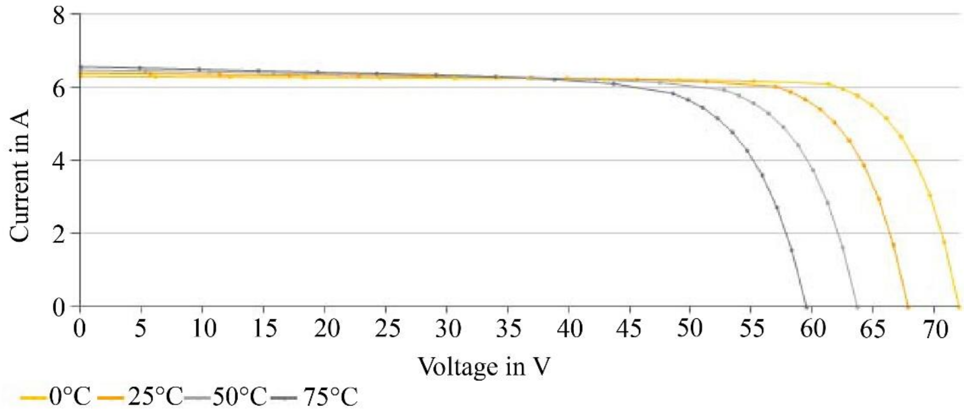

Fig. 5 I-V Characteristics curve under constant irradiance

Figure 5 shows the current-voltage characteristics curve of 345w solar panel varying different temperatures at an irradiance of 1000W/m^2

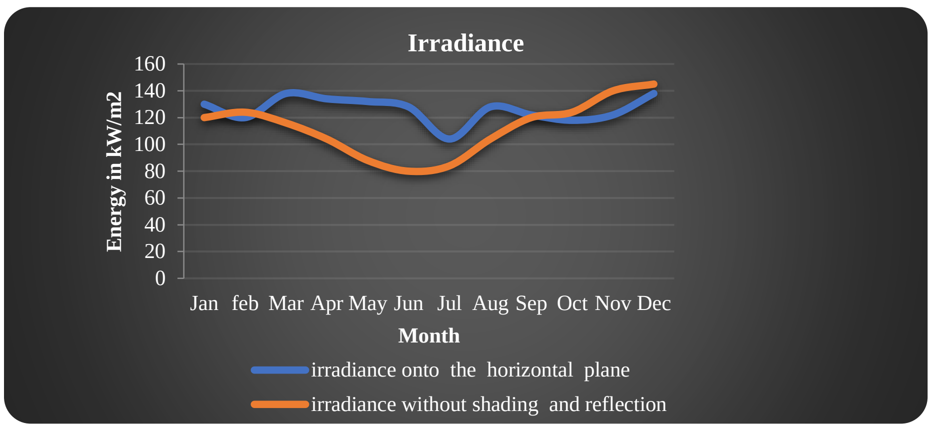

Fig. 6 Irradiance curve

The blue and brown curves in Figure 6 denote the irradiance onto the horizontal plane, while the brown line represents irradiance without shading or reflection.

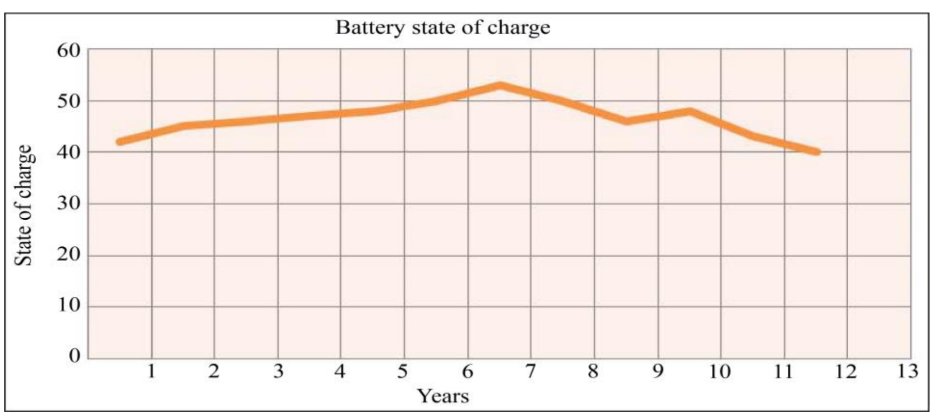

Fig. 7 State of charge

Figure 7 shows the curve of the battery state of charge. It gives details of the obtainable capacity of the battery in relation to the reference capacity.

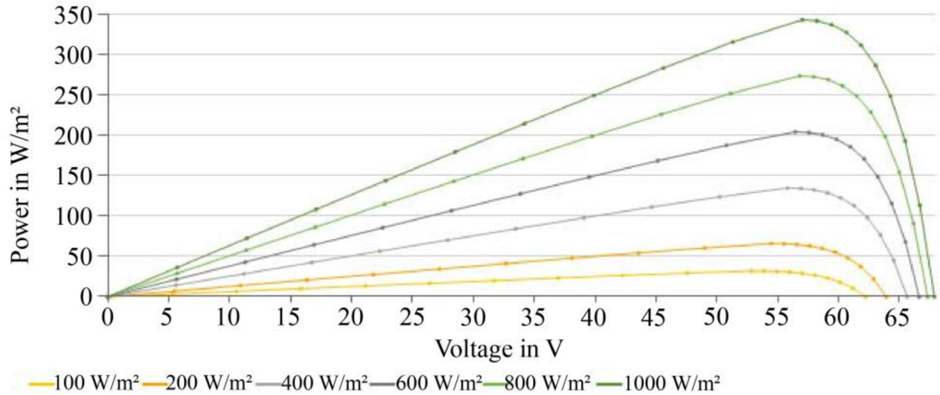

Fig. 8 P-V characteristics curve of 345w solar panel at constant temperature

Figure 8 represents the P-V characteristics of the PV module's different irradiance levels at standard temperature (25^0C); from the graph, it can be deduced that the maximum power is approximately 345W and occurs at a voltage of 68.20V.

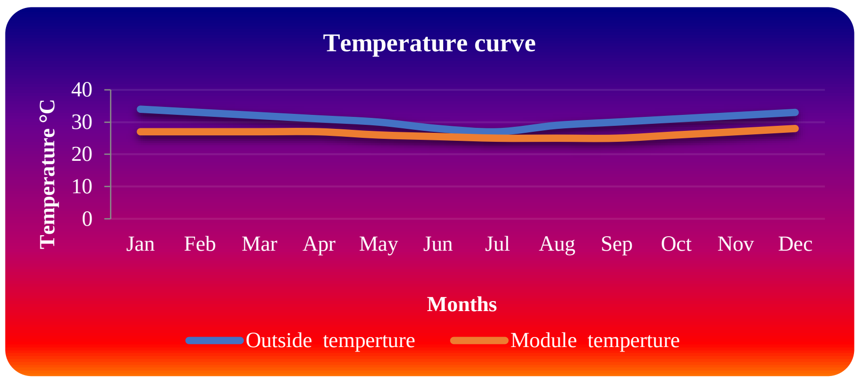

Fig. 9 Temperature curve

The temperature curve is shown in Figure 9. From the curve, the outside temperature is identified with a blue line, while the module's is marked with an orange line.

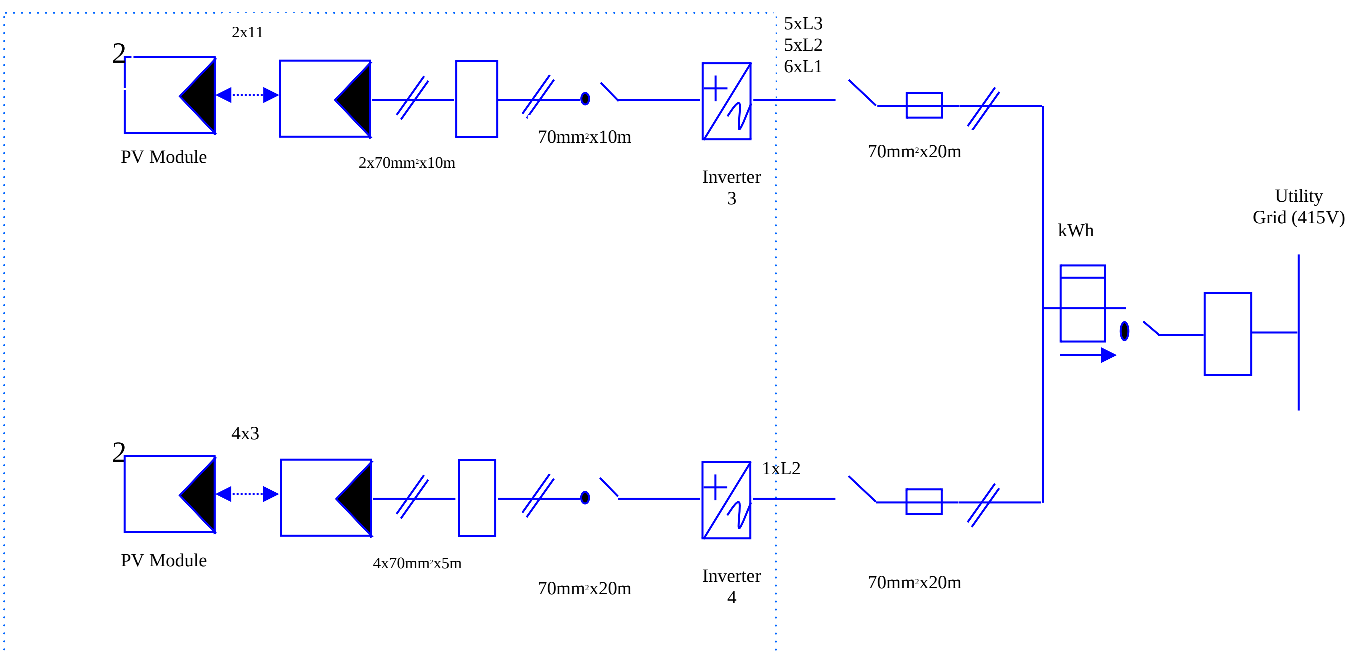

Fig. 10 Oneline diagram of on-grid-system incorporated with battery and net meter devices

The oneline diagram of the entire system configuration was automatically generated by PV*SOL and exported in PDF or Microsoft Word format, as shown in Figure 10 above.

Table 4. Cost evaluation of materials

Description of Item	Quantity	Unit price ($)	Cost ($)
Solar Panel SPR-X21-345	532	US$144.0	692,640
Battery DC Battery System Voltage 480 VKACO Capacity 67.44 kWh			60,576
3 Phase Solar Hybrid Inverter PVS300-TL-3300W-2 Output: 380Vac, 50HZ WIFI Monitoring	38	US$9,028	343,064
PV combiner XTC40NA-4T 4 in 1 out 1000VDC Protection	133	US$163	21,679
Solar Panel Mounting Aluminum+stainless steel, Angle adjustable, with installation parts	For Full system		1,720
Cables & MC4 Connector 50mm^2 battery cable 32PCS 4mm2 PV cable 1000M MC4 9 pairs	for full system		1,000
Contingencies			2,000
Total			**$1,122,679**

5. Conclusion

Design and simulation of a 500 kW on-grid photovoltaic power system using PV*SOL "case study of pacesetter FM Umuahia" was conducted. The system displayed quite promising results of a specific annual yield of 1,177.03kWh/kWp, a Performance Ratio of 80.3 % with minimal shading losses of 8.3%/year. It prevented the emission of 129,337 kg of CO_2 per year.

Additionally, the P-V and I-V curves plotted provided information on the operating performance of the panels. At the same time, an aspect of economic analysis like return on assets and amortization Period gave the following values: 18.72 %, 5.6 years in line with the sustainable energy target. The total cost for the realization of the project amounted to $1,122,679.

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