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Investigation of 10MW Grid – Connected PV Renewable Solar Energy System for Igbinedion University Crown Estate Okada Using PVsyst

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Abstract: *Among renewable energy sources, photovoltaic Solar System is more promising around the world in the 21st century, and Grid-connected PV systems are becoming more acceptable for large scale PV solar power generation. This research work focused on investigation of Grid-connected PV system for Igbinedion University Crown Estate Okada. The goal was achieved by simulation of 10MW Grid-connected PV system using PVsyst simulation software. The major materials used in the research include: PVsyst software, the estate metrological data imported from meteonoum 7.1(1954 – 2003), Sat = 19%, and a monthly power consumption of the estate for one year. The results revealed that a 10MW grid-connected PV system with 24678 units of 405W panels in 914 strings and 27 in series arrangement linked 44 units of inverters could inject 17842MWp into the grid per year with a performance ratio of 95%. The generated energy per year is 10% of yearly energy consumption of the estate. The highest energy injected to the grid occurred in March and the lowest in August.*

Keywords: *Photovoltaic Solar System, Renewable Energy, Metrological Data, Power Consumption, Investigation*

INTRODUCTION

Availability of power energy is one of the keys to national development (Adeyemi *et al.*, 2019). In the 21st century, sources of energy have drawn attention due to global warming. Nowadays, renewable energy sources have proved to be one of the best energy sources due to their cleanliness and sustainability, unlike fossil fuels that inject harmful gases into the atmosphere and also get depleted over time (Adamu *et al.*, 2018).

Limited energy sources have increased energy costs, leading to poor economic activities in production, preservation, academic work, and Agriculture, hence keeping many countries underdeveloped (Adamu *et al*., 2018). However, solar energy is adding clean energy to the world energy output thereby reducing the cost of energy for national development. The two main technologies for converting solar radiation to electricity are the solar thermal process and the Solar cell in which an electronic process called photovoltaic action takes place on solar modules to produce electricity. Ebunilo *et al*. (2013) Solar cell (photovoltaic) technologies are the most promising renewable energy systems around the world, because of their simplicity in installation and cost-effectiveness. Ashok *et al*. (2018). The Photovoltaic Solar energy generation systems can be built in three main different structures; Standalone photovoltaic solar system structure has been the most popular type of photovoltaic system (Humberto *et al*., 2020). It comprises different components like PV modules, battery charger, battery bank for energy storage, and inverter for energy conversion without connection to the grid. This type of photovoltaic structure has the major disadvantage of the high cost of battery purchase and maintenance. The grid-connected photovoltaic solar system structure is a PV structure that comprises PV modules, a DC-DC converter (Franklin, 2019) (MMPT), Inverter, Isolator switches and the power meter through which the system is connected to the national grid (Humberto *et al*., 2020). This structure has no battery charger or battery bank which makes it simple and less expensive. However, a Hybrid Photovoltaic solar system structure is a Standalone battery system connected to the national grid.

Many countries like India have started generating a large amount of power/ energy through PV – Grid-connected solar system, while countries in Africa like Nigeria still concentrate on small-scale residential standalone PV solar system that uses batteries. This method is costly to deploy for a very large-scale power system and has a high rate of failure due to the fragility of most of the batteries used in the solar system because they require a lot of maintenance, unlike Grid-connected systems without battery banks (Ashok *et al*., 2018). Most African countries are still backward in the ongoing fight against global warming due to their dependence on oil and gas for their major energy generation. In addition, the scarcity of electrical energy in Nigeria and its cost is a problem for class A consumers like manufacturing companies and large institutions like universities. Most establishments pay heavily for constant power supply, yet do not get the equivalent of the payment due to scarcity of power/ energy. At present Igbinedion University pay a huge amount of money for energy consumed and most of the energy is consumed at the residential estate of the university. This paper aimed to investigate a 10MW grid-connected PV renewable energy system for Igbinedion University Crown estate Okada with a view to reduce the huge amount of bills paid on monthly bases by this institution. This was achieved by simulating a 10MW PV solar plant for the university estate using PVsyst simulation Software

Many research and practical installation of the mega grid-connected power generation projects have been done in different countries all over the world. According to Ashok, *et al*. (2018), a feasibility study of a grid-connected solar system was done for teaching hospital which showed that almost 950kWp could be installed on the rooftop of the hospital. A grid-connected system of 115.2kWp, which has been providing power backup to intensive care units and operation theatre loads such as X-rays, Ventilator, and MRI Machine, has already been installed at the hospital in India (Ashok *et al*., 2018). In a conference paper E3S Web of Conferences 22, 00052 (2017), the power generated from installed fixed PV system and sun-tracking PV system was experimentally recorded for one year. Different parameters like solar irradiation, temperature, humidity, wind speed/direction, and pressure were recorded with resolution. They adopted a novel cost optimization strategy to show that solar tracking PV panels provide lower costs by enabling a reduced number of installed batteries in the case of standalone systems where the battery is involved. Aditya *et al*., (2021) researched on design and analysis of a 4.6kWp solar rooftop in Motihari. In their work, the total appliances, their wattage, and the number of running hours were used to calculate the total energy needed per day for the building in Motihari as 12,972.2Wh per day multiplied by a fudge factor of 1.2 which gave 15.6kWh / day. Thereafter the system was simulated and analyzed with PVsyst simulation software.

MATERIALS AND METHODS

2.1 PVsyst Simulation Software

The main materials used in this research were PVsyst simulation software which contains other components that were put together to model the expected Grid-connected PV solar system, Igbinedion University Metrological data generated from meteoneom 7.1 (1954 – 2003), sat = 19%, which served as one of the input data for the simulation in PVsyst software and 2020 Approximated IUO Crown Estate monthly power consumption from BEDC (Benin electricity Distribution Company) Okada branch. This was used to estimate the percentage of the power 10MW will offset for the estate. There are other software for solar system simulation like Homer, PVGIS, Helioscope, Arc GIS, Google Sketch-up, SolarMAT, etc, but PVsyst is easy to use for design and analysis (Kailash *et al.*, 2020).

Table-1 *2020 Approximated power capacity of IUO Crown Estate from BEDC (Benin* electricity *Distribution Company)*

Month	Power consumption (MWh)
January	13794.315
February	14117.673
March	14486.064
April	14747.587
May	14965.563
June	15178.862
July	15415.473
August	15682.704
September	159251.702
October	16115.393
November	16136.736
December	13962.134
Appr. Monthly Average	14985MWh
Yearly Approximated	179827MW

2.2 Solar Components in PVsyst

PVsyst simulation software contains components that help in simulating three types of solar system structures, which include standalone solar system structures, pumping solar system structures and grid-connected solar system structures. In this research, which focused on the grid-connected systems, the components used for the simulation are as follows:

- PV modules
- Inverters
- Optimizers
- Trackers
- 3D shading scenarios (trees, overhead tanks, etc.)
- MPPT'S

The steps in PVsyst simulation method adopted in this research are illustrated in Fig. 1. The solar structure considered is grid-connected PV structure.

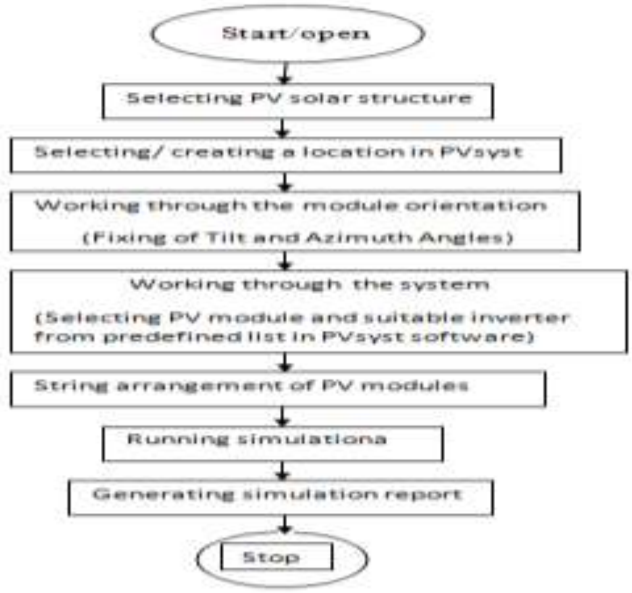

Fig. 1 Stages of the design simulation (Kailash *et al.,* 2020)

2.3 Description and the Geographical Location of the Study Area

Igbinedion crown estate is in Okada town in Ovia North-East local Government of Edo state. As found on Google map, Igbinedion University Crown estate Okada is located on latitude 6.71967^0N and longitude 5.47121^0E with solar radiation of about 4.5kWh/m^2, as shown in Fig. 2.

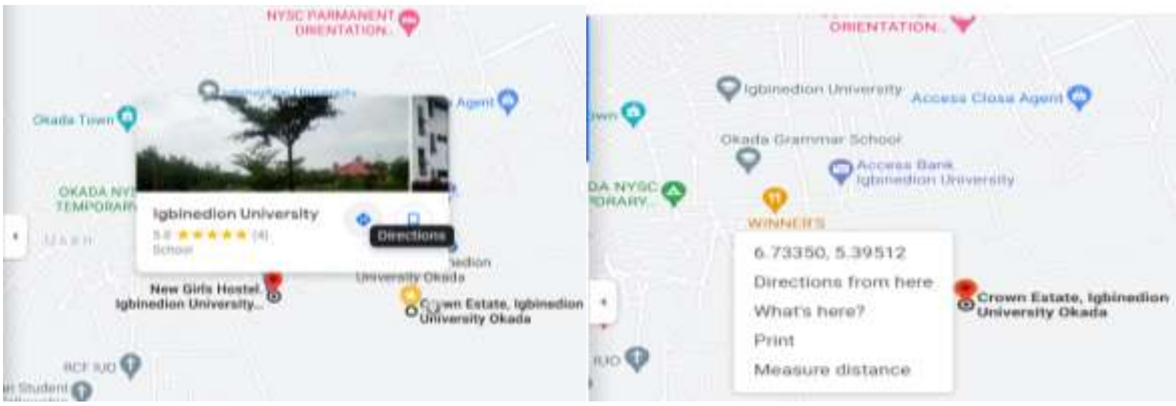

Fig. 2 Latitude and Longitude of Igbinedion University Crown Estate on Google Map

The geographical area or location of a PV solar system has a lot to do with the output behavior of the system, because the solar radiation, temperature, air mass and other parameters, which determine the output of any PV solar system, are different from one location to another. Therefore, it was necessary to create Igbinedion University Okada as a site in PVsyst and import the monthly geographical data of the estate called metrological data for proper simulation design and analysis of the PV solar system for the site. The metrological data of the estate was generated from meteonoum 7.1. This was achieved by obtaining the latitude and longitude of the estate (6.71967, 5.47121) and using them to import the metrological data from meteonoum 7.1. The metrological data contains Global Irradiation, Diffuse irradiation, Temperature and the wind velocity of the location. This can be obtained from already existing data with solar institutions like NASA or by using measuring instruments to obtain the data directly from the site. In this research work, Igbinedion university crown estate metrological data were obtained from meteonoum 7.1 (satellite data) as shown in Table-2.

Table-2 Igbinedion Crown Estate Metrological Data

Months	Global Irradiance kWh/m²	Diffused Irradiance kWh/m²	Temperature °C	Wind Velocity m/s
January	138.6	81.9	27.2	2.20
February	134.7	98.6	28.7	3.10
March	150.3	89.0	29.2	3.40
April	145.3	91.9	28.3	3.10
May	147.8	81.1	28.1	2.49
June	130.2	76.6	26.3	2.60
July	111.3	74.6	26.0	3.71
August	108.5	77.1	25.3	3.90
September	117.7	86.0	25.6	3.40
October	138.2	84.5	27.0	3.60
November	146.1	78.5	27.7	3.40
December	140.1	86.9	28.2	2.29
Year	1608.7	986.7	27.3	2.9

2.4 Orientation

After creating Igbinedion Crown Estate in PVsyst through the metrological data generated from meteonoum 7.1, it was necessary to work through the design modules. The first module that was considered was orientation. In the orientation section, the position of the solar modules in relationship with the sun irradiation (tilt and azimuth) was considered. Unlimited tracker with backtracking field type was chosen instead of a fixed tilt and azimuth angle. This field type helps systems to track the maximum power point of the sun to achieve higher power production.

2.5 System

In the system section, all the components that work together for the proper operation of the PV solar system were selected.

2.6 PV Modules Selection

The needed power capacity, 10MWp expected from the solar system project, the module type, voltage and power rating of the module at STD as well as the inverter type were inputted into the software, and the software suggested the number of PV modules that can produce 10MW and the needed inverter capacity to match the voltage and power output of the PV array using nominal power ratio of 1.298.

$$\text{Pnom} = \frac{P_{DC}}{P_{Ac}} \quad (1)$$

Pnom = Nominal power
P_{DC} = DC power of the array
P_{AC} = AC power of the invert

Table-3 PV Array characteristic

Number of PV modules	24678 units
Nominal power at STC	9995kWp
Module's arrangement	914strings x 27 in series
Operating condition	50℃
P_{mpp}	9123kWp
U_{mpp}	1007V
I_{mpp}	9056A
Module Area	$5072m^2$

Table-4 DC characteristic of the solar panel

Trina Solar TSM-405 DEG15MC.20(II)	(405W) Bifacial Solar Panel
STC power rating	405W
PTC power rating	383.03W
STC power per unit of area	$18.3W/ft^2(197.2W/m^2$
Peak efficiency	19.72%
I_{mp}	9.86A
V_{mp}	41.1V
I_{SC}	10.37A
V_{oc}	49.1
Series Fuse rating	20A
Maximum system voltage	1500

2.7 Inverter Selection

Inverter is an important component in this design. The working of all PV solar systems depends on the behavior of the inverter in response to the output of the PV array, hence matching the inverter and PV Array carefully is very crucial in Solar PV designs. In this research, care was taken to choose an inverter which has a voltage window that could accommodate the Voltage output of the PV module array at Maximum and minimum operating temperature. In the same vein, the power output of the PV module array was also matched with the inverter at a Nominal power ratio of 1.30 for optimum operation with loss reduction. Forty-four (44) units of inverter rated at 175kWp each were used in the design as seen in Fig. 3 with other information about the inverter.

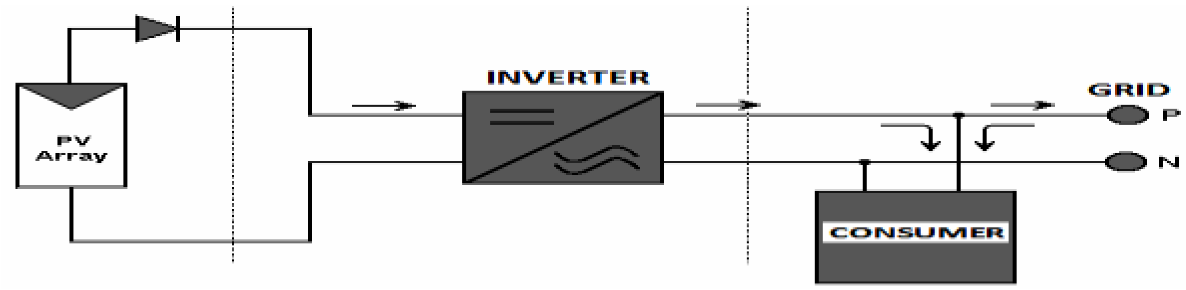

Fig. 3 Simple Schematic diagram of a Grid connected PV system (Kailash *et al.,* 2020)

Umeozor and Guiawa (2022). ***Investigation of 10MW Grid – Connected PV Renewable Solar Energy System for Igbinedion University Crown Estate Okada Using PVsyst. Nigeria Journal of Engineering Science Research (NIJESR). 5(2), pp. 17-27***

Table-5 Inverter Parameters

SUN2000-175KTL-H0	
Unit nominal power	175kWp
Number of inverters	44 units
Total power	7700kWac
Operating Voltage	600 – 1500V
Maximum Power at 25℃	193kWac
Nominal power ratio Pnom	1.30

RESULTS AND DISCUSSION

The results of the 10MW grid-connected PV system investigated for Igbinedion University Crown estate are presented in this section.

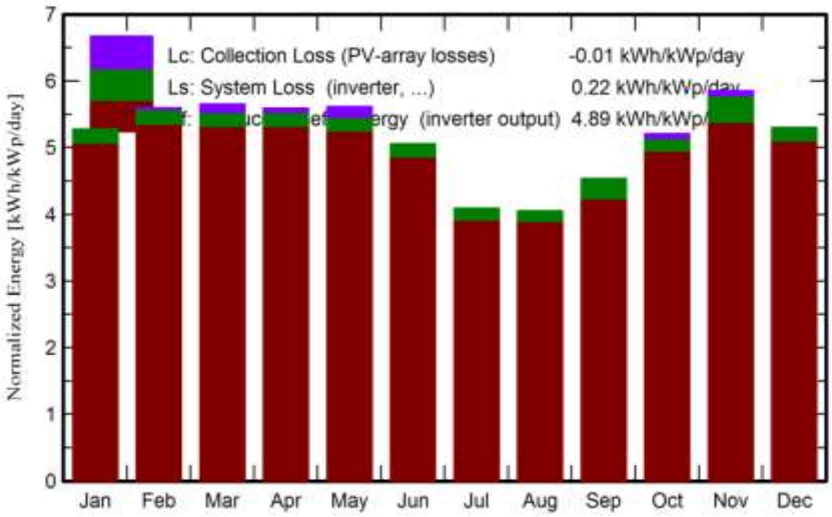

Fig.4 Normalized production (Per installed KWP)

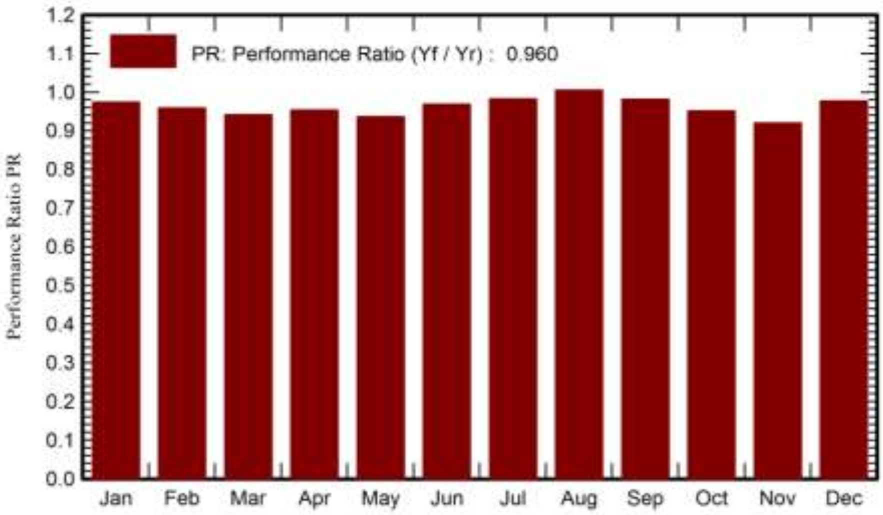

Fig. 5 Performance ratio

Table-6 Balance of the main result

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR Ratio
January	136.6	81.92	27.23	161.7	153.3	1635	1573	0.974
Febuary	134.7	78.56	28.69	156.7	150.4	1561	1501	0.958
March	150.3	89.02	29.21	175.4	168.3	1716	1650	0.942
April	145.3	91.87	28.30	167.7	160.6	1650	1598	0.954
May	147.8	81.14	28.12	174.2	167.2	1694	1630	0.936
June	130.2	76.60	26.31	151.0	144.7	1518	1460	0.968
July	111.3	74.58	25.96	123.8	118.2	1267	1216	0.982
August	108.5	77.13	25.30	120.3	116.0	1257	1209	1.005
September	117.7	85.95	25.63	129.7	125.0	1360	1273	0.982
October	138.2	84.49	26.99	161.6	154.6	1595	1535	0.951
November	146.1	78.51	27.71	175.7	165.2	1735	1616	0.920
December	140.1	86.93	28.22	162.0	152.0	1643	1582	0.977
Year	1608.7	986.70	27.30	1859.7	1775.4	18641	17842	0.960

Table-7 2020 Approximated power capacity of IUO Crown Estate from BEDC (Benin electricity Distribution Company)

Month	Power consumption (MWh)
January	13794.315
February	14117.673
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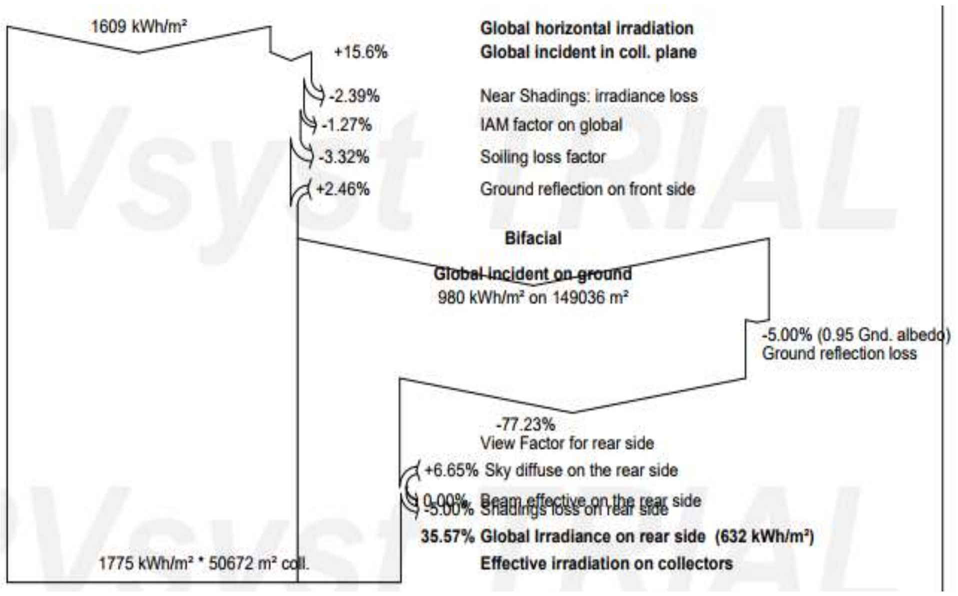

Fig.6a PV module losses

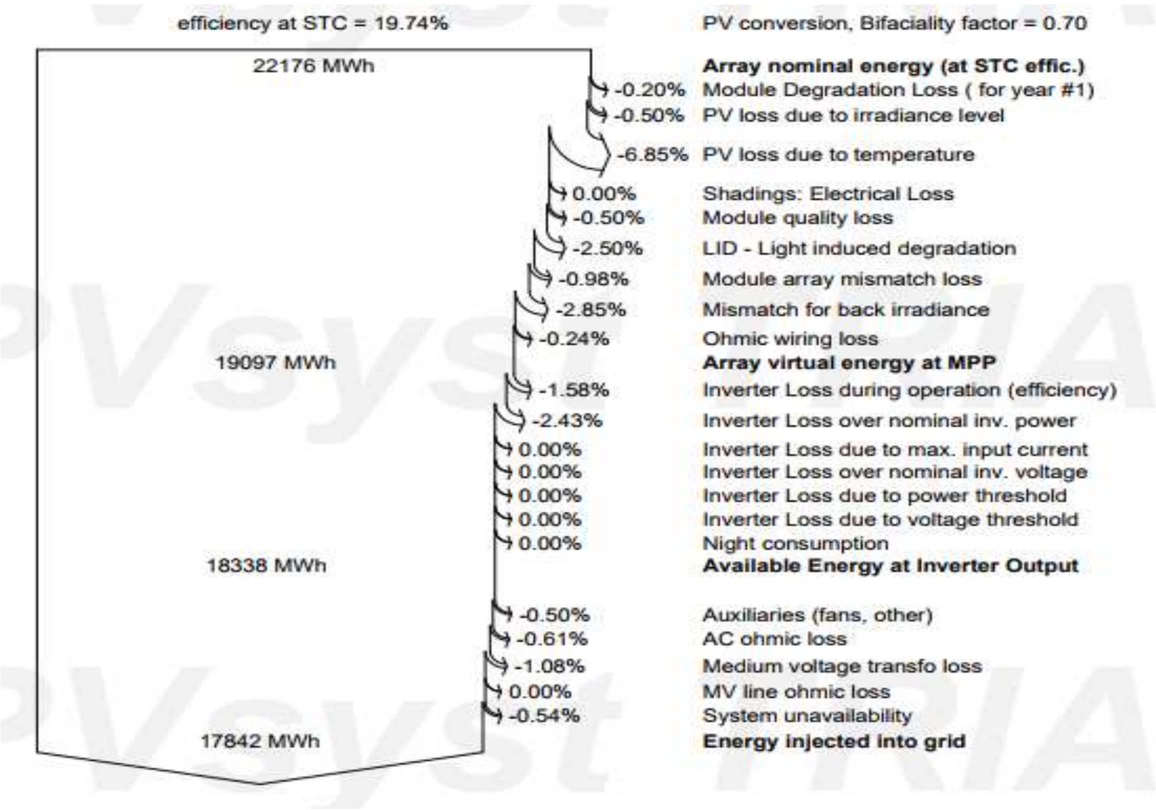

Fig. 6b Loss diagram showing the losses in the 10MW designed system

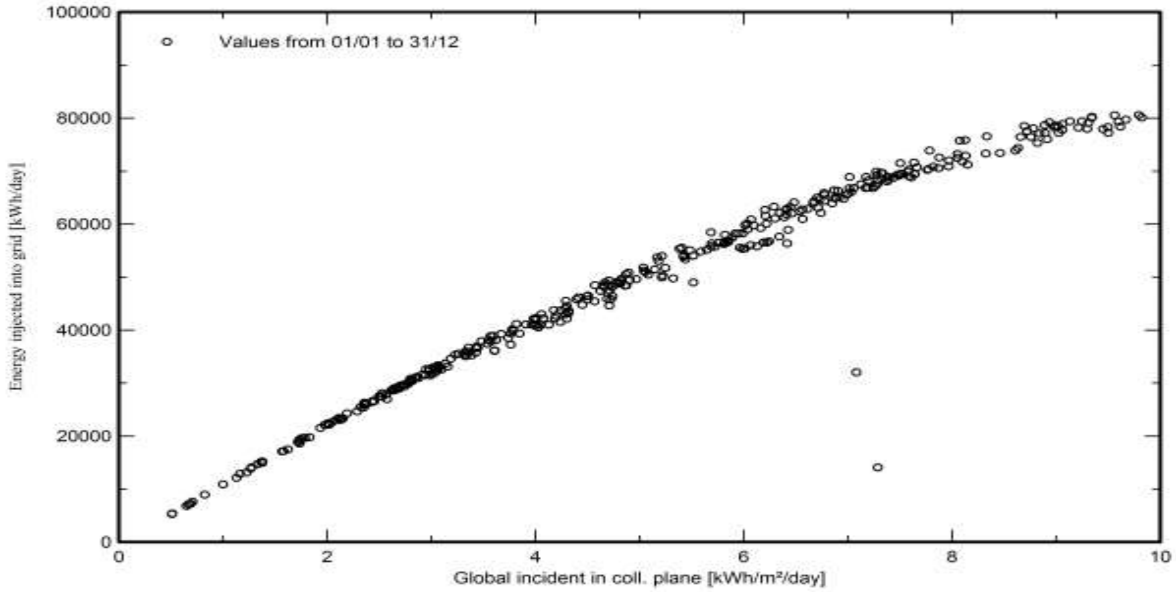

Fig. 7 Daily input/ Output diagram

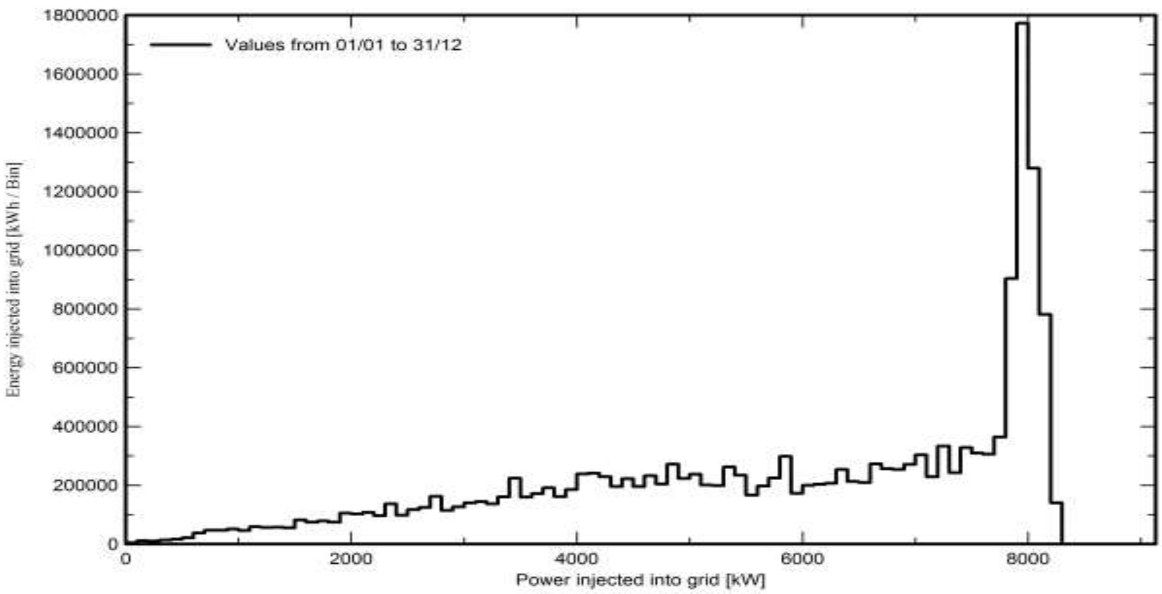

Fig. 8 System output power distribution

The simulation results of a 10MW grid-connected PV plant for Igbinedion crown Estate are shown in Fig. 4, Fig. 5, Fig. 6, Fig. 7 and Table-5. They were generated as a report from the PVsyst simulation software. Figure 4 is a bar-chart representation for the normalized energy in kWh/kWp/day. The collection loss L_C is -0.01kWh/kWp/day. The system loss L_S (inverter) is 0.22kWh/kWp/day. Produced useful energy is 4.8kWh/kWp/day. The bar-chart shows that produced useful energy/ kWh/kWp/day, collector loss and system loss are highest in the month of November followed by March, and lowest in the month of August followed by July. Table-5 is a balance of the main results, which shows important parameters like Energy injected to the grid E-Grid, Global Horizontal irradiation, diffuse Horizontal irradiance, Global incident irradiation, Global Effective Irradiation and Ambient temperature. All the above parameters in Table 5 are highest in the month of March and lowest in August except Energy of the array (E-array) and Global incident irradiation (Globinc) which has highest value in November and lowest in August. Therefore, useful energy produced/kWh/kWp/day in Fig.4 is more related to Global incident irradiation and Energy of the array (E-array) in Fig.5 because both are highest in November and lowest in August.

The Energy injected to the grid E-Grid which is the most important parameter has highest value in March and lowest in August, therefore the system will inject the highest power energy to the grid in March and lowest power energy in August. The total Energy injected to the grid per year is 17482MW. The highest performance ratio occurred in August and lowest in November Fig. 5. This is the direct opposite when compared with the useful energy in Fig. 4 because useful energy was highest in November and lowest in August. However, the simulation gave a total performance ratio of 95%. Table-7 is the monthly energy consumption of the estate obtained from Benin Distribution Company of Nigeria (BDC) which shows that the estate consumes 14985MWh every month on the average and 179827MW yearly. The proposed 10MW Grid-connected system generated 17842MW per year which is approximately 10% of the yearly energy consumption of the estate. Fig. 6 shows the losses that were encountered by the PV system which resulted in produced energy less than 100% of the power present in the irradiation received from the sun. Fig. 7 and Fig. 8 show the Daily input/output diagram of the system and system output power distribution respectively.

CONCLUSION

The investigation and analysis of grid-connected PV system for IUO crown estate in this research paper shows that IUO crown estate could generate 17842MWh worth of energy per year, through a 10MW grid-connected PV system, with 24678 units of 405W solar panel connected in 914 strings X 27 in series arrangement, and 44 number of inverters with 600 – 1500V voltage window. The highest energy could be generated by the system in the month of March and lowest in the month of August which is in line with the meteorological data of the crown estate in Table-2, where Global irradiance, Diffuse irradiance and Global Effective Irradiation were highest in March and Lowest in August.

CONFLICT OF INTEREST

This research work is our original work. It has not been published or considered for publication elsewhere. Therefore, has a conflict of interest.

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