Improving Power Availability of the National Power System Using Solar-Based Enhanced Distributed Generation Technology

Ofure Imomon[1], James Eke[2], Linus Anih[3], Dorathy Abonyi[4]
[1,2,4]*Enugu State University of Science and Technology, Nigeria*
[3]*University of Nigeria, Nsukka*

Abstract: **In this paper, the method for connecting a solar-based enhanced distributed generation technology to the national utility grid was developed, which is expected to improve the poor state of electric power supply in Nigeria. All countries in the world need an available power supply to improve its economy. The power sector is an important sector that requires good funding for the constant availability of electricity for its citizens. Nigeria has not yet met the population requirement as far as power availability is concerned. The utilization of solar photovoltaic generated electricity will improve the nation's power supply and ensure power availability in the country. The study aims to improve the power availability of the national power system using solar-based enhanced distributed generation technology. The photovoltaic system generated 250MW solar power which was injected into the national utility grid. The 250MW was gotten from five locations in the country as each location generated 50MW to the national utility grid. The performance of power output from the photovoltaic array as well as the power output from the inverter into the grid and losses that arose from the solar photovoltaic system was analysed. The simulation carried out in this work was done with PVsys and AutoCAD software. From the analysis done using PVsys software, to analyse the annual performance of the photovoltaic system for the five locations, the system gave a percentage performance of 79.1percent for the photovoltaic system and the total energy the arrays will inject into the grid annually is 387.765GWh.**

Keywords- **Solar, Generation, Power system, Technology, Photovoltaic system**

I INTRODUCTION

Reliable electricity generation is paramount to every country as renewable energy is widely utilized for the generation of electricity. The development of renewable energy such as hydro, wind, solar, etc. to generate electricity in the past decade is enormous in many countries of the world. Reference[13] researched specialized solar energy capabilities in Nigeria looking at a 5% transformation productivity of the device put at valuable energy worth 15.0×10^{14} kJ yearly. It can be said to be oil which amounts to relatively 258.62 million barrels yearly, this compares to the country's public non-renewable energy source creation yearly. About 4.2×10^5GW/h will similarly be added to the electricity generation every year, as a result, bringing about electricity creation multiple times the new yearly production in the country to 16,000GW/h. This investigation has been done for quite a while; with the increment in the dollars to naira trade, this time we can reason that the circumstance of generation of power is more terrible right now. In their work, [2] show that Nigeria gets bountiful solar energy that can be usefully harnessed with a yearly average of about 5.25kWh/m^2/day worth of solar radiation. This brings about a difference of 3.5kWh/m^2/day experienced around the southern regions and in the northern area a 7kWh/m^2/day. These results in a yearly average power from solar energy of 1,934.5kW/ m^2/year; along these lines, in Nigeria the solar energy that falls on its surface throughout the span annually is an average of about 6,372,613PJ/year (roughly 1,770TW h/year). From this analysis, it is about one hundred and twenty thousand times the complete average yearly electrical energy that the Generating Company of Nigeria (GenCos) creates. This gives rise to a ten percent moderate change in productivity, based on the Energy Commission of Nigeria's (ECN) expectations of the final energy demand in the year 2030 for Nigeria the accessible resource of solar energy is about twenty-three times [6]. To improve the formative pattern in the country, there is a need to help the current questionable power sector with a manageable wellspring of power supply through solar energy.

II METHODOLOGY

A. Materials Utilized

The materials utilized for the generation of a 250MW grid-connected photovoltaic array system are as follows:

i. Solar photovoltaic array
ii. Inverter with maximum power point tracker
iii. Battery Energy Storage System (BESS)
iv. Step-up transformers

The solar photovoltaic array used for the 250MW (for the 5 locations) was 603,680 solar modules of 415W; it was divided into 20 blocks which had 980tables. There are 980 inverters connected to the 603,680 solar modules. Each inverter of 250kW was connected to a table of the solar module. The 250MW solar power was divided into five locations with each location giving 50MWp of solar. The battery energy was needed to back up the power in the case of the night hours or when there is poor sunlight; the average sunlight for good energy for solar power generation in Nigeria is approximately eight hours.

Therefore the batteries must deliver electrical energy to supply the loads for approximately 16 hours; 24 – 8 = 16hours

In one location the battery should be able to store 50MWh of battery. The total battery size needed is 50MW * 16 = 800MWh

The required size of the battery must be at least 800MWh to deliver the power of 50MW for 16 hours.

There are two batteries of 250kWh that were connected to each inverter, since there are 196 inverters per location the total batteries are 392. The total battery capacity for the grid is 0.98GWh/location. All locations have a total of 1,960 batteries giving a total of approximately 4.9GWh of battery capacity. The Characterisation of the materials used is explained fully in paper 1.

The step-up transformers were used to step up the voltage from the solar module block. The step-up transformers have ratings of 12.5MVA, 0.800kV/33kV. The total number of step-up transformers for the five locations is 20units (5units per location). The installation utilized 378 acres of land for each location. The estimated cost of the Bill of Engineering Measurement and Evaluation (BEME) is one trillion, four hundred and twenty-three billion, nine hundred and ten million naira (₦1,423,910,000,000) only (detailed breakdown in Paper 1).

B. Location and Solar Power Size Selection

To select the location for installation of solar modules some factors needed to be considered which include the location's latitude, longitude, altitude, annual average temperature, utility zone, interconnection distance to the utility grid etc. It was also necessary to consider the installation across the Northern and Southern states of the country where solar power generation is possible. The location in Nigeria selected for the solar power generation is FCT Abuja, Enugu State, Oyo State, Kano State and Kaduna State. The five locations in Nigeria where the solar PV systems were designed with the information on their latitude, longitude, altitude and the annual average temperatures are shown in table 1.

For the increase in the availability of electric power supply across the country, which should be sustainable the 250MW solar power was selected to be added to the national utility grid. The solar generation was split into five locations due to the number of solar modules involved to be installed for its generation; as it took a total of 603,680 solar modules to generate 250MW of solar power.

Each state selected has a total of 50MW solar power generation installed. To generate this power it utilized 120,736 solar modules to be installed in that location and it will take about 378 acres of land.

C. 250MW Grid-Connected Photovoltaic Array System

The 250MW solar power was split into five locations so that each location generates 50MW solar power. The sun shines on the solar photovoltaic array which converts solar energy into electrical energy. This electrical energy varies as the climate condition changes so there was a need for balancing this variable electrical energy to maintain constant power as well as voltage at its output. This is the point the maximum power point tracker (MPPT) comes into functionality. The voltage and current from the MPPT were fed into Battery Energy Storage System (BESS) as well as the inverter. The solar charge controller is responsible for the charging and discharging of the battery in the BESS, as charging of the battery is eight hours and discharge of the battery is for sixteen hours. The inverter converts the direct current and voltage to alternating current and voltage which are then fed into the step-up transformer to increase and balance the voltage from the inverter output with that of the grid. The output of the step-up transformer is then fed into the 132/33kV substation and then transferred to the national utility grid. Figure 1 is a block diagram showing the process of integration of solar power into the national utility grid. Figure 2 shows a single block layout of the tables alongside the block connected to the inverters as well as the BESS and the 132/33kV substation. Table 2 presents the block identification colour base on design while table 3 gives the summary of the locations equipment with the quantity required.

Table I. Latitude, Longitude, Altitude and Altitude and the annual average temperature of some locations in Nigeria

Location	Latitude	Longitude	Altitude (m)	Annual Average Temperature(°C)
Kabi in FCT Abuja	8.73°N	7.31°E	503	25.3
Onitsha Agu Enugu State	6.38°N	7.72°E	83	25.2
Gbalajobi in Oyo State	8.58°N	4.02°E	443	25.4
Maigarin Damo in Kano State	11.90°N	8.32°E	452	25.3
Rigwallo in Kaduna State	10.21°N	8.12°E	745	24.4

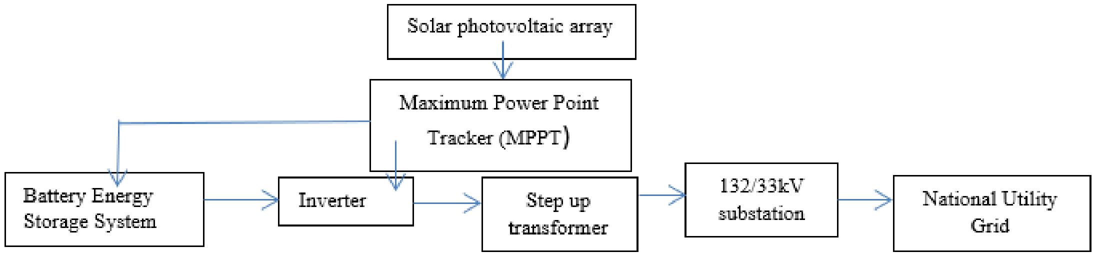


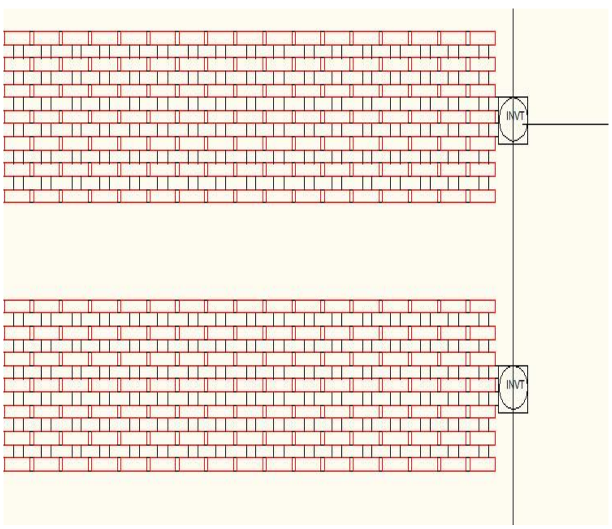
Figure 1 Block diagram showing the process of integration of solar power into the national utility grid

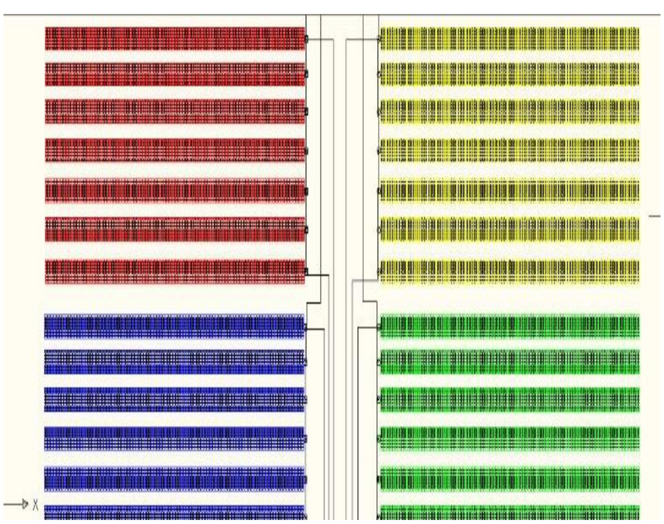
Table II. Block identification colour based on design

Block Number	Block Identification Colour
Block 1	Red colour
Block 2	Yellow colour
Block 3	Blue colour
Block 4	Green colour

Table III. Summary of location's equipment with the quantity required

Equipment	Quantity (one Location)	Quantity (five Locations)
Tables	196 Units	980 Units
Inverters	196 Units	980 Units
Step up transformers	4 Units	20 Units
Blocks	4	20 Units
BESS	392 units	1960 units





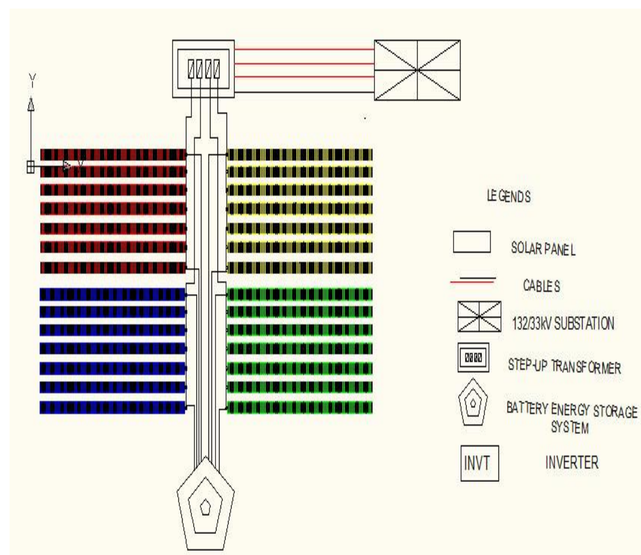


Figure 2 Single block layout of the solar modules, tables, blocks connected to the inverters as well as the BESS and the 132/33kV substation of a location

III. DATA ANALYSIS

A. Additional 250MW solar PV system analysis

There is an additional 250MW injected into the national utility grid. This additional solar power was supplied from five locations with each location adding 50MW to the national grid. Figure 3 shows a line diagram of the injection of solar power into the grid through Enugu, Abuja, Kaduna, Kano and Oyo states.

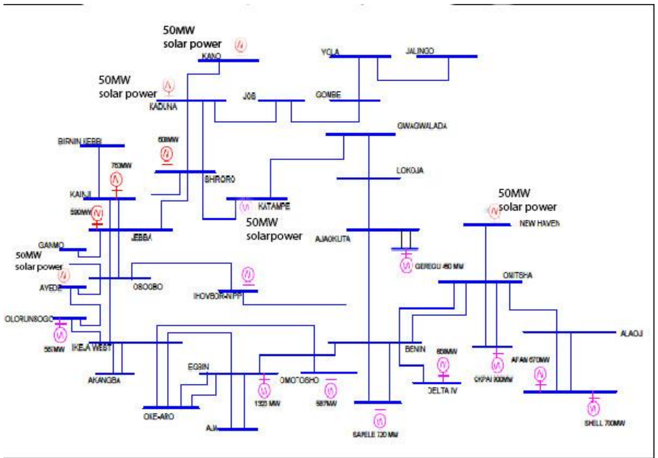


Figure 3 250MW solar power addition to the national grid

In this paper, five locations were proposed for the installation of 50MW power solar these locations are Onitsha-Agu in Enugu state, Kabi in Federal Capital Territory (F.C.T), Maigarin Damo in Kano state, Rigwallo in Kaduna state and Gbalajobi in Oyo state. To analyse the performance of the system for solar usage in the different locations will require simulating software known as PVsys.

The parameters of the design described in the paper were the input of the variant of the PVsys software. The performance of the PV array for the eight hours of full solar production at different locations as well as the output performance for a year was analysed.

Tables 4 to 8 show the proposed grid-connected PV system for the average of eight hours of generation during daylight for the five locations. Figures 4 to 8 and figures 9 to 13 show the performance ratio and the losses of the PV system in different locations respectively.

Table IV. Proposed annual grid-connected PV system for the average eight hours production of daylight for Kabi located in Federal Capital Territory Abuja

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	182.6	54.26	26.65	222.0	217.9	8.888	8.636	0.778
February	170.0	53.45	27.30	189.4	185.4	7.555	7.339	0.775
March	189.4	66.55	26.63	187.4	182.6	7.541	7.325	0.782
April	173.1	68.99	25.92	152.1	147.1	6.189	6.008	0.790
May	167.4	67.40	25.51	133.1	127.5	5.419	5.255	0.790
June	146.7	77.28	24.61	115.2	110.1	4.785	4.640	0.805
July	140.1	74.13	23.79	112.4	107.5	4.668	4.524	0.805
August	132.4	81.89	23.68	114.7	110.6	4.803	4.658	0.812
September	138.0	79.61	24.05	129.3	125.7	5.391	5.232	0.809
October	158.7	72.57	24.32	166.7	163.0	6.854	6.655	0.799
November	174.0	55.97	24.59	204.7	200.8	8.275	8.039	0.785
December	180.4	50.61	25.97	226.2	222.0	9.069	8.812	0.779
Year	1952.8	802.71	25.24	1953.2	1900.1	79.438	77.126	0.790

Legends
GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Table V. Proposed grid-connected PV system for the average eight hours production of daylight for Onitsha-Agu located in Enugu

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	176.1	59.79	26.21	207.6	203.7	8.356	8.119	0.782
February	160.7	59.25	26.53	173.3	169.4	6.974	6.774	0.782
March	172.7	69.68	26.14	166.7	162.2	6.787	6.592	0.791
April	157.5	75.44	26.03	137.7	133.2	5.651	5.487	0.797
May	153.1	74.46	25.83	121.8	116.3	5.007	4.857	0.797
June	136.2	74.93	24.92	105.6	100.7	4.383	4.248	0.804
July	128.3	77.29	24.22	103.0	98.5	4.298	4.164	0.809
August	121.2	67.79	24.19	101.7	97.8	4.227	4.094	0.805
September	125.7	76.43	24.34	116.9	113.5	4.882	4.736	0.810
October	141.7	72.95	24.60	144.8	141.2	5.986	5.809	0.802
November	153.3	63.93	24.66	173.6	170.1	7.093	6.889	0.794
December	169.3	64.15	25.17	202.6	198.8	8.240	8.008	0.791
Year	1795.8	836.10	25.23	1755.3	1705.5	71.886	69.778	0.795

Legends
GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Table VI. Proposed grid-connected PV system for the average eight hours production of daylight for Rigwallo located in Kaduna

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	178.3	50.53	23.55	220.2	216.2	8.935	8.681	0.788
February	173.0	54.58	25.38	194.8	190.9	7.849	7.627	0.783
March	198.1	60.61	27.21	198.0	193.1	7.890	7.665	0.774
April	188.4	64.14	26.21	166.4	160.9	6.732	6.538	0.786
May	183.8	69.09	25.09	147.4	141.5	6.040	5.864	0.795
June	164.1	72.98	23.87	127.3	121.5	5.251	5.094	0.800
July	155.3	73.97	22.96	124.4	119.2	5.186	5.030	0.809
August	145.7	79.49	22.86	126.9	122.5	5.315	5.155	0.813
September	153.6	71.40	23.47	145.1	140.9	5.992	5.817	0.802
October	176.4	65.48	23.94	190.1	185.9	7.800	7.578	0.797
November	180.6	49.50	24.63	217.4	213.3	8.732	8.482	0.780
December	177.0	46.26	23.78	225.5	221.4	9.095	8.835	0.784
Year	2074.3	758.04	24.40	2083.4	2027.2	84.817	82.365	0.791

Legends
GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Table VII. Proposed grid-connected PV system for the average eight hours of production of daylight for Maigarin Damo located in Kano State

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	172.1	51.84	23.07	213.9	209.8	8.691	8.441	0.789
February	176.1	45.64	24.94	202.4	198.3	8.101	7.870	0.778
March	206.1	57.80	28.09	209.6	204.7	8.312	8.076	0.771
April	200.7	55.35	28.18	177.9	172.1	7.083	6.879	0.773
May	197.5	67.99	26.90	159.4	153.1	6.440	6.252	0.784
June	177.9	65.58	25.05	137.6	131.5	5.632	5.466	0.795
July	169.0	75.84	23.99	136.1	130.4	5.616	5.449	0.801
August	160.0	68.88	23.92	138.7	134.1	5.710	5.539	0.799
September	165.9	71.98	24.60	160.5	156.0	6.593	6.404	0.798
October	178.9	63.80	25.78	194.3	190.0	7.854	7.629	0.785
November	169.5	52.12	25.91	205.6	201.6	8.255	8.020	0.780
December	165.9	48.53	23.63	213.8	209.9	8.672	8.425	0.788
Year	2139.5	725.35	25.34	2149.7	2091.4	86.958	84.449	0.786

Legends
GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Table VIII. Proposed grid-connected PV system for the average eight hours production of daylight for Gbalajobi located in Oyo state.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	175.8	55.76	26.69	213.1	209.0	8.580	8.336	0.782
February	163.5	56.10	27.00	180.8	176.9	7.260	7.052	0.780
March	186.6	61.33	26.47	184.3	179.4	7.419	7.205	0.782
April	171.3	73.96	25.90	150.6	145.7	6.151	5.973	0.793
May	166.5	70.79	25.60	132.6	127.0	5.441	5.281	0.797
June	144.6	68.78	24.75	111.6	106.5	4.608	4.468	0.801
July	130.5	79.94	23.88	106.3	101.9	4.456	4.319	0.813
August	122.5	75.34	23.83	105.6	101.7	4.418	4.280	0.810
September	129.9	72.22	24.26	121.8	118.2	5.057	4.906	0.806
October	151.6	68.86	24.59	158.1	154.6	6.511	6.324	0.800
November	164.1	62.97	25.28	191.4	187.6	7.755	7.535	0.787
December	173.0	56.08	26.04	213.7	209.8	8.610	8.366	0.783
Year	1879.8	802.13	25.35	1870.0	1818.4	76.266	74.047	0.792

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

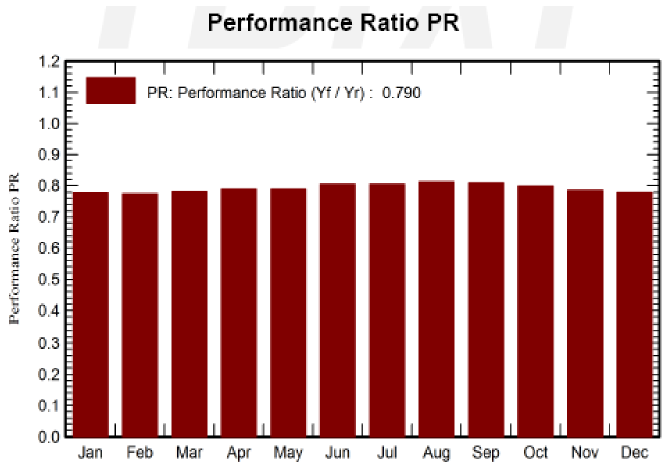


Figure 4 Performance ratio for Kabi located in Federal capital Territory Abuja

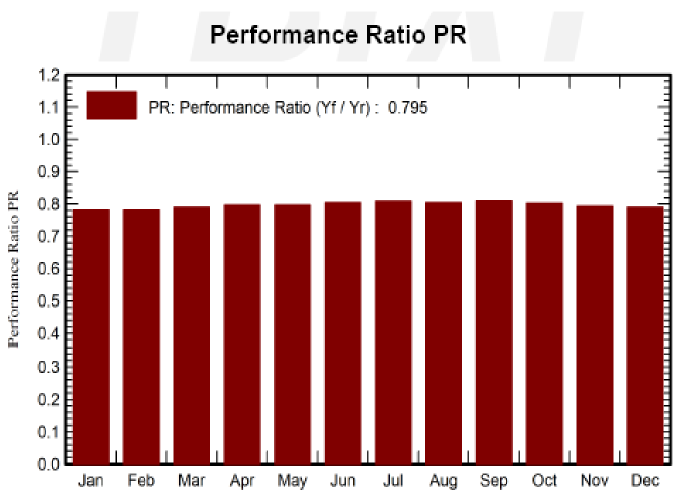


Figure 5 Performance ratio for Onitsha-Agu located in Enugu State

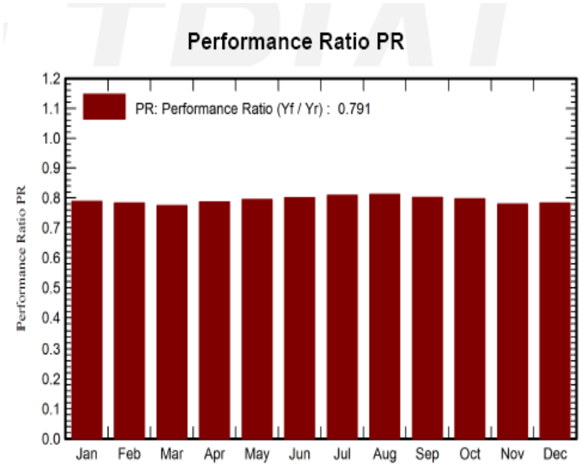


Figure 6 Performance ratio for Rigwallo located in Kaduna State

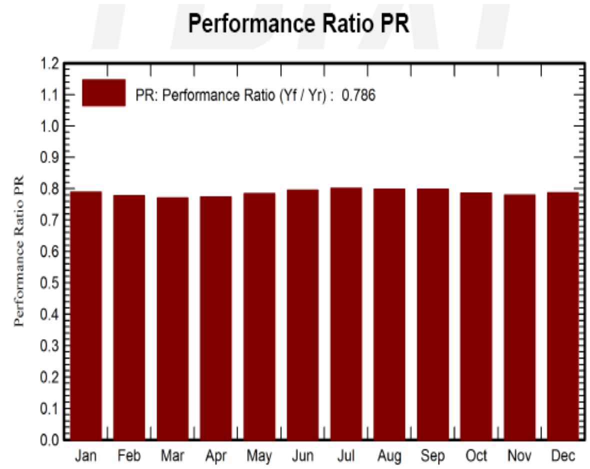


Figure 7: Performance ratio for Maigarin Damo located in Kano State

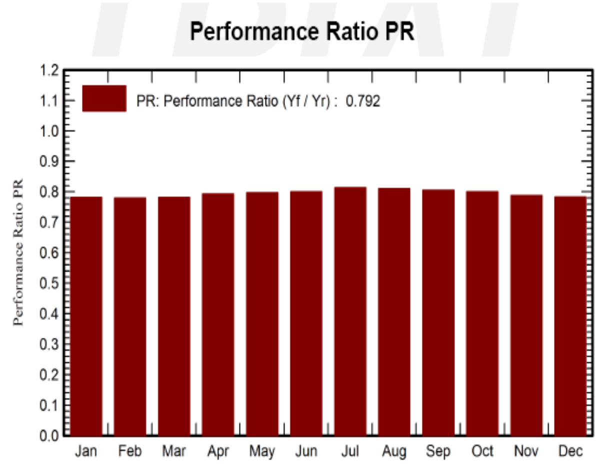


Figure 8: Performance ratio for Gbalajobi located in Oyo state

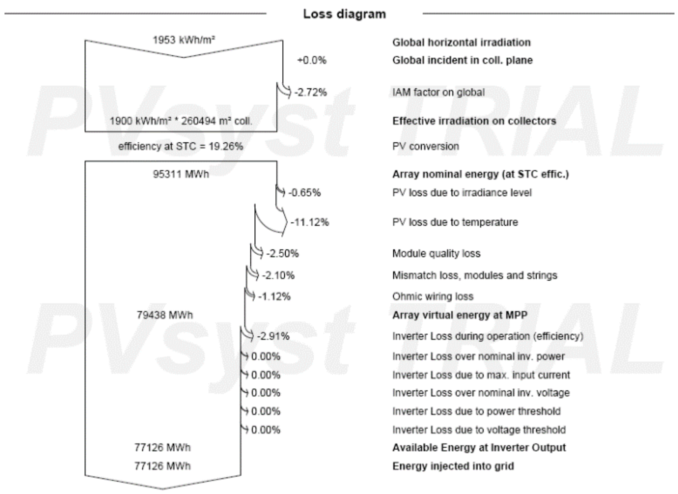


Figure 9 Loss diagram for Kabi located in Federal capital Territory Abuja

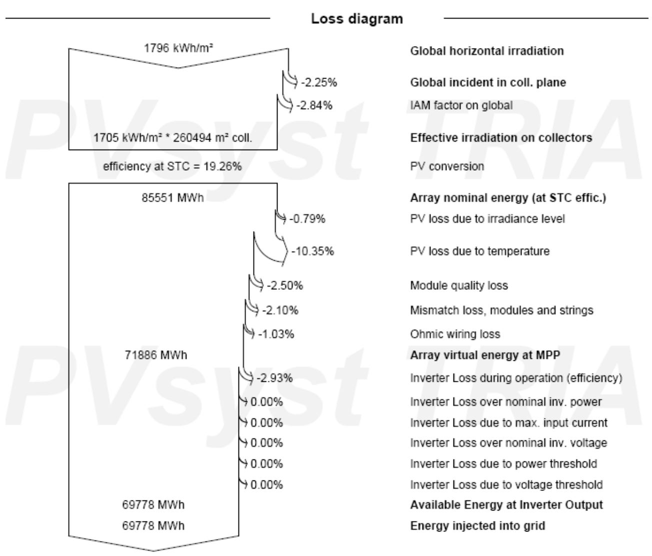


Figure 10 Loss diagram for Onitsha-Agu located in Enugu State

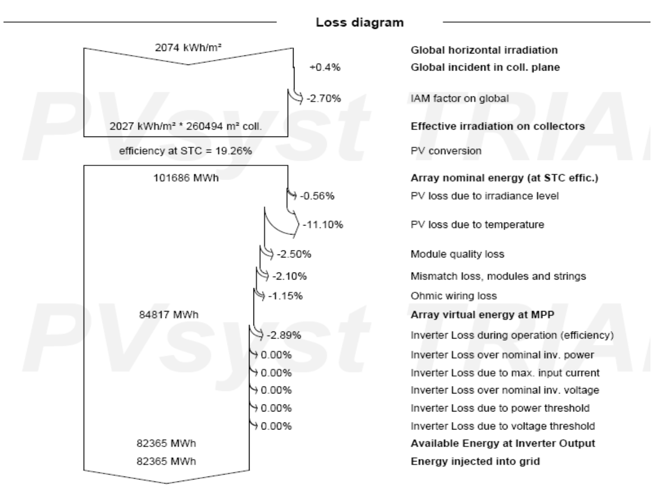


Figure 11 Loss diagram for Rigwallo located in Kaduna state

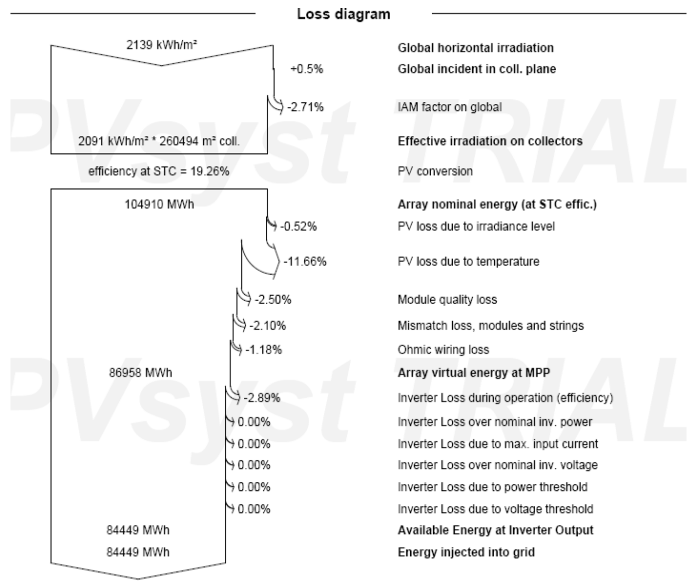


Figure 12 Loss diagram for Magarin Damo located in Kano state

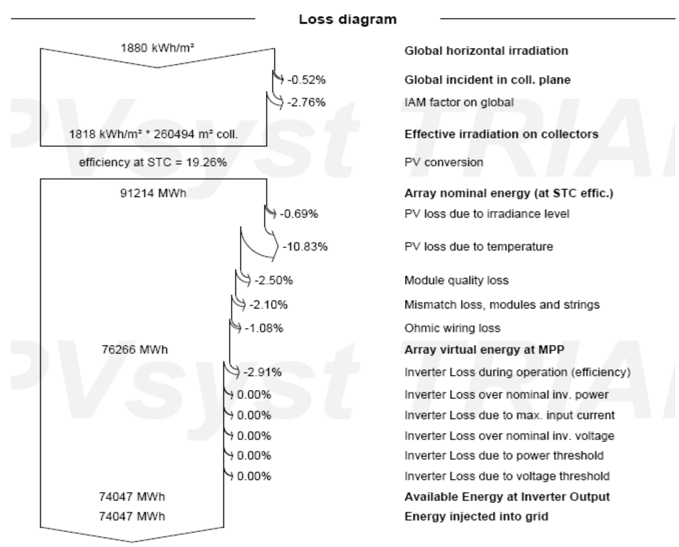


Figure 13 Loss diagram for Gbalajobi located in Oyo state

III. DISCUSSION

From tables 4 to 8 it can be seen that the annual global horizontal irradiation for Kabi is 1952.80kWh/m^2, Onitsha-Agu is 1795.88kWh/m^2, Rigwallo is 2074.38kWh/m^2, Maigarin Damo is 2139.508kWh/m^2 and Gbalajobi is 1879.8. It can be noted that Maigarin Damo and Onitsha-Agu represent the highest and lowest annual global horizontal irradiation respectively based on reviewed locations. This annual global horizontal irradiation had an effect on the energy the array delivered at the output as seen in the column of effective energy at the output of the array as follows; Kabi is 79.438GWh, Onitsha-Agu is 71.886GWh, Rigwallo is 84.817GWh, Maigarin Damo is 86.958GWh and Gbalajobi is 76.266GWh. The energy the arrays will inject into the grid for the eight hours of daylight annually are as follows; Kabi is 77.126GWh, Onitsha-Agu is 69.778GWh, Rigwallo is

82.365GWh, Maigarin Damo is 84.449GWh and Gbalajobi is 74.047GWh which gives a total of 387.765GWh.

From figures 4 to 8 it can be deduced that the average performance ratio for Kabi is 0.790, Onitsha-Agu is 0.795, Rigwallo is 0.791, Maigarin Damo is 0.786 and Gbalajobi is 0.792, having an average performance ratio of 0.791. The entire design base on the PV array and inverter capacity can be said to have a 79percent performance from this analysis. Figures 9 to 13 show that the losses at different locations differ. The losses for different parts of the system were stated. The losses identified are PV loss due to irradiance level, PV loss due to temperature, Module quality loss, mismatch loss, ohmic wiring loss etc.

IV CONCLUSION

This paper was to improve the power availability of the national power system using a solar-based enhanced distributed generation technology. The components for solar energy inclusion in the national utility grid were being analysed and utilised in the system. The proper method for setting the solar photovoltaic panels was explained. The photovoltaic system for the 250MWp needed 603,680 solar modules, 980 solar inverters, 1,960 Battery Energy Storage Systems (BESS), 20 step-up transformers etc. The land area used for the 250MWp solar system is 1,890 acres of land. The estimated cost of the Bill of Engineering Measurement and Evaluation (BEME) is one trillion, four hundred and twenty-three billion, nine hundred and ten million naira (₦1,423,910,000,000) only. The simulation done in this paper was carried out with AutoCAD and PVsys software. To evaluate the performance of the system the PVsys software was utilized. Finally, the national utility grid had an additional 250MW of solar power which was gotten from five locations in the country. On the analysis of the irradiance on the PV array as well as the power output delivered to the national grid annually, it was realised to have a performance ratio of 79.1 percent on the average of the five locations. and the total energy the arrays will inject into the grid annually is 387.765GWh.

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REFERENCES

[1]. CBN (1985), Central Bank of Nigeria Annual Reports and Statement of Account
[2]. Chineke T.C, Igwiro E.C (2008), Urban and rural electrification: enhancing the energy sector in Nigeria using photovoltaic technology.
[3]. Council for Renewable Energy, Nigeria (CREN) (2009), Nigeria Electricity Crunch. available at www.renewablenigeria.org
[4]. Department of Petroleum Resources (DPR) (2007) Nigeria, Nigeria, retrieve from http://www.DPR.gov.ng
[5]. Design on AutoCAD
[6]. Energy Commission of Nigeria (ECN) (2005), Renewable Energy Master Plan Energy Commission of Nigeria, retrieve from: http://www.energy.gov.ng on 16 Dec 2016.
[7]. Energy Commission of Nigeria. Draft of national renewable energy and energy efficiency policy 2014 retrieve from: http://www.energy.gov.ng/ on 15 Dec, 2016.https://www.agreate.com/commercia-battery-energy-storage/aten-250kw-bess-battery-energy-storage-system https://www.tanfon.com/products/Solar-Off-Grid-System/Three-Phase-Solar-System/250kva-250kw-off-grid-solar-panel-system-with-battery-power-storage.html https://www.sungrowpower.com
[8]. Onohaebi O. S., (2009) "Power outage in the Nigeria Transmission Grid "Research journal of Applied Sciences, vol. 4, pp.1-9.
[9]. Onyebuchi EI (1989), Alternative energy strategies for the developing world's domestic use: A case study of Nigerian household's final use patterns and preferences. The Energy Journal 10(3):121–138
[10]. Output performance on PVsyst simulation software
[11]. Panciatici P., Bareux G., and Wehenkel L., Sep. (2012), Operating in the fog: security management under uncertainty", IEEE Power and Energy Magazine, vol. 10, no. 5, pp. 40–49.
[12]. The Nigerian Energy Support Programme (NESP) (2014). The Nigerian energy sector - an overview with a special emphasis on renewable energy, energy efficiency and rural electrification. Nigeria: The Nigerian Energy Support Programme; 2014.
[13]. Villalva M. G., Gazoli J. R., and Filho E. R., "Modeling and circuit-based simulation of photovoltaic arrays," in *Power Electronics Conference, 2009. COBEP '09. Brazilian*, 2009, pp. 1244-1254.
[14]. Weidong X., Dunford W. G., and Capel A., (1950-1956) "A novel modeling method for photovoltaic cells," in *Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual*, 2004, pp. Vol.3.