Performance and Yield Assessment of Grid – Connected Solar Photovoltaic (PV) Dispersed Generation in Nigeria

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Abstract: The problem of Renewable Dispersed Generation (RDG) and renewable resource harnessing in most cases, is not the inadequacy in resource distribution at a particular location, but rather the perpetually deprived exploitation of these resources. The existing dread for the performance of distributive generation systems that utilize renewable source for power generation has crippled generation expansion in most parts of Nigeria for several years. This study is therefore aimed at performing a practical assessment on the productivity of solar PV systems in Nigeria. In this study, five states with diverse geographical or meteorological data were selected from the cardinal regions of the country to include Sokoto State in North West, Borno State in North East, Ogun State in South West, Rivers State in South East and Abuja, the Federal Capital Territory at the center. The global horizontal radiations available from the National Aviation and Space Agency, NASA for these cities were used in simulating the performance of a 1- MW grid-tied solar PV plant using the PVsyst software. PVsyst simulation findings revealed that the performance parameters with respect to energy production favor the cities in the northern region more than the cities in the southern region with capacity factors decreasing from 20.46% in the northern region to 16.21% in the southern region for a 1- MW solar PV plant located in these regions. This was seen to reflect on the corresponding annual energy yield of similar systems sited in these locations. Also, the performance ratios of these systems given their respective reference yields were observed to be better in the southern region than the northern region of Nigeria, this could be attributed to external factors that can influence system efficiency. These factors tend to favor the systems located at the southern region better than those at the northern validating this study as a decision tool for the predictability of the performance of any Renewable Dispersed Generation, RDG systems utilizing solar energy at other regions of the country.

Keywords: Dispersed generation, photovoltaic, yield assessment, renewable, resource harnessing.

1. INTRODUCTION

The danger posed by traditional power generation to general economic sustainability, development and substantial growth is obvious in the way each country of the world seeks for countless alternative energy sources of electric power generation in the best economic and conservational method [1]. The basic aim for generation expansion in developed countries has been to advance the economic and commercial performance of the sub-sector which contrasted to the rather critical role played by the macroeconomic status in the developing and transition countries [2]. There is always an apparent tie between economic growth and electric power consumption per capital growth such as that seen in Middle Eastern countries like the United Arab Emirate (UAE) and Qatar [1].

In Nigeria, electric power supply has never kept phase with demand despite the fact that the country is one of the leading oil producing nation in Africa. In spite of this, it boast of the highest oil and natural gas reserve which is supplemented by renewable resources such as water, wind and abundance solar energy that can be used to generate a substantial amount of electricity as emphasized in [2].

Increase in load demand necessitates generation, transmission and distribution expansion by building new generation power plants and corresponding expansion of the transmission and distribution systems. Viewed from modern economic and environmental perspective, this is not recommended particularly at this stage when there is a global struggle to meet the targets set in the Kyoto Protocol in order to reduce greenhouse gas emissions [3]. The need to reduce greenhouse gas emissions led to the increase of probing into other alternative sources of energy generation. Renewable dispersed generation (RDG) which is defined as a small-scale electricity generation fueled by renewable energy sources, such as wind and solar, or by low-emission energy sources, like fuel cells and micro-turbines; which is also referred to as embedded generation (small size generation units connected to the distribution power system) readily came to mind [3, 4, 5].

According to sustainable energy regulation network (SERN) [6], Nigeria has available capacity of 6,056 MW out of total installed capacity of 10,396 MW from the 23 grid-connected generating plants in the country of which fossil fuel generation accounts for about 79% of the total installed capacity and the remaining 21% from

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E-ISSN: 2409-5817/17

hydro source. There is also a forecasted increment in peak demand from 5,000 MW in 2011 to about 16,000 MW in the year 2020 [1, 6, 7, 8]. The EIA estimate states that Nigeria has one of the lowest net electricity generations per capita rates in the world [6].

Nigeria has been estimated to produce about 227,500 tons of fresh animal waste daily, meaning that Nigeria can produce about 6.8 million m^3 of biogas, since only 1 kg of fresh animal waste is needed to produce o.o3 m^3 of biogas [6]. Statistics has also revealed that hydropower generation is the only renewable source of power generation currently utilized in the country from which only about 19% of the potential have been tapped despite the fact that hydropower resource is widely distributed throughout the country.

According to [9], while studying voltage stabilization for grid-tied RDG systems, wind source, revealed that some places in the northern part of the country have average annual wind speed of about 5.4 m/s at height of 30 m, also the wind energy intensity perpendicular to wind direction is estimated to range from 4.4W/m^2 to 35.2 W/m^2 between the coastal areas and the northern regions of Nigeria [6, 9]. From the solar energy perspective, Nigeria has been grouped among countries with best solar resource distribution [10], with annual average total solar radiation reaching 5.5 KWh/m^2/day with 6 hours/day sunshine hours an annual total of about 1,770 thousand TWh/m^2/day can be reached which is very favorable for PV generation in the country [10].

From these findings, one can conclude that, if there is an effective harnessing of available renewable energy resources in Nigeria a good mix of power generation expansion through renewable dispersed generation can be achieved in a short time. Thus, this study focused on performance and yield assessment of grid-tied solar PV plant which, according to the U.S. Department of Energy (DOE), is classified among the renewable dispersed generations.

2. SOLAR ENERGY APPLICATIONS

For a number of good reasons which may include concerns for the environment and the opportunity for demonstration of the willingness to involve in the green world move, a country may choose to embark on power generation from renewable sources. A country like Nigeria will count power generation from solar applications as one of its renewable majors [11, 12]. Power generation from solar application can utilize solar thermal energy systems or solar photovoltaic systems depending on resource availability as shown in figure **1**.

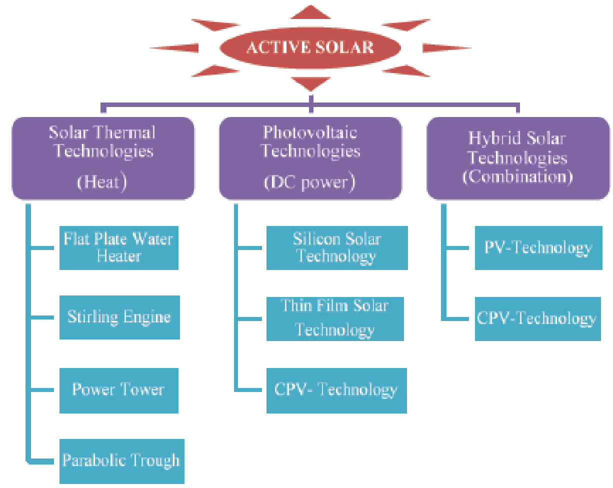

Figure 1: Present Da Major Solar Technologies.

Solar thermal systems are solar energy application systems that can extract and concentrate heat energy from the sunlight and use it at varying temperatures; low, medium or high range depending on the applied technology. These applications have found usefulness in areas such as space heating and cooling, crop drying and solar distillation [13]. Solar photovoltaic systems covert solar radiation directly to DC electricity using photovoltaic cells made from semiconductors such as silicon. These systems may be applied as a standalone unit or off-grid unit and can also be applied as grid connected or grid-tied unit depending on the power need and consumer location [13, 14].

3. THE STANDALONE SYSTEMS

These are solar PV plants that are operated off-grid, that is, they are not connected to the public power distribution grid. These systems are preferred where it is not economical to obtain electricity from the public supply due to the remoteness of the consumer or when there is preference for solar energy as alternative source for power generation above other alternatives. A standalone system may range from a simple PV generator that supplied a common DC load to a more complex system with mixed supply to both DC and AC loads in the system. At that level, the standalone system will require energy storage device designed to cover for days of autonomy [15].

A typical off-grid or standalone system comprises the following components:

a. Solar PV array: This comprises the PV modules that convert sunlight directly to DC electricity.

b. Charge Controllers: To maintain a healthy rate of charging and discharging of the batteries in order to maximize their functionality and avoid operational problems

c. Battery: To store surplus energy generated by the solar PV arrays

d. Off-grid Inverter: converts the DC electricity generated by the solar PV arrays to AC electricity for AC system load.

4. THE GRID-TIED SOLAR PV SYSTEMS

These are solar PV systems that are connected to the public utility either for metering purpose or as a renewable dispersed generation. These systems have no provision for autonomous supply hence; no energy storage device is required. They may range in size from small decentralized rooftop systems of few kilowatts to very large central grid-tied systems with capacity in the megawatts range [13, 16]. An inverter is used to convert the DC electricity from solar PV array to AC electricity which is fed directly into the utility grid. Since they supply AC electricity into the public grid, their load seems to be unlimited and their performance is usually evaluated on annual interval [15].

5. PROPOSED SYSTEM

The proposed system is a 1- MW grid-connected solar PV plant that utilizes polycrystalline silicon modules with inverters in an array configuration to supply power to both industrial and domestic loads on the utility grid (figure **2**). The location of this system is strategic to be at the cardinal regions of Nigeria and Abuja (Lat. 9.0^{o}N, Long.7.4^{o}E) at the center. The other locations are: Sokoto (Lat. 13.0^{o}N, Long. 15.0^{o}E) in the North West region, Borno State (Lat. 11.9^{o}N, Long. 13.2^{o}E) in the North East region, Ogun State (Lat.

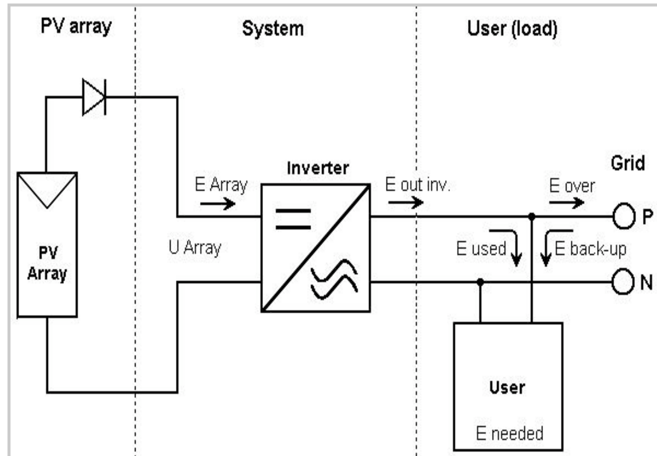

Figure 2: A Grid-tied System Schematic illustration showing the irrelevance of Storage Device.

Table 1: Annual Global Solar Radiation for the Locations

Months	Sokoto (Kwh/m^2)	Maiduguri (Kwh/m^2)	Ogun State (Kwh/m^2)	Rivers State (Kwh/m^2)	Abuja FTC (Kwh/m^2)
January	171.6	173.9	170.5	171.4	182.3
February	178.9	176.4	159.6	156.5	170.5
March	203.8	207.7	174.8	164.9	194.4
April	201.3	198.6	160.5	152.7	181.8
May	196.7	197.2	157.8	146.3	173.0
June	188.2	179.1	137.1	129.3	151.8
July	179.0	168.3	124.0	119.3	137.6
August	170.8	159.3	117.5	116.9	129.9
September	178.8	167.1	123.3	118.2	141.9
October	190.5	182.6	145.7	132.4	164.6
November	177.9	175.2	153.3	145.2	179.4
December	168.7	165.8	165.8	164.0	181.7
Year	2206.2	2151.3	1790.0	1717.2	1988.8

Source: NASA.

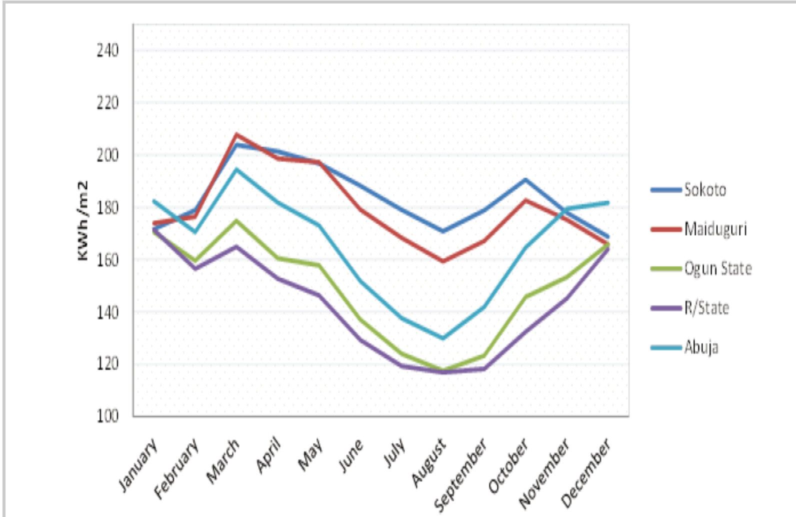

Figure 3: Comparison of Annual Global Solar Radiation on the selected Cardinal Regions in Nigeria.

7.1°N, Long. 3.3°E) in the South West region and River State (Lat. 5.1°N, Long. 7.1°E) in the South East region. The site and meteorological data for these locations were imported from the satellite measurements provided by the American National Agency for Space and Aviation NASA for PVSyst software. A summary of annual global horizontal solar radiation on a plane inclined on 15° at these regions is presented in table **1** and compared in the plot of figure **3**.

6. RESULT ANALYSIS

The International Energy Agency IEA has laid down measures to follow in order to evaluate and compare the performances of solar PV systems. The criteria include the description of the energy conversion chain beginning from the solar irradiation input to the final electricity injected into the grid by appropriate and normalized quantities which is based on the IEA Performance Database Standard IEC 61724 for PVPS [17, 18]. Table **2**

Table 2: Basic Design Parameters for the 1-MW Grid-Tied Solar PV System General System Module-Inverter Details

Module Type	Polycrystalline Silicon (generic)
Space Requirement	6508 m^2
Module Efficiency	15.5%
Module Capacity	250Wp
Installed Capacity	1000kWp
Total Number of Modules	4000 (16 series by 250 parallel string)
Inverter Capacity	2 x 500KWac
PV Array Orientation	
Inclination	15°
Operation Temperature	50°C
Configuration	Array Type

These performance parameters are illustrated in figure **4** and they include the Reference System Yield, Final System Yield, Collection Loss, Array Yield,

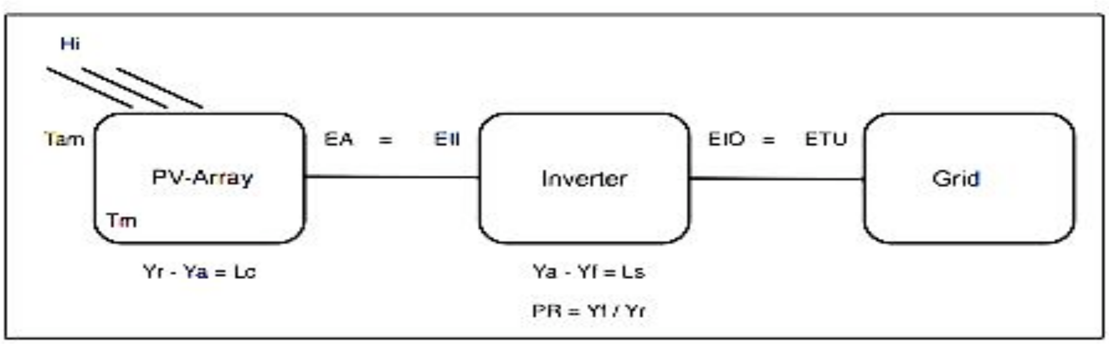

Figure 4: Illustration of System Performance Parameters.

System Loss and Performance Ratio for the grid connected system as shown in figure **4**; where, Hi and EA represent the incoming solar irradiation onto the PV Array and the DC energy output of the array respectively. EA is assumed be equal to energy input to the inverter, EII. Tam and Tm represent the PV modules ambient temperature and module operating temperature respectively. EIO represents the equivalent AC electricity obtained from conversion of the inverter input EII and is fed into the grid as (ETU) as illustrated in figure **4**.

6.1. Total Energy Yield

This is the total energy that the PV array can inject into the utility grid at a particular reference time, usually evaluated at annual bases for grid connected solar PV systems and is measured in MWh for a particular time. For the solar PV systems at selected regions, the energy injected into the public grid is Sokoto: 1792.6 MWh, Borno: 1765.7 MWh, Abuja FCT: 1669.5 MWh, Ogun: 1488.7 MWh and Rivers: 1419.7 MWh. The monthly comparison of the total energy yield is presented in figure **5**.

6.2. Reference System Yield

The Reference System Yield Y_r or the ideal array yield is numerically equal to the incident energy in the array plane and is expressed in kWh/m²/day. The annual daily average reference yield obtained for the five (5) regions are Sokoto: 6.27 kWh/m²/day; Borno State: 6.093 kWh/m².day; Ogun State: 5.010 kWh/m²/day; Rivers State: 4.768 kWh/m²/day and 5.626 kWh/m²/day for Abuja FCT. Figure **6** shows their graphical comparison [13].

$$Y_r = \frac{(total\ insolation)}{(reference\ irradiance)} = \frac{KWh/m^2}{1000W/m^2}$$

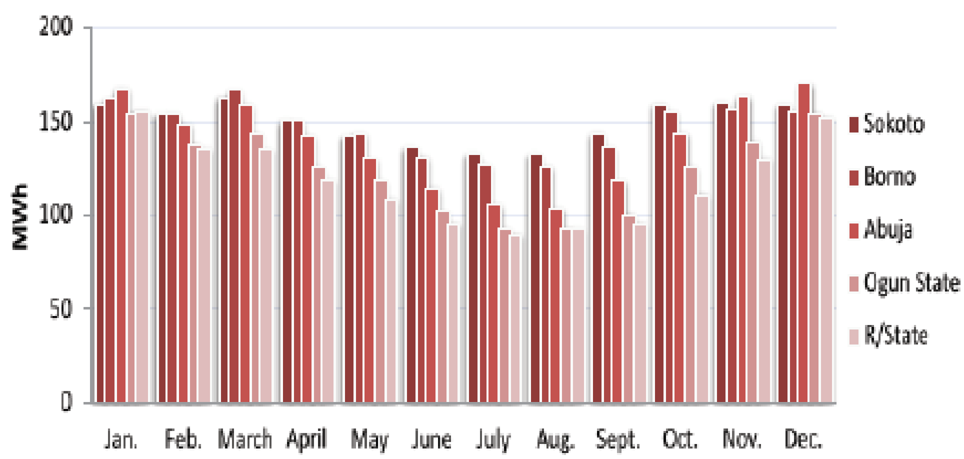

Figure 5: Comparative plot of total energy yield (MWh).

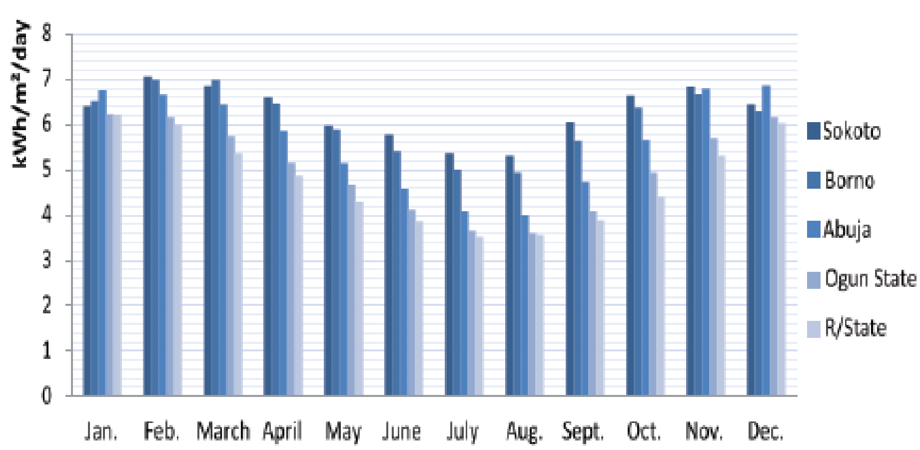

Figure 6: Comparison of average daily reference yield for the selected regions (kWh/m^2/day).

6.3. Final System Yield

The Final System Yield Y_f, is the system daily useful energy or the inverter output, referred to the nominal power expressed in kWh / KWp / day [19, 20].

$$Y_f = \frac{Net\ Energ\ Output\ \ KW\ AC}{Array\ \ Output\ \ Power\ \ KW\ DC}\ \text{kWh/kWp/day}$$ kWh/kWp/day

The results for the selected systems are Sokoto: 4.91 kWh/kWp/day, Borno: 4.84 kWh/kWp/day, Abuja: 4.57 kWh/kWp/day; Ogun: 4.08 kWh/kWp/day and Rivers: 3.89 kWh/kWp/day, monthly values are compared in the plot of figure **7**.

6.4. Collection Loss

The Collection Loss L_c, is the array losses including thermal, wiring, module quality, mismatch and IAM losses, shading, dirt, MPPT, regulation losses, as well as all other inefficiencies. It can be expressed mathematically as $L_c = Y_r - Y_a$ kWh/kWp/day [19].

The collection losses for similar grid-tied 1- MW solar PV system located at selected regions are Sokoto: 1.21 kWh/kWp/day, Borno: 1.11 kWh/kWp/day, Abuja FCT: 0.92 kWh/kWp/day, Ogun: 0.81 kWh/kWp/day and Rivers: 0.76 kWh/kWp/day and compared on the plot of figure **8**.

6.5. The Performance Ratio (PR)

This is the global system efficiency with respect to the *nominal* installed power and the incident energy expressed mathematically without unit as [13].

$$P_R = \frac{Y_f\ (Final\ Yield)}{Y_r\ (Referecne\ Yield)}$$

The performance ratios obtained from the PVSyst simulation results for the grid –tied 1 MW solar PV system located at the selected regions are as follows: Sokoto: 0.783, Borno: 0.794, Abuja FCT: 0.813, Ogun:

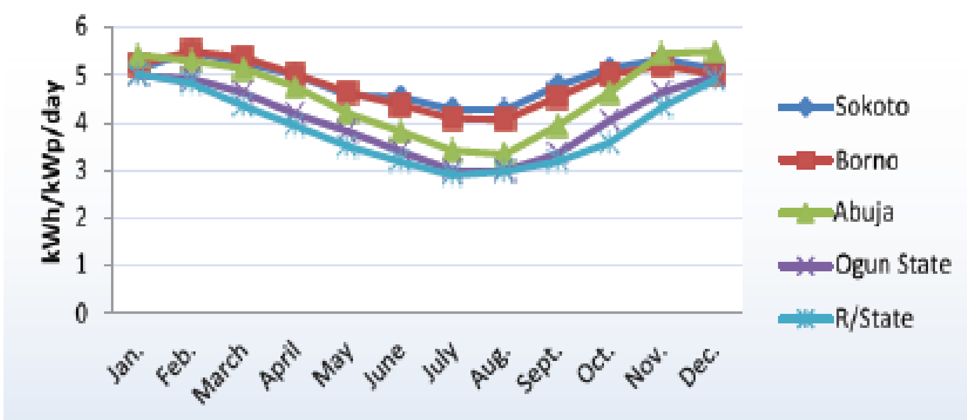

Figure 7: Comparison of final system yield for system at the selected regions kWh/m^2/day.

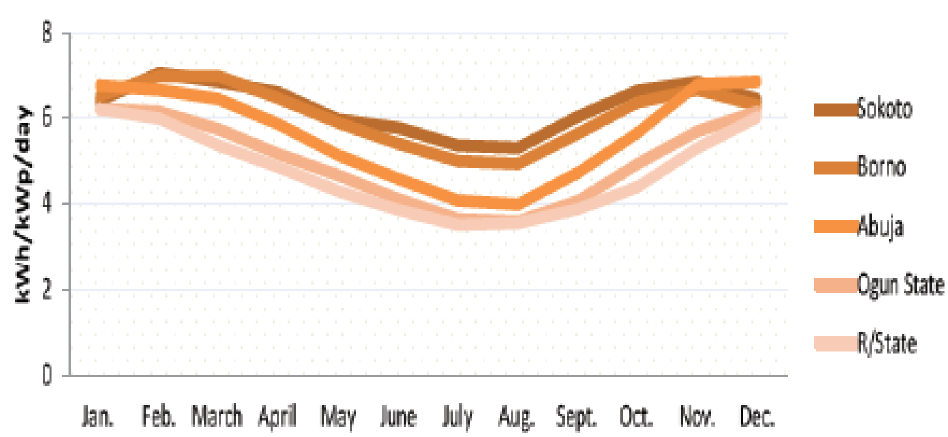

Figure 8: Comparison of monthly collection losses for same system at the selected regions.

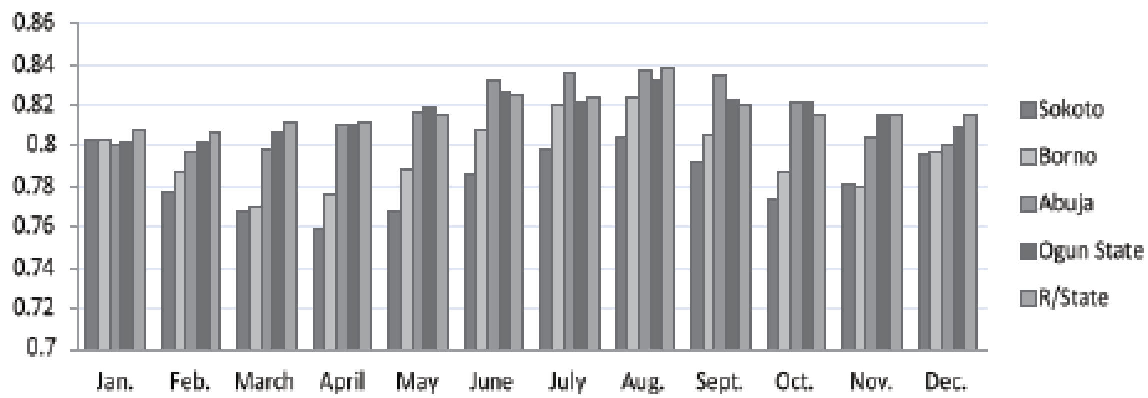

Figure 9: Comparison of average PR for the same system at the Selected Regions.

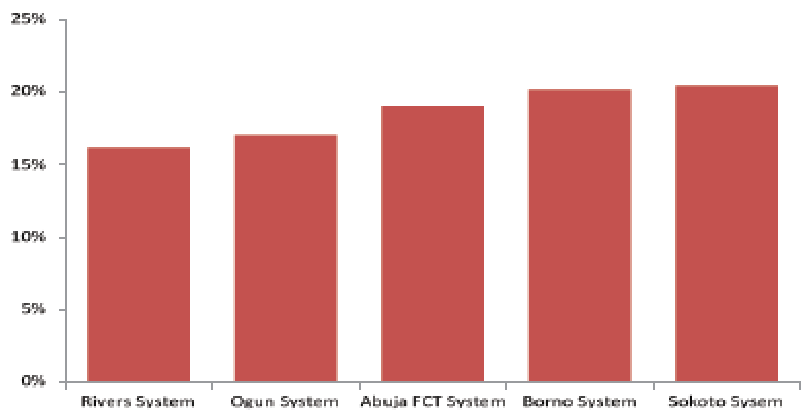

Figure 10: Comparing capacity factors.

0.814 and Rivers: 0.816. The average values are plotted in figure **9**.

6.6. Capacity Factor

The Capacity factor of a power plant is obtained by dividing the actual yield of a power plant by its potential yield if it was functional at full nameplate capacity over a given reference time. It can be expressed mathematically as the ratio of the overall energy to the amount of energy the plant would have produced at full capacity in a period of time, usually annually [15]. It can be expressed as a percentage as follows:

$$Capicity\ Factor = \frac{Annual\ Energy\ output}{Nameplate\ Capacity \times 8760 hours}.$$

The capacity factor for the system in Sokoto region is obtained as 20.46%, the system in Borno has 20.16%, the system in Abuja FCT has 19.06%, the system located at Ogun has 17% and similar system in Rivers State has 16.21% capacity factors. Figure **10**

Table 3:

Performance Parameters	Sokoto System	Borno System	Abuja System	Ogun System	Rivers System
Total Energy Yield *(MWh)*	1792.6	1765.7	1669.5	1488.7	1419.7
Reference Yield *(KWh/m^2/day)*	6.27	6.093	5.626	5.01	4.768
Final Yield *(KWh/kWp/day)*	4.91	4.84	4.57	4.08	3.89
Collection Loss *(KWh/kWp/day)*	1.21	1.11	0.92	0.81	0.76
Performance Ratio	0.783	0.794	0.813	0.814	0.816
Capacity Factor *(%)*	20.46	20.16	19.06	17.0	16.21

The general performance parameter of the 1 MW grid-connect solar PV plants in the selected cardinal regions of Nigeria is summarized and presented in table **3** below;

CONCLUSION

Findings from the performance and productivity assessment of the 1- MW grid-connected solar PV systems located at the selected cardinal regions of Nigeria presented in table 3 revealed that best values for average daily incident energy in the PV array plane of the 1- MW solar PV plant is obtainable around the northern region of the country with a comparative daily average values ranging from 4.768 KWh/kWp/day to 6.27 KWh/kWp/day. This corresponds to the findings reported by Olayinka, S. (2011) in [2] and the annual global solar radiation for the different regions presented in table **1**, which shows that there is a progressive increment on the average solar energy received on PV array as you measure from the southern region to the northern region of the country. The resulting advantage of the comparatively high reference yield in the northern region of the country is its harmonious reflection on other performance parameters of these systems such as the total energy yield which is seen to rise from 1419.7 MWh and 1488.7 MWh in Rivers State and Ogun State respectively, in the southern region to 1792.6 MWh and 1765.7 MWh in Sokoto and Borno States respectively, in the northern region of the country leaving Abuja, FCT on the middle with an in-between value of 1669.5 MWh; also on the plants' capacity factors which are seen to increase on the average from 16.21 % and 17.0 % for the system in Rivers State and Ogun State respectively, in the southern region to 20.16% and 20.46 % for the system Borno State and Sokoto respectively, in the northern region with Abuja the FCT at the center having 19.06%.

It is interesting to note that the global system efficiency with respect to the nominal installed power referred to as the performance ratio PR, obtained for the 1 MW solar PV system is rather better for the systems in the southern region of the country than the systems located at the northern region. This is due to other factors such as the ambient temperature which affects the operating temperature of these systems with corresponding influence on the thermal loss and component efficiency of these systems [2, 6 & 8]. The performance ratio values obtained for the systems are Sokoto: 0.783, Borno: 0.794, Abuja FCT: 0.813, Ogun: 0.814 and Rivers: 0.816.

The relevance of this study therefore, can be seen to serve as a decision tool for the predictability of the performance of any Renewable Dispersed Generation, RDG systems utilizing solar energy at other regions of the country.

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Received on 21-11-2017 Accepted on 26-12-2017 Published on 31-12-2017

DOI: http://dx.doi.org/10.15377/2409-5818.2017.04.5