Performance and Yield Assessment for Renewable Dispersed Generation in Nigeria: Case Study on Grid-Tied Solar PV Systems

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Abstract: The problem of Renewable Dispersed Generation (RDG) and renewable resource harnessing in most cases, is not the inadequacy of resource distribution at a particular location but rather, it is the perpetually deprived exploitation of these resources. The existing dread for the performance of distributed generation systems that utilize renewable sources for power generation has crippled sustainable power generation expansion for several years. Hence, this study performs a practical assessment of the productivity of solar PV systems in Nigeria. In this study, five states with diverse geographical or meteorological data are selected from the cardinal regions of the country. These include Sokoto State (North West), Borno State (North East), Ogun State (South West), Rivers State (South South) 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. The result shows that the performance parameters with respect to energy production are better in the northern region compared with the southern region with capacity factors decreasing from 20.46% to 16.21% for a 1 MW solar PV plant located at these regions. This was seen to reflect on the corresponding annual energy yield of similar systems sited at these locations. Also, the performance ratios of these systems, given their respective reference yields, were observed to be better in the southern region compared with the northern region of Nigeria. This can be attributed to external factors that can influence system efficiency. These factors tend to favor systems located at the southern region as opposed to those at the northern region. These findings validate this study as a decision tool for predicting the performance of any Renewable Dispersed Generation (RDG) systems utilizing solar energy as the source at other regions of the country.

Keywords: Performance Assessment; Solar PV Systems; global horizontal radiations; Renewable Dispersed Generation (RDG).

I. Introduction

The danger posed by traditional power generation to general economic sustainability, development and substantial growth is very obvious. This is reflected on how each country of the world seeks countless alternative energy sources for electric power generation [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]. In Nigeria for example, electric power supply has never kept phase with demand despite the fact that the country is leading among the oil producing countries of Africa. This is supplemented by renewable resources such as water, wind and abundance solar energy that can be used to generate a substantial amount of electricity [2].

Increase in load demand necessitates generation expansion by building new generation power plants and corresponding expansion of the power networks. This is far from real solution from modern economic and environmental perspectives where there is a global struggle to meet the targets set in the Kyoto Protocol in order to reduce greenhouse gas emissions [3]. This has led to an increase of interest in Renewable Dispersed Generation (RDG), which is defined as 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. RDG can also be referred to as embedded generation which means small size generating units connected to the distribution power system [3, 4, 5]. 

According to Sustainable Energy Regulation Network SERN [6], Nigeria has available capacity of 6,056 MW out of the total installed capacity of 10,396 MW from the 23 grid-connected generating
plants in the country from which the fossil fuel generation accounts for 79% of the total installed capacity and the remaining 21% is derived from the 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 - 8]. The Energy Information Administration (EIA) estimates state that Nigeria has one of the lowest net electricity generation 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 m3 of biogas, since 1 kg of fresh animal waste is needed to produce 0.03 m3 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 has been tapped despite the fact that hydropower resource is widely distributed throughout the country. According to [9, 10], while studying voltage stabilization for grid-tied RDG systems utilizing wind energy, it was 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 as an opportunity for possible power generation. From the solar energy perspective, Nigeria has been grouped among countries with best solar resource distribution [10], with annual average total solar radiation reaching about 5.5 KWh/m2/day. With 6 hours/day sunshine hours, an annual total of about 1,770 thousand TWh/m2/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 focuses on the 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 generation.

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 be involved 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 energy source majors [11, 12]. Power generation from solar applications can utilize solar thermal energy systems or solar photovoltaic systems availability. Solar thermal systems are solar energy application systems that can concentrate heat energy from the sunlight and use it at varying temperatures; such as 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 unit depending on the power need and consumer location [13, 14].

3. 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].

4. Proposed System
The proposed system is a 1-MW grid-tied solar PV plant that utilizes polycrystalline silicon modules with inverters in an array configuration to supply power to unlimited load on the utility grid as shown
in figure 1. The location of this proposed system will be at strategic places in the cardinal regions of Nigeria and Abuja (Lat. 9.0oN, Long.7.4oE) at the center. These locations are- Sokoto (Lat. 13.0oN, Long. 15.0oE) in the North West region, Borno State (Lat. 11.9oN, Long. 13.2oE) in the North East region, Ogun State (Lat. 7.1oN, Long. 3.3oE) in the South West region and Rivers State (Lat. 5.1oN, Long. 7.1oE) in the South South 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 15o at these regions are presented in Table 1.0 and the plot of Figure 2. Table 2 shows the basic design parameters for the 1MW grid-tied solar PV system.

Table 1: Annual global solar radiation for the locations

| Months      | Sokoto (Kwh/m2) | Maiduguri (Kwh/m2) | Ogun State (Kwh/m2) | Rivers State (Kwh/m2) | Abuja FTC (Kwh/m2) |
|-------------|-----------------|---------------------|---------------------|-----------------------|--------------------|
| 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             |

Table 2: The basic design parameters for the 1MW grid-tied solar PV system.

| Module Type       | Polycrystalline Silicon (generic) |
|-------------------|----------------------------------|
| Space Requirement | 6508 m2                          |
| Module Efficiency | 15.5%                            |
| Module Capacity   | 250Wp                            |
5. Result Analysis
The International Energy Agency IEA has laid down measures that can be followed 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 radiation input to the final electricity injected into the grid by appropriate and normalized quantities which are based on the IEA Performance Database Standard IEC 61724 for Photovoltaic Power Systems (PVPS) [17, 18].
These performance parameters are illustrated in Figure 4 and include the Reference System Yield ($Y_r$), Final System Yield ($Y_f$), Collection Loss ($L_c$), Array Yield ($Y_a$), Performance Ratio ($P_R$) and Capacity Factor for the grid connected system as shown in Figure 3;

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.

a. 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 it is measured in MWh for a particular time. For the solar PV systems at selected regions, the energy injected into the public grid are- 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 presented in figure 4 showed that total energy yield is better for systems in the northern region than systems located at the southern region.
b. 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.

\[
Y_r = \frac{\text{total insolation}}{\text{reference irradiance}} = \frac{\text{KWh/m}^2}{1000 \text{W/m}^2}
\]

It is observed from the result that the reference system yield increased as one moves from southern to the northern regions. This is due to the higher clearness index in the northern region [10].

c. 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].

\[
Y_f = \frac{\text{Net Energy Output KWAC}}{\text{Array Output Power KWDC}} \text{ (KWh/kWp/day)}
\]

The result 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. It is seen from these results that systems located in the northern region have higher final system yield compared with systems located at the southern region because of the better reference yield in the northern region.

d. 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, according to [19] as:

\[
L_c = Y_r - Y_a \text{ (kWh/kWp/day)}
\]

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. The result showed that collection loss is better for systems located at the southern region compared with those at the northern regions.

e. 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 according to [13] as:

\[
P_R = \frac{Y_f(\text{Final Yield})}{Y_r(\text{Reference Yield})}
\]

The performance ratios obtained for the grid-tied 1-MW solar PV system located at the selected regions are as given below: Sokoto: 0.783, Borno: 0.794, Abuja FCT: 0.813, Ogun: 0.814 and Rivers: 0.816.
From this result, it is observed that the performance ratio improves across the country from the northern region to the southern region for the 1-MW PV plant. This is due to better collection loss that characterized systems located at the southern region.

f. Capacity Factor
The Capacity factor (CF) 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.

\[
C, F = \frac{\text{Annual Energy output}}{\text{Nameplate Capacity} \times 8760 \text{ hours}}
\]

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.

The result for the capacity factors for the 1-MW PV Solar plant at the selected locations showed that systems located at the northern region have better capacity factors compared with similar systems located around the southern region. This is due to the better system reference yield obtained in the northern region of the Country compared with the southern region.

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.

| Table 3: General Performance Parameters for the 1 MW solar PV plants at selected Regions |
|------------------|------------------|------------------|------------------|------------------|
| 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/m2/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 |

6. 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 are as presented in Table 3. It can be seen that best values for average daily incident energy in the PV array plane of the 1-MW solar PV plant is obtainable in the country with a comparative daily average values ranging from 6.27 KWh/m2/day in the North to 4.768 KWh/m2/day in the South. This corresponds to the findings reported by [10]. Also, the annual global solar radiation for the different regions presented in Table 1, 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 high reference yield in the northern region of the Country reflects harmoniously on other performance parameters of the system such as the total energy yield (Table 3). 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 functionality of these systems. This, in turn, has a 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.

References

[1] Titus Koledoye Olugbenga, A.-G. J. “The Current and Futrue Challenges of Electricity Market in Nigeria in the Face of Deregulation Process”. African Journal of Engineering Research, 1(2), 33-39, 2013.

[2] Isola, W. A. “An Analysis of Electricity Market structure and its Implications for Energy Sector Reforms and Management in Nigeria”. Global Advanced Research Journal of Management and Business Studies Vol. 1(5), 1, 141-149. Retrieved from http://garj.org/garjmbs/index.htm, May 2017.

[3] Zeineldin, H., El-Saadany, E., & Salama, M. M. “Impact of DG Interface Control on Islanding Detection and Non Detection Zones.” IEEE Transactions on Power Delivery, Vol. 21, 1515-1523, 2006.

[4] Kurt D. Jr. “Africa’s Renewable Energy Potential:” www.africa.com/africasrenewable-energy-potential, energy potential, 2015.

[5] Zellagui, M., Karimi, M., Mokhlis, H., Benabid, R., & Chaghi, A. “Impact of Renewable Dispersed Generation on Performance of Directional Overcurrent Relay on MV Distribution Power System.” International Conference on Electrical Engineering CEE. Batna, Algeria: Researchgate, 2014.

[6] National Renewable Energy And Energy Efficiency Policy (Nreeep). “Approved FEC for the Electricity Sector.” 2015 also available at www.power.gov.ng/download/NREEE%20POLICY%202015%20FEC%20APPROVED%20COPY.pdf retrieved May 2017.

[7] Onagoruwa, B. “Nigerian Power Sector Reforms and Privatisation. Nigeria.” Director General, Bureau of Public Enterprises, 2011.

[8] Joseph, I. O. “Issues and Challenges in the Privatized Power Sector in Nigeria”. Journal of Sustainable Development Studies, 6, 161-174, 2014.

[9] Agbetuyi. A. Felix, Akinbulire Toluope O, Abdulkareem Ademola and C.O.A Awosope “Wind Power Potential In Nigeria” International Electrical Engineering Journal (IEEJ) 3(1) pp 595-601, 2012.

[10] Olayinka, S. “Estimation of global and diffuse solar radiations for selected cities in Nigeria”. International Journal of Energy and Environmental Engineering, 2, 13-33, 2011.

[11] Offiong, A. “Assessing the Economic and Environmental Prospects of Stand-by Solar Powered Systems in Nigeria”, J. Applied Sci. and Env. Management, 7 (1): 37-42, 2003.

[12] Akpabio, L.E and Etuk, S.E. “Relationship between Global Solar Radiation and Sunshine Duration for Onne, Nigeria”, Turk. J. Phys, 27, pp 161–167, 2003.

[13] Blazev A. “Solar Tecnologies for the 21st Century.” Fairmont Press, Inc.ISBN0-88173-697-X, USA, 2013.

[14] Anthony F., Durschner C., and Remers K. “Photovoltaics for Professionals: Solar Electric Systems; Marketing, Design and Installation” Germany, Beuth Verlag, 2010.

[15] The German Solar Energy Society (DGS LV Berlin BRB), Ecofys. “Palning and Installing Photovoltaic Systems: A guide for installers, architects and engineers.” USA: James & James Science Publishers Ltd., 2006.
[16] Alsema, E. A. “Energy pay-back time and CO2 emissions of PV systems; *progress in photovoltaic Resource Application,*” 8, pp.17-25, 2000.

[17] Nordmann, T., Clavadetscher, L., Sark, W. G., & Mike Green. “Analysis of Long-Term Performance of PV Systems:” *Different Data Resolution for Different Purposes.* IEA International Energy Agency, 2014.

[18] Quaschning V. “Understanding Renewable Energy Systems,” Earthscan Publications Ltd, London, 2005.

[19] PVSyst Version 6.0 Help Documents/ Simulation variable: Standalone System. Accessed May 2017

[20] Hay J. E.. “Calculation of Monthly Mean Solar Radiation for Horizontal and Inclined Surface,” Solar Energy, Vol. 23, No. 4, pp. 301-308, 1979.