International Journal of Recent Engineering Science (IJRES)
ISSN: 2349 – 7157 / doi: 10.1445/23497157/IJRES-V7I3P113

Volume 7 Issue 3, 61- 71, May-Jun 2020

Economic Feasibility of Integrating Solar Photovoltaic Distributed Generation with Nigerian Power System

[1] John Nweke, [2] Arthur Ekwue, and [3]Emenike Ejiogu
[1]*Department of Electrical Engineering, University of Nigeria, Nsukka*
[2]*Department of Electrical Engineering, University of Nigeria, Nsukka/Jacobs Engineering Inc., London United Kingdom*
[3]*Department of Electrical Engineering, University of Nigeria, Nsukka*

Abstract

The recent trend of Nigeria's power system connection with renewable energy resources cannot be feasible without assessing the economic viability of the investment. This depends on the technical evaluation and economic feasibility of connecting distributed generation (DG) with the grid. The Nigeria power system is not yet connected with solar photovoltaic (SPV) renewable energy, and hence, this paper evaluates the economic feasibility of solar integration with the Nigerian grid. The task depends on technical issues via the optimal size and location of the distributed generation and global irradiation level of the renewable energy sourced electricity. A validated sensitivity-based method of optimization with the developed algorithm to obtain optimal size and location of DG for Nigeria grid connection carried out using Power System Software for Engineering (PSS/E). A generic method using financial sensitivity appraisal tools: present value (NPV), energy payback time (EPBT), and Levelized cost of electricity (LCOE) were used to evaluate the economic feasibility. The results of the analysis proved economically feasible in all ramifications for a 20-year lifetime with an optimal size of 1.0 MW of solar DG with a saving energy loss of 3.4 million dollars.

Keywords - *Distributed generation, economic, irradiation, net present value, solar*

I. INTRODUCTION

It has been stated [1] that the increasing need for energy sustainability has made green technology such as solar a promising energy source. This solar photovoltaic (SPV) system is not only a clean source of power which does not emit greenhouse gasses but serve as a supplement to fossil-powered source that can reduce the unit cost of power. According to [2], the sun's power reaching the earth is typically about 1000W/m^{2,} and the total amount of energy that the earth receives daily is 1353W/m^2. Nigeria, as the case study, is approximately located between latitude 4^{0}N and 13^{0}S with a landmass of 9.24 x 105 km^2. The North is drier with a temperature range between 32 ºC and 42 ºC, and the humidity is about 95%. The terrestrial irradiation on Nigeria's land area is measured about 2.079 x 10^{15} kWh/ year [3]. The annual average solar irradiation is about 25.2MJ/m^2-day in the North, whereas the coastal region is about 12.6MJ/m^2-day [4]. It is estimated that the country has an average daily sunshine of 6.5 hours annually, which ranges from 4 hours in the coastal region to 9 hours in the Northern states [5]. This natural potential of high solar irradiation, especially in the Northern part of the country, makes it feasible for investment in solar photovoltaic renewable energy. However, the economic feasibility of harnessing and connecting the solar energy into the national grid depends on the government regulatory and legal framework to accommodate it [5], technical issues based on optimal size and location of the distributed generation, and global irradiation potential [6].

Several researchers have worked on technical issues via optimal location and size of distribution generation (DG) into the Nigerian power grid using different optimization methods but did not consider its integration feasibility. In [7] Genetic algorithm (GA) technique was utilized to select the most suitable Distributed Generator (DG) technology for better performance of the power system. The applied method was used to obtain the optimal size and location of the DG to minimize power loss on the network. IEEE 14-bus network was used to test the algorithm's applicability, but the optimal location was not specified. In [8], Smart grid technology was applied to Nigeria's 330kV power system to reduce the high active and reactive transmission losses. The effectiveness of this method yielded an improved network, yet the size of the DG was not considered. The authors [9] highlighted the existing policies and made recommendations for additional policies and laws that support solar energy integration into the Nigerian power system. The paper reviewed the status of past, current, and feasible future recommendations for solar integration. However, technical issues of size and location DG were not considered. The paper [10] studied policies enhancing renewable energy development and implications for Nigeria. The authors classified support mechanisms to include; capital, fiscal, tax incentives, legislative, political, technological, and environmental support. The lessons from the case study were used to develop implications of renewable energy technologies through effective policies and strategies in Nigeria but failed to recommend addressing technical issues of renewable energy development. The optimal location and sizing of distributed generation on the Nigerian power system were considered in [11]. The paper optimized the size of DG as well as the location in the Nigerian power system. The effectiveness of the study resulted in an improved voltage profile and total reliability of the network, but the economic feasibility of integrating the DG was not considered.

Presently there is no solar photovoltaic distributed generation connected to the national grid [9]. This paper aims to assess the economic feasibility of integrating the optimal size of solar photovoltaic distributed generation with the Nigerian power system. Power system software for Engineering (PSS/E) was used to model the network and carry out the study. A generic method using economic analyzing tools via Net Present Value (NPV), Levelized Cost of Energy (LCOE), and Energy Payback Time (EPBT) were used to evaluate the economic feasibility of the optimized sized DG-grid connection. Section 2 explored the intensity of potential solar irradiation in the country. Section 3 shows the methodology. Finally, sections 4 and 5 dealt with the results and conclusion, respectively.

II. SOLAR ENERGY POTENTIAL RESOURCES IN NIGERIA

Nigeria is located in high sunshine and well-distributed solar irradiation geographical region. The annual average total solar irradiation ranges from about 7.0 kWh/m^2/day in northern regions to about 3.5 kWh/m^2/day in southern parts. Nigeria's annual average intensity is 1934.5 kWh/m^2/year [12, 13] and thus, have a better potential for photovoltaic (PV) systems than concentrating optical equipment [14]. Fig.1 below shows the irradiation levels of global horizontal irradiation (GHI) in Nigeria. The Solar irradiation intensity depends on the climatic condition of the location. This results in varying intensity from North to South states of the country. However, which depends on the climatic conditions. This is attributed to the long rainy season and cloudy weather often obtained in the southern part of the country. The optimum solar irradiation is about 7000Wh/m^2 in the Northern part of the country and about 4000Wh/m^2 in the south per day [15]. With this level of solar irradiation, Nigeria has the potential for production of electricity from solar PV technology in the range of 207,000 GWh/year if theoretically only 1% of the land area were covered with polycrystalline PV module 20 to yield output of 1,500Wh/Wp/year [14]. Comparatively, the annual solar energy value is about 27 times the country's total fossil energy resources in energy units and is over 115,000 times the electrical power produced. Therefore, it implies that about 3.7% of Nigeria's landmass is required to generate solar energy equal to the conventional source of electrical energy [16].

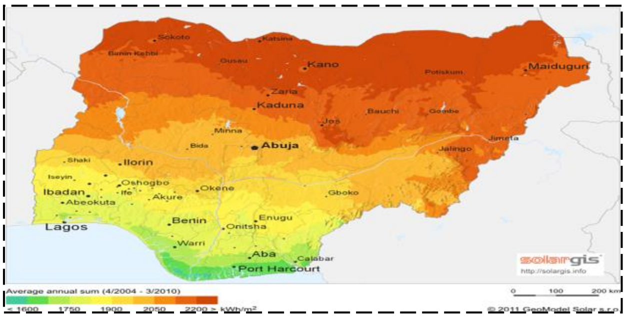

Fig. 1 Map of Nigeria showing the solar irradiation (kWh/m^2) [17]

A. Nigeria Average Irradiation Zones

The yearly average of daily irradiation in Nigeria comprising the 36 states has been classified into zones, as shown in Fig. 2. Each of the zones is classified according to the solar irradiation intensity, as indicated in figure 2 legend [15]. The irradiation range for each zone comprises Zones 1, II, and III as distributed in the North-East, North –West, North – Central, South-East, South-West, and South-south geopolitical zones of the country. Fig.2 depicts the average range of the global horizontal range of irradiation classification according to each zone. The annual average global solar energy intensity decreases from the range of 2186, 2006 to 1822 kWh/m^2/year [17] in the respective zones. These data show good and viable prospects for solar PV development in the country according to each zone or state of their location. Zone 1 has the highest solar irradiation incident on the horizontal surface of Nigeria makes it the most viable potential for large-scale solar photovoltaic (PV) investment. Likewise, zone II consisting of the northwest and north-central belt of the country, also has viable solar radiation required for most solar projects. Whereas, zone III with low potential of yearly global solar irradiation comprising all south zone locations, including the coastal region, can only be suitable for stand-alone PV systems. However, some locations in the southern region are feasible for decentralized energy projects [17].

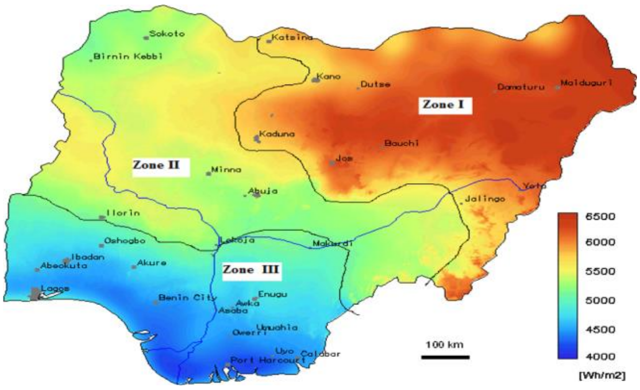

Fig. 2 Yearly averages of daily irradiation zones in Nigeria [15]

Each of the average irradiation for each geopolitical zone depicts the solar potential for the location. This figure indicates that the North-East geopolitical zone has the highest average irradiation potential for solar PV investment. Other potential locations include North-West, North-Central, South-West, South-East, and South-South states of the country. Currently, there is no PV-grid connected in the country. It is the only off-grid capacity of about 0.15 MW, or less solar PV was installed [16]. Nigeria is interested in installing utility-scale grid-connected solar PV plants in the North-East region of the country, which has higher irradiation values. The significant limitations to the development of solar technologies include capital costs, and institutional capacity, which heighten the overall project-risk and deterring private sector investments [18].

III. METHODOLOGY

This paper evaluates the economic feasibility of solar integration with the Nigerian grid. The task depends on technical issues via the optimal size and location of the distributed generation and global irradiation level of the renewable energy sourced electricity. Having explored the renewable potential in the previous section, a validated sensitivity-based method of optimization with the developed algorithm will be used to obtain the optimal size and location of DG for Nigeria grid connection. This is carried out in a Power System Software for Engineering (PSS/E) environment, whereas a generic method that uses financial sensitivity appraisal tools: present value (NPV), energy payback time (EPBT), and Levelized cost of electricity (LCOE) are used for the economic feasibility of the project.

A. Validated Sensitivity-based optimization Method.

a) Permissible Headroom Capacity

The magnitude of the fault level is generally determined by the rating of the existing switchgear in the vicinity of the connection point. This upper limit is usually referred to as the design fault level in the network [19]. This forms a limiting factor in the connection of new DGs, which is determined by the headroom capacity (γ_b)

$$(\gamma_b) = (K_b + 0.05 K_b) - (I_f)\ (kA) \quad (1)$$

where: K_b = switchgear rated capacity (kA)

I_f = fault current

b) Optimal Size and Location of Solar DG

Integration of solar PV energy into the Nigerian power network has the primary goal of minimizing losses and expressed mathematically as [20]:

$$Minimze\ f(x) = \sum_{i=1}^{k} P_{Loss} \quad (2)$$

The power loss in the network is given by

$$P_{Loss} = Minimize \sum_{i=1}^{k}\sum_{j=1}^{k} I_{ij}{}^2 Z_{ij} \quad (3)$$

Impedance between the sending node bus and receiving end-node bus is given as:

$$Z_{ij} = R_{ij} + j X_{ij} \quad (4)$$

$$I_{ij} = \frac{V_i - V_j}{Z_{ij}} \quad (5)$$

The real power flow injected P_i at the node bus i is given as:

$$P_i = (P_{Solar} - P_{Load}) \quad (6)$$

Where: P_i = the real power flow injected at the node bus I; P_{Solar} = power generated from solar and P_{Load} = Power load demand.

The real power loss in the system is as derived from the exact loss equation [21]

$$P_{Loss} = \sum_{i=1}^{N}\sum_{j=1}^{N} [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j - P_i Q_j)] \quad (7)$$

Where:

$\alpha_{ij} = \frac{r_{ij}}{V_i V_j}\cos(\partial_i - \partial_j)$, $\beta_{ij} = \frac{r_{ij}}{V_i V_j}\sin(\partial_i - \partial_j)$ and α_{ij}, β_{ij} = loss coefficient.

The optimal placement of the PV DG is based on linearization of the original non-linear equation to reduce the search space for optimization. Differentiating the power loss to a power injection from the solar generator at the ith bus to obtain the loss sensitivity factor as in equation (8)

$$\alpha_i = \frac{\delta P_L}{\delta P_i} = 2\sum_{j=1}^{N}\sum_{j=1}^{N}(\alpha_{ij} P_j - \beta_{ij} Q_j) \quad (8)$$

The possible condition for minimum loss in the network will mark the optimal position for the solar DG as given by [22]. The rate of change of power loss will be minimum to injected power due to introducing the new DG under the condition in equation (9).

$$\frac{\delta P_L}{\delta P_i} = 2\sum_{j=1}^{N}(\alpha_i P_j - \beta_i Q_j) = 0 \quad (9)$$

This implies that: $\alpha_{ij} P_j - \beta_{ij} Q_i + \sum_{j=1\, j\neq i}^{N}(\alpha_i P_j - \beta_i Q_j) = 0$

(10)

$$P_i = \frac{1}{\alpha_{ij}}[\beta_{ij} Q_i + \sum_{j=1\, j\neq i}^{N}(\alpha_i P_j - \beta_i Q_j)] \quad (11)$$

Where; Pi is the real power injection at the ith node, which is the difference between real power generation and equation (12) that satisfies real power demand at that node.

The minimum optimal size of the DG will be given:

$$P_{Solar} = P_D + \frac{1}{\alpha_{ij}}[\beta_{ij} Q_i - \sum_{j=1\, j\neq i}^{N}(\alpha_i P_j - \beta_i Q_j)] \quad (12)$$

The power injection from the solar generator must satisfy the following constraints:

Equality Constraints: Power flow constraints related to the non-linear equation for balancing constraints expressed in equation (13).

$$P_{bus} = (P_{Solar} - P_{Load}) \quad (13)$$

Inequality constraints: Voltage constraints (PU) at each bus ($\pm 5\%$ of rated voltage) must be:

$$V_{\min} \leq V_i \leq V_{\max} \quad (14)$$

The right-of-way buses: The buses which are not appropriate for DG allocation due to some restricting considerations such as non-availability of solar energy in that locality should be excluded.

DG Capacity: The capacities of the different nominal value of solar power generations must be maintained with an acceptable limit as:

$$P_{Solar\_\min} \leq P_{Solar} \leq P_{Solar\_\max} \quad (15)$$

Where: $P_{Solar\_\min}$ and $P_{Solar\_\max}$ are the minimum and maximum active power generated, respectively.

$$P_i = (P_{Solar} - P_{load}) \quad (16)$$

The real power loss sensitivity index is evaluated to determine the candidate bus for the placement of DGs. Based on this method, the optimal location is obtained by creating a priority list for the location of DG by evaluating the loss sensitivity index (PLSI). Then, a priority list is created, and buses are placed according to the descending order of the PLSI values. The bus with the highest sensitivity indicates the weakest bus and is selected as the best position for DG placement. Thus, this reduces the search space among the selected candidate buses in the priority order of DG allocation in the network. The equation (3.91) defines the numerical evaluation of PLSI for the ith bus in the power system network.

$$PLSI = \frac{Loss_{without\ DG} - Loss_{with\ DG}}{Size\ of\ DG} \quad (17)$$

In the power system network, bus voltage continuously reduces with an increment of load on the system. This causes a reduction in the voltage stability margin, and the system becomes more vulnerable to unreliability. The voltage profile improvement is the central part of the objectives of this study. Hence the bus voltage of the system is obtained through load flow analysis, and the voltage profile is replaced by cumulative voltage deviation (CVD) [23].

$$CVD = \left| \sum_{i=1}^{n} (1 - V_i) \right| \quad (18)$$

$$BVSI = \frac{Cumulative\ voltage\ deviation}{number\ of\ bus\ (N)} \quad (19)$$

$$BVSI = \sqrt{\frac{\sum_{i=1}^{n} (1 - V_i)^2}{N}} \quad (20)$$

Bus voltage sensitivity index analysis as expressed in equation (3.94) is another method for reducing the search space in optimal placement and sizing of DG in a power system network [24]. It gives a direct indication of the maximum bus voltage deviation at the point of voltage collapse. The bus with the highest voltage sensitivity index (VSI) could be identified as the ‘‘weakest bus” in a system, hence the best location for DG placement [25, 26].

B. Evaluation of Economic Feasibility for DG –Grid Connection

A generic method that uses financial sensitivity appraisal tools via; net present value (NPV), Levelized cost of electricity (LCOE), and energy payback time (EPBT) was used to evaluate the feasibility of the DG-grid connection.

a) Net Present Value (NPV)

This is a standard method for using the time value of money to appraise long-term projects. It compares the present value of money today to the present value of money in the future, considering inflation and returns [27]. The decision making on investment depends on the value of NPV. If NPV > 0, the investment would add value to the investor, and that the project may be accepted. If NPV < 0, then the project can be acceptable if there are other strategic reasons attached to it, like employment, telecommunication. This can be evaluated using the Black-Scholes technique of option theory [28]. On the other hand, if NPV= 0, then the project adds no monetary value for that period; therefore, the investor should be indifferent in deciding whether to accept or reject the project. In general, a positive net present value reveals an economically feasible project. The formula for the discounted sum of all cash flows can be rewritten as [29].

$$NPV = \sum_{t=1}^{N} \frac{EC_t}{(1+i)^t} - C_{inv} \quad (21)$$

b) Levelized Cost of Electricity (LCOE)

The LCOE of renewable energy technologies varies by technology, country, and project-based on the renewable energy resource, capital, operating costs, and the efficiency or the performance of the technology. LCOE is the implied price ($/kilowatt hour) of energy generated by the PV system, which is the minimum price needed to break-even over the technology's lifetime [30]. It is defined as the ratio of the net present value of the total capital and operating costs of a generic plant to the net present value of the net electricity generated over its operating life. The mathematical formula applied for calculating the LCOE of the PV DG resources is given as [31]:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (22)$$

c) Energy Payback Time (EPBT)

The EPBT depends on irradiation, type of system (integrated or not, orientation, inclination), and the technology. This is because types of PV have different manufacturing processes and hence different sensitivities to solar irradiation. The number of years taken for the energy savings from the PV system to offset the initial cost of the investment is referred to as the Simple payback time [32].

$$EPBT = \frac{E_{in}}{E_{PV}} \quad (23)$$

The developed algorithm showing the step processes to obtain the optimal size of solar DG and location for Nigeria grid connection and evaluate the economic feasibility include:

I. Input the load, generator, and line data from Appendix A
II. Run Newton Raphson load flow (base case) using PSS/E software and evaluate the losses.
III. Run the short circuit fault current analysis using bus voltages from load flow studies as the pre-fault voltages.
IV. Evaluate permissible headroom capacity of candidate buses to host DG in equation (1)
V. Connect DG to candidate buses that have permissible headroom capacity.
VI. Obtain the optimal sizes of DGs for each candidate bus using equation (12),
VII. Place the optimum size DG at the corresponding position as obtained in step (VI)
VIII. Check for constraint violation after the placement of DG.
IX. Run the full NR load flow for each placement of DG on the candidate bus.
X. Evaluate and record the real power losses for each DG placement.
XI. Evaluate the power loss sensitivity index (PLSI) through equation (17).
XII. Check the number of candidate buses if it is equal to the total number, or else return to step (V).
XIII. Compare the results obtained and locate the optimal position of DG with the bus having the highest PLSI.
XIV. Display the results of the optimal size and location.
XV. From step (IX), evaluate the bus voltage sensitivity indices (BVSI) for each bus from the equation (20).
XVI. Locate the optimal position for DG at a bus with the highest BVSI (weakest bus).
XVII. Display the result of the optimal size and optimal location of stage 2.
XVIII. Check the validity of the results of both stages 1 and 2 and display the result's output.
XIX. Evaluate the energy loss saving and NPV for a 20-year lifetime using equation (21)
XX. Evaluate the LCOE using equation (22)
XXI. Evaluate the energy payback time (EPBT) using equation (23)
XXII. Display the output results of XIX – XXII
XXIII. End the process

IV. RESULTS AND DISCUSSION

A. Base Case Load Flow Solution

The modeled case study of Nigeria power system [33] as shown in figure 3, used a validated sensitivity-based method of optimization with a developed algorithm to obtain optimal size and location of DG into the network

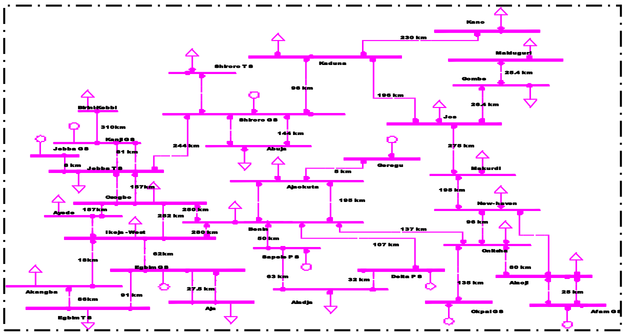

Fig. 3 Nigeria 31-bus, 330 kV Grid modeled in PSS/E

This study applied two-frame modes of the optimization techniques via active power loss sensitivity index and bus voltage sensitivity index. The load, bus, and generator data were entered as input to PSS/E software to run the Newton Raphson base-case load flow solution. The voltage profile for the base-case load flow is shown in Fig. 4. The result showed that some of the buses are below statutory voltage limits (0.95 ≤ voltage ≤ 1.05). These buses are Gombe (16), Jos (19), Kano (22), and Maiduguri (31). Also, a total active power loss of 92.81 MW was obtained after the base-case load flow solution.

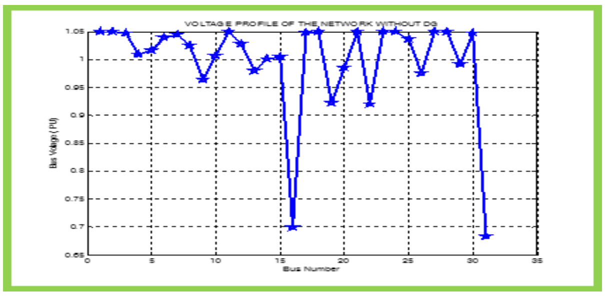

Fig. 4 Voltage profile for the base-case load flow

B. Permissible Headroom Capacity

The short circuit current fault analysis was carried out through PSS/E software. The apparent base power used is 100 MVA, the base kV is 330, and the initial bus voltages from load flow studies were used as the pre-fault voltages before computation. Fig.5 shows the result of the short-circuit fault current level of candidate buses. According to the transmission company of Nigeria (TCN), the switchgear current rating for the 330kV transmission line operates at 3.5kA [34 - 35]. Hence, each of the buses is subject to a switchgear headroom capacity of 3.5kA fault current level with a 5% safety margin as a base constraint for DG connection. The results indicate that four (4) out of twenty-one (21) candidate buses have a positive permissible headroom capacity for DG connection. Hence, the search for an optimal position for a single DG connection to the network is navigating within these individual buses, via; bus 21 (Maiduguri), bus 20 (Gombe), bus 11 (B/ Kebbi), and bus 18 (Kano).

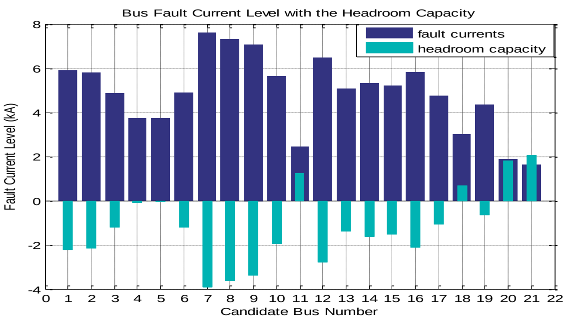

Fig.5 Bus fault level with the headroom capacity

C. Optimal Location and Sizing of DG through PLSI

For every candidate bus, the optimal size of DG is evaluated according to equation (12) and installed. The highest sensitivity index indicates the weakest bus and is selected for DG placement through equation (17). Figure 6 shows the various values of the power loss sensitivity index (PLSI) at different buses in the network. These were obtained after single DG placement with optimal size placed on the buses with the permissible headroom capacity via; buses 11, 18, 20, and 21, respectively. Each bus position displayed the power loss sensitivity indices with DGs. The result indicated the optimal location on bus 20 with a DG size of 1.00MW. The impact of the DG produced an output of 74.57MW, which gives rise to an active power loss reduction of 20% in the system. The arrow indicated in Fig. 6 marked the bus with the highest sensitivity index as the optimal position.

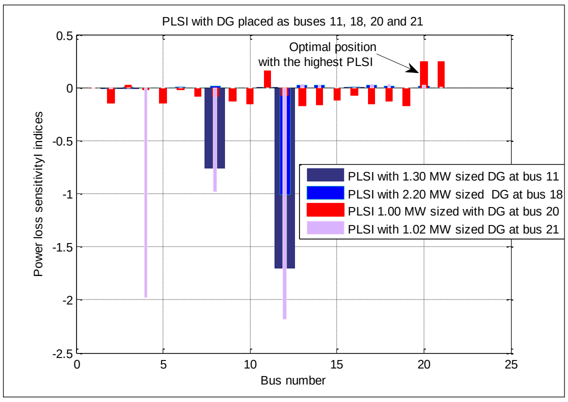

Fig.6. PLSI with DG placed at bus 11, 18, 20 and 21

D. Optimal Location of DG through BVSI

Bus voltage sensitivity index analysis is another method for reducing the search space in optimal placement and sizing of DG in the power system network. It gives a direct indication of the maximum bus voltage deviation at the point of voltage collapse. The bus with the highest voltage sensitivity index (VSI) could be identified as the ‘‘weakest bus” in a system, hence the best location for DG placement. This is evaluated by penetrating at a time with the optimized sized DG. For each of the buses, its voltage sensitivity index is then evaluated, and the bus with the highest value indicates the optimum location of the DG placement. The obtained results are shown graphically in Fig. 7, which displayed the BVSI for the candidate bus positions via; 11, 18, 20, and 21 after single DG placement with optimal sizes. The graph depicted bus 20 as the highest voltage sensitivity index, which marks the optimal DG placement position in the network.

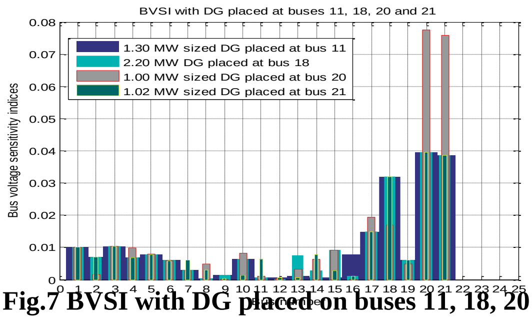

Fig.7 BVSI with DG placed on buses 11, 18, 20 and 21

E. Validated Optimal Sizing and Placement of DG

The power loss sensitivity index (PLSI) and bus voltage sensitivity index (BVSI) registered their peak values at the same 20^{th} bus network. The resultant effects of these sensitivity indices help to predict the bus that is most susceptible to voltage collapse. This is because; the candidate bus having the peak value of the sensitivity index indicates the weakest bus in the network. Hence the optimal position for DG placement. The points A and B in Fig. 8, as indicated through arrows, are on the same bus as the validated optimal location of the DG in the power system network. Hence, an optimal size of 1.0MW of solar DG with a percentage active loss reduction of 20% at an optimal position (Gombe busbar) is needed to compensate the Nigeria grid for more improved performance.

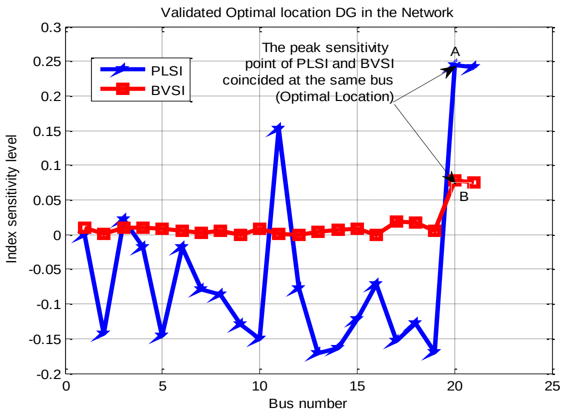

Fig. 8 validated optimal location of DG

F. Net Present Value (NPV) Evaluation

The optimal size of Solar PV DG at the optimal location for technical loss minimization in the Nigerian power system given as Solar PV capacity = 1.00 MW (1000kW). The energy saved is the difference in technical losses before and after PV DG connection with the national grid. Thus: (92.81 – 74.57) MW = 18.24 MW (18240 kW).

Table 1 is sourced from Nigeria Electricity Regulatory Commission (NERC) 2016 feed-in tariff approved for renewable energy [36] for up to 1.00 MW solar PV generated capacity.

Capital Cost ($/kW) = 1500

(O&M) $/kW/yr = 30

Variable cost ($/MWh) = 0.06

Weighted Average Capital Cost (WACC) (%) = 11

Feed –in tariff (FiT) for 2018 as shown in table 5.4 (177.00 $/MWh) = 1.77$/kWh

Cost of energy losses = Technical loss (KW) * Load loss factor (LLF) *8760*Long Run Marginal Cost (LRMC) ($/kWh) [37].

Table 1 NERC 2018 feed-in tariff approved for renewable energy [36]

The assumption for Renewable Energy Feed-in Tariff Computation			
			Solar
Capacity		MW	5
Capital Cost		$/kW	1500
Capacity Utilization Factor		%	19%
Fixed O & M		$/kW/yr	30.00
Variable O & M		$/MWh	0.06
Fuel Cost		$/MWh	0
Aux. Power Requirement		%	1
Decline Rate of Price		%	5
Construction Time		Year	2
Exchange rate (N to $)		Naira	307(July 2019)
Real WACC		%	11 (NERC 2018)
Local Inflation rate		%	.11.4 ((. May 2019)
FIT2016 (Naira)	Capital Cost	Naira/MWh	35,370.05
	O & M	Naira/MWh	29.49
	Total	**Naira/MWh**	**35,399.54**
FIT2016 (US$)	Capital Cost	$/MWh	176.85
	O & M	$/MWh	0.15
	Total	**$/MWh**	**177.00**

Cost of energy loss = 18240 x 0.0357 x 8760 x 0.06 = $342253.90 (Saving in energy loss)

Considering the impact of losses on the rest of the system, Long Run Marginal Costs (LRMC) which is the cost of supplying an extra of electricity (kW) to a consumer during the system at peak load demand. Load Loss Factor (LLF) (estimate losses between the grid supply point and the consumers**)** [38] Thus, the load factor (*Lf*) is taken as 0.097 for the solar photovoltaic system [39]. Thus;

LLF = $k * Load\ factor(Lf) + (1-k)*(Lf)^2$; \k (transmission loss factor) = 0.3 [38]. LLF = 0.0357 Capital cost ($/kW) = Energy generated (kW) x price ($/kW) = 1500 x 1000 = $1,500,000.

Operation and maintenance (O & M) Cost ($/kW/yr) = 30 x 1000 = $30,000.

Annual Payment = $\left(Energy\ \ generated(kW)*Lf*FiT*8670\right)$ = (1000 x 0.097 x 1.77 x 8760) = $1504004.4

Total investment = Annual Payment + Savings in energy loss + O & M Cost = 1504004.4 + 342253. 90 - 30,000 = $1876258.30

Present Value Factor = $1.0/(1 + i)^n$ where n is the investment for N years and i is the discount rate in percentage [40]. Taking into account the local inflation rate, Fisher formula via; Discount rate (%) = ((1 + WACC) *(1 + inflation)) – 1 [27].

Present value = Annual cash flow * Present Value Factor

Net Present Value = Σ Present Value from N= 1 to 20, Capital cost incurred is $1,500,000.00.

. The results are shown in Table 2. It shows the energy loss saving, annual payment, the total investment cost, present value factor, and present net value for each successive year. The values represent the stream of cash flows that the project generates.

G. Evaluation of the Levelized Cost of Electricity (LCOE)

Evaluating for the value of LCOE according to equation (5.38) above through Excel Spread Sheet: The investment expenditure is given as Annual Payment + Savings in energy loss - operation & maintenance cost = 1504004.4 + 9107596.8 – 30000 = $1816258.3

Operation and maintenance (O & M) Cost ($/kW/yr) = 30 x 1000 = $30,000. Fuel cost = 0,

Present Value Factor = $1.0/(1 + i)^n$

Total Investment Cost = Investment Expenditure + Operation & Maintenance Cost + fuel cost = 1816258.3 + 30000 + 0 = $1846258.3

Net present value for total investment cost = *Present Value Factor * total investment cost*

Power generated (kWh) = Energy capacity (kW)*degrading factor (f_{Epv})* Load loss factor (LLF) *8760*Long Run Marginal Cost (LRMC) ($/KWh). where fEpv is 0.005 [41]

Net present value of generated power = *Present Value Factor* * power generated (kWh).

LCOE ($/kWh) = Net present value for total investment cost / Net present value for generated power. As shown in Table 3, the computation of Levelized cost electricity from solar PV grid connection with the Nigerian power system is $0.49. This is the price of the energy generated from solar PV must be sold to break even over the lifetime of the system technology. Alternatively, the value represents the ratio of the lifetime cost of the solar PV to the lifetime energy production of the project. LCOE can be directly compared to the price of local conventional utility charges. If the renewable system generates electricity less than the utility price, then it will be economically feasible. Thus, with the present exchange rate of N307 per dollar, the PV electricity will be sold cheaper than the conventional cost at N450 kWh.

Table 2 Net Present Value (NPV)

NET PRESENT VALUE EVALUATION COST ($)							
YEAR	**CAPITAL**	**O & M**	**ENERGY LOSS SAVING**	**ANNUAL PAYMENT**	**TOTAL INVESTMENT COST**	**PRESENT VALUE FACTOR**	**NET PRESENT VALUE**
0	1,500,000				-1,500.00	1	-1,500,000
1		30000	342253.90	1504004.4	1876258.30	0.808708	1216300.65
2		30000	342253.90	1504004.4	1876258.30	0.654009	983632.26
3		30000	342253.90	1504004.4	1876258.30	0.528902	795471.45
4		30000	342253.90	1504004.4	1876258.30	0.427728	643304.26
5		30000	342253.90	1504004.4	1876258.30	0.345907	520245.41
6		30000	342253.90	1504004.4	1876258.30	0.279738	420726.71
7		30000	342253.90	1504004.4	1876258.30	0.226226	340245.13
8		30000	342253.90	1504004.4	1876258.30	0.182951	275159.01
9		30000	342253.90	1504004.4	1876258.30	0.147954	222523.34
10		30000	342253.90	1504004.4	1876258.30	0.119652	179956.44
11		30000	342253.90	1504004.4	1876258.30	0.096763	145532.24
12		30000	342253.90	1504004.4	1876258.30	0.078253	117693.11
13		30000	342253.90	1504004.4	1876258.30	0.063284	95179.38
14		30000	342253.90	1504004.4	1876258.30	0.051178	76972.34
15		30000	342253.90	1504004.4	1876258.30	0.041388	62248.16
16		30000	342253.90	1504004.4	1876258.30	0.033471	50340.60
17		30000	342253.90	1504004.4	1876258.30	0.027068	40710.85
18		30000	342253.90	1504004.4	1876258.30	0.02189	32923.20
19		30000	342253.90	1504004.4	1876258.30	0.017703	26625.26
20		30000	342253.90	1504004.4	1876258.30	0.014316	21532.06
Net Present Value					**$ 4767322**		

Table 3 Levelized cost of electricity (LCOE)

LEVELIZED COST OF ELECTRICITY (LCOE) ($/kW)										
YR	INVESTMENT EXPENDITURE	O + M	FUEL COST	TOTAL INVESTMENT COST	PRESENT VALUE FACTOR	NET PRESENT VALUE OFC & O COST	TOTAL ENERGY GENERATED (kWh)	PRESENT VALUE FACTOR	NET PRESENT VALUE OF GENERATED ENERGY	LCOE
1	1816258.3	30000	0	1846258.3	0.808708	1493084.2	3752784	0.808708	3034907.07	0.49
2	1816258.3	30000	0	1846258.3	0.654009	1207469.4	3752784	0.654009	2454354.14	0.49
3	1816258.3	30000	0	1846258.3	0.528902	976490.34	3752784	0.528902	1984856.25	0.49
4	1816258.3	30000	0	1846258.3	0.427728	789695.72	3752784	0.427728	1605169.46	0.49
5	1816258.3	30000	0	1846258.3	0.345907	638633.38	3752784	0.345907	1298113.66	0.49
6	1816258.3	30000	0	1846258.3	0.279738	516468.03	3752784	0.279738	1049795.12	0.49
7	1816258.3	30000	0	1846258.3	0.226226	417671.92	3752784	0.226226	848977.89	0.49
8	1816258.3	30000	0	1846258.3	0.182951	337774.69	3752784	0.182951	686575.35	0.49
9	1816258.3	30000	0	1846258.3	0.147954	273161.15	3752784	0.147954	555239.10	0.49
10	1816258.3	30000	0	1846258.3	0.119652	220907.65	3752784	0.119652	449026.39	0.49
11	1816258.3	30000	0	1846258.3	0.096763	178649.82	3752784	0.096763	363131.31	0.49
12	1816258.3	30000	0	1846258.3	0.078253	144475.57	3752784	0.078253	293667.26	0.49
13	1816258.3	30000	0	1846258.3	0.063284	116838.58	3752784	0.063284	237491.11	0.49
14	1816258.3	30000	0	1846258.3	0.051178	94488.311	3752784	0.051178	192061.00	0.49
15	1816258.3	30000	0	1846258.3	0.041388	76413.469	3752784	0.041388	155321.30	0.49
16	1816258.3	30000	0	1846258.3	0.033471	61796.197	3752784	0.033471	125609.60	0.49
17	1816258.3	30000	0	1846258.3	0.027068	49975.089	3752784	0.027068	101581.51	0.49
18	1816258.3	30000	0	1846258.3	0.02189	40415.263	3752784	0.02189	82149.80	0.49
19	1816258.3	30000	0	1846258.3	0.017703	32684.153	3752784	0.017703	66435.21	0.49
20	1816258.3	30000	0	1846258.3	0.014316	26431.942	3752784	0.014316	53726.70	0.49

Table 4 Energy Payback Time (EPBT) Cash flow

EVALUATION OF ENERGY PAYBACK TIME (EPBT)								
YEAR	**CAPITAL**	**O & M**	**ENERGY LOSS SAVING**	**ANNUAL PAYMENT**	**TOTAL INVESTMENT COST**	**PRESENT VALUE FACTOR**	**NET PRESENT VALUE**	**CUMULATIVE CASH FOW**
0	1,500,000				-1,500.00	1	-1,500,000	-1,500,000
1		30000	342253.90	1504004.4	1876258.30	0.808708	1216300.65	-283,699
2		30000	342253.90	1504004.4	1876258.30	0.654009	983632.269	699,933
3		30000	342253.90	1504004.4	1876258.30	0.528902	795471.451	1,495,404
4		30000	342253.90	1504004.4	1876258.30	0.427728	643304.261	2,138,709
5		30000	342253.90	1504004.4	1876258.30	0.345907	520245.412	2,658,954
6		30000	342253.90	1504004.4	1876258.30	0.279738	420726.715	3,079,681
7		30000	342253.90	1504004.4	1876258.30	0.226226	340245.131	3,419,926
8		30000	342253.90	1504004.4	1876258.30	0.182951	275159.017	3,695,085
9		30000	342253.90	1504004.4	1876258.30	0.147954	222523.345	3,917,608
10		30000	342253.90	1504004.4	1876258.30	0.119652	179956.447	4,097,565
11		30000	342253.90	1504004.4	1876258.30	0.096763	145532.249	4,243,097
12		30000	342253.90	1504004.4	1876258.30	0.078253	117693.119	4,360,790
13		30000	342253.90	1504004.4	1876258.30	0.063284	95179.3866	4,455,969
14		30000	342253.90	1504004.4	1876258.30	0.051178	76972.3475	4,532,942
15		30000	342253.90	1504004.4	1876258.30	0.041388	62248.1663	4,595,190
16		30000	342253.90	1504004.4	1876258.30	0.033471	50340.6006	4,645,531
17		30000	342253.90	1504004.4	1876258.30	0.027068	40710.855	4,686,241
18		30000	342253.90	1504004.4	1876258.30	0.02189	32923.201	4,719,165
19		30000	342253.90	1504004.4	1876258.30	0.017703	26625.2616	4,745,790
20		30000	342253.90	1504004.4	1876258.30	0.014316	21532.0666	4,767,322

H. Evaluation of Energy Payback Time (EPBT)

The EPBT is evaluated through the EXCEL spreadsheet for a 20-years lifetime of the solar DG, and the result is shown in Table 4. It shows the energy loss saving, annual payment, the total investment cost, present value factor, present net value, and cumulative cash flow for each successive year. The values repres**ent** the stream of cash flows that the project generates, and the value of the cumulative cash (balance) falls in the 1st year, which marks the time where the investor will begin to get returns from the investment [42].

The energy payback time (EPBT) is evaluated: EPBT as $1+(\frac{283699}{699,933}\times 12)$ = 1year and 5 Months. This implies that after a period of 1year and 5 months, the investment under the lifetime of 20 years will start yielding income to the investor. This justifies the project to be feasible economically.

V. CONCLUSIONS

This paper explored the feasibility of grid integration of 1.00 MW of solar PV, which was designed using a validated two-step optimization novel technique with full Newton Raphson load flow. This optimization is carried out through Power System Software for Engineers (PSS/E) to obtain the optimum size and location of PV DG for integration with the Nigerian 31-bus power system. Economic appraisal tools via Net Present Value (NPV), Levelized Cost of Energy (LCOE), and Energy Payback Time (EPBT) were used for the economic feasibility analysis. This is carried out in Microsoft Excel software to address the cash flow, Payback period, and cost of energy saved when solar PV is connected to the grid. The sensitivity of cash flow at different discount rates was evaluated. The results of the analysis proved economically feasible in all ramifications for the 20 year lifetime of the PV project. The net present value is positive ($6064270.63) with saved energy of $1504004.4. The Levelized Cost of electricity is 0.492 $/kW, and the energy payback time is one year and months. The result is a good pointer for local and foreign investors in renewable energy development in the country.

Acknowledgments

The authors wish to acknowledge Prof. O. U Oparaku (University of Nigeria Nsukka) for his technical support in writing this paper. My gratitude also goes to Dr. Barry Rawn (Brunel Institute of Power Systems, Brunel University, London) for his useful discussion that helped track this work.

REFERENCES

[1] M. S Okundamiya and O, Omorogiuwa., Viability of a Photovoltaic Diesel Battery Hybrid Power System in Nigeria, Iranica Journal of Energy and Environment. 6(1)(2015) 5- 12.
[2] J. O. Oji, N. Idusuyi, T. O. Aliu, M O. Petinrin, O A. Odejobi, and A. R.Adetunji., Utilization of Solar Energy for Power Generation in Nigeria, International Journal of Energy Engineering. 2(2) (2012) 54-59.
[3] E J, Bala, J O Ojosu, and. I H. Umar., Government Policies and Programmes on the Development of Solar PV Sub-sector in Nigeria, Nigeria Journal of Renewable Energy. 8(1) (2000)1-6.
[4] U B Akuru, I E, Onukwube, O I Okoro, and E S. Obe., Towards 100% Renewable Energy in Nigeria, Sustainable Energy Reviews. 71 (2017) 943 – 953.
[5] M F, Akorede, O. Ibrahim, S A, Amuda, A. O Otuoze, and B J. Olufeagba., Current Status and Outlook of Renewable Energy Development in Nigeria, Nigerian Journal of Technology (NIJOTECH). 36(1) (2017) 196 – 212.
[6] P. C Carolina, B. S Filipe, and L., Carlo., An Assessment of the Regional potential for Solar Power Generation in EU-28, Energy Policy,. 88 (2016) 86–9.
[7] T R, Ayodele, A. S. O, Ogunjuyigbe, and O. O. kinola., Optimal Location, Sizing, and Appropriate Technology Selection of Distributed Generators for Minimizing Power Loss Using Genetic Algorithm, Journal of Renewable Energy. (2015) 1 -10.
[8] P. Oshevire, T. Oladimeji, and S. Onohaebi., Smart Grid Technology and Its Possible Applications to the Nigeria 330 kV Power System, Smart grid and Renewable Energy. 4 (2013) 391-397.
[9] C G, Ozoegwu, C.A Mgbemene, and P.A. Ozor., The status of solar energy integration and policy in Nigeria, Renewable and Sustainable Energy Reviews. 70 (2017) 457-471.
[10] V E Nnaemeka and E E. Nebedum., Policies Enhancing Renewable Energy Development and Implications for Nigeria, Sustainable Energy Review. 4 (1) (2016) 1- 16.
[11] J. N. Nweke, A. O Ekwue, and E. C, Ejiogu., Optimal Location of Distributed Generation on the Nigerian Power System, Nigerian Journal of Technology (NIJOTECH). (35)2 (2016) 398 – 403.
[12] S O. Olayinka, S A. Muyiwa, M O. Olanrewaju., and O. F. Richard., Solar energy applications and development in Nigeria Drivers and barriers, Renewable and Sustainable Energy Review. 32(2004) 294 – 30.
[13] N. V. Emodi and D Y. Samson., Integrating Renewable Energy and Smart Grid Technology into the Nigerian Electricity Grid System, Smart Grid and Renewable Energy, Available online at http://dx.doi.org/10.4236/sgre.2014.59021. 5 (2014) 220-238.
[14] E. Christie, A. Ademola, and A. Olayinka,, The Daunting Challenges of the Nigerian Electricity Supply Industry, Journal of Energy Technologies and Policy. 5(9) (2015) 25 – 32.
[15] A M. Abdullahi, V W. Asan, M S, Firdaus, A M, Ibrahim, B. M, Abu, and M. Y. Norhidayah., An Assessment of Renewable Energy Readiness in Africa: A case study of Nigeria and Cameroon, Renewable and Sustainable Energy Reviews. 51 (2015) 775 – 784.
[16] S Mohamed and J.O. Petrin., Renewable Energy potentials in Nigeria: Meeting rural energy needs, Renewable and Sustainable Energy Reviews. 29 (2014) 72 -84.
[17] I A. Fidelis, N N, Bertrand, S O Olayinka, and A O. Sunday., Energy Resource Structure and On-Going Sustainable Development Policy in Nigeria: A Review, International Journal of Energy and Environmental Engineering. 5 (2014) 1 – 16.
[18] Clean Technology Fund Investment Plan for Nigeria Update Note. Available online at: http//www.google.com.ng/search?q=Technology+Fund+Investmen [accessed 23:07:2019].
[19] S. Boljevic., Maximizing Penetration Distributed Generation in Existing Urban Distribution Network, Ph.D. thesis, Dublin Institute of Technology. (2015) 44 – 100.

[20] R S, Yogendra, S. R Daka, and R G. Kesava., Optimal Siting and Sizing of Solar Power Sources in Interconnection Grid System, Indian Journal of Science and Technology. 9(12) (2016) 1-9.
[21] N. M. Duong Quoc Hung, and l R C. Bansa., Analytical Expressions for DG Allocation in Primary Distribution Networks, IEEE Transactions on Energy Conversion. 25(3) (2010) 814-820.
[22] M. Abbagana, G. A Bakare, and I. Mustapha., Optimal placement and sizing of Distributed Generator in a Power Distribution system using Differential Evolution, International Journal of Research in Engineering. (2)4 (2001) 26-42.
[23] N. Mohan, T. Ananthapadmanabha and A D Kulkarni., A Weighted Multi-Objective Index Based on Optimal Distributed Generation Planning in Distribution System, ELSEVIER Science Direct Procedia Technology. 21 (2015) 279 – 286.
[24] JVB Subramanyam and C. Radhakrishna., Distributed Generation Placement and Sizing in Unbalanced Radial Distribution System, World Academy of Science, Engineering and Technology. (3)4 (2009)753 – 760.
[25] T. K. A. Rahman, S. R. A. Rahim and I. Musirin., Implementation of Embedded Generator for Voltage Regulation and Loss Minimization in Distribution System, International Journal of Engineering and Technology. (1)1 (2004) 1 –12.
[26] P. Mehta, P. Bhatt, and V. Pandya., Optimal Selection of Distributed Generating Units and its Placement for Voltage Stability Enhancement and Energy Loss Minimization, Ain Shams Engineering Journal. 10(9) (2015) 1 – 15.
[27] A. O. Ekwue., Economic Evaluation of the Benefits of Distributed Generation on Distribution Network, International Conference on Electrical Power Engineering (ICEPENG), University of Nigeria Nsukka. (2015) 126 – 133.
[28] A O. Ekwue., Economic Evaluation of the Benefits of Distributed Generation on Distribution Networks based on NPV and Black-Scholes Techniques, Faculty of Engineering, University of Nigeria, Nsukka International Conference on Engineering and Technology as tools for sustainable economic and industrial growth in the 21st century. (2018) 1-10.
[29] D. M. Suzi and K. O. Gül., Energy and Cost Analyses of Solar Photovoltaic (PV) Micro-generation Systems for Different Climate Zones of Turkey, Energy and Power Engineering. (8)3 (2016) 117 – 129.
[30] International Renewable Energy (IRENA), Wind Power Renewable Energy Technologies: Cost Analysis Series. (1)5 (2012) 42 -52.
[31] Saule B. and Glenn P. J., On-Grid Solar PV versus Diesel Electricity Generation in Sub-Saharan Africa: Economics and GHG Emissions, Sustainability. 9(3) (2017) 1-15.
[32] European Photovoltaic Industry Association (EPIA) Greenpeace, "Solar Generation", Solar Photovoltaic Electricity Empowering the World. 6 (2011) 79 -86.
[33] Power Holding Company of Nigeria (PHCN) National Control Centre, Osogbo, (2015).
[34] Transmission Company of Nigeria (TCN), online at www.scribd.com/doc/35230315/Niger [Accessed: 12:05: 2019]
[35] U. O. Emmanuel, N. N. Samuel and K. I Gerald., Electric Power Transmission Enhancement: A Case of Nigerian Electric Power Grid, American Journal of Electrical And Electronic Engineering. 4(1) (2016) 33-39.
[36] Nigerian Electricity Regulatory Commission (NERC)., Regulations on Feed-in Tariff for Renewable Energy Sourced Electricity in Nigeria.
[37] C. Javier, P. Santiago, and S. P. Felix., Analytical Calculation of Photovoltaic Systems Maximum PowerPoint (MPP) Based on the Operation Point, Journal of Applied Sciences.7(9) (2017) 1-15.
[38] A. O. Ekwue., Technical Note: on the Correctness of Load Loss Factor, Nigerian Journal of Technology (NIJOTECH). 34(3) (2015) 546 – 547.
[39] A. O. Ekwue., Integration of solar photovoltaic (PV) to LV Distribution Network: A Case Study, Int. J. Renewable Energy Technology. 5(3) (2014) 217–228.
[40] S. Mathew, Fundamentals., Resource Analysis and Economics, Wind Energy (Springer Berlin Heidelberg New York). (2006) 209 – 235.
[41] S. Riccardo, S. Filippo, T. Salvatore, M. T. Anna, and T. Riccardo., Post Feed-in Scheme Photovoltaic System Feasibility Evaluation in Italy: Sicilian Case Studies, Energies. 7 (2004) 7147-7165.
[42] S. M. Najmulhoque, D. Barun Kumar and A. B. Mohd Rafique., Evaluation of Energy Payback and CO2 Emission of Solar Home Systems Bangladesh, Science Direct Procedia Engineering. 90 (2014) 675 – 679.