Performance Analysis of Utility Scale Photovoltaic Systems Integrated into an Islanded Nigeria Electric Power Grid

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Abstract: This paper is on the performance analysis of photovoltaic (PV) system integrated into an islanded Nigeria electricity grid. Electricity supply in Nigeria is abysmal and the effects on the economy and quality of life of Nigerians. This work carried out load flow studies of a part of the existing network, namely Afam Power Substation to Yenegoa Transmission Substation and the network with utility scale PV system integrated. Contingency analysis of the system was carried out using a set of possible contingency scenarios. PowerWorld Simulator was deployed in carrying out these analyses. With the incorporation of PV systems, stability was achieved when there was loss of generation. For example, when Afam Generation station was opened, system violations went from 14 (without PV) to 3 (with PV). Finally, the levelized cost of electricity (LCoE) for combined cycle gas turbines and PV systems was conducted. The LCoE for PV systems was 0.08985$/KWh which is less than LCoE of 0.245$/KWh as at 2013. The results also show that such hybrid generation planning can provide a high degree of redundancy in our fragile network.

Keywords: Utility Scale PV systems, Power Flow Analysis, Contingency analysis, PowerWorld.

1 Introduction

The issue of electric power demand supply in Nigeria has been seemingly intractable over the years. Several government and industry players have done a lot to improve the system, yet outcomes remain abysmal. Sambo (2008) showed that based on the so- called reference scenario, at 7% GDP growth, electricity demand projections for Nigeria is expected to peak at 119,200MW in the year 2030. With a base year of 2005, this would have implied a yearly addition of 4,538MW. It is estimated the installed capacity of off grid generation in Nigeria is about 14 GW (African-EU Renewable Energy Corperation Programme, 2016). This capacity exceeds the overall installed capacity. It has been shown that with average generation of 4000 MW, the per capita consumption is 0.03KW, a very poor performance (Ezirim, Eke, & Onuoha, 2016). Many manufacturing industries rely mostly on off grid generators for their electricity needs. In addition, overall, electricity consumption only accounts for one fifth of our final energy demand today, but contributes about 40% of energy related CO_2 emission. (International Energy Agency, 2018). Therefore, to improve generation capacity in Nigeria and reduce carbon emission it will be necessary to deploy as many as possible renewable energy sources in our energy mix.

Utility scale solar power plants are energy generating facilities capable of producing large amounts of electricity that can be fed into the electricity transmission grid; they range in size from 10 MW to over 200 MW(Xoubi, 2015). The integration of photovoltaic systems into the grid is gaining more traction today as a very important application of PV systems. According to levelized cost studies conducted by Lazard, an international financial advisory and asset management firm, the mean levelized cost of energy of utility-scale PV technologies is down approximately 13% from 2017 and the mean levelized cost of energy of onshore wind has declined almost 7% (Lazard, 2018). Utility scale photovoltaic systems promise to be a viable option in ramping up generation capacity of Nigeria, while protecting the environment.

Nigeria has recorded a total of 18 total system collapse and 6 partial system collapse between 2018-2019. The Nigeria National Grid is highly vulnerable to voltage instability. It was observed that the high rate of system collapse is largely due to faults (technical challenges) on the network, the state of the power system equipment and to some extent political issues (Samuel, Katende, Daramola, & Awelewa, 2014).

This reinforces the need for intentional power system islanding. Islanding refers to the condition in which a portion of the grid becomes temporarily isolated from the main grid but remains energized by its own distributed generation resource(s). Islanding may occur accidentally or deliberately. Traditionally, islanding has been seen by utilities as an undesirable condition due to concerns about safety, equipment protection, and system control(Greacen, Engel, Quetchenbach, & Berkeley, 2013). Islanding operation can be intentional and may be desired in cases where the central grid is prone to reliability problems. This reflects the Nigeria electric power scenario.

There is the need to conduct thorough analysis before integrating alternative and variable PV systems. In doing this, Powerworld a user-friendly and highly interactive power system analysis and visualization platform is employed. It integrates many commonly performed power system tasks–Contingency Analysis, Time-Step Simulation, OPF, ATC, PVQV, Fault Analysis, SCOPF, Sensitivity Analysis, Loss Analysis, Transient Stability, etc (PowerWorld Corporation, 2019).

2 Methodology

2.1 Procedure for the project.

The algorithm for the project is as stated below;

i. Collection of data: This involves the data of the generation stations, transmission lines, inter-bus transformers and connected loads.

ii. Model system in PowerWorld: This will include creating models of the network the system without Utility Scale PV systems and with PV systems integrated.

iii. Carry out load flow analysis of the system: This will include load flow analysis of the system

a. Without PV systems integrated

b. With PV systems integrated

iv. Develop a contingency list.

v. Conduct contingency analysis.

vi. Carry out cost analysis of the different plants.

2.2 Data Collection.

The data used for this study are generation Stations, inter-bus transformers and transmission line data. These are shown in Tables 1, 2 and 3.

Table 1: Generation station Voltage and power ratings.

S/N	Generating Stations	Voltage (kV)	Power (MW)
1	AFAM PS	330	1396
2	GBARAIN PS	132	120

Table 2: Data of the inter-bus transformers

S/N	Transformers	Power (MVA)	Reactance P,u	%impedance
1	330/132kV Tx @Alaoji (T2)	150	0.07573	11.36
2	330/132kV Tx @Alaoji (T3)	150	0.07573	11.36
3	330/132kV Tx @Alaoji (T4)	300	0.04523	13.57
4	330/132kV Tx @Afam (T1)	164	0.07074	11.46
5	330/132kV Tx @Alaoji (T2)	150	0.07573	11.36

Table 3: Transmission line data.

S/N	Lines	Voltage kV	Power MW	Len KM	R p.u	X p.u
1	Afam---Alaoji L1	330	400	25	0.0009825	0.0073898
2	Afam---Alaoji L2	330	400	25	0.0009825	0.0073898
3	Afam---Alaoji L1	132	300	30	0.0047001	0.058801
4	Afam---Alaoji L2	132	300	30	0.0047001	0.058801
5	Alaoji—PH Main L1	132	144	37	0.0002121	0.0770005
6	Alaoji—PH Main L2	132	144	37	0.0002121	0.0770005
7	Alaoji—Aba L1	132	100	7	0.0011204	0.01412
8	Alaoji—Aba L2	132	100	7	0.0011204	0.01412
9	Alaoji—Umuahia L1	132	80	57	0.0022401	0.016845
10	Alaoji—Umuahia L2	132	80	57	0.0022401	0.016845
11	Alaoji—Owerri L1	132	100	60	0.0112947	0.1412004
12	Alaoji—Owerri L2	132	100	60	0.0112947	0.1412004
13	Owerri---Ahoada L1	132	100	74	0.0029084	0.021869

14	Owerri---Ahoada L2	132	100	74	0.0029084	0.021869
15	Ahoada---Gbarain L1	132	50	37.5	0.0014542	0.0109345
16	Ahoada---Gbarain L2	132	50	37.5	0.0014542	0.0109345
17	Gbarain—Yenogoa L1	132	50	37.5	0.0014542	0.0109345
18	Gbarain—Yenogoa L2	132	50	37.5	0.0014542	0.0109345

2.3 Load Flow Analysis.

The derivation of power flow equations for power system networks are shown in Fig. 1.

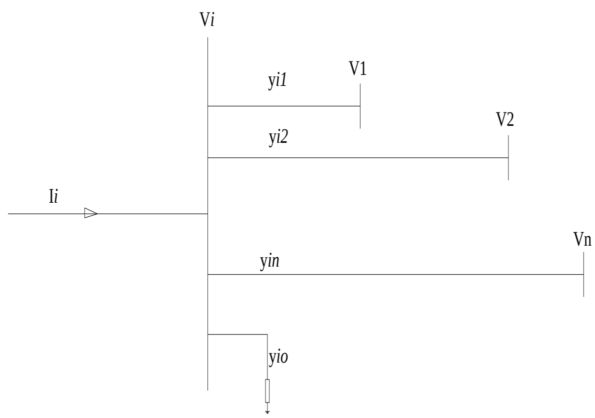

Figure 1: Typical Power System Network

The current entering the *i*th bus is given as

$$I_i = y_{io}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{ik}(V_i - V_k) \quad (2.0)$$

Collecting like terms in equation 2.0, we have,

$$I_i = (y_{io} + y_{i1} + y_{i2} + \cdots + y_{ik})V_i - y_{i1}V_1 - y_{i2}V_2 - \cdots - y_{ik}V_k \quad (2.1)$$

The term $(y_{io} + y_{i1} + y_{i2} + \cdots + y_{ik})$ is the self-admittance and the coefficients of $V_1, V_2, \ldots V_k$ are the mutual admittances.

We simplify equation (2.1) as

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k;\ i = 1,2 \ldots, n \quad (2.2)$$

The complex power injected into the *i*th bus of the power system is

$$S_i = P_i + jQ_i = V_i I_i^* \text{ ;where } i = 1,2, \ldots n \quad (2.3)$$

Where V_i is the ith bus voltage with respect to the earth and I_i^* is the conjugate of the current I_i. The power conjugate therefore becomes,

$$S_i = P_i - Q_i = V_i^* I_i \text{ ; where } i = 1,2 \ldots, n \quad (2.4)$$

Substituting I_i into eqn 2.4

$$S_i = P_i - jQ_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k; \text{ where } i = 1,2, \ldots, n \quad (2.5)$$

Separating the real and reactive components of the above equation

$$\text{Real power} = P_i = R_e \{V_i^* \sum_{k=1}^{n} Y_{ik} V_k\} \quad (2.6)$$

$$\text{Real power} = S_i = -I_m \{V_i^* \sum_{k=1}^{n} Y_{ik} V_k\} \quad (2.7)$$

The Voltage and the admittance in polar form as given as

$$V_i = V_i \angle \delta_i, \quad V_i^* = V_i \angle -\delta_i \quad \text{and } Y_{ik} = Y_{ik} \angle \theta_{ik}, \quad (2.8)$$

The real and reactive powers in polar form are expressed

$$\text{Real power} = P_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k \cos(\theta_{ik} + \delta_{k-}\delta_i) \quad (2.9)$$

$$\text{Reactive power} = Q_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k \sin(\theta_{ik} + \delta_{k-}\delta_i) \quad (2.10)$$

Due the non-linearity of the above equations, numerical methods are employed in the evaluation of the solutions to the equations. Several techniques exist like the Newton Raphson, Gauss Seidel and the Fast Decouple methods. The Newton Method is employed in this project.

2.4 PowerWorld Load Flow Simulation

The PowerWorld model of the islanded network and the modified network are shown in Figs. 2 and 3.

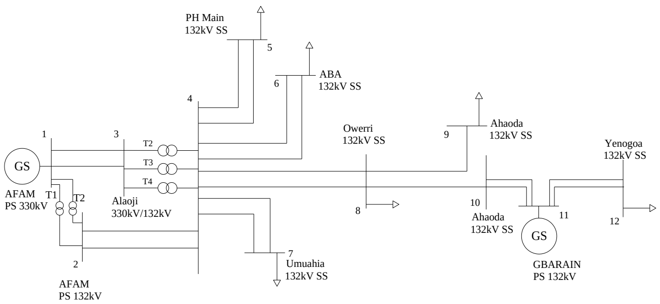

Figure 2: Single Line Diagram of the network

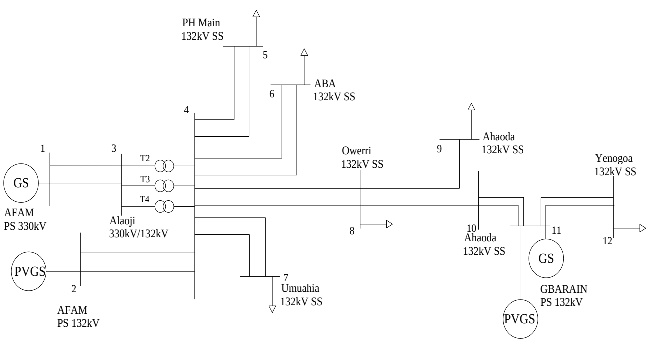

Figure 3: Single Line Diagram of the modified network

The data of the various part of the network were input in the PowerWorld Simulator. This was used to calculate the voltages, power flows, the voltage angles of the busses. The PowerWorld base settings include

i. Base MVA = 100

ii. Voltage tolerance = $\pm 5\%$

iii. Maximum number of iterations = 100

iv. Range of Voltage angle= $\pm$ 10°

v. Power Factor = 0.8

vi. Slack bus voltage and angle = 1.05 $\angle$ 0.00°

vii. Slack Bus = Afam 330kV

viii. Machine models: REG-C (Renewable Energy Generator- Controller) for PV generators and GENTPF for Combined Cycle Gas Turbine.

2.5 Contingency Analysis

Since the Photovoltaic system is a still a budding development, it is crucial to explore the behaviour of the system under an unexpected or planned system outage to detect the weakness that the network will bear. Contingencies can exist as the result of the outages of the system elements such as: generator, network transmission lines and system transformer for the purpose this work, we focus on the effect of outages of generating stations, particularly with the PV systems integrated and the effect of variability of the photovoltaic source on the system.

2.6 Contingency List

The contingency list is set in order to identify the effect of contingencies on the system operation and to experience which critical contingencies causes most violation of the system.(Alex, 2015) In this project, the contingencies tested are

i. Open Afam 330kV power station **without** the photovoltaic systems

ii. Open Gbarain 132kV power station **without** the photovoltaic systems

iii. Open Afam 330kV power station **with** the photovoltaic systems

iv. Open Gbarain 132kV power station **with** the photovoltaic systems

v. Zero Insolation at Afam 132kV Photovoltaic Station

vi. Zero Insolation at Gbarain 132kV Photovoltaic Station

The PowerWorld simulator was used for the simulation of each of the contingencies.

2.7 Cost Analysis

The levelized cost of electricity (LCoE) was evaluated for the two different power generation sources namely natural gas and solar energy. The Nigerian Electricity Regulation Council employs the US Department of Energy method of calculating LCOE. The formula is given by equation 11.

$$LCOE = \frac{\text{Capital Cost}*CRF*(1-T*D_{pv})}{8760*\text{Capacity factor}*(1-T)} + \frac{\text{Fixed O \& }M}{8760*\text{Capacity Factor}} + \text{Variable O \&M} + \text{Fuel Price} * \text{Heat Rate} \quad (2.11)$$

CRF = capital recovery factor, turning capital costs into annual values (if capital is financed at discount rate D)

Fixed O & M = Fixed Operation and maintenance Costs.

Variable O & M = Variable Operation and maintenance Costs.

T= Tax rate, DPv = Depreciation Factor

$$CRF = \frac{D*(1+D)^N}{(1+D)^N-1} \quad (2.12)$$

D = Discount rate

N= Lifetime of System.

The cost components for evaluating LCOE are itemized in Table 4.

Table 4: Cost Components of the LCoE for CCGT and PV systems(Roche, Ude, & Donald-Ofoegbu, 2017)

PARAMETERS	UNIT	CCGT	Photovoltaic
Capital Cost	$/KW	1000	1150
Fixed O & M	$/KW-Yr	15.50	17.30
Variable O & M	$/KWh	0.006	0
Capacity Factor	%	80	19
Discount Rate	%	11	11
Fuel Cost	$/MMBtu	7	0
Depreciation	%	10	10
Tax Rate	%	5	0
Heat Rate	Btu/KWh	11039	0

Assuming N = 30 years and calculating the LCoE using equation (3.18)

1. For combined cycle gas turbine.

$$CRF = \frac{0.11*(1.11)^{30}}{(1.11)^{30}-1} = 0.1150$$

$$LCoE = \left(\frac{1000*0.1150*(1-(0.05*0.1))}{8760*0.8*(1-0.5)}\right) + \left(\frac{15.50}{8760*0.8}\right) + 0.006 + \left(\frac{7}{10^6} * 11039\right) = 0.1027\$/KWh$$

2. For PV systems

$$LCoE = \left(\frac{1150*0.1150*(1-(0*0.1))}{8760*0.19*(1-0)}\right) + \left(\frac{17.30}{8760*0.19}\right) + 0 + (0 * 0) = 0.08985\ \$/KWh$$

3. Results and Discussion

This chapter presents results and discussion of the of the objectives in chapter 3:

i. Load flow analysis of the network without PV system

ii. Load flow analysis of the network with PV system integrated

iii. Contingency analysis of the network without PV system integrated.
iv. Contingency analysis of the network with PV system integrated.
v. Cost Analysis of the system.

3.1 Results from Load Flow Analysis of The Network Without PV System

From the results of the load flow analysis of the system as shown in Table 5, the following is deduced.

a. All the bus voltage magnitudes are within the acceptable limit of ±5%

b. There are violations of buses 8, 9, 10, 11, 12, which are not within the ± 10° range. This is explained by the fact that Gbarain PS is not sufficient to boost the real and reactive power supply at that end and there are reactors installed at the downstream station for compensation of losses. Hence the need for a system that can boost supply and compensate for losses. The Photovoltaic system comes as a viable option.

c. The major active and reactive power demand is on Afam 330kV.

d. which will definitely have impact on system stability. Therefore, the system is always close to the tipping point and this explains clearly the partial collapses often experienced in this segment. The graphical representation of the bus voltage and voltage angle profile in Figs. 4 and 5 further explains the results.

3.2 Results from Load Flow Analysis of the Network with PV System

The results in Table 6 and Figs. 6 and 7 show a clear improvement when the PV systems were integrated into the select segment of the grid. The following can be clearly seen.

a. All the bus voltage magnitudes are within the acceptable limit of ±5%, even with more improvement in values.

b. There are no violations of buses angles as all are within the ± 10° range. This is due to the fact that the PV systems assisted in improving the bus angle by supplying more active power.

Table 5: Results of the PowerWorld Load Flow Simulation without PV.

Bus No	Name	Pu Volt	Ang. Deg	Gen MW	Gen MVar
1	Afam PS	1.05	0.00	537.8	225.97
3	Alaoji TS	1.04238	-0.72		
2	Afam PS	1.03063	-2.82		
4	Alaoji PS	1.01356	-5.10		
7	Umuahia TS	1.01151	-5.39		
5	Aba TS	1.01006	-5.68		
6	PH Main TS	0.998	-8.24		
11	Gbarain PS	0.96317	-12.02	120	30
10	Ahaoda TS	0.96164	-12.07		
8	Owerri TS	0.96089	-12.28		
12	Yenogoa TS	0.96286	-12.36		
9	Ahoada TS	0.95593	-13.12		

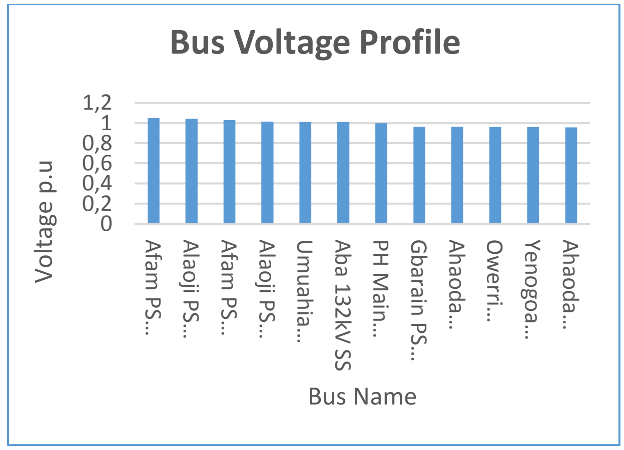

Figure 4: Bar chart of the Bus voltages without PVsystem.

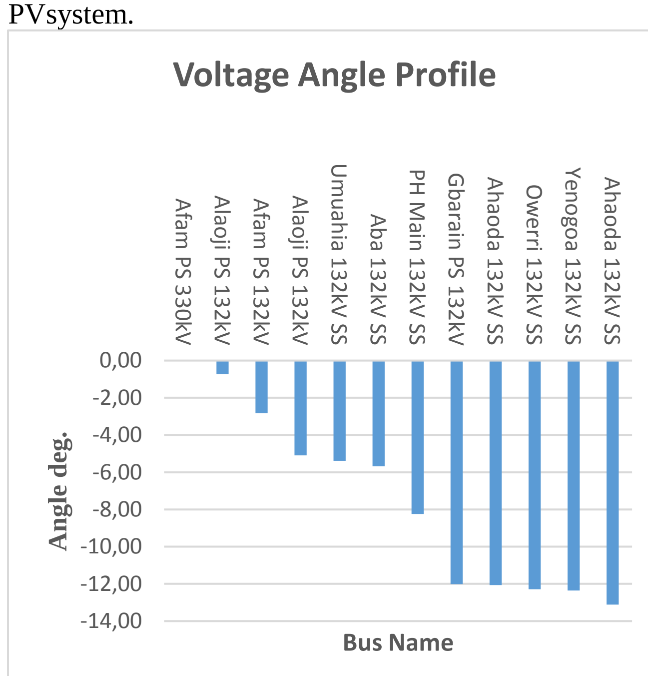

Figure 5: Bar chart of Voltage angles without PV system.

Table 6: Results of the PowerWorld Load Flow Simulation with PV.

Bus No	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)
1	Afam PS 330kV	330	1.05	346.5	0
2	Afam PS 132kV	132	1.03328	136.392	2.46
3	Alaoji TS 132kV	330	1.04438	344.646	-0.24
4	Alaoji TS 132kV	132	1.0173	134.283	-1.85
5	Aba 132kV TS	132	1.0138	133.822	-2.43
6	PH Main 132kV TS	132	1.0018	132.238	-4.97
7	Umuahia 132kV TS	132	1.01525	134.013	-2.14
8	Owerri 132kV TS	132	0.97648	128.895	-4.00
9	Ahaoda 132kV SS	132	0.97086	128.153	-4.82
10	Ahaoda 132kV TS	132	0.98055	129.433	-2.23
11	Gbarain PS 132kV	132	0.98171	129.586	-1.79
12	Yenogoa 132kV TS	132	0.97948	129.291	-2.12

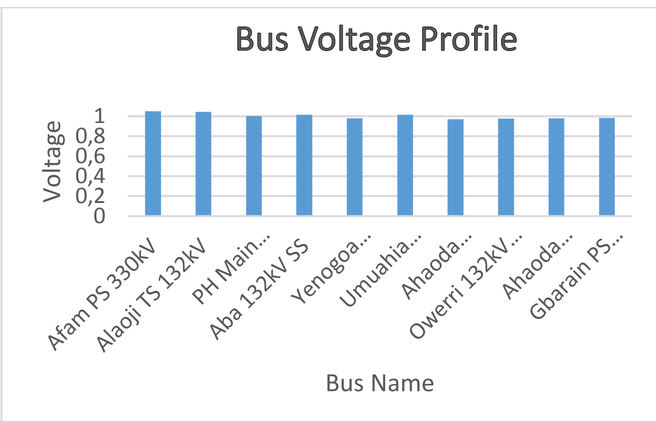

Figure 6: Bar chart of the Bus voltages with PV System.

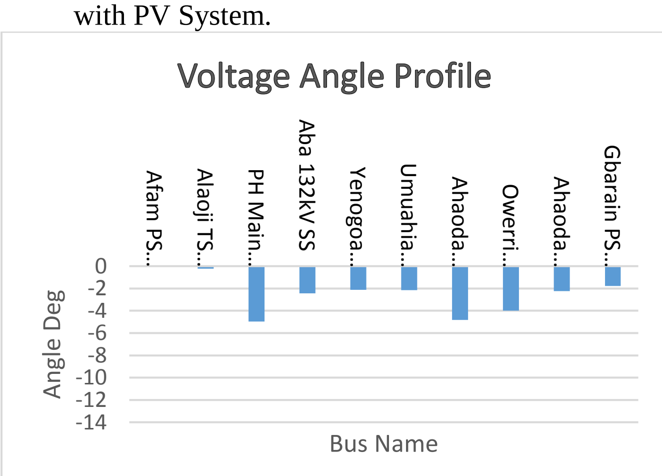

Figure 7: Bar chart of the Bus voltages without PV System.

3.3 Results from Contingency Analysis of the Network Without PV System

The contingency lists and the results of the simulations are shown in Tables 7, 8 and 9.

The results above registered 14 violations when Afam PS was suddenly lost. The violations are severe as seen from the 9 bus voltage violations and 5 transmission line violations, thus whenever Afam PS is lost, the segment must collapse. Again, losing Gbarain PS recorded 5 bus voltage violations which exceeded the ±5% voltage limits and overloaded Alaoji-Owerri line with above 30%, this could lead to loss of that transmission line thus compromising the system. Thus, this network as is, requires further redundancies as this contingency tested can trigger a system collapse of the entire grid.

Table 7: Results of the Power World contingency analysis without PV system

VIOLATION SUMMARY WHEN AFAM 330kV PS WAS OPENED WITHOUT PV				
Category	**Element**	**Value**	**Limit**	**Percent**
Branch MVA	Bus(4)-Bus(8)	247.2	125	197.82
Branch MVA	Bus(4)-Bus(8)	247.2	125	197.82
Branch MVA	Bus(8)-Bus(10)	779.8	125	623.85
Branch MVA	Bus(10)-Bus(11)	404.3	62.5	646.99
Branch MVA	Bus(10)-Bus(11)	404.3	62.5	646.99
Bus Low Volts	Bus(1)	0.567	0.95	59.75
Bus Low Volts	Bus(2)	0.567	0.95	59.75
Bus Low Volts	Bus(3)	0.567	0.95	59.75
Bus Low Volts	Bus(4)	0.567	0.95	59.75
Bus Low Volts	Bus(5)	0.561	0.95	59.13
Bus Low Volts	Bus(6)	0.537	0.95	56.61
Bus Low Volts	Bus(7)	0.564	0.95	59.39
Bus Low Volts	Bus(8)	0.829	0.95	87.35
Bus Low Volts	Bus(9)	0.823	0.95	86.64

Table 8: Results of the Power World contingency analysis without PV system

VIOLATION SUMMARY WHEN AFAM 330kV PS WAS OPENED WITHOUT PV				
Category	**Element**	**Value**	**Limit**	**Percent**
Bus Low Volts	Bus(12)	0.8661	0.95	96.23
Bus Low Volts	Bus(8)	0.882	0.95	98
Bus Low Volts	Bus(9)	0.8757	0.95	97.31
Bus Low Volts	Bus(10)	0.8712	0.95	96.8
Bus Low Volts	Bus(11)	0.8686	0.95	96.51
Branch MVA	Bus(4)-Bus(8)	173.07	125	138.46
Branch MVA	Bus(4)-Bus(8)	173.07	125	138.46

3.4 Results from Contingency Analysis of the Network with PV System

The contingency lists and the results of the simulations are shown in Table 9.

The results showed improvements when the Afam 330kV PS was opened. The following could be deduced.

a. There were only 3 violations which is far removed from the 13 violations recorded without PV system.

b. There were no bus voltage violations.

c. The percentage violations of the transmissions are negligible compared to the results got without PV systems. These line overload can be remedied by simply increasing line capacities.

Hence, the PV systems will provide a high degree of stability when there is outage of any of the generation plants. As expected, no violations occurred when Gbarain PS was lost.

Table 9: Results of the Power World contingency analysis with PV system

VIOLATION SUMMARY WHEN GBARAIN 132 kV PS WAS OPENED WITH PV				
Category	Element	Value	Limit	Percent
Branch MVA	Ahaoda(10)-Owerri(8)	135.79	125	108.63
Branch MVA	Gbarain(11)-Ahaoda(10)	67.98	62.5	108.76
Branch MVA	Gbarain(11)-Ahaoda(10)	67.98	62.5	108.76

3.5 Results from Contingency Analysis of the Network when there is Zero Insolation at the PV Power Stations

The basic challenge faced with PV systems is the variability of the source. The results here tested the effect of losing any of the PV systems. The violations observed in Table 10 are transmission lines overload occasioned by the demand for more active power from

a. Gbarain PS when there was zero insolation at Afam 132kV PVGS, Owerri-Ahoada line2 and Gbarain-Ahoada Line1&2 being the trunk lines in this case (see appendix for branch flows).

Table 10: Results of the Power World contingency analysis without PV system

Violations when there is Zero insolation at AFAM PVGS				
Category	**Element**	**Value**	**Limit**	**Percent**
Branch MVA	Ahaoda TS (10) - Owerri TS (8)	135.79	125	108.63
Branch MVA	Gbarain PS (11) - Ahaoda SS (10)	67.97	62.5	108.76
Branch MVA	Gbarain PS (11) - Ahaoda SS (10)	67.97	62.5	108.76
Violations when there is Zero insolation at GBARAIN PVGS				
Branch MVA	Alaoji TS(4) - Owerri TS (8)	163.88	125	131.1
Branch MVA	Alaoji TS (4) - Owerri TS (8)	163.88	125	131.1

b. Afam PS when there was zero insolation at Gbarain PVGS, Alaoji-Owerri transmission lines.

electricity tariff because while deploying the system, cheaper electricity costs are likely going to be achieved.

3.6 Results from Cost Analysis

The LCoE calculation in chapter three was based on 2017 variables. The tax rate was based only on the VAT for gas supply. The calculated LCoE for the combined cycle gas turbines is 0.1027$/KWh, while

LCoE for PV system is 0.08985$/KWh. This implies that the PV systems over its lifetime will provide cheaper electricity than the conventional sources.

4. Conclusion

The performance analysis of Nigeria electricity network was effectively carried out with the clear set objectives in focus throughout the study. Using PowerWorld simulator, the load flow analysis and contingency analysis of the modified network, that is the network with PV system integration, were studied. The results showed that PV systems whose source is in abundance in Nigeria can help us achieve power system adequacy and stability to reasonable extent.

This work is recommended for all power generation companies in Nigeria (Gencos). Once Nigeria power network is strengthened, the next challenge will be low generation capacity. This will lead to more electricity supply challenges in Nigeria. Generation companies can use the PV systems as relief stations when there is good insolation and gas supply is low. They can also use PV systems integrated to the grid to control

REFERENCES

African-EU Renewable Energy Corperation Programme. (2016). Captive Power in Nigeria Comprehensive Guide to Project Development. Retrieved from https://www.ctc-n.org/sites/

Alex, M. (2015). *Power Flow And Contingency Analysis: Case Of Rwanda High Voltage Power System*.

Ezirim, G., Eke, O., & Onuoha, F. (2016). The Political Economy of Nigeria's Power Sector Reforms: Challenges and Prospects, 2005-2015. *Mediterranean Journal of Social Sciences MCSER Publishing*, *7*(4), 443–453. https://doi.org/10.5901/mjss.2016.v7n4p

Greacen, C., Engel, R., Quetchenbach, T., & Berkeley, L. (2013). A Guidebook on Grid Interconnection and Islanded Operation of Mini - Grid Power Systems Up to 200 kW.

International Energy Agency. (2018). World Energy Outlook 2018 The gold standard of energy analysis. Retrieved from https://www.iea.org/weo2018/electricity/

Lazard. (2018). Levelized Cost of Energy and Levelized Cost of Storage 2018. Retrieved May 15, 2019, from https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

PowerWorld Corporation. (2019). PowerWorld – The Visual Approach to Electrical Power Systems. Retrieved May 18, 2019, from https://www.powerworld.com/

Roche, M., Ude, N., & Donald-Ofoegbu, I. (2017). *True Cost of Electricity: Comparison of Costs of Electricity Generation in Nigeria*. Retrieved from https://ng.boell.org/sites/default/files/true_cost_of_power_technical_report_final.pdf

Sambo, A. (2008). Matching electricity supply with demand in Nigeria. *International Association for Energy Economics*, 32–36. Retrieved from https://www.iaee.org/documents/newsletterarticles/408sambo.pdf

Samuel, I., Katende, J., Daramola, S. A., & Awelewa, A. (2014). Review of System Collapse Incidences on the 330-kV Nigerian National Grid. *International Journal of Engineering Science Invention*, *3*(4), 55–59. Retrieved from www.ijesi.org55%7C

Xoubi, N. (2015). Viability of a Utility-Scale Grid-Connected Photovoltaic Power Plant in the Middle East. *Journal of Applied Sciences*, *15*(11), 1278–1287. https://doi.org/10.3923/jas.2015.1278.1287