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Performance Evaluation of the Nigeria Power System Dynamics Using Distributed Generator

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Abstract
In this paper, the Nigeria 330kV grid network was evaluated using the power system analysis tool (PSAT) simulation software to determine the impact of the DG placement on stability of the 41 bus Nigeria grid Network System. The effect of the installation of the distributed generators on the distribution network in the Nigeria power system was analyzed and the result was compared with the base case without the installation of the distributed generators. To achieve this, power flow analysis using the Newton-Raphson technique was used to estimate the system variables such as voltage, angle, active and reactive power without DG, with DG and in the presence of fault. Results showed a reduction in the transmission line loss from 107.23MW to 83.16MW which is about 22% reduction and the rotor speed of the generator at Shiroro and was stabilized after 16.9 seconds compared to the base case that took after 17.43 seconds. Thus, the installations of distributed generators have the capacity to reduced line losses, voltage profile improvement and transient stability in the Nigeria power system.

Keywords: *Dynamics, Power system, Generator, Distributed, Perfomance, Analysis, Transient*

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I. INTRODUCTION

The traditional power system consist of a central plants with large generating facilities usually located either close to resources or located far from populated load centers. This in turn, supplies the transmission and distribution network that distributes bulk power to load centers and from there to consumers. In recent year, it has been found that efficiency gains no longer come from increasing the generating capacity, but from smaller units located closer to sites of demand [1]. Distributed Generators are small generators (less than 10MW) that are connected to the distribution network of the power system. Their advantages are the ability to reduce or postpone the need for investment in the transmission and distribution infrastructure when optimally located; the ability to reduce technical losses within the transmission and distribution networks as well as general improvement in power quality and system reliability [2]. The impact of distributed generator (DG) on the electricity industry is always determined in planning by carrying out load flow computations, especially when the penetration ratios are still relatively small. However, as the installed capacity of DG increases, its impact on the power system behavior becomes more expressed and will eventually require full-scale detailed dynamic analysis and simulations to ensure a proper and reliable operation of the power system with large amounts of DG [3]. Power flow provides a systematic mathematical approach to various bus voltage, their phase angles, active and reactive power through different branches, generators and loads under steady state condition. It is an important tool involving numerical analysis applied to power system [4]. Most widely used technique is load flow technique for stability analysis [5]. Modal analysis method which shows the sensitivity of reactive power with respect to voltage magnitude is another commonly used method of stability analysis. Another method to predict voltage stability is the minimum singular value of Newton Raphson power flow Jacobian matrix [6]. In modern power system setting, distributed generator (DG) plays an important role. To meet the growing power demand, Distributed Generators are very much useful. To increase the reliability of the system, the distributed generators can be placed with an appropriate size; this improves the voltage profile of the system which also improves the voltage stability margin of the system [7].

In [8], a Monte Carlo technique was demonstrated to analyze the impacts of residential PV on a real LV network located in the island of Gozo, Malta. The PV location was considered from two scenarios: first, when PVs are located from the substation to the last customer (downstream) and second, when they are located from the last customer to the substation (upstream). Fifteen-minute resolution data was considered for this analysis. For each corresponding Monte Carlo simulation and penetration level, PV impacts on voltages were calculated using European Standard EN50160.

Solar photovoltaic generation and its integration impact on the existing power grid was studied by [9], the research study looked at the impact with photovoltaic connected at selected bus of the test system. The impacts on the voltage level, voltage profile and voltage drop were observed. Results were obtained when solar PV was integrated to the grid. When the results are compared to those without solar PV integration, it is observed that the voltage of the bus improved while a reduction in voltage drop is realized.

In [10], the effects of distributed generator on electric power systems was described. Distributed generator is a term that refers to the production of electricity near the consumption place. The effects of distributed generator are: short circuit levels are increased, load losses change, voltage profiles change along the network, voltage transients will appear, congestions can appear in system branches, power quality and reliability may be affected and the networks protections may not function properly. A load flow analysis is done for the IEEE 14 system in which a distributed generator is added, that is on-grid or off-grid.

The integration of renewable energies into the Nigeria grid is vital. This is due to the growing demand in electric power, environmental and economic concerns [11]. Unfortunately, none of the works reviewed above has demonstrated the dynamic impact of DGs integration using parameters specific to the Nigeria grid. Hence, this work is positioned to analyze and simulate the Nigeria grid dynamics using distributed generators with the intention to explore the impact of DGs integration on voltage profile improvement and power loss minimization.

1.2 MATERIALS AND METHODS

The line diagram and data of the Nigeria transmission network were gotten from the National Control Centre of Power Holding Company of Nigeria, Osogbo. Nigeria transmission network power flow analysis was investigated in Matlab/PSAT environment as shown in Figure 2.1

Table 2.1: Nigeria bus Data

S/N	Bus Number	Bus Name	V [kV]	phase [rad]	P gen [MW]	Q gen [MVar]	P load [MW]	Q load [MVar]
1	Bus1	B. Kebbi	330	0	0	0	162	122
.2	Bus10	Ganmo	330	0	0	0	100	75
3	Bus11	Mando	330	0	0	0	142	107
4	Bus12	Katampe	330	0	0	0	303	227
5	Bus13	Gwagwalada	330	0	0	0	220	165
6	Bus14	Olorunsogo	330	0	296	-73.8410781	0	0
7	Bus15	Akangba	330	0	0	0	203	152
8	Bus16	Egbin	340.23	0	1071.38924	836.9751162	0	0
9	Bus17	Omotosho	330	0	211	-98.2210824	0	0
10	Bus18	Oke-Aro	330	0	0	0	120	90
11	Bus19	Benin	330	0	0	0	144	108
12	Bus2	Kainji	330	0	715	-232.998959	0	0
13	Bus20	Kano	330	0	0	0	194	146
14	Bus21	Jos	330	0	0	0	72	54
15	Bus22	Lokoja	330	0	0	0	120	90
16	Bus23	Aja	330	0	0	0	115	86
17	Bus24	Onitsha	330	0	0	0	100	75
18	Bus25	Ajaokuta	330	0	0	0	120	90
19	Bus26	Delta	333.96	0	105	71.16199671	0	0
20	Bus27	Sapele	333.96	0	115	5.860233657	0	0
21	Bus28	Makurdi	330	0	0	0	160	120
22	Bus29	Gombe	330	0	0	0	97.4616553	53.835962
23	Bus3	Jebba Ts	330	0	0	0	260	195
24	Bus30	New Haven	330	0	0	0	196	147
25	Bus31	Okpai	333.96	0	438	121.6946766	0	0

26	Bus32	Alaoji	330	0	65	42.82414846	0	0
27	Bus33	Geregu	330	0	56	64.8467285	0	0
28	Bus34	Aladja	330	0	0	0	210	158
29	Bus35	Ugwuaji	330	0	0	0	175	131
30	Bus36	Yola	330	0	0	0	86.9746673	47.8360670
31	Bus37	Damaturu	330	0	0	0	83.7144562	38.7730113
32	Bus38	Afam	330.99	0	446	75.17309729	0	0
33	Bus39	Ikot Ekpene	330	0	0	0	165	127
34	Bus4	Jebba Gs	339.9	0	506	455.664525	0	0
35	Bus40	Adiabor	330	0	0	0	90	68
36	Bus41	Odukpani	330	0	223	70.57891546	0	0
37	Bus5	Shiroro	330	0	554	0	0	0
38	Bus6	Osogbo	330	0	0	0	127	95
39	Bus7	Aiyede	330	0	0	0	174	131
40	Bus8	Ikeja West	330	0	0	0	847	635
41	Bus9	Ihovbor	330	0	93	00	0	0

Table 2.2: Transmission Line Data

S/N	Transmission Line	Resistance	Inductance	Susceptance
1	Kainji-Jebba	0.0031834	0.0239429	0.31
2	B. Kebbi- kainji	0.0121836	0.0918336	1.21
3	Shiroro-katampe	0.005121	0.043588	0.56587
4	oshogbo-Ganmo	0.00311	0.026403	0.341432
5	Jebba-oshogbo	0.005575	0.047487	0.617196
6	Jebba-oshogbo	1.005575	1.047487	1.617196
7	Ikeja West- Oshogbo	0.008813	0.075657	0.972381
8	oshogbo-Ayede	0.004102	0.034861	0.451573
9	Ganmo – Jebba	0.002505	0.021255	0.274643
10	ikeja West-olorunsango	0.003855	0.032749	0.414631
11	oshogbo-olorunsango	0.0077425	0.058231	0.77
12	Jos-Mando	0.0007074	0.0053206	0.05
13	Ikeja West-Akangba	0.0024367	0.0183267	0.2
14	Egbin-Ikeja West	0.0005502	0.0041382	0.04
15	Aja – Egbin	0.0098648	0.0741936	0.98
16	Egbin-Benin	0.000369	0.003131	0.040387
17	Ikeja West - Oke Aro	0.001275	0.010818	0.139606
18	Oke Aro – Egbin	0.0110045	0.0827658	1.09
19	Ikeja West – Omotosho	0.0110045	0.0827658	1.09
20	Omotosho – Benin	0.000287	0.002431	0.002431
21	Jebba GS – Jebba	0.0076639	0.0576404	0.76
22	Ajaokuta – Benin	0.0053843	0.0404961	0.63
23	Benin – Onitcha	0.0076639	0.056404	0.76
24	Ajaokuta – Benin	0.0043296	0.0541521	0.019608
25	Geregu-Ajaokuta	1.0043296	1.0541521	1.019608
26	Geregu-Ajaokuta	0.0019651	0.0147796	0.19

27	Benin-sapele	0.002476	0.0186223	0.24
28	sapele-Delta	0.0031834	0.0239429	0.31
29	Kainji-Jebba	0.003817	0.03245	0.42
30	Benin – Delta	0.003773	0.0283768	0.37
31	Onitcha-New Haven	0.00213	0.018086	0.233596
32	Okpai – Onitcha	1.00213	1.018086	1.233596
33	Okpai – Onitcha	0.0060525	0.0455212	0.6
34	Onitcha-Alaoji	0.0009825	0.0073898	0.09
35	Alaoji-Afam	0.000346	0.002935	0.037867
36	New heaven - Ugwuaji	0.001361	0.011547	0.149041
37	Ajaokuta – Lokoja	0.000287	0.002431	0.031373
38	Jebba GS – Jebba	0.0098648	0.0741936	0.98
39	Ihovbor-Benin	0.002476	0.0186223	0.24
40	alaoji-Sapele	0.0010218	0.0076853	0.1
41	alaoji-Delta	0.0047	0.039982	0.51
42	Yola-Gombe	0.0090394	0.0079862	0.9
43	Mando-Kano	0.008942	0.076811	1.010504
44	Gombe-Jos	0.004876	0.041485	0.538257
45	Gombe-Damaturu	0.004981	0.042387	0.55009
46	Gwagwalada-lokoja	0.008543	0.073297	0.962559
47	Jebba-Shiroro	0.0184481	0.2307352	0.04
48	Gwagwalada-lokoja	0.0061704	0.3696472	0.07
49	Shiroro-Gwagwalada	0.009977	0.1247853	0.02
50	katampe-Gwagwalada	0.0060525	0.0455212	0.6
51	Ugwuaji-Markurdi	0.010415	0.0783319	1.04
52	Jos-Markurdi	1.010415	1.0783319	2.04
53	Jos-Markurdi	0.0300841	0.3837738	0.08
54	Ugwuaji-Markurdi	0.0060525	0.0455212	0.6
55	Ikot Ekpene-Ugwuaji	0.0095897	0.0721245	0.05
56	Jebba-Shiroro	0.0135537	0.1695197	0.03
57	Ikot Ekpene-Adiabor	0.0098648	0.0741936	0.98
58	oshogbo-Ihovbor	0.0112947	0.1412664	0.2
59	Ikot Ekpene-Alaoji	0.0135537	0.1695197	0.03
60	Ikot Ekpene-Afam	0.003773	0.0283708	0.37
61	Mando-Shiroro	0.0122359	0.1530386	0.03
62	Adiabor-Odukpani	0.000538	0.004559	0.058825
63	Mando-Shiroro	0.0122359	0.1530386	0.03

1.3 The Newton-Raphson Method

There are several methods of solving the non-linear system of equations. The most efficient one is the Newton-Raphson method. This method begins with initial guesses of all unknown variables such as voltage magnitude and angles at load buses and voltage angle at generator buses. Next, a Taylor series is written for each of the power balance equations included in the system of equations. The result is a linear system of equations that can be expressed as follows:

$$\begin{bmatrix} \Delta\theta \\ |\Delta V| \end{bmatrix} = J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad (2.1)$$

$$\Delta P_i = -P_i + \sum_{k=1}^{n} |V_i|\,|V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \qquad (2.2)$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^{n} |V_i|\,|V_k|(G_{ik}\cos\theta_{ik} - B_{ik}\sin\theta_{ik}) \qquad (2.3)$$

$$J = \begin{vmatrix} \frac{\partial \Delta P}{\partial \theta} & \frac{\partial \Delta P}{\partial |V|} \\ \frac{\partial \Delta Q}{\partial \theta} & \frac{\partial \Delta Q}{\partial |V|} \end{vmatrix} \qquad (2.4)$$

Where ΔP *and* ΔQ are called the mismatch equations and J is a matrix of partial derivatives known as a Jacobian. The linear system of equation is solved to determine the next guess (m+1) of voltage magnitude and angles based on

$$\theta^{m+1} = \theta^m + \Delta\theta \qquad (2.5)$$

$$|V|^{m+1} = |V|^m + \Delta|V| \qquad (2.6)$$

The process continues until a stopping condition is met. A common stopping condition is to terminate if the norm of the mismatch equation is below a specified tolerance.

II. RESULT AND DISCUSSION

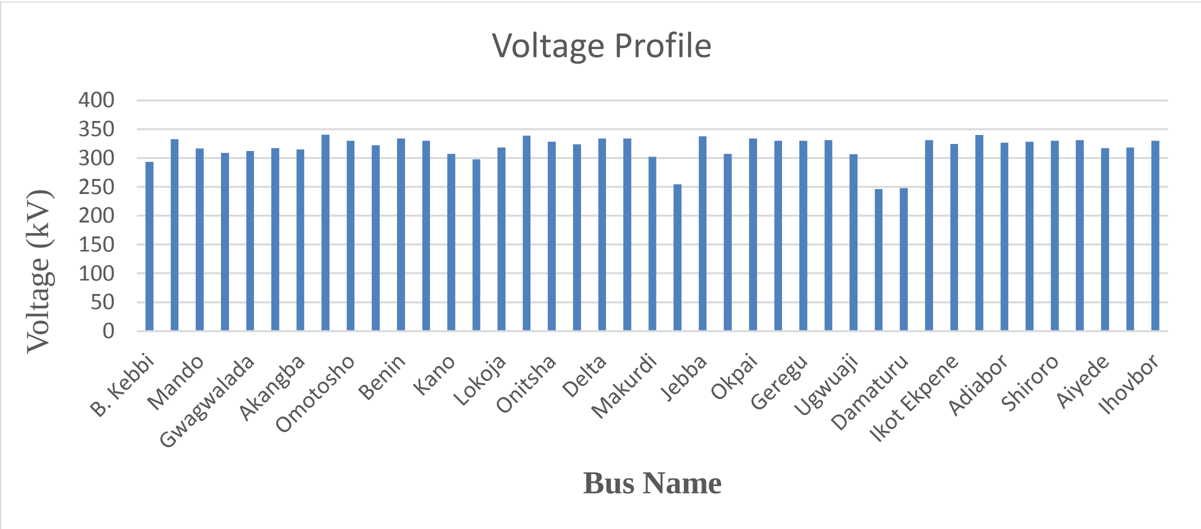

Figure 3.1: Load flow analysis of the network

Figure 3.1 shows the voltage profile of the network. The standard operating range of voltages is between 0.95PU – 1.05PU (346.5kV – 313.5kV). If the bus value falls below 0.95PU, it is known as under-voltage while the bus that has a value higher than 1.05PU is known as over-voltage. The buses that fall below or above the standard operating range of voltages is shown in Table 3.1.

Table 3.1: The violated load bus

Bus Name	Voltage (KV)	Load (MW)	Load (Mvar)
B. Kebbi	293.2535545	162	122
Katampe	308.8549825	303	227
Gwagwalada	312.193636	220	165
Kano	307.1481114	194	146
Jos	297.5906992	72	54
Makurdi	302.3938295	160	120
Gombe	254.3467362	97.46165537	53.83596201
New Haven	307.238366	196	147
Ugwuaji	306.8867434	175	131

Yola	246.2069539	86.97466734	47.83606704
Damaturu	247.823425	83.71445629	38.77301134

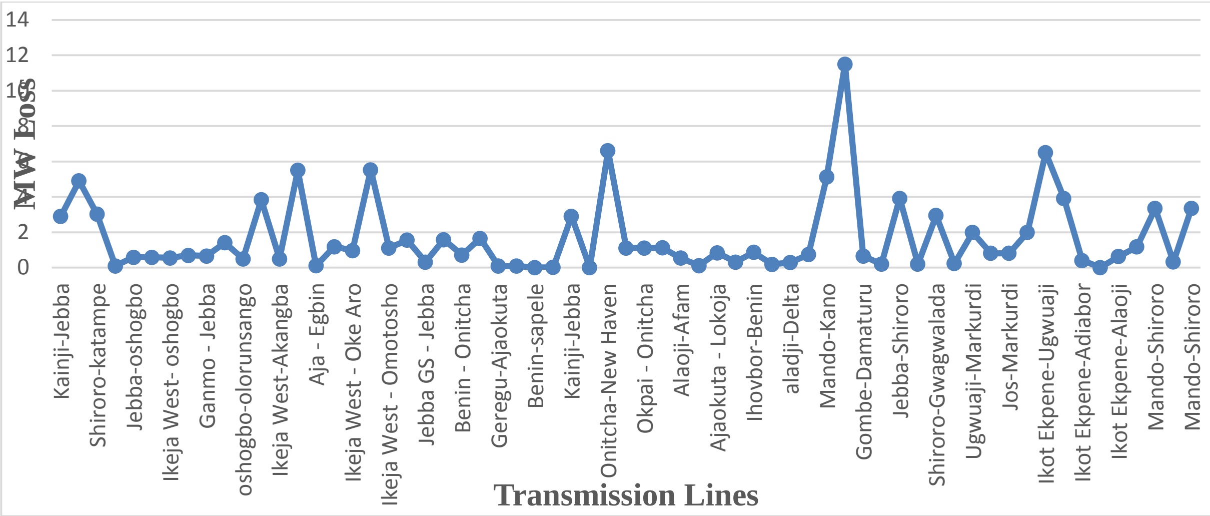

Figure 3.2: Transmission line loss

Figure 4.2 shows the transmission line loss of the network. The total line loss in the network is about 107.23MW. The transmission lines between Gombe and Jos experienced highest transmission line loss occupying about 11.5% of the total line loss in the network while others experienced less than 7% loss in the network.

3.2 Simulation of Transient Stability Study Based on the Application of a Three-Phase Fault

Simulations were carried out using MATLAB Power system analysis tool box to examine the behavior of Nigeria 330KV power system network during a large-scale disturbance such as the three-phase fault on Ajaokuta, the critical clearing time was observed at 0.153sec, after the fault has been cleared. The simulation results shown in figure 4.4, is the generator´s rotor speed. The result of the simulation shows that the generators were in synchronism after the fault has been cleared. So a single generator was used for analysis and the generator chosen for this analysis it the generator at Shiroro.

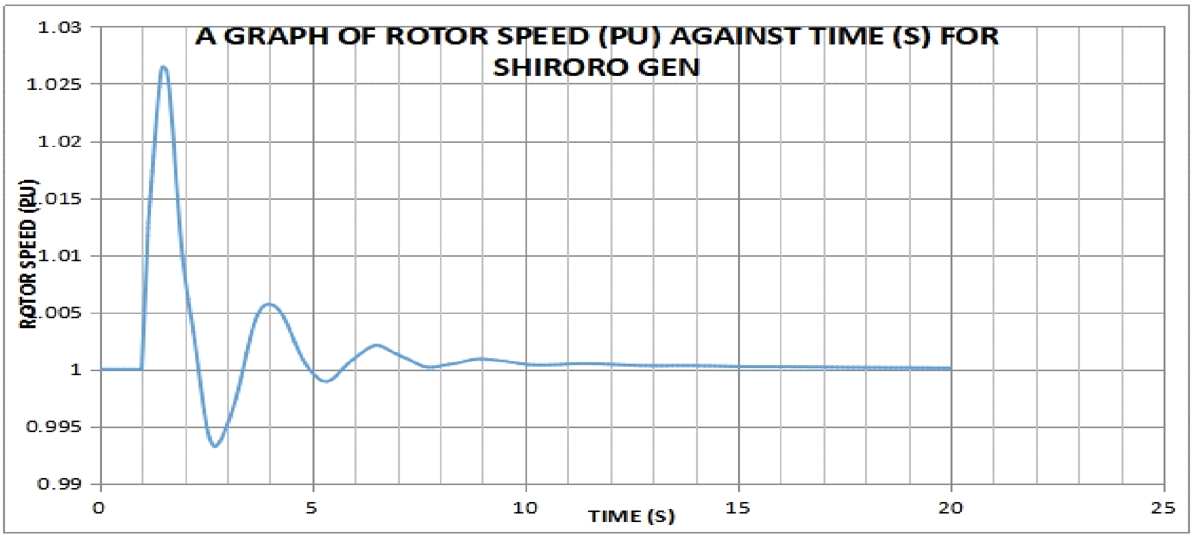

Figure 3.3: A plot of the speed against time without the connection of the DGs.

Figure 3.3 shows the response of the generator at Shiroro without the connection of the distributed generators. The time duration for this simulation was from 0 to 20seconds. When the fault was applied and cleared after 1.153 seconds, it was also observed that the oscillation of the rotor speed of the generator at Shiroro settled after 17.43 seconds and the amplitude of the oscillation is 1.026PU.

3.3 Simulation of Transient Stability Study Based on the Application of a Three-Phase Fault on the Distributed Network

Simulations were carried out using MATLAB Power system analysis tool box to examine the behavior of Kebbi 33KV power system distribution network during large scale disturbance such as the three-phase fault on 33KV distribution line, the critical clearing time was observed at 0.13sec after the fault has been cleared.

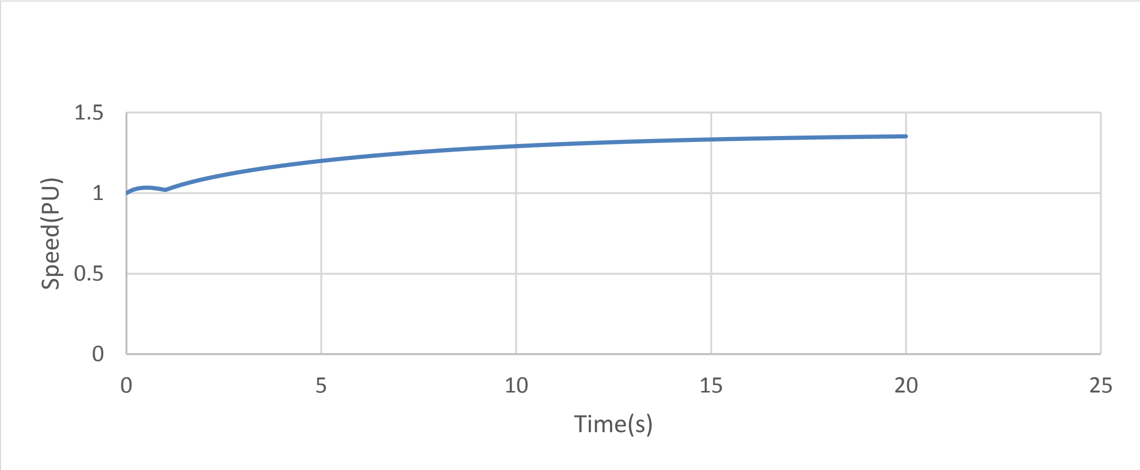

Figure 3.4: A plot of the speed against time without integrating to the transmission network.

Figure 3.4 shows the response of the distribution generator at 33kV distribution network without integrating in to transmission network. The time duration for this simulation was from 0 to 20seconds. When the fault was applied and cleared after 1.13 seconds, it was observed that the oscillation of the rotor speed of the distribution generator in Kebbi was increasing uncontrollably. This behavior has displayed a form of instability in the distribution network.

4.4 Installation of the Distributed Generators in the Network

The Distributed Generators were installed at the distribution networks (33KV distribution lines) of the violeted buses at B.Kebbi, Kano, Damaturu, Yola, Gwagwalada and Kamtampe. The capacity of each generator is at 30 MW each.

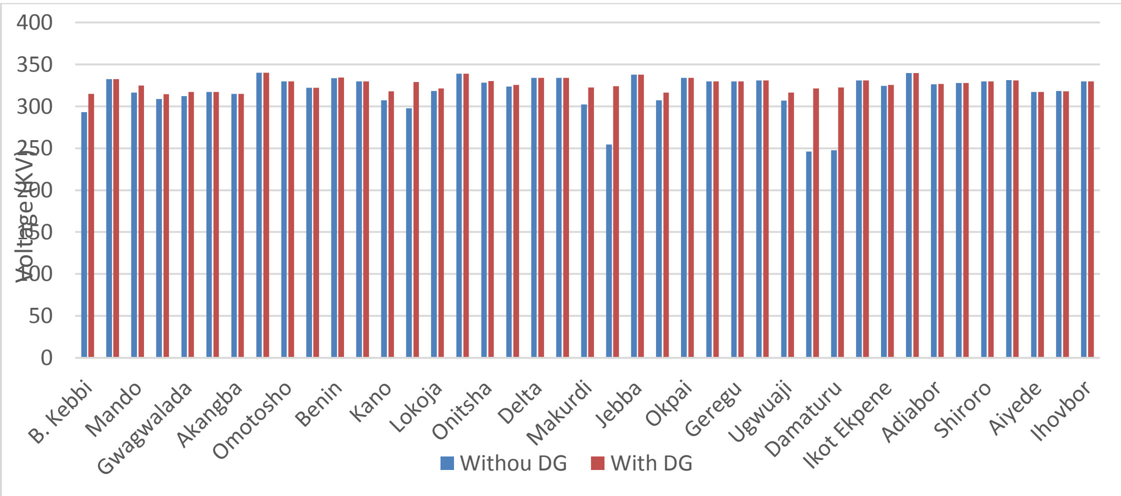

Figure 3.5: Showing the Bus Voltage of the Nigeria grid after the Distributed generators was connected.

Figure 3.5 show the coloration representing the bus voltage of the Nigeria grid. The bar charts with the blue colour represent the Nigeria grid without the connection of the distributed generators and the red bar charts represent the Nigeria grid with the connection of the distribution generators. There was a general improvement in the voltage at the load bus. The average voltage of the network moved from 318KV to 326KV which about 2.5% improvement. The corrected buses that were violated buses are shown in Table 3.2

Table 3.2 The corrected load bus.

Bus Name	Voltage (KV)	Voltage (KV)	Load (MW)	Load (Mvar)
B. Kebbi	293.2535545	314.8570485	162	122
Katampe	308.8549825	314.3590747	303	227
Gwagwalada	312.193636	317.0851602	220	165
Kano	307.1481114	317.8415469	194	146
Jos	297.5906992	328.9968556	72	54
Makurdi	302.3938295	322.5358244	160	120
Gombe	254.3467362	323.926003	97.46165537	53.83596201
New Haven	307.238366	316.2766455	196	147
Ugwuaji	306.8867434	316.5823644	175	131
Yola	246.2069539	321.3393786	86.97466734	47.83606704
Damaturu	247.823425	322.7284215	83.71445629	38.77301134

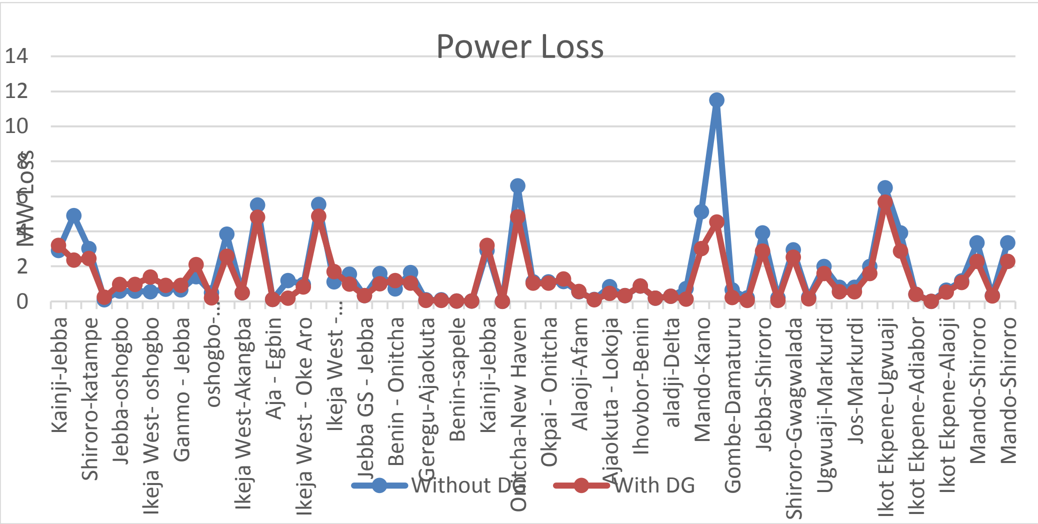

Figure 3.6: Line loss of the network after the DG has been connected.

Figure 3.6 shows the coloration representing the transmission line loss of the Nigeria grid. The bar charts with the blue colour represent the Nigeria grid loss without the connection of the distribution generator and the red bar charts represent the Nigeria grid loss with the connection of the distributed generator. The total line loss of the network, which was about 107.23MW without the connection of the Distributed Generators, is now reduced to 83.16MW; which is about twenty-two percent (22%) reduction.

4.5 Simulation of Transient Stability Study Based on the Application of a Three-Phase Fault after Distributed Generators were Connected

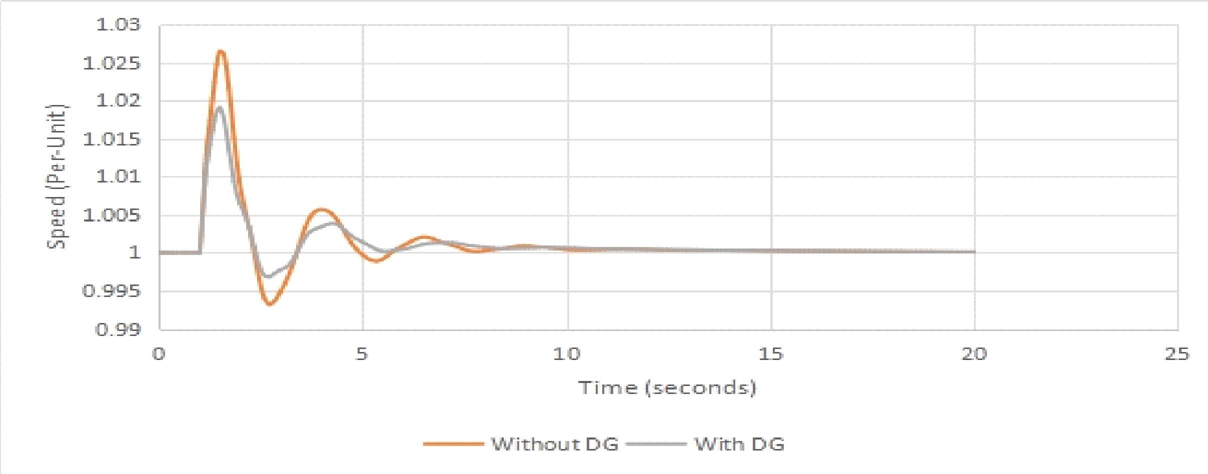

Figure 3.7: A plot of the speed against time with the connection of the Distributed generator.

Figure 3.7 shows the speed response of the generator at Shiroro with the connection of the distributed generator. The brown graph in figure3.7 represents the speed response of the generator when the distributed generators were not connected after the fault has been applied and the ash colour graph represent the speed response when there is fault and extra generators were connected to the network. The time duration for this simulation was from 0 to 20seconds. When the fault was applied and cleared after 1.153 seconds, it is observed that the rotor speed of the generator at Shiroro was stabilizing after 16.9 seconds compared to the base case that took after 17.43 seconds for the rotor speed to stabilize. The amplitude of the rotor speed reduced from 1.026PU to 1.017 PU.

4.6 Simulation of Transient Stability Study Based on the Application of a Three-Phase Fault on the Distribution Network After Integration into the Network

Simulations were carried out to examine the behavior of the distributed generators in Kebbi 33KV power system distribution network during large scale disturbance such as the three-phase fault on 33KV distribution line after it was integrated into the transmission network, the critical clearing time was determined at 0.13sec after the fault has been cleared.

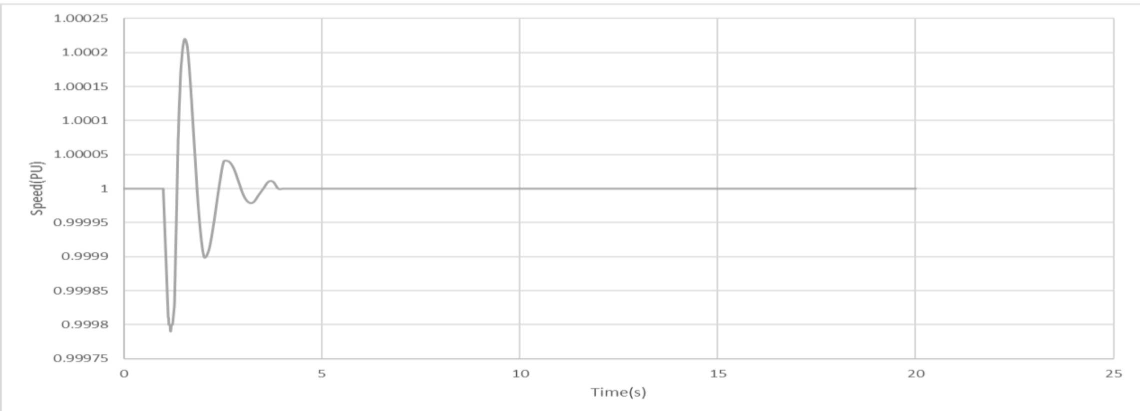

Figure 3.8: Plot of time against rotor speed after the integration to the transmission network.

Figure 3.8 shows the response of the distributed generator at Kebbi distribution network after integration into the Transmission Network. The time duration for this simulation was from 0 to 20seconds. When the fault was applied and cleared after 1.13 seconds, it is observed that the oscillation of the rotor speed of the generator at Kebbi settled after 4.5 seconds. The speed of the distributed generators was maintaining the rotor speed of 1PU.

III. CONCLUSION

From the result of the simulation, it was observed that the network was operating at an average voltage of 318KV and the total number of buses that were below the standard operating voltage range, (313.5KV-346.5KV), was eleven buses. The total line loss of the network was at 107.23MW. In order to observe the transient stability of the network, a disturbance such as a three-phase fault was applied with the critical clearing time observed at 0.153 seconds for the fault to be cleared and the system returned to normalcy. When the relay acted due to the presence of the fault, it was observed that the oscillation of the rotor speed of the generator at Shiroro settled after 17.43 seconds. The distributed generators were connected at the distribution end of the substations that were below the standard operating range. After running another load flow simulation, it was observed that the average voltage of the entire buses in the network moved from 318KV to 326KV which was about 2.5% improvement. Even the violated buses were made to operate within the standard operating voltage range; the connection of the distributed generators was not able to cause the substations to operate at nominal voltage of 330KV. There was reduction in the transmission line loss from about 107.23MW to about 83.16MW. In checking the transient stability of the network, it was observed that the rotor speed of the generator at Shiroro was stabilizing after 16.9 seconds compared to the base case that took 17.43 seconds for the rotor speed to stabilize. The amplitude of the rotor speed reduced from 1.026PU to 1.017PU.

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