Analysis and Simulation of Nigeria Grid Dynamics Using Distributed Generator

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Abstract — Distributed Generators (DG or embedded generators) are generators that are connected to the distribution network of the power system. In this paper, the Nigeria 330kV grid network system was analyzed and simulated using the power system analysis tool (PSAT) simulation software to evaluate the impact of the distributed generator placement on stability of the 41 bus Nigeria grid Network System. The effect of the installation of the distributed generators on the grid was studied and analyzed and the result was compared with the grid, without the installation of the distributed generators. To achieve our aim, a load flow method using Newton-Raphson technique was used to estimate unknown variables in the network such as voltage, angle, MVar and MW on the power system analysis tool box simulation software (PSAT). Before the installation of the distributed generators, 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), were about eleven buses. The total line loss in the network was at 107.23MW. A large-scale disturbance such as a three-phase fault was applied at Ajeokuta with the critical clearing time observed at 1.153 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. After the connection of the distributed generators on the network at the load buses below the standard operating voltage range, which are Kano, Katampe, Damaturu, Gwagwalada, Yola and B. Kebbi, it was observed that the average voltage of the entire bus in the network improved from 318kV to 326kV which is about 2.5% improvement. Even the violated buses were made to operate within the standard operating voltage range. There was reduction in the transmission line loss from about 107.23MW to about 83.16MW which is about 22% reduction and 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. From the result obtained, it was observed that the installations of distributed generator in the Nigeria grid has the capacity to reduced line losses, voltage profile improvement in the grid and line flow reduction leading to the resolution of the congested network as well as improvement in power quality and stability across the grid network. It was also observed from the analysis that the distributed generator technology can be used to enhance the Nigeria grid system.

Keywords— Distributed Generators, Voltage Violation, Transmission Line Losses, Critical Clearing Time, Rotor Speed.

1. INTRODUCTION

There has been incessant daily increase in load demand, this increase in demand causes increased stress in the interconnected network. The transmission and distribution networks are over loaded and experience great loss. The poor availability of power supply, frequent power cuts and indiscriminate power outages pose a great threat to the technological and economic advancement of the country (Boemer and Gibescu, 2019 and Yesbol, 2018). One of the main tasks for power engineers is to generate electricity from renewable energy sources, improving the energy profile and availability of the country to mitigate these lapses and at the same time reducing environmental impact of power generation (Gusnanda, 2019).

These incessant power outage (blackout), epileptic power supply, the frequent power cut, poor power availability and a very low voltage supply by the utility companies is a thing of concern and worrisome to an average Nigerian. In view of the above, the thought of the feasibility of having a close to steady electricity power supply at an acceptable operating voltage level was conceived and borne as the motivation to embark on this research paper to proffer solution to the problem.

This paper work centered on the impact of installation of distributed generator on the transmission network of the Nigeria grid system. To achieve this, the Nigeria 41 bus system is provided with their associated parameters and as well investigating the feasibility of expanding the network to remote villages using the distributed generators. The impact of distributed generator and penetration level on the dynamics of the Nigeria grid is investigated.

2. SYSTEM MODELING AND LOAD FLOW SIMULATION

The Nigerian grid, consists of 330kV 41 bus transmission lines. The existing load in the system was specified and used. The parameters of the existing transmission line in the system are also used. The load and the power sources of the Nigeria grid with the specific transmission line data were extracted from the Nigerian Transmission Company. Load flow solution was obtained from the model in Figure 1. Load flow solution is a solution of the network under steady state condition subjected to certain inequality constraints under which the system operates invalid source specified. These constraints can be in the form of load magnitude, bus voltages, reactive power generation of the generators, etc (Ogunjuyigbe 2016 and Conti, Nicolosi, & Rizzo, 2016). The load flow solution gives the bus voltages and phase angles, hence the power injection at all the buses and power flow through interconnecting transmission lines can be easily calculated. These analyses require a number of load flow solutions under both normal and abnormal (outage of transmission line or outage of some generators) operating conditions. Figure 2 shows the voltage profile of the network. The standard operating range of voltages is between 0.95pu – 1.05pu (313.5kV – 346.5kV) (Debjani, 2017). 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 1.

Table 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

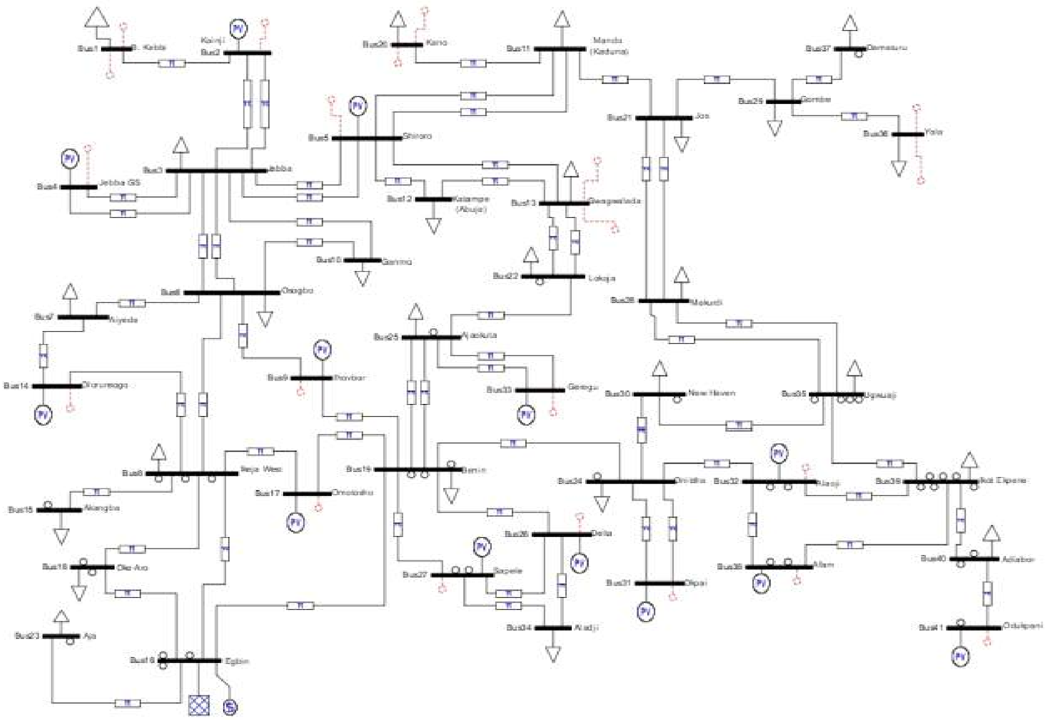

Figure 1: Nigeria 41 bus grid

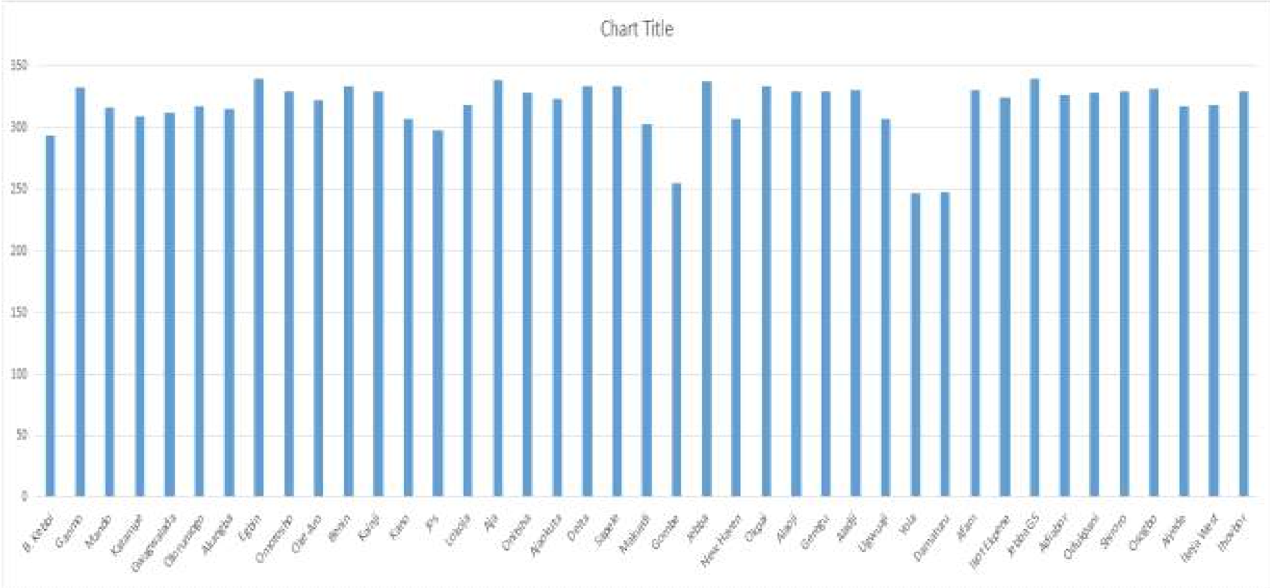

Figure 2: Load flow analysis of the network

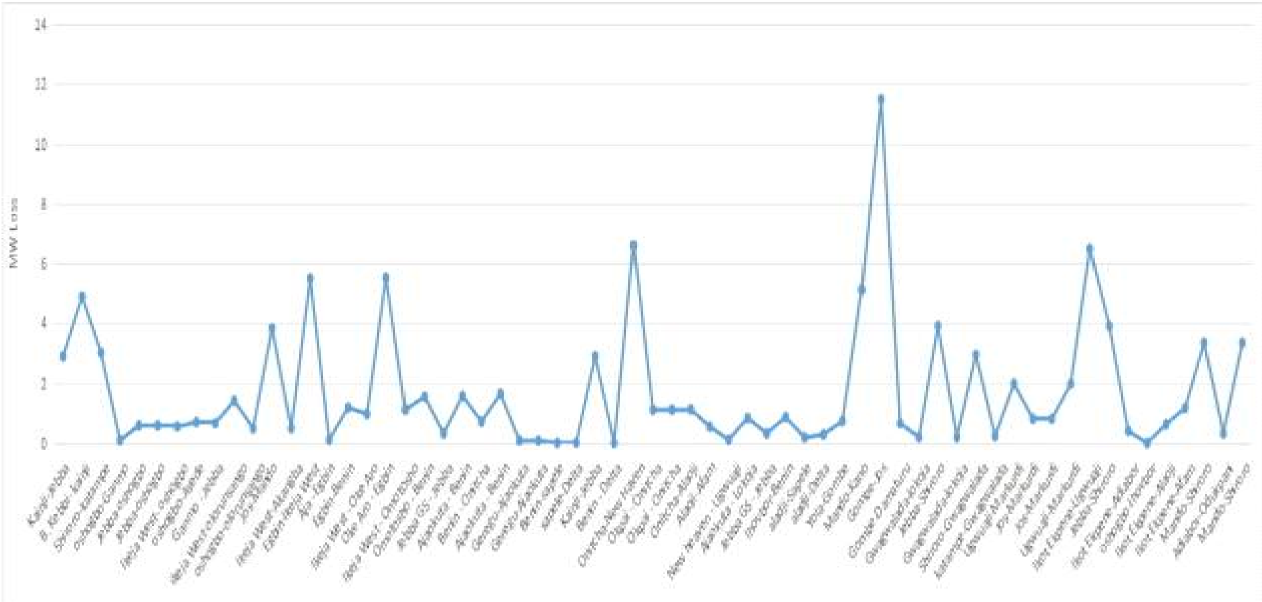

Figure 3: The Transmission line losses

Figure 3 shows the transmission line losses of the network. The total line loss in the network is about 107.23MW. The transmission line 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. SIMULATION OF TRANSIENT STABILITY 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 1.153sec, after the fault has been cleared.

The simulation results shown in Figure 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.

In this paper, a single generator was used for analysis and the generator chosen for this analysis the generator at Shiroro.

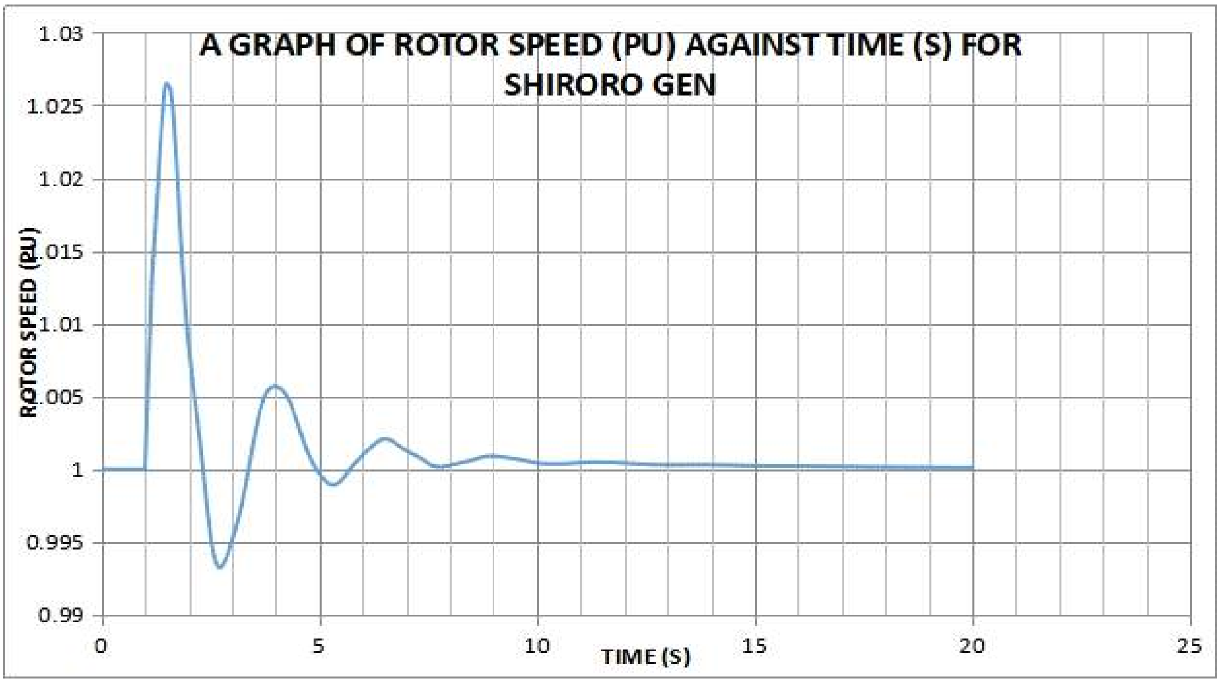

Figure 4: A plot of the speed against time during three-phase fault without the connection of the DGs.

Figure 4 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.

4. INSTALLATION OF THE OF DISTRIBUTED GENERATORS IN THE NETWORK

The Distributed Generators were installed in the buses at B. Kebbi, Kano, Damaturu, Yola, Gwagwalada and Kamtampe as shown in Figure 5. The capacity of each generator is at 30 MW each.

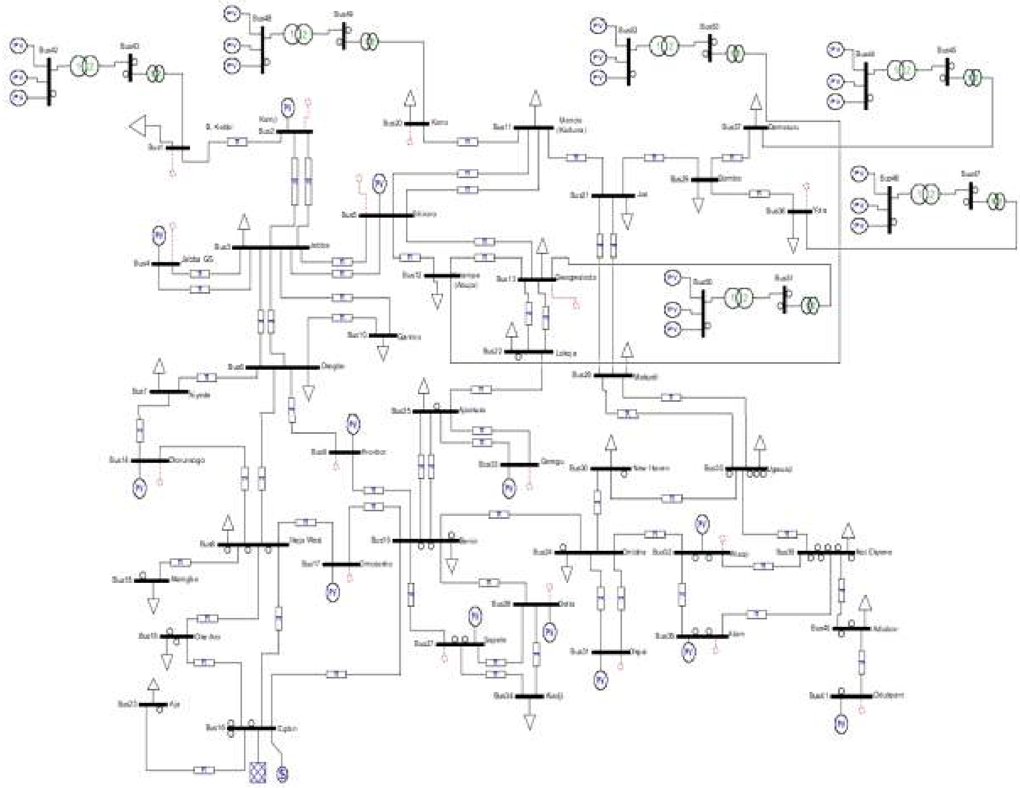

Figure 5: The Nigerian Grid with the integration of distributed generators

Figure 6: Showing the Bus Voltage of the Nigeria grid after the Distributed generators was connected.

Figure 6 shows 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 improved from 318kV to 326kV which about 2.5% improvement. The corrected buses that were violated buses is shown in Table 2

Table 2: The corrected load bus.

Bus Name	Voltage (kV)	Corrected 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 7 show the coloration representing the transmission line loss of the Nigeria grid. The bar charts with the blue colour represent the Nigeria grid without the connection of the distribution generator and the red bar charts represent the Nigeria grid with the connection of the distribution generator. The total line loss of the network, which was about 107.23MW without the connection of the Distribution Generators, is now reduced to 83.16MW; which is about twenty-two percent (22%) reduction.

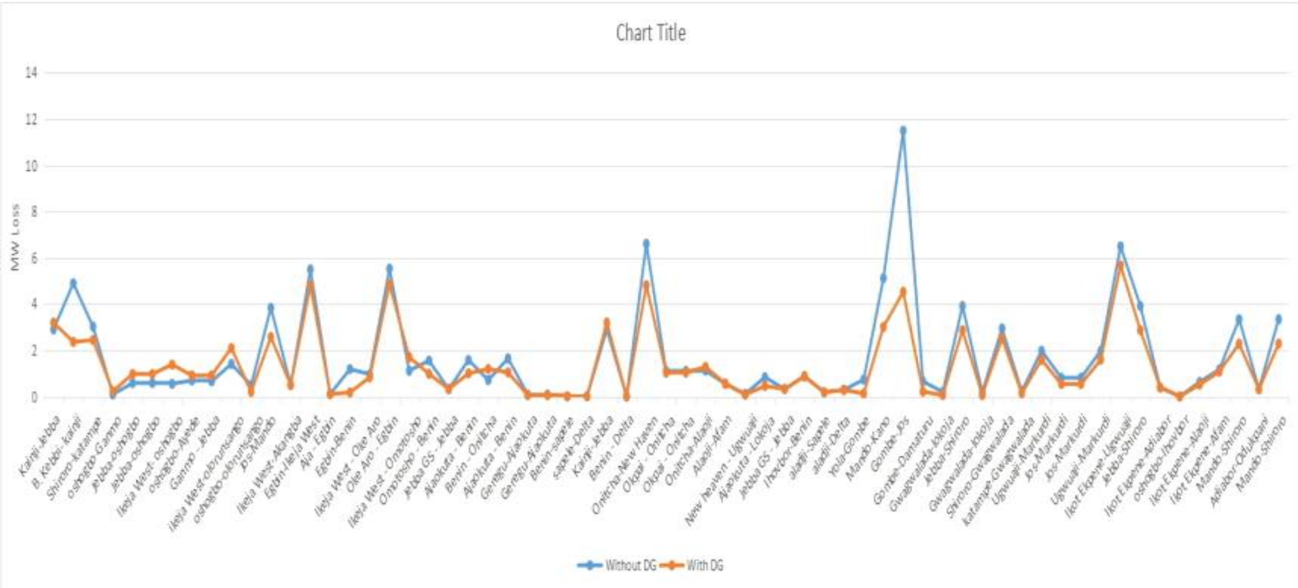

Figure 7: Line losses of the Nigeria network after the DG has been connected.

5. SIMULATION OF TRANSIENT STABILITY AFTER DISTRIBUTED GENERATORS WERE CONNECTED AND THREE-PHASE FAULT APPLIED

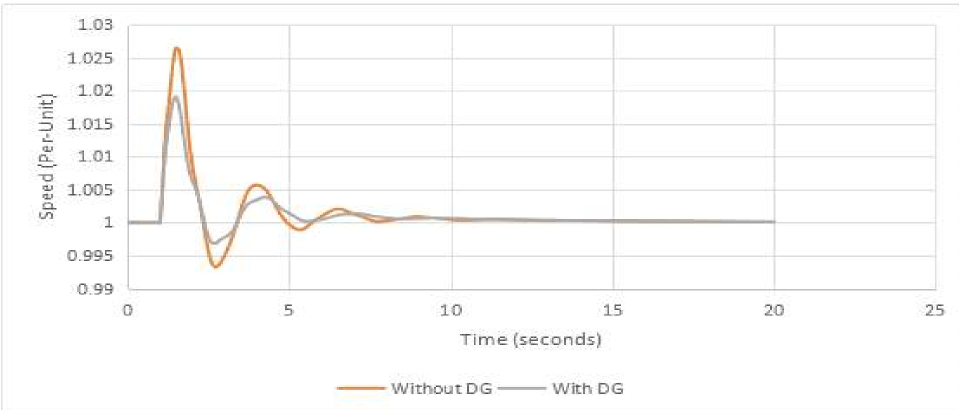

Figure 8: A plot of the speed against time with the connection of the Distributed generator.

Figure 8 shows the speed response of the generator at Shiroro with the connection of the distributed generator. The brown graph in Figure 8 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 1.017pu.

6. CONCLUSION

This paper analyzed and simulated the Nigeria 41 bus network (Nigeria grid) dynamics using distributed generator. A load flow was carried out in the network to determine unknown variables such as bus voltages and angle at the load bus, the reactive power at the generator bus and the transmission line loss. The technique used to solve this problem is the Newton-Raphson technique. The load flow simulation of the network was used to check for the voltage stability of the network. 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 about 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 is 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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