ANALYSIS

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The Effect of Distributed Generation on Voltage Profile of a Distribution Network

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ABSTRACT

This study analyzed the effect of Distributed Generation (DG) on power system voltage stability of a distribution network. Port-Harcourt Electricity Distribution Network was modelled and simulated in Electrical Transient Analyser Programme (ETAP 16.0) using data obtained from Port Harcourt Electricity Distribution Company (PHEDC). Stability of the network was studied upon occurrence of three-phase fault at constant load demand, but with different penetration levels of DGs of 10%, 20%, 30% and 40% respectively. The response of the system was compared with DG units placed in the network and without DG. The result showed that voltages at load buses collapsed to zero without DG and improved by more than 30% with the addition of DG units.

Keywords: Distributed generation, Voltage profile, Power, Voltage stability

1. INTRODUCTION

The demand for electricity will continue to increase due to its importance in modern-day society. Power utilities are required to continuously satisfy the continuous increased-demand of electricity by consumers. The conventional trend in electric power generation is the vertical approach where electricity is generated in large generating stations far away from load centres and strategically located very close to primary energy sources (Davda et al., 2011). The generated electricity is delivered to the consumers through interconnected networks. However, due to some social, economic and environmental constraints, there is limitation to the expansion and usage of large power plants which has necessitated a move towards the use of small decentralized power plants (Angelo et al., 2007). The electric power sector all over the world is currently evolving mainly due to energy-related challenges such as environmental sustainability, security of supply and competitiveness within a context of growing electricity demand. These challenges have led to the increase penetration of Distributed Generation technologies in both the advanced and developing countries of the world (Angelo et al., 2007).

Distributed Generation is the method of integrating generating units into the distribution networks of an electric power system as the alternative means of generating electricity. These generating units are not centrally planned and dispatched (Ackermann et al.,). Distributed power generation technology can be divided into DG with synchronous generator interface, induction generator interface and inverter interface (Sharma and Bartel, 1998). Renewable energy is energy from natural resources such as wind, sunlight, tides, waves, geothermal heat and biomass which can be employed to generate electricity (Lucian et al., 2013). Distributed generation can be of great advantage in isolated locations where central generation is impracticable or where grid extension is difficult (Ogunjuyigbe et al., 2017).

The use of DG as alternative generating units inherently offers several technical, environmental and economic benefits for electrical utilities and offer customer satisfaction due to their location being close to the customers. The advantages of DG include modularity, voltage profile improvement, and deferment of transmission and distribution investment and low emission of pollutants (Slootweg and Bartel, 2002).

The performance of power sector in Nigeria has not improved substantially since its reform/privatization. Despite the provision of continued subsidy by the government for some users, the sector is continuously being characterized by unstable electricity supply and frequent blackouts. The existing centralized power generation units are not sufficient to meet the continuously rising power demand. There is therefore a growing interest in alternative energy resources known as distributed generation systems to produce clean and sustainable energy.

The available generated electricity in Nigeria is not enough to meet the demand of the consumers due to outdated and ill maintained infrastructures. As a result, we have perennial epileptic power supply to industrial consumers as well as commercial and domestic customers. No doubt, the economic growth of the country is negatively impacted. The available generated electricity can only serve less than half of the country population. In order to bridge the gap, the independent power producers (IPP) have resorted to the use of distributed generation technologies (Hachimenum, 2017).

The aim of this paper is to study the effect of Distributed Generation on the voltage profile of a distribution network. To achieve this, various penetration levels of DG are studied. A section of Port-Harcourt Electricity distribution network is used as a case study. ETAP 16.0 is the electrical software that is used to model the network.

2. MATERIAL AND METHODS

2.1. Description of Port Harcourt Electricity Distribution Network

The Port-Harcourt Electricity Distribution Company (PHEDC) is a private distribution company responsible to distribute electricity to consumers in four states of the South-South region of Nigeria. The states are Rivers, Bayelsa, Cross River and Akwa Ibom and there are about 14 million people in the four states of Nigeria. A section of the PHEDC network in Port Harcourt metropolis is used for this study. The Port Harcourt Mains Transmitting station known as Z2, located at Oginigba, Port Harcourt is one of the transmitting stations of this company in Port-Harcourt metropolis and is used as a case study for this paper. It is a 132/33kV transmitting station consisting of three 60MVA, 132/33kV transformers. There are eleven 33kV feeders from this transmitting station. Ten of the feeders supply different customers made up of domestic, commercial and industrial customers while the remaining one is used as a spare feeder. The parameters of these feeders are shown in tables 1 and 2.

Table 1: Port-Harcourt Distribution Parameters (33kV Feeder)

S/n	33kV Feeder Line	Line Load (MW)	Length (KM)	Size (mm^2)	Resistance in ohms
1	Refinery Line 2	16	5.1	150 mm^2	0.93228
2	Rumuola Feeder 3	18.2	18.2	150 mm^2	3.32696
3	Rumuodoumaya Feeder	22.1	55.42	150 mm^2	10.12712
4	Airport Feeder	21	45.3	150 mm^2	8.28084
5	Oyigbo	11.5	19	150 mm^2	3.47
6	Woji	7.6	9	150 mm^2	1.6452
7	Abuloma	9.5	11.82	150 mm^2	2.107684
8	Transamadi Feeder	17.1	8.19	150 mm^2	1.497132
9	Akani Feeder2	13.5	0.22	150 mm^2	0.040216
10	Rainbow Feeder	13.7	12	150 mm^2	2.1936

2.2. Distribution Capacity for 33/11kv Substations

The transformer capacity of various 33/11 kV injection substations in Port Harcourt zone Z2 is shown in the table 2.

Table 2: Distribution Capacity for 33/11KV Substations

NAME	DISTRIBUTION CAPACITY	
	Number	MVA
Golden Lily Rumuola	3	15
Shell Ind	2	15
Presidential Hotel	1	2.5
Liberation stadium	1	2.5
Agipokporo	1	15
Rumuduomoya	1	15
Eliozu	1	15
Airport	1	2.5
Aweto guest house	1	2.5
Eneka Town hall	2	15
Woji	1	15
Azubie	2	15
Stallion 2	1	2.5
Abuloma	1	15
Okuru Gulf Estate	2	15
Fist Aluminium	1	7.5
Elf	2	7.5
Galba	1	1.5
Stallion1	1	2.5
Air Liquid	1	4.5
Rivoc	1	7.5

The single line diagram of the network of the 132/33 kV transmission station is shown in figure 1.

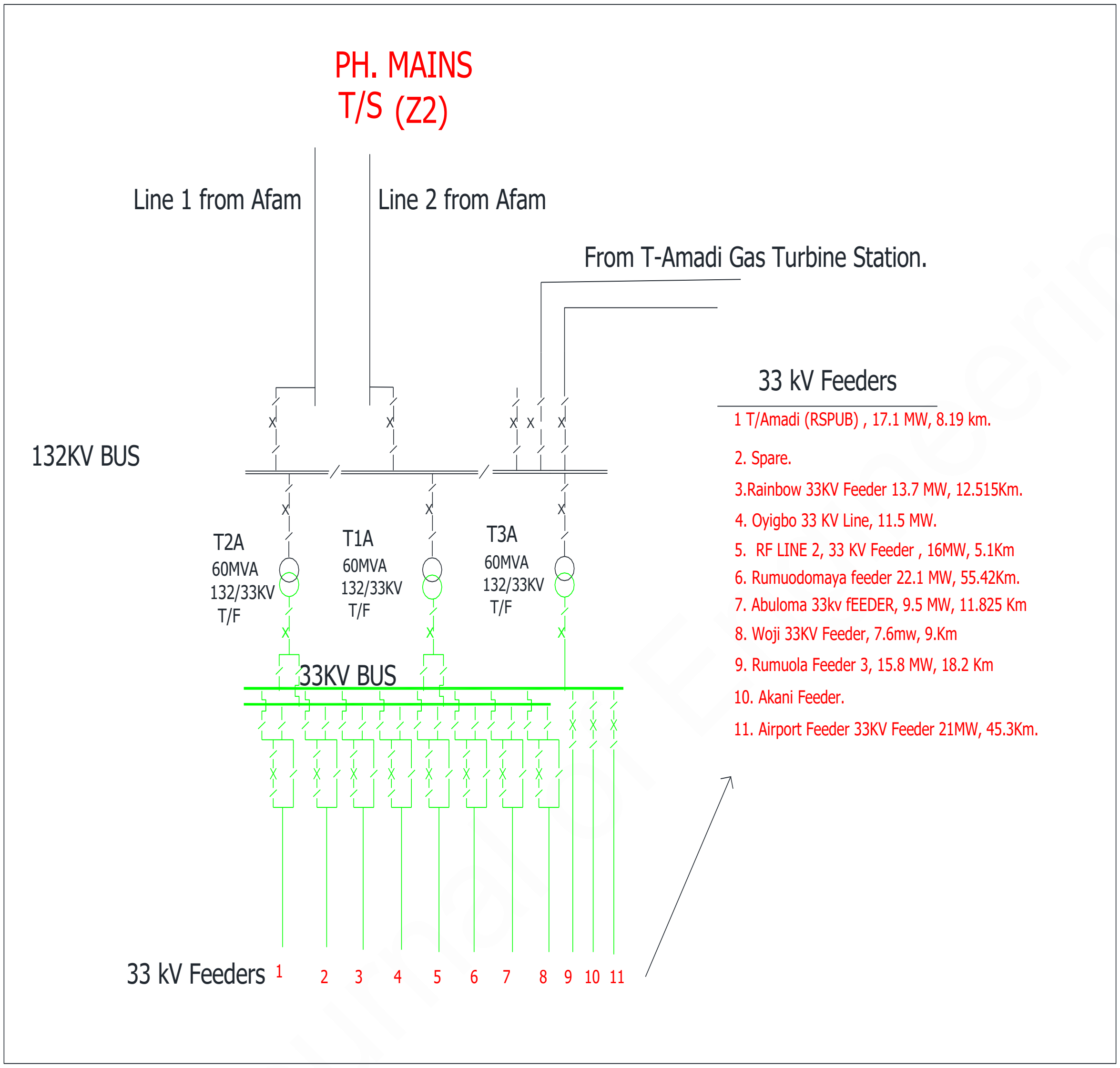

Figure 1: Port Harcourt Mains Transmission 33 kV Feeders

2.3. Material Consideration

The following materials were considered for this study.

- The capacity of one Distributed Generation unit used is 4.8MW.
- 33/11 kV and 132/33 kV transformers.
- Model of the network with and without DG units.
- Cross sectional area of overhead conductor used is 150 mm^2.The calculated D.C. resistance per km length of bare Aluminium multi-stranded conductor (AAC-type for 150 mm^2 is 0.1825 ohms/km. Pre-calculated resistance per km length of bare Aluminium multi-stranded conductor Steel Reinforced (ACSR-type) for 150 mm^2 is 0.1828ohms/km (Nigerchin, 2019)

2.4. Simulation Methodology

Port-Harcourt Electricity Distribution (PHED) network is used as a case study for this work. Firstly, this distribution network does not contain distributed generation. Subsequently Distributed Generation is introduced into the network with increasing penetration level from 0% to 40%. DG units are attached to the load buses in the low-voltage area of the network. The study is done at constant load demands at the load buses. DG units will be introduced to the load buses at different locations in the network.

In order to investigate the effect of Distributed Generation on the voltage profile of distribution network, a fault will be made to occur at the 132kVbus. The effect on the system in each of the penetration levels will be modelled. The penetration level can be calculated as a function of the total DG power generation over the total load demand.

$$\text{Penetration Level }(\%) = \frac{P_{DG}}{P_{Load}} . 100\ \%. \qquad 1$$

Where P_{DG} is the total power generated by all distributed generation units. P_{LOAD} is the total load demand of the system (Angelo et al., 2007).

2.4.1 Simulation Procedure

For the purpose of analysis, the following feeders were selected, Trans-Amadi, Abuloma and Woji as shown in figure 2 which is the ETAP model of the network.

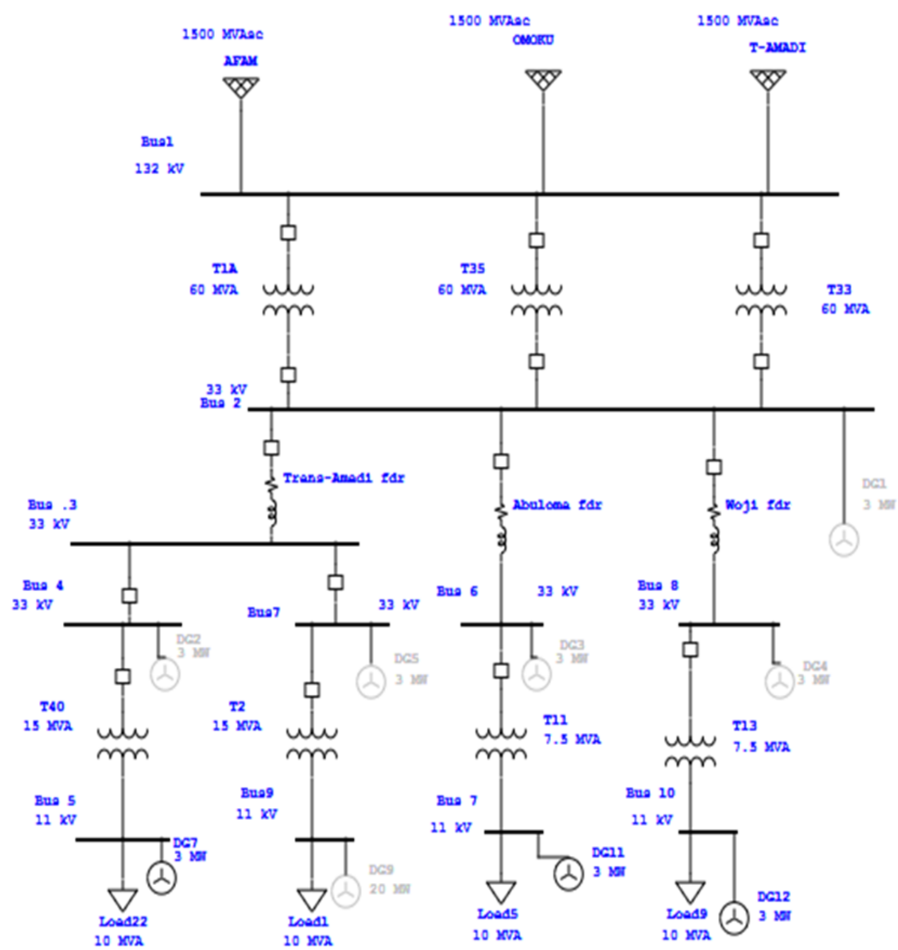

Figure 2: Port Harcourt Main Zone distribution network Showing Three Feeders with DG

In this case study the voltage levels of the distribution system are 33kV, 11kV and 0.415kV. The capacity of each DG unit is 3MW while load level remains constant as DG penetration level increases. To investigate the voltage stability of the test system, a fault will be applied to the 132 kV main busbar at the transmission station. The impact of each study scenario will be studied. The different scenarios for the study are as follows:

Scenario 1. No DG unit is attached. Run load flow on the network. Record the voltage values at different buses.

Scenario 2. Connect DG unit to load bus at location 1. DG penetration level is at 10%. Run load flow and record voltage values at different buses.

Scenario 3.Connect DG unit to load bus location 2 at 10% penetration level. Run load flow and record voltage values at different buses.

Scenario 4. Connect DG unit to load bus location 3 at 10% penetration level. Run load flow and record voltage values at different buses.

Scenario 5. Connect DG unit to load bus location 4 at 10% penetration level. Run load flow and record voltage values at different buses.

Scenario 6. Connect DG unit to load bus location 2, 3 and 4 at 10% penetration level. Run load flow and record voltage values at different buses.

A 3-phase short circuit fault will be initiated to happen at one bus at every case to test the system voltage stability during fault. The duration of the fault is 0.1s during the simulation. Figure 2 shows the ETAP model of the distribution network.

3. RESULT AND DISCUSSION

3.1. Scenario 1: Base case with fault without DG Placement

In the scenario 1 which is the base case with no DG attached, the voltage values measured at different busbars are as shown in table 3.The values of the voltage at different buses before the application of the fault was between 98 % and 100 % nominal values. But during the duration of the fault from 0.4 sec to 0.52 sec, the voltage value collapsed to zero and then returned to nominal values after the clearing of the fault.

Table 3: Voltage values of the network without DG

	Bus Voltage at Zero DG										
Time	**Bus 9**	**Bus 5**	**Bus 3**	**Bus 4**	**Bus 7**	**Bus 2**	**Bus 10**	**Bus 8**	**Bus 7**	**Bus 6**	**Bus 1**
0.00	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.04	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.08	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.12	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.16	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.20	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.24	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.28	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.32	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.36	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.40	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00
0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.52	98.27	98.27	98.62	98.62	98.62	99.87	99.49	99.84	99.45	99.80	100.00

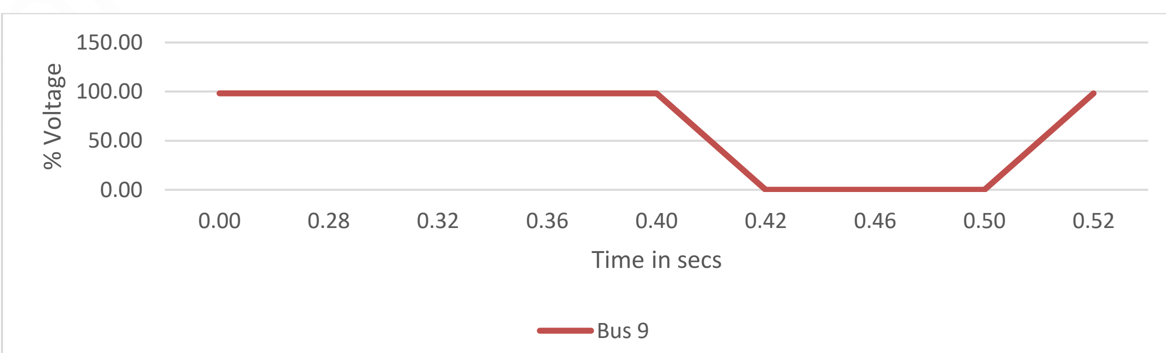

Figure 3: Voltage Profile of Load bus 9 without DG Unit

Figure 3 shows the voltage profile for load bus 9. As seen from the figure, the bus voltage level collapsed to zero at the application of three phase fault to 132 kV bus when no DG unit was connected to the network. The fault was initiated at time t= 0.4secs and cleared at time t = 0.5secs. The voltage profiles at the load buses from time t = 0 secs to 0.4secs were very close to 100% of the base value. But during the 0.1 sec of the fault duration, the voltage collapsed to 0%. The value of voltage at the bus returned to normal after the clearance of the fault.

The voltage profile for all the other load buses follow this voltage profile at bus 9.

3.2. Profile of Bus Voltage at different penetration level of Distributed Generation

DG units were placed at different locations in the network. A DG unit was first placed at location 1 and its impact was observed. After, DG unit at location1 was disconnected and connected at location 2.This same process was repeated for locations 3 and 4.

In order to analyze the impact of DG on the load voltage profile of a distribution network, let us look at the effect of DG unit connected to the upstream 33 kV bus supplying power to the three load buses5, 10 and 7. We shall look at the penetration levels of 10 % and 40 %. This will show us the impact variation from 10 % to 40 %.

Location 1 is the 33 kV upstream bus 6 that supply power to all the load buses in the network.
Location 2 is the 33 kV bus that supplies power to 11 kV load bus 5.
Location 3 is the 33 kV bus that supplies power to 11 kV load bus 7.
Location 4 is the 33 kV bus that supplies power to 11 kV load bus 10.

3.2.1. Scenario 2a: The voltage profile at 10 % Penetration Level at the upstream 33 kV Bus 2

Table 4: Voltage values of Load buses of the network at 10% DG Penetration at Bus 2

10% DG Penetration at 33kV Bus 2			
Time	24	32	76
0.40	98.77	98.87	98.89
0.40	0.59	0.59	0.59
0.42	0.64	0.64	0.64
0.44	0.63	0.63	0.63
0.46	0.62	0.62	0.62
0.48	0.62	0.62	0.62
0.50	0.61	0.61	0.61
0.52	98.71	98.89	98.92
0.56	98.72	98.81	98.83

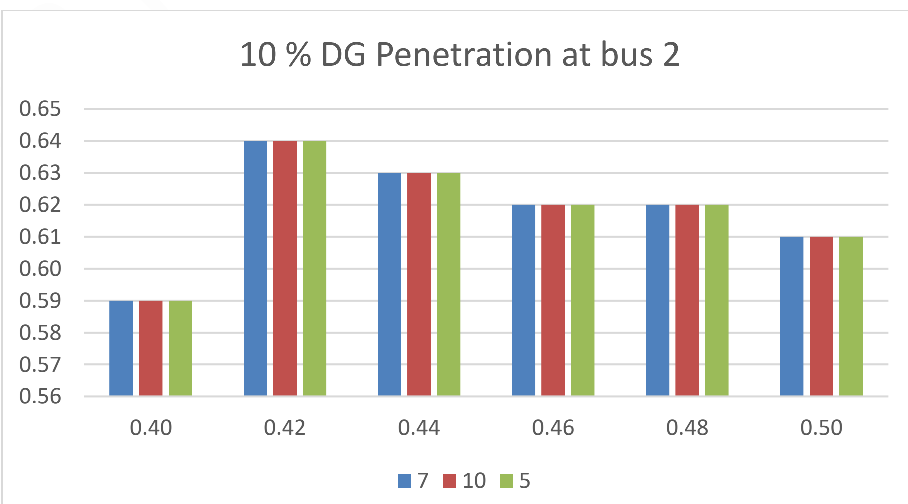

Figure 4a: Voltage Profile of Load buses at 10% DG Penetration at Bus 2

Figure 4a shows the voltage profiles for the three load buses 5, 10 and 7. The figure explains the result when DG unit was attached to bus 2 (i.e location 1) which is the 33kV bus feeding all the load buses. The DG penetration level was 10%. Bus 7 is Abuloma bus, bus 10 is Woji bus while bus 5 is Trans-Amadi bus.

AS shown in figure 4a and table 4, the DG unit provided some voltage level to the load buses as compared to zero voltage when there was no DG connected.

3.2.2. Scenario 2b: The voltage profile at 40 % Penetration Level at the upstream 33 kV Bus 2

Table 5: Voltage values of Load buses of the network at 40% DG Penetration at Bus 2

40% DG Penetration at 33kV Bus 2			
Time	7	10	5
0.4010	2.32	2.32	2.32
0.4210	2.51	2.51	2.52
0.4410	2.48	2.48	2.48
0.4610	2.45	2.45	2.45
0.4810	2.42	2.42	2.42
0.5000	2.39	2.39	2.39

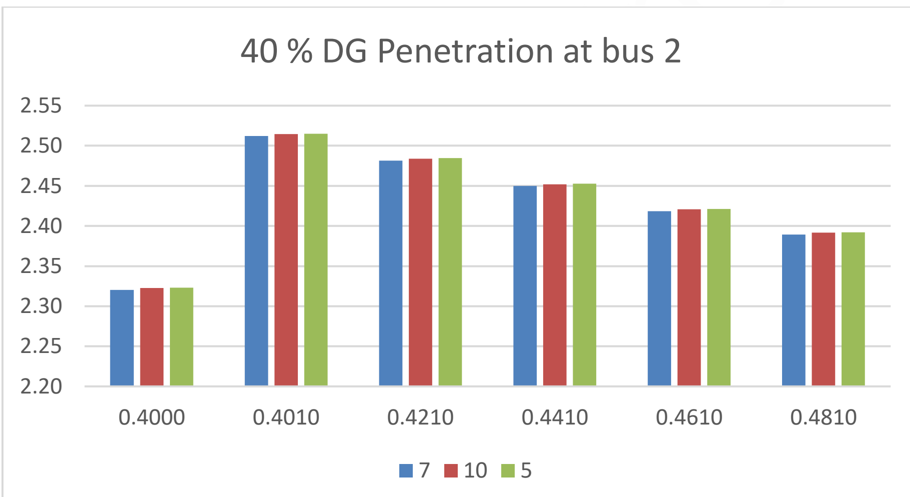

Figure 4b: Voltage Profile of Load buses at 40% DG Penetration at Bus 6

The result as shown in figure 4b and table 5, the voltage level at the load buses appreciated more as the penetration level increased from 10 % to 40%. Comparing figures 4a and 4b, we can see more than 100% improvement in the voltage level when the DG penetration increased from 10% to 40%.

3.2.3. Scenario 3: The voltage profile at 10 % Penetration Level at the upstream 33 kV Bus6that supply power only to load bus 7

Table 6: Voltage values of load buses of the network at 10% DG Penetration at Bus 6

DG at 33kV Bus 6 at 10%			
Time	Bus 7	Bus 10	Bus 5
0.4010	1.18	0.58	0.58
0.4210	1.28	0.63	0.63
0.4410	1.27	0.63	0.63
0.4610	1.25	0.62	0.62

0.4810	1.23	0.61	0.61
0.5000	1.22	0.60	0.60

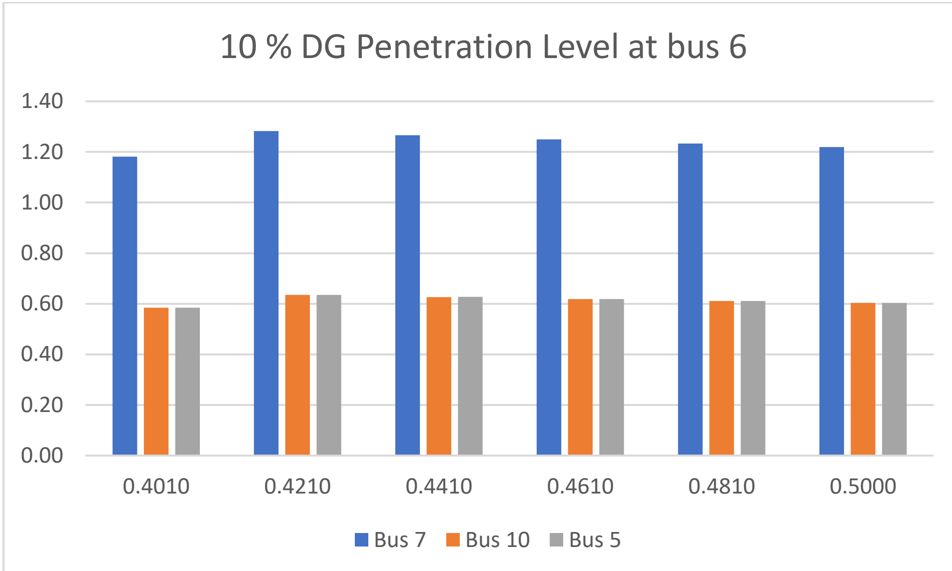

Figure 5: Voltage Profile of Load buses at 10% DG Penetration at Bus 6

The result as shown in figure 5 shows that Load bus 7 had much more improvement than load buses 10 and 5 because the DG unit was connected to the upstream bus that supply power to bus 7 only. Similar result would be achieved at any other load bus that has DG connected to its upstream 33kV bus. This explains the results for scenarios 4 and 5.

3.2.4. Scenario 6: The voltage profile at 10 % Penetration Level at each of the Load Buses

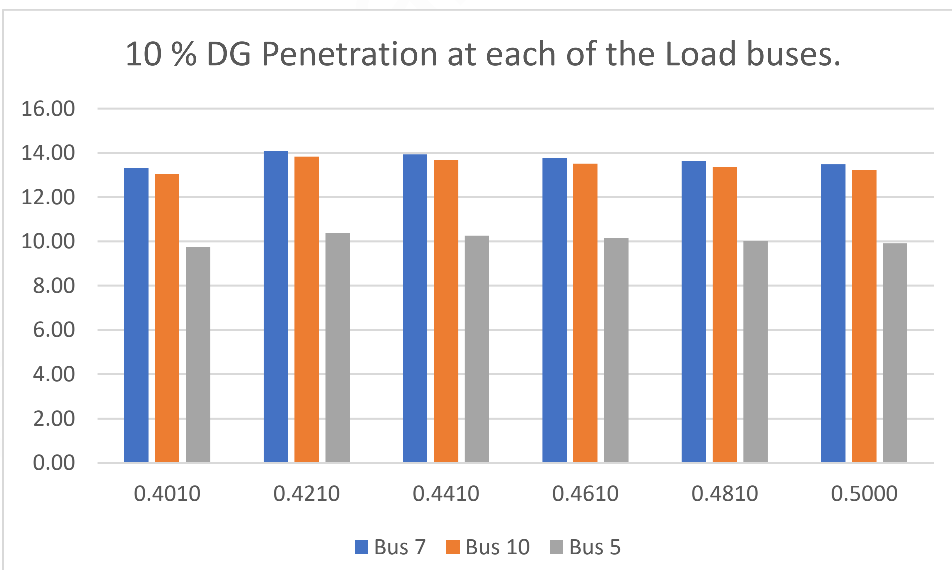

Figure 6: Voltage Profile of Load buses at 10% DG Penetration at each of the Load Buses

Table 7: Voltage values of the network at 10% DG Penetration at each of Load buses 5, 7 and 10).

10% at each of the 3 buses.			
Time	Bus 7	Bus 10	Bus 5
0.4010	13.31	13.05	9.75
0.4210	14.09	13.82	10.39

0.4410	13.94	13.67	10.27
0.4610	13.78	13.52	10.15
0.4810	13.62	13.36	10.03
0.5000	13.48	13.22	9.92

In figure 6 the result shows higher voltage profile at buses 7 and 10 than bus 5. The reason is because bus 5 shared the DG voltage with another load bus 9. Both load buses 5 and 9 are connected to the same upstream 33 kV bus. This figure also shows that when DG unit is connected directly to the load bus, the level of the available voltage is higher than when it is connected to the upstream bus.

4. CONCLUSION

This research investigated the effect of distributed generation on the voltage profile of Port Harcourt Electricity distribution network. It was demonstrated in this work that the addition of Distributed Generation unit to distribution network will enhance the voltage stability of the system if it is optimally placed. The optimal location is the one that gives higher voltage level. The author is therefore recommending that a further study should be done to investigate the protection scheme of the network since DG will cause bi-directional flow of current in the system.

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Conflicts of Interest: The authors declare no conflict of interest.

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