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Enhancement of Electricity Supply in Port Harcourt using Distributed Generation (DG) Technology

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Keywords: *generation, electricity, energy, enhancement.*

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ENHANCEMENTOFELECTRICITYSUPPLYINPORTHARCOURTUSINGDISTRIBUTEDGENERATIONDGTECHNOLOGY

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Enhancement of Electricity Supply in Port Harcourt using Distributed Generation (DG) Technology

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I. Introduction

Generators that are linked to the distribution network are known as distributed generators (DG or embedded generators). Their benefits include the potential to minimize or eliminate waste. When transmission and distribution infrastructure is strategically placed, the opportunity to minimize technological losses within transmission and distribution networks, as well as overall improvements in power quality and system efficiency, can be postponed. Among the several issues in developing country nations like Nigeria is the lack of a valid and predictable power supply; this has caused several factories to close down, and others to depend on personal power generation, driving up production costs. Nigeria's power supply needs range from 50,000MW to 70,000MW, with less than 10MW coming from the electrical grid, resulting in many load sheddings and the outage of some businesses for an extended amount of time.

So many studies have suggested ways to boost the grid by implementing Distributed Generation (DG). The recommendations for DG were focused on taking electricity closer to customers, reducing power loss, and thereby lowering maintenance and delivery costs. DG also lowers emissions, provides renewable electricity, and lowers installation costs. These variables have given DG a significant advantage over other forms of power generation in recent years, particularly in rural areas. Since it accounts for more than 70% of global energy consumption, DG has been suggested as the possible alternative. Germany, for example, uses DGs to meet more than 55 percent of its electricity demand, while the United States uses them to meet more than 45 percent (Shasha et al. 2018Installing DGs into a network does not ensure the system's stability or reliability, particularly when faults occur due to a lack of load or generation. These faults may cause the system to adapt, resulting in a variety of issues such as voltage breaches, increased actual and reactive power losses, a decrease in potential excess power when more load is taken into account, and so on. Knowledge of these factors would help in proper network management for optimum utilization; however, failure to consider these factors could result in system instability, which could result in system collapse.

The majority of studies have focused on device stability, using indexes that are dependent on future behavior predictions that do not fully represent the system's actual future behavior in the near future (Anumaka, 2016). As a result, the current system's stability in relation to potential behaviour was examined in this study. The job regarded as a fraction of the Nigeria Network for successful research (Port Harcourt Network). The analysis of reliability can be approached from a variety of perspectives, including system stability, line losses, generation losses, and so on.

Most scholars have suggested too many methods with respect to the activities recognized when analyzing a system's reliability and stability. The research used in this dissertation would reveal the system state by looking at voltage stability, actual and responsive transmission loss, system loadability, and related indices. Power flow analysis, continuation power flow analysis, and measured indices can be used to do this. The machine will be investigated using power flow analysis, which will display the state of the network under constant load. The machine will be investigated further under load increment and at full loading using continuation power flow analysis. This will demonstrate that the infrastructure is on the verge of collapsing, while the stability indices will look at how the network reacts

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when a fault causes DG failure. To stop a server failure or crash, this will show which areas need further work.

a) Statement of the Problem

Device faults, which result in either a loss of load or generation, are one of the issues with the Port Harcourt power system. The lack of generation has a greater effect on the network and has the potential to bring the grid down. After the loss of DG, the machine can become unreliable. As a result, improving the power grid in Port Harcourt seems to be such a big issue over time that it has drawn so many researchers and investors. The issue is mostly caused by a lack of generation capacity and transmission line improvements. Though there have been proposals to use DGs as an additional source of power to increase current generation, there is a need to checkmate DG positioning in the network to ensure voltage reliability, minimize actual and reactive power losses, and effectively handle more load.

b) Aim and Objective of the Study

The main aim of this dissertation is to enhancement electricity supply in Port Harcourt using Distributed Generation (DG) Technology. The specific objectives are:

1. Investigation of the condition of the present Port Harcourt network.
2. Reliability study considering faults leading to loss of DG.
3. System maintenance based on reliability indices result.

II. Review Related Literatures

Anumaka (2016) presented a work on fundamentals of reliability of electric power system and equipment. The author stated that in recent days power system consists of complex interconnections that can prone a network from different network to various difficulties, which mitigate against network reliability inadequate planning and reliability check. This could lead to high failure rate of the power system installations and consumers equipment, transient and in transient fault, symmetrical faults etc.

The reliability study considered in power system according to the author is the measure of power interrupted load connected, frequency of interruption, amount of consumers and duration of interruption. The indices highlighted for measuring reliability are the Customers Average Interruption Duration Index (CAIDI), System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Momentary Average Interruption Frequency Index (MAIFI). Equipment failure and component failure follows a similar pattern which is described in the curve in fig 2.1. The curve shows three distinct regions or phase in the total life duration of the equipment. The equipment passes through three stages which also affects their efficiency. The first stage is the infant equipment. Failure rate is high due to manufacturing fault, design fault, misuse, misappropriation and other specifiable problems. The next stage is the useful life or normal operation region which is an interesting time period of the life of an equipment failure are minimized in this stage and failure could happen due to poor operating maintenance. The last stage which have a very high rate of failure is the wear out or old age region. High failure rate at this period of time could be decreased by changing the component parts, and the wear out stage could be avoided if proper maintenance is followed in the useful life stage.

Hussien et al (2010) considered a work on assessment of distributed generation (DG) impacts on Distributed networks using Global performance index, considering high penetration of DGs. According to the author(s), power injection from the DG can change the network power flow modifying energy losses and the voltage profile. The author stated that the reason is that proper location could bring DGs closer to the consumers thereby reducing line losses which in turn could optimize the energy output thereby accepting more consumers. The indices defined by the authors are Voltage Profile Index (VPI), Real and Reactive Power Loss Index (ILP and ILQ), Voltage Regulation Index (IVR), Current Capacity of Conductors (ICC) Index, Transformer Loading Index (ICT), three-phase and single-phase-to-Ground short circuit Index (Isc_3, Isc_1) and harmonic Index.

$$ILP = \frac{P_{LDG}}{P_L} \quad (2.1)$$

$$ILQ = \frac{Q_{LDG}}{Q_L} \quad (2.2)$$

$$\mathrm{VPI} = \max_{T=2}^{N}\left[\frac{V_1 - V_i}{V_1}\right] \quad (2.3)$$

$$\mathrm{IVR} = \max_{T=2}^{N}\left[\frac{V_{iLmin} - V_{1Lmax}}{V_{1Lmax}}\right] \quad (2.4)$$

$$ICC = max_{i=1}^{ml}\left[\frac{|S_i|}{|S_{ci}|}\right] \quad (2.5)$$

$$ICT = max_{t=1}^{mT}\left[\frac{|S_t|}{|S_{ct}|}\right] \quad (2.6)$$

Where P_{LDG} is the real power losses using DG, P_L is the real power losses without DG, Q_{LDG} and Q_L are the reactive power losses with and without DG, V_1 is the root voltage V_i is the bus i voltage, V_{iLmin} is the bus i voltage magnitude loaded with minimum demand, V_{iLmax} is the voltage magnitude at bus i loaded with maximum demand, S_i is the MVA flow in line i, S_{ci} is the MVA capacity at line i, S_t is the transformer loading in MVA, S_{ct} is the maximum transformer capacity and mt denotes the number of transformers. The author could only analyze the data with only one value.

Mehdi et al (2011) considered a quantitative assessment of DG benefits to improve power system indices. In addition to the indices proposed above, the author included a new indices called the greenhouse gasses effective reduction index, which account for pollution into the environment. Simulation was done on Zanjan Regional Electric company (ZREC) using Dig SILENT software. The result indicated benefits of DG on the Network which include the improvement in the line losses, voltage profile, environmental impact and relieved transmission and distribution congestion. Also the result shows that increasing the numbers of buses with DGs will create a greater impact.

Hassen et al. (2011) used genetic algorithm (GA) for optimization of DG location and capacity for enhancing voltage profile and reducing losses. The author(s) suggested that DGs plays a vital advantage to the network as it could aid to reduce electricity cost, manage congestion in transmission lines, reduce line losses, improve voltage profile etc. The author also stated that DG will be the most reliable energy supply in the near future which is incorporated with artificial intelligence. GA consists of four stages; produces an initial population randomly, calculates fitness function for each chromosomes, produces new chromosomes from the ones selected (crossover) and execute mutation on the chromosomes created. Mathematically, the function is given as;

Minimize $$g = f(x) = F(x)\ldots, f_i(x)\ldots, f_K(x) \qquad (2.7)$$

Which is subject to;

$$x = (x_1, x_2, \ldots x_n) \sum X \qquad (2.8)$$

$$y = (y_1, y_2, \ldots y_n) \sum Y \qquad (2.9)$$

The results shows that applying the proposed index, there was a very huge improvement in the network using DG. Suggestions were also proffered on the best positioning of DGs for optimal usage.

Gopiya et al (2012) presented a work on planning and operation of DG in distributed networks. The work suggested that optimum sitting and sizing of DG and other compensation devices in the distribution networks are the two most important factors to get maximum performance such as technical, economic and environmental to utility and consumer. The work concentrated on different DG technologies, available capacities merits and demerits. The author(s) compared different optimization technologies on analysis of optimal placement of DGs. According to the work, one of the widely used optimization technique is the GA, but it suffers from divergence and local optima. Another efficient technique used is Particle Swarm Optimization (PSO) because it is simple, less computerized. It is used for those mathematical models that are difficult but prone to local maxima and premature convergence. For integer variables, simulated annealing, evolutionary programmable search, particle search algorithm and out of colony can proffer best solution. Tabu search is an efficient technique to achieve either optimal or sub-optimal solution in a short duration.

Shasha et al. (2018) summarized a review of reliability analysis of distributed power access on distribution network using the characteristics of analytical solution and simulation method in reliability calculation of traditional distribution network. The work suggested that DG can proffer a great help to the network, but can also lead to a lot of problems if not well managed. Distribution power supply can be affected by the access location, capacity, order different types of access and the mode of operation of the distribution system. The analytic method of solution can analyze the failure probability of the network components, consequences of expectant failure event, establish a mathematical model of the system reliability and calculate reliability indices of load point and system, and it include network way and state space way. The theoretical basis of state space is Markov process, which mainly includes state enumeration method, state space truncation, minimum cut set state method etc. State enumeration method though generally applicable, cannot be used to solve practical problems. The simulation method generally refers to Monte carol simulation according to the work, which simulates the formulation of all the random processes of the system to predict the behaviour of the network for a long time.

Kaduru and Gondlala (2015) presented a work on distribution system reliability base on consumer scattering. The work suggested that since DGs installed close to consumers will proffer better efficiency, it will be proper to scatter customers and use different DG sizes base on their load demand to supply power. This will reduce complexities caused by installing the DGs into the grid network. The work was done on size location based on customers scattering pattern, which will also affect the optimal usage and efficiency of the DG. Each system consists of nine load points and the reliability indices considered are SAIFI, SAIDI, CAIDI, AENS. Conclusions were drawn that the customer scattering and restoration time affects the optimum placement of DG in terms of system reliability.

Jaser et al. (2019) gave a specified analytical approach for optimal planning of DG in electrical distribution networks considering majorly the power losses. The author(s) stated that power losses could be affected by the location, capacity and the power factor of the DG units. The network considered a new approach to reduce the power losses which was implemented in MATLAB software and analyzed on 12-bus, 33-bus and 69-bus IEEE distributed test system. The result shows that the new approach provides a simple and accurate solution and do not require exhaustive computations, and the voltage profile will improve when DGs are optimally connected to the distribution network.

Sachin et al. (2020) presented a work on the reliability assessment of wind-solar PV integrated distribution system using electrical loss minimization technique considering electric loss minimization (ELM). The loss minimization was aimed at minimizing the consequences of real and reactive power losses in the distribution network, the technique considered a collection of renewable energy source, network redesign and enlargement and planning. Location to accommodate DGs were investigated using single and multiple DG locations which was simulated using construction-based particle swarm optimization to improve reliability, battery effects were still included in the model. The result shows that reliability was optimally improved by using DGs. The objective functions considered are the active power loss which is given as:

$$\text{Min AP}_{\text{loss}} = \sum_{i=1}^{\text{Nbus}} \sum_{j=1}^{\text{Nbus}} C_{1ij}\left[P_{\text{real } i}P_{\text{real } j} + Q_{\text{real } i}Q_{\text{real } j}\right] + G_{ij}\left(Q_{\text{real } i}P_{\text{real } j} - P_{\text{real } i}Q_{\text{real } j}\right) \quad (2.10)$$

Where $P_{\text{real } i}P_{\text{real } j}$, $Q_{\text{real } i}Q_{\text{real } j}$ are the active and reactive power at i and j buses respectively and N bus i is the number of buses and nodes C_{ij} and G_{ij} . Also, the reactive power loss and the reliability indices expressed in the equation below as;

$$RP_{loss} = \sum_{i=1}^{Nbus} Q_{geni} - \sum_{i=1}^{Nbus} Q_{demi} \quad (2.11)$$

Reliability indices $C_f(X_p, RT)$ where Q_{geni} and Q_{demi} are the reactive generation and demand at ith bus Xp is the failure rate and RT is the repair time. Constraint considered are the equality and inequality constraint, power flow, DG capacity, bus voltage and branch current.

Abdulaziz (2012) evaluated reliability of distributed systems containing renewable DGs using Monte Carlo simulation algorithm. The network considered three DG sources; PV, wind turbine (WT) and gas turbine (GT). The supply was done using islanded micro grid operation. The power output from the PV can be expressed as:

$$P_{out} = \begin{cases} \frac{nc}{R} * S * I(t)^2 & 0 < 1(t) \leq k \\ \eta C * S * I(t) & I(t) > k \end{cases} \quad (2.12)$$

When $\eta C$is the efficiency of the PV system while K is a threshold, and I(t) is the hourly solar isolation. The solar isolation can be affected by several factors such as cloud, temperature and relative humidity. The predicted PV output power can be seen as the summation of the actual output power and change in output power.

$$P_{PV} = P_{out} + \Delta P_{out} \quad (2.13)$$

The correlation between the output power and wind velocity can be expressed as:

$$f(x) = \begin{cases} 0 & 0 \leq V_t \leq V_{CT} \\ A + Bvt + CV_t^2 V_o \leq V_t \leq V_r \\ P_r V_r \leq V_t \leq V_{co} \\ 0 & V_c \geq V_{co} \end{cases} \quad (2.14)$$

Where

$$A = \frac{1}{(V_{ci} - V_r)^2}\left[V_{ci}(V_{ci} + V_r) - 4V_{ci}V_r\left(\frac{V_{ci} - V_r}{2v_r}\right)^3\right], \quad (2.15)$$

$$B = \frac{1}{(V_{ci} - V_r)^2}\left[4(V_{ci} + V_r)\left(\frac{V_{ci} + V_r}{2V_r}\right)^3 - (3V_{ci} + V_r)\right] \quad (2.16)$$

$$C = \frac{1}{(V_{ci} - V_r)^2}\left[2 - 4\,(4V_{ci} + V_r)^3\right] \quad (2.17)$$

And C are constants as a function of cut-in wind speed (V_{ci}) and rated wind speed (V_r). V_{CO} is the cut-out wind speed and P_r is the rated power output. The load point i can be predicted using equation (2.18);

$$P_i(t) = W_h(h) \times W_h(m) \times P_{Li} \quad (2.18)$$

Where $W_h(h)$ is the hourly weight factor, $W_m(m)$ is the monthly weight factor and P_{Li} is the peak load for load point i.

III. Methodology

- Load flow analysis using Newton Raphson method.
- Port Harcourt distribution network Power flow simulation using MATLAB version 7.9.
- Placing of DGs and evaluation of its impact

a) Voltage Profile Improvement Index (VPII)

DG installation usually results in enhanced voltage profile at different buses. The Voltage Profile Improvement Index determines the enhancement of voltage profile (VP) with DG. It is expressed as;

$$\text{VPII} = \frac{\text{VP}_{\text{wDG}}}{\text{VP}_{\text{woDG}}} \quad (3.45)$$

The following attributes are based on these expressions:

$\text{VPII} > 1$, DG is non advantageous,

$\text{VPII} = 1$, DG has no effect on the system voltage profile

$\text{VPII} < 1$, DG has upgraded the system voltage profile

Where VP_{wDG} and VP_{woDG} are the system voltage profile with and without DGs approximately. VP is generally expressed as:

$$\text{VP} = \sum_{i=1}^{N} V_i L_i W_i \quad \text{with} \quad \sum_{i=1}^{N} W_i = 1 \quad (3.46)$$

Where V_i is voltage magnitude at bus i in per unit, L_i is load described as complex bus power at bus i in per unit, W_i is weighting factor for bus i, and N is total number of buses in the distribution system. Weighting factors are selected based on the relevance of various loads.

As outlined, the formulation for VP gives a chance to express and aggregate the value, quantity and voltage levels in which loads are provided at different load buses of the system. This formulation is used after making sure that the voltages at all load buses are within permissible lowest and highest limits, commonly within 0.95p.u. and 1.05p.u. beginning with comparable weighting factors, thereby implementing changes. Acceptable voltage profile can be chosen after evaluating the simulation results which are continually done after each weighting factor modification. If all load buses are weighted equally, the value of W_i is given as shown below:

$$W_1 = W_2 \ldots = W_n = \frac{1}{N} \quad (3.47)$$

In this instance, all the load buses are given equal value. DG can be mounted almost anyplace in the system in reality. Generally, highest amount of VPII implies the foremost position for the DG installation in terms of boosting voltage profile (Ajay et al, 2008; Ochoa et al, 2006).

b) Real and Reactive Power Loss Indices (ILP and ILQ)

Other leading performance offered by installation of DG is reducing the electrical line losses (Victor et al, 2006). Line currents can be decreased by installing DG, thereby reducing electrical line losses. The real and reactive power loss indices are given below:

$$ILP = \frac{[P_{LDG}]}{[P_L]} \quad (3.48)$$

$$ILQ = \frac{[Q_{LDG}]}{[Q_L]} \quad (3.49)$$

Where PL_{DG} and QL_{DG} are the total real and reactive power losses of the distribution system with DG while ILP and ILQ are the total real and reactive system losses without DG in the distribution system. In terms of reducing loss accumulated to DGs placement and sizes, the lower the amount, the better the benefits.

The following attributes are based on this definition:

$\text{ILP} / \text{ILQ} < 1,$ DG has decreased the electrical line losses

$\text{ILP} / \text{ILQ} = 1,$ DG has none effect on the line losses

$\text{ILP} / \text{ILQ} > 1,$ DG has increased electrical line losses

These indices can be used to determine the best placement to position the DG that maximizes electrical line loss decrease. Obviously, minimal amount of ILP and ILQ correlates to the best DG positioning assumption with respect to the electrical line loss decrease.

c) Excess Power Loss Index (EPLI)

This accounts for the excess power obtained through CPF, also known as loading factor (λ), loss as a result of fault leading to loss of DG. The percentage EPLI can be calculated as,

$$EPLI = \frac{(\lambda - EP_{wf})}{\lambda} \times 100 \quad (3.50)$$

Where EP_{wf} is the loadability when fault occurs. The implications of the index are,

EPLI < 100, DG Fault have reduced excess load,

EPLI = 100, DG Fault has no impact of excess load,

EPLI > 100, DG Fault have increased excess load.

EPLI > 0, DG Fault cannot permit extra load or system will collapse.

d) Research Algorithm and Flowchart

The algorithm below gives a detailed approach of the work as follows:

- Step 1: Enter the line data, bus data, and number of DGs
- Step 2: Run Power Flow (PF) and Continuation Power Flow (CPF) on the Network data
- Step 3: Run eigenvalue analysis to ascertain the weakest bus
- Step 4: Attach DGs to selected buses
- Step 5: Investigate network performance after adding DG
- Step 6: Introduce fault that could lead to loss of DG
- Step 7: Investigate network performance after DG loss and its reliability
- Step 8: From result suggest system maintenance priority

IV. Result

The study of power system stability and reliability using DGs in the Port Harcourt network is the focus of this research. PSAT MATLAB 7.9 was used to simulate the method, and the results of Eigenvalue analysis were used to identify the weakest buses before performing a power flow analysis and a CPF analysis to determine voltage breaches, loadability, and actual and reactive power losses. The thesis also included a stability analysis that took into account the lack of individual DGs in the network. VPII, ILP, ILP, and EPLI are the reliability indices considered.

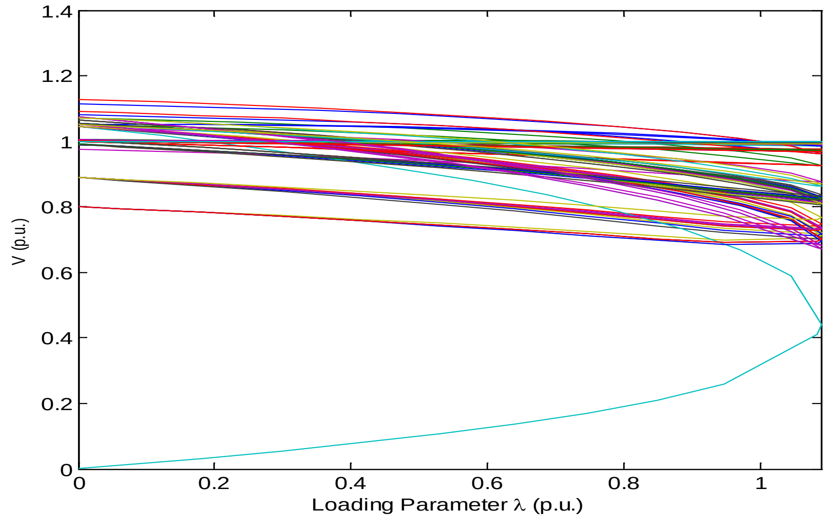

Figure 1: V-P curve for loss of DG at Bus 5

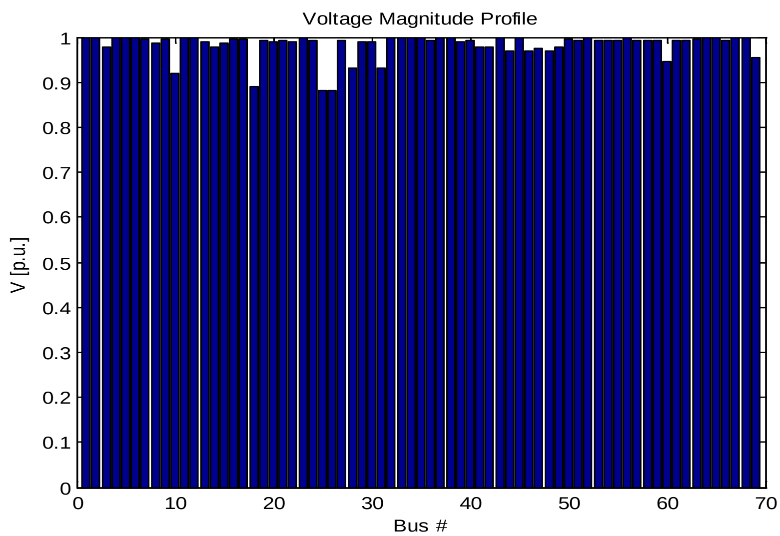

Figure 2: Voltage profile for loss of DG at Bus 6

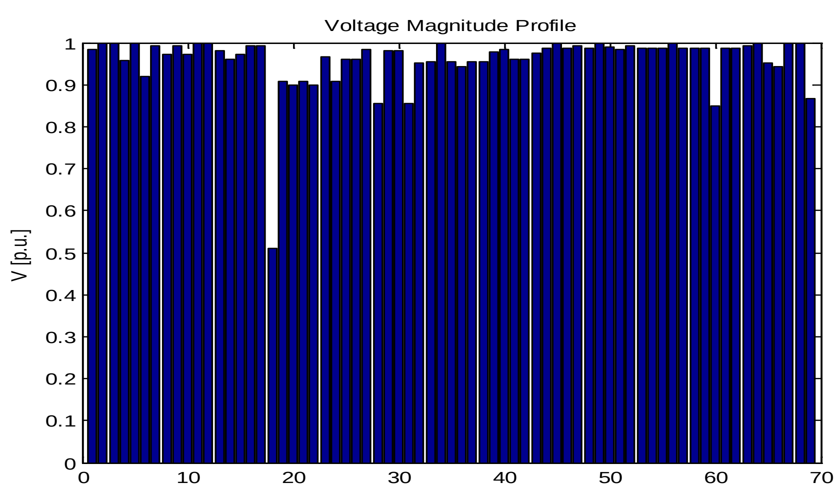

Figure 3: Voltage profile at collapse point for Bus 6

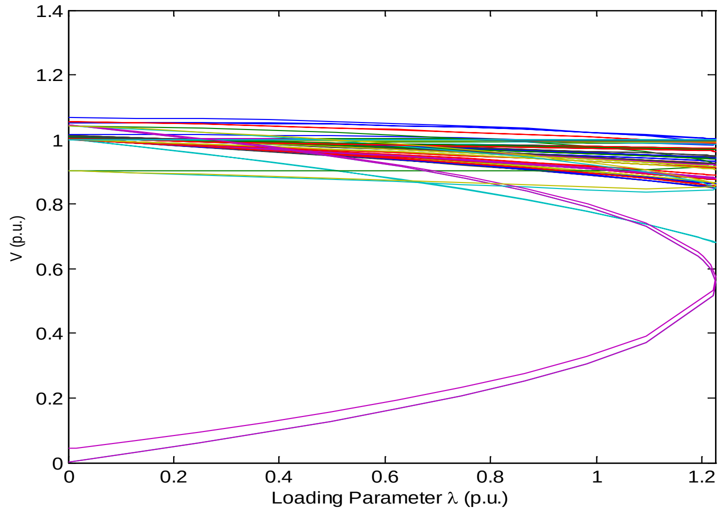

Figure 4: V-P curve for loss of DG at Bus 6

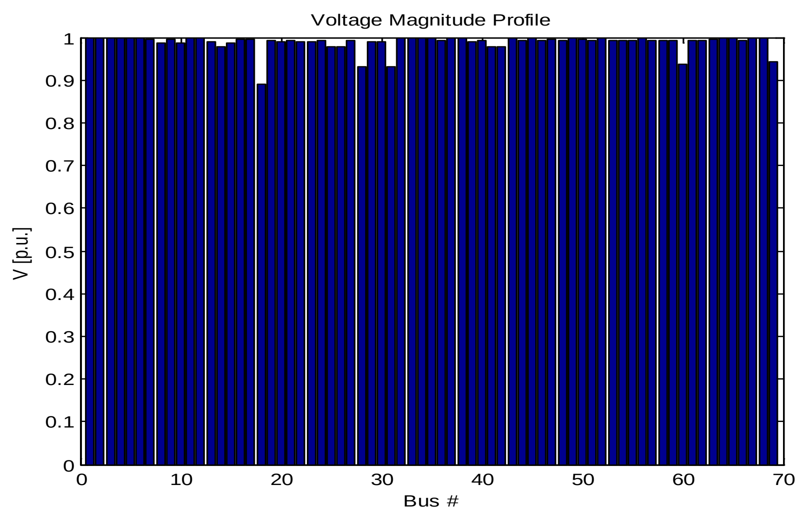

Figure 5: Voltage profile for loosing DG at Bus 7

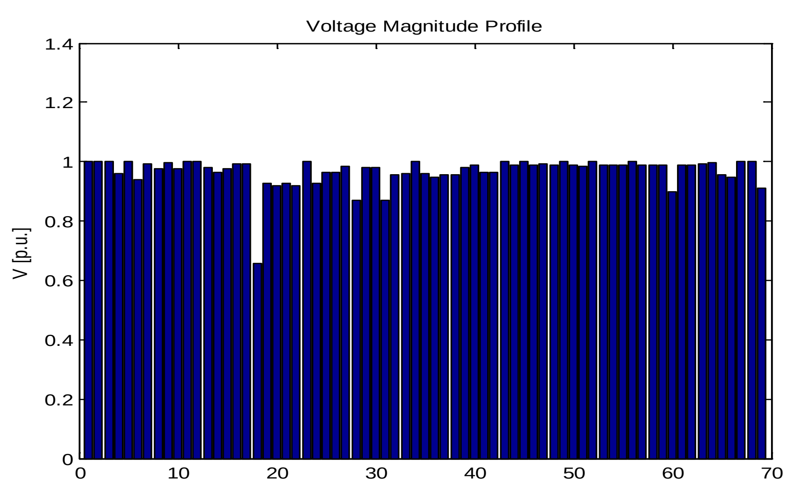

Figure 6: Voltage profile at collapse point for loss of DG at Bus 7

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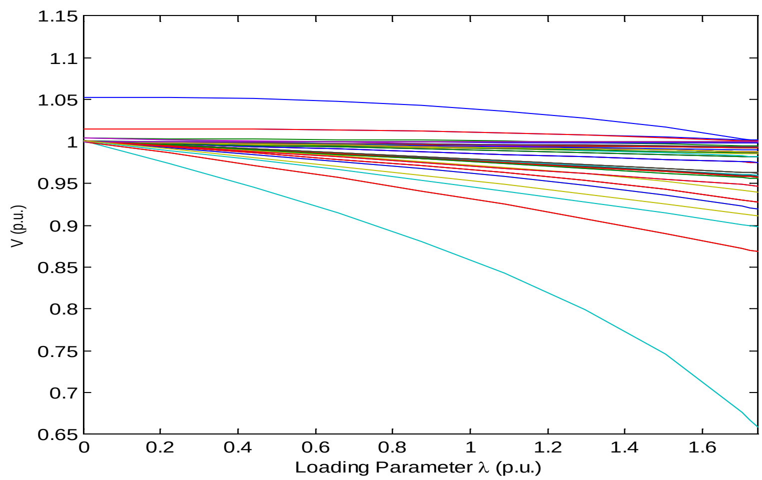

Figure 7: V-P curve for loss of DG at Bus 7

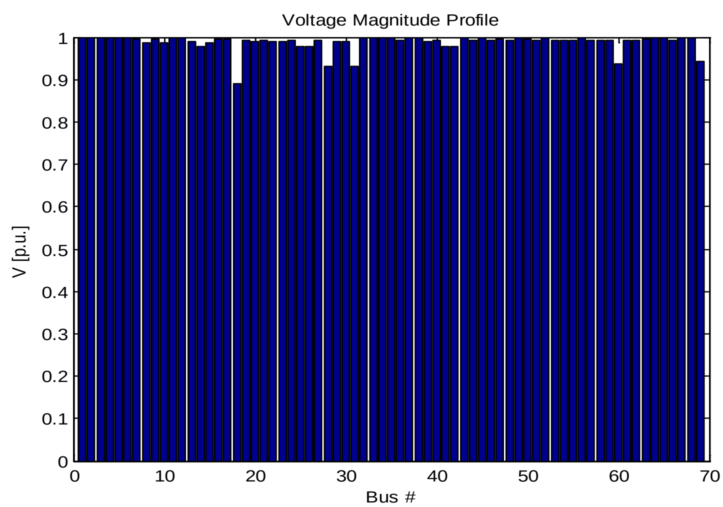

Figure 8: Voltage profile for loosing DG at Bus 65

Table 4.3: Power Flow and Continuation Power Flow Result Summary for Loss of a DG

	VV	RPL	RePL	Loadability	CVV	CRPL	CRePL
3	5	0.08235	0.8838	1.8968	8	0.11923	1.4295
5	7	0.10470	1.2561	1.0529	12	0.21241	1.9895
7	5	0.09345	0.9845	1.6756	7	0.12142	1.7204
65	4	0.08032	0.8212	1.9998	6	0.10998	1.2993
10	5	0.09148	1.0004	1.9024	8	0.13452	1.3675
11	9	0.15641	1.8758	-	-	-	-
12	10	0.12411	1.8672	-	-	-	-
13	7	0.11202	1.3564	0.9738	13	0.18529	2.2424
14	8	0.13680	1.3648	1.0003	13	0.20021	2.2876
6	6	0.09768	1.2425	1.2468	11	0.18162	1.7845
2	6	0.08868	1.1878	1.4241	10	0.19186	1.6261
19	8	0.11261	1.5987	0.7696	14	0.2529	2.3729
4	5	0.09263	0.8576	1.3752	8	0.14112	1.3241

Table 4.4: Reliability indices for loss of DG unit

	VPII	ILP	ILQ	EPLI	CVPII	CILP	CILQ
Normal	1	1	1	0	1	1	1
3	0.6000	0.8605	0.9014	8.80	0.6250	0.8968	0.8440
5	0.4256	0.6768	0.6342	49.37	0.4167	0.5034	0.6063
7	0.6000	0.7583	0.8089	19.43	0.7143	0.8807	0.7012
65	0.7500	0.8822	0.9701	3.85	0.8558	0.9723	0.9248
10	0.6000	0.7746	0.7963	8.53	0.6250	0.7949	0.8821
11	0.3333	0.4530	0.4247	100	0	0	0
12	0.3000	0.5709	0.4267	100	0	0	0
13	0.4286	0.6326	0.5873	53	0.3846	0.5771	0.5380
14	0.3750	0.5180	0.5837	51.90	0.3846	0.5341	0.5273
6	0.5000	0.7254	0.6412	40.05	0.4545	0.5888	0.6760
2	0.5000	0.7991	0.6707	31.53	0.5000	0.5573	0.7418
19	0.3750	0.6293	0.4983	67.00	0.3571	0.4228	0.5084
4	0.6000	0.7650	0.9289	33.88	0.6250	0.7577	0.9110

V. Discussion

Power flow analysis was conducted and indices calculated using the values of voltage violations, real and reactive power losses both for normal system and that at the collapse point and the maximum loading for the voltage violation as demonstrated in figures 4.6 - 4.37 and Table 4.3 and 4.4. The maximum violation was seen when DG is lost in Bus 11 and Bus 12 with the lowest indices of 0.3333 and 0.3000 respectively, there is no much significant impact when DG is lost in Bus 65 with a violation indices of 0.75. At the collapse point, the greatest impact is seen when DG is lost at Buses 19, 13, and 14 with voltage violation indices of 0.3571, 0.3846 and 0.3846 respectively. The best result was also seen when DG is lost in Bus 65 with voltage violation indices of 0.8558. No account for voltage violation for DG loss at Buses 11 and 12 since no additional load can be included to the network or a collapse will be encountered. Generally, much negative impact was not seen when DG is lost in Buses 65, 3 and 4, while worst impact was seen in Bus 12 (Rumuola feeder), Bus 11(Rumuodumaya), Bus 14 (T/Amadi) and Bus 19 (Onne feeder), while Bus 11(Rumuodumaya) and Bus 12 (Rumuola feeder) removed could lead to system collapse when considering voltage violation indices.

For real power indices, the worst case was seen in Bus 11 (Rumuodumaya) with the real power indices of 0.4530, while the best result was seen in loosing DG in Bus 65 (Agip base). For the continuation power flow to ascertain more load to be added to the network, the worst case was seen in bus 19 (Onne feeder) with real power indices of 0.4228, while the best was seen in removing DG in bus 65 with real power indices of 0.9723, though no result for bus 11 (Rumuodumaya) and bus 12 (Rumuola feeder) showing that a collapse will be encountered on the network when more load is added after losing the DGs attached to them.

Aside bus 11 (Rumuodumaya) and bus 12 (Rumuola FDR) which cannot accept more load or collapse, the worst case was seen in loss of DG at bus 19 (Onne FDR) also and the best was seen in removing DG at Bus 65 (Agip base) considering reactive power indices of 0.5084 and 0.9248 respectively. For normal system, the worst case was encountered at the removal of DG at Bus 11 (Rumuodumaya) with reactive power indices of 0.4247 and the best was seen at loss of DG at Bus 65 with reactive power index of 0.9701.

The percentage loading factor which accounts for percentage of loading parameter lost at the loss of a DG unit shows that all excess load is lost when DG is lost in bus 11 (Rumuodumaya) and bus 12 (Rumuola feeder). Smaller fraction of the excess load is lost when DG unit is lost in buses 65 (Agip base), bus 10 (T2A 24) and bus 3 (PH 24) with loadability indices of 3.85%, 8.53% and 8.80% respectively. Higher lost in excess power was also encountered in loosing DG unit in buses 19 (Onne FDR), bus 13 (Oyibo) and bus 14 (T/Amadi), with loadability lost percentage of 67%, 53% and 51.90% respectively, which is more than half of the excess load.

VI. Conclusion

This study considers the impact of DG installation in the Port Harcourt Network and what happens if a failure occurs, which could result in the loss of a DG device at every place where the DGs are located. According to the findings, DGs should be installed at Buses PH (Z2) (buses 2), PH (Z4) (bus 3), T2A (ZA) (bus 4), T3A (Z2) (bus 5), T1A (Z2) (bus 6), T1B (Z4) (bus 7), T2A (Z4) (bus 10), Rumuodumaya (bus 11), Rumuola FDR (bus 12), OYIGBO (bus 13), (bus 65). With reduced actual and reactive power losses, the system maintains reliability and can accept additional load with 5 voltage violations.

The possibility of missing a DG device was also investigated in order to see how stable the network would be if the DG went down. The results show that losing DG units at Buses 11 (Rumuodumaya) and 12 (Rumuola FDR) may have a significant impact on the network, raising the number of breaches, actual and reactive power losses, and overall excess load losses of 67 percent, 53 percent, and 51.9 percent, respectively. Apart from the impact on buses 11 (Rmuodumaya) and 12 (Onne FDR), bus 19 (Onne FDR) registered the worst case in terms of voltage violation at collapse stage (Rumuola feeder).

When DG was lost at bus 65 (Agip Base), which gave the best overall result, there was little impact. This demonstrates the importance of taking strict steps to protect the DG units on buses 11 (Rmuodumaya) and 12 (Rumuola feeder), as they decide the network's power to a large degree.

VII. Recommendation

After the study, the following recommendations could be proffered;

- Proper positioning of the DGs in Port Harcourt could aid in maximizing the power output and considering more load.
- Constant maintenance of the most affected area of DG lost could be of great relevance as it largely determines the state of the network.
- DGs could be considered as alternative for the weak power supply in Nigeria.

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