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Optimization of Nigerian Power System Distribution using Distributed Generation

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Abstract : The main aim of this paper is to enhance the performance of power system distribution in Enugu State Nigeria using distributed Generation System. The main function of power system distribution is to transfer electrical energy to the consumers, while maintaining an acceptable reliability and voltage quality to all customers. It is sad to know that such services is lacking from the Electrical distribution company at Enugu State Nigeria. This paper proposed to setup a centralized plants distributing electricity within the state through Distributed Generation (DG). The implemented DG was abletoreducethe Power Loss from the transmissiona n d distribution stations within the state and also improve voltage profile. The author was able to optimize the power generationfrom wind Energy source to the Distribution network and the DG system was able tostabilize the network by normalizing the fluctuating voltage profile at the distribution end of power system. In order to achieve that, the power system network wasmodeled and simulated using MATLAB/SIMULINK software. The results of the simulation with DG system and without DG system were compared. The result from power Network without DG shows instability of per-unit voltage between 0 to 5 seconds and while that from DG system shows stabilization per-unit voltage between 5 to 10 seconds. The total power system Loss without DG system was 2350KW while the power loss with DG system was 1883KW. Hence, the percentage of power system improvement was 11.03%. Therefore from the results, there is reduction of power Loss when DG is applied in the power system.

Keywords: Optimization, Distributed Generation, Power system, MATLAB, Power System.

I. INTRODUCTION

The need for steady and quality power supply in Nigeria was the main motivation to this paper. Federal Government of Nigeria had spent billions of Nigeria in Power sector but it seems as giving ingestion to a dead person. Unsteady power supply has crippled economic activates in the country, so researcher should provide alternative ways to solve the problem. From the review of other works, several definition and suggestions were made on power system.The electric power system basically comprises of the generating stations, the transmission stations, the distribution stations and the load centers.

They are all connected in such a way that electrical power can be transmitted from the generation unit to the end users, while ensuring the operational requirements of the system are not violated in order the provide a reliable service to the customers. The conventional power system was designed to transfer electrical power from the generating unit to other parts of the power system in a radial configuration via long transmission and distribution networks. Many of these generating units are found at large power plants and are majorly thermoelectric and hydro dependent, which are usually isolated from load centers (Kashem, Tas, Le, Negnevitsky & Ledwich, 2006).Since electricity is generated to be consumed at the same time it is demanded due to the fact that it cannot be stored efficiently in large amounts, power system operators must balance power generation and demand constantly without violating the active and reactive power constraints (Horowitz and Phadke, 2016). As distribution systems were designed for radial operation the presence of generation units at distribution level was not considered in the design. This in itself does not mean that distributed generation will cause problems but it does lead to a serious fear among many power system operators that the reliability and quality of the supply can no longer be guaranteed. This change in structure demands the coordination of the operation of a large number of systems and the electricity networks (Anderson et al, 2005; Abu-Mouti, 2011). Thus, the importance of information and communication technology for energy systems will further increase. Several potential problems have been reported in literature, with voltage control being widely considered the most serious one Marimuthu, Gnanambal, Eswari and Pavinthra, 2016, often leading to blackouts and ultimately system collapse.A major blackout occurs when a large area, or a complete area of a power system, collapses. The main cause of a major blackout is a succession of cascading failures that trip a transmission line or some generation units.These failures or faults are called contingencies. A partial blackout may start with a severe contingency which can cause a large variation in power flow and bus bar voltage which, in turn, can cause the outage of generation units or transmission lines. This certainly causes an imbalance in the demand for and generation of power. This process can be the beginning of a major blackout when it spreads uncontrollably throughout the power system IEEE Standard, 2003; Brown, 2008).

II. DISTRIBUTED GENERATION

Distributed generation (DG) are sources integrated with the distribution systems to offer various means of energy production and conversion in contrast to the vast generators which are connected to the transmission systems.

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These alternative sources of energy like the wind turbines, diesel power generators, gas turbines, photovoltaic cells and other renewable energy technologies require converters to make them useful to the distribution network Bollen et al, 2008; Tas & Das, 2016). These alternative sources of energy however have their peculiar characteristics which majorly depend on their means of conversion in order to synchronise with the energy utility at the distribution end. Electrical energy converters are majorly classified into three: synchronous generators. Asynchronous (induction) generators, and static(or electronic) inverters (Rashid, 2012; MohdZamri, IstvanErlich&Azah, 2010).

Figure 1.1 shows the block diagrams of Distributed generation.

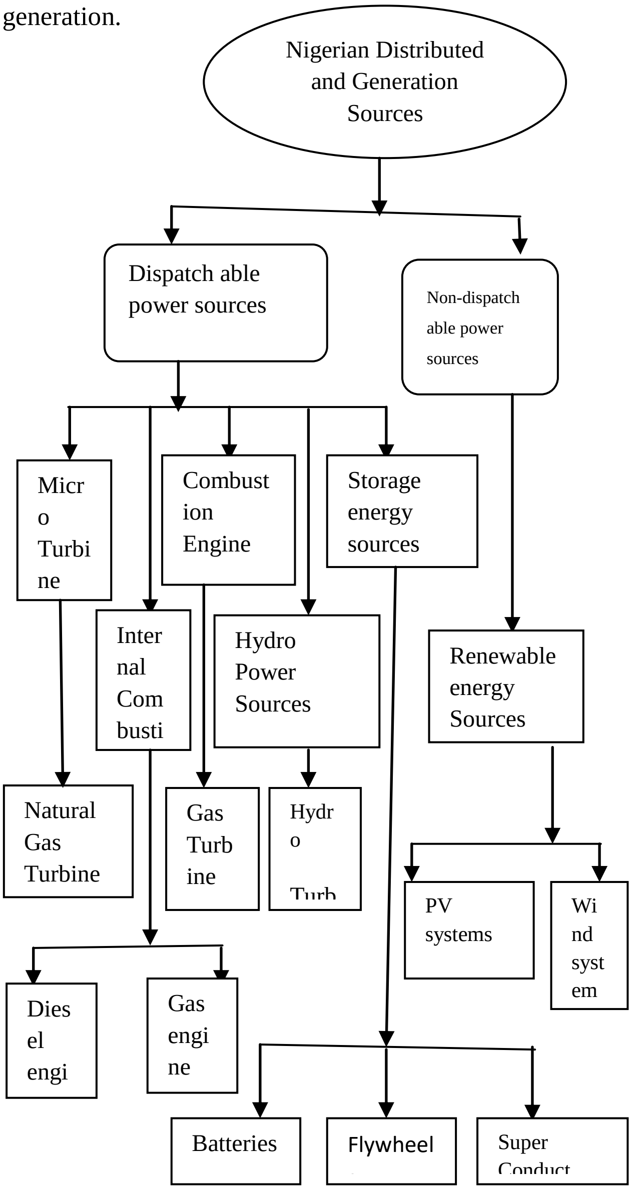

Figure 1.1: Distributed Generation.

DG units are usually of lesser sizes compared to the central generators and can be located near the customers owing to the fact they may be attached to any voltage level. This reduces transmission losses hence, improving the efficiency of the entire power system. Distributed generation (DG) units vary in capacity ranging from a few kVA values to hundreds of MVA and they employ varying technologies for generation. Load-following DG units often utilize synchronous generators (Roberto, 2009).

III. WIND TURBINES

A wind turbine is a machine which traps and changes the kinetic energy of the wind into mechanical energy and then to electrical energy by means of an AC induction generator. The availability of wind appears stochastic, hence making it almost impossible to forecast the wind speed and the wind power production more than few hours before time. It is also important to forecast correctly the time when wind speed would be sufficient enough to drive the turbines so that wind generating stations may be able to participate in electric power generation. The annual quantity of electrical energy generated by the wind turbine is greatly influenced by the location of the turbine. Wind turbines are majorly located with regards to adequate wind availability and condition rather than being located in favor of the grid. Wind energy is one of the most used DG source across the globe. Group of wind turbines installed and operated in a place is referred to as a wind farm. The most appropriate place to locate the wind farm is a windy environment, because the degree of availability of wind determines the amount of electrical energy generated(CIGRE, 2000; Johnson, 2006; Slootweg, 2005).

IV. MATERIALS AND METHODOLOGY

This study analyzed the New-haven 33/11kv substation system with impact of DG for optimization of active and reactive power using Simulink model. The load flow analysis was programmed in MATLAB/Simulink.

The method adopted while doing load flow analysis was Newton Raphson technique. The Newton -Raphson method is very effectiveness to achieve visual iterative solutions to the power flow analyses because it depends on the selection of suitable initial values for state variables involved in the study. The power flow solution started with voltage magnitudes of 1pu at all PQ buses. The slack, PV and PVT buses are given their specified values, which remain constant throughout the iterative solution if no generator reactive power limits are violated. The initial voltage phase angles were selected to be 0 at all buses.

(a) Newton-Raphson power flow Analysis

The Newton-Raphson solution is a set of nonlinear power flow equation which occurs between voltage and power in a 3 phase AC power system. The equations (1) and (2) were applied to analyze 3-phase AC power system at New Heaven Enugu State, Nigeria

$$P_k = |V_i|^2 G_{ii} + \sum_{n=1}^{N} |Y_{kn} V_k V_n| Cos(\theta_{in} + \delta_n - \delta_i) \quad (1)$$

$$Q_k = -|V_i|^2 B_{ii} - \sum_{n=1}^{N} |Y_{kn} V_k V_n| Sin(\theta_{in} + \delta_n - \delta_i) \quad (2)$$

The newton-Raphson solution for the power flow equation was represented by the Jacobian matrix in equation (3).

$$\begin{bmatrix} \Delta P_m \\ \Delta P_l \\ \Delta Q_m \\ \Delta Q_l \end{bmatrix} = \begin{bmatrix} \frac{\partial P_m}{\partial \delta_m} & \frac{\partial P_m}{\partial \delta_l} \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \delta_l} V_l \\ \frac{\partial P_l}{\partial \delta_m} & \frac{\partial P_l}{\partial \delta_l} \frac{\partial P_l}{\partial V_m} V_m & \frac{\partial P_l}{\partial \delta_l} V_l \\ \frac{\partial Q_m}{\partial \delta_m} & \frac{\partial Q_m}{\partial \delta_l} \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \delta_l} V_l \\ \frac{\partial Q_l}{\partial \delta_m} & \frac{\partial Q_l}{\partial \delta_l} \frac{\partial Q_l}{\partial V_m} V_m & \frac{\partial Q_l}{\partial \delta_l} V_l \end{bmatrix} \begin{bmatrix} \Delta \delta_m \\ \Delta \delta_l \\ \frac{\Delta V_m}{V_m} \\ \frac{\Delta V_l}{V_l} \end{bmatrix} \quad (3)$$

The state variables $_m$, $\boldsymbol{\delta}_l$, V_m and V_l with correction values $\Delta\boldsymbol{\delta}$ and ΔV were added for each iteration. The derivative of P and Q forms the Jacobian matrix's element. Iterations was started with initial estimates of state variables. The new voltage profile at bus m was given in equations (4) and (5). Figure 1.2 shows the 11KV distribution network.

$$V_m^{(i)} = V_m^{(i-1)} + \Delta V_m^{(i)} \quad (4)$$

$$\delta_m^{(i)} = \delta_m^{(i-1)} + \Delta\delta_m^{(i)} \quad (5)$$

Where 'i' is the number of iteration

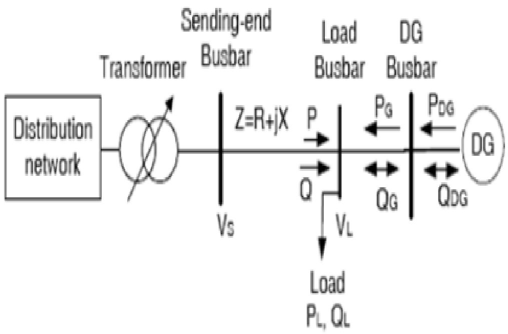

Figure1.2: An 11KV Distribution Network With DG Connection Horowitz &Phadke, 2003)

The items are composed with constraints to obtain the proper objective functions. The main constraints are:

(a) Load Losses

Before installing DG to power grid, there should be more power losses in the system and after the installation there should be lesser power loss ieLoss with DG ≤ Loss without DG

(b) Voltage constraint

V bus min ≤ V bus ≤ V bus max

The objective function, with constraints and goals, was determined as following:

$$\max\ F = k_1\left[\max\left[0, \frac{1}{n}\sum_{i=1}^{n} R + k_2(\max(0,T)) + k_3(\max(0,W))\right]\right] \quad (6)$$

$$R = Voltage\%i_{withDG} - Voltage\%i_{withoutDG} \quad (7)$$

$$T = \sum_{i=1}^{m} Pi_{withoutDG} - Pi_{withDG} \quad (8)$$

$$W = \sum_{i=1}^{m} Qi_{withoutDG} - Qi_{withDG} \quad (9)$$

First term in this expression, related to difference between average voltage profile percentage in base case and other cases according to DG's locations. By so doing, summation of active and reactive power losses and difference are computed to enable the objective function to be established. Maximum operator was used for enforcing the constraints. The parameters are stated below:

$voltage\%i_{withDG}$: Voltage Percent in i_{th} bus with DG resource.

$voltage\%i_{withoutDG}$: Voltage Percent in i_{th} bus without DG resource.

Pi_{withDG}: Active Power Losses in j_{th} branch with DG resource.

$Pi_{withoutDG}$: Active Power Losses in j_{th} branch without DG resource.

Qi_{withDG}: Reactive Power Losses in j_{th} branch with DG resource.

$Qi_{withoutDG}$: Reactive Power Losses in jth branch without DG resource.

K1,k2, k3: Emphasis or penalty factors

n: Number of Buses

m: Number of Branches.

In case that voltage limits are violated, Pand Q loads are modified as:

$$P_k = \frac{-P_{Lk} V^2{}_k}{(V^{lim}{}_k)^2} \quad (10)$$

$$Q_k = \frac{-Q_{Lk} V^2{}_k}{(V^{lim}{}_k)^2} \quad (11)$$

Where $V_L{}^{lim}$ is dependent on the case $V_L{}^{max}$ or $V_L{}^{min}$.

The overall efficiency of the Wind was between 20-40% of the distributed generation and its power rating varies between 0.3 to 7 MW in order to avoid waste in the system.

Wind turbine mechanical output power= 1.4MW
Base power of electrical generator=1.6MVA
Base wind speed=12m/s
Maximum power at wind speed =0.73p.u
Base rotational speed=1.2p.u

V. DISCUSSION OF RESULT

The simulation results are presented after the optimization of Power system without DG and with DG system. The comparisons of power loss without DG and with DG were done. The New-haven 33/11KV substation data was collected in order to ascertain the effect of DG in the substation. Figure1.3 shows the SIMULINK design for optimization of power system with DG. Figure 1.4 shows the Voltage stability of power system without DG. This insinuate that after the Load flow analysis of 30 buses, the faulty buses that do not fall between ranges of 0.9 to 1.05 and per-unit voltages are bus1, bus2,bus3,bus9,bus10, bus11, bus12, bus13, bus16 and1.16p.u,1.09p.u,1.069p.u,1.065p.u,1.060p.u,1.082p.u,1.072p.u,1.071p.u and 1.06p.u respectively. Figure1.5 shows Per-Unit Voltage of power system with DG. This result shows that the optimization of per-unit voltage power system and faulty buses with DG are 1.046p.u, 0.9829p.u, 0.9639p.u, 0.9603p.u, 0.9558p.u, 0.9757p.u, 0.9666p.u, 0.9657p.u, 0.9558p.u and bus1, bus2,bus3, bus9, bus10, bus11, bus12, bus13, bus16 respectively. Figure1.6: Comparison of per-unit Voltage with and without DG. This shows the comparison of per-unit faulty voltage without DG and with DG. The per-unit faulty voltages without DG and with DG are 1.16p.u, 1.09p.u, 1.069p.u, 1.065p.u, 1.060p.u, 1.082p.u, 1.072p.u, 1.071p.u, 1.06p.u and 1.046p.u, 0.9829p.u, 0.9639p.u, 0.9603p.u, 0.9558p.u, 0.9757p.u, 0.9666p.u, 0.9657p.u, 0.9558p.u respectively. Finally per-voltage faullty power system stabilizes when DG is applied. Figure1.7 shows the Comparison of power Loss with and without DG. The relationship between power loss in power system without DG and with DG are 400KW, 350KW, 380KW, 390KW, 280KW, 178KW, 122KW, 100KW, 150KW and 315KW, 300KW, 340KW, 309KW, 217KW, 120KW, 83KW, 74KW,125KW respectively. therefore from the results, there is reduction of power Loss when DG is applied in the power system. The total power system Loss without and with DG are 2350KW and 1883KW. Hence, the percentage of power system improvement is 11.03%. Figure1.8 shows the Voltage stability of power system with DG. The result shows the per-unit voltage stability with time of operation. The per-unit faulty voltages with DG are1.046p.u, 0.9829p.u, 0.9639p.u, 0.9603p.u, 0.9558p.u, 0.9757p.u, 0.9666p.u, 0.9657p.u, 0.9558p.u. Thus, there was instability of per-unit voltage between 0 to 5 seconds and system stabilizes the per-unit voltage between 5 to 10 seconds.

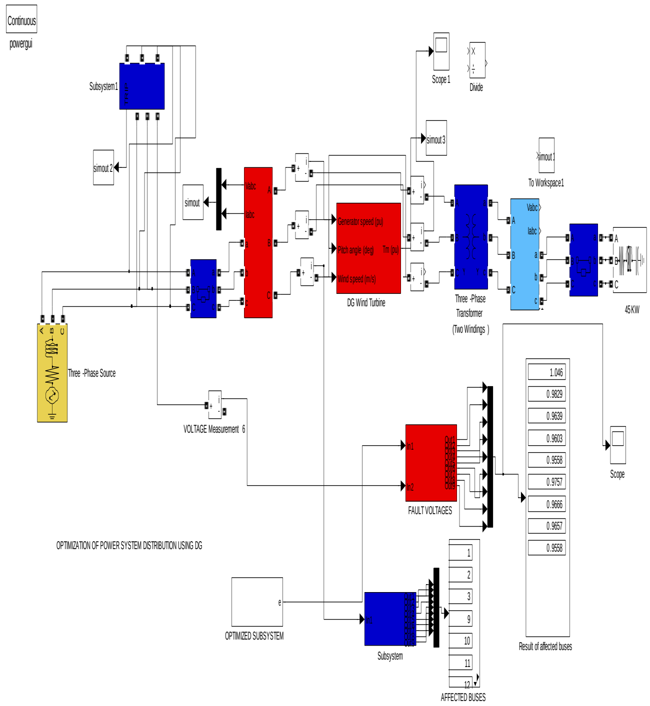

Figure1.3: SIMULINK Model of Power System with Distributed generation

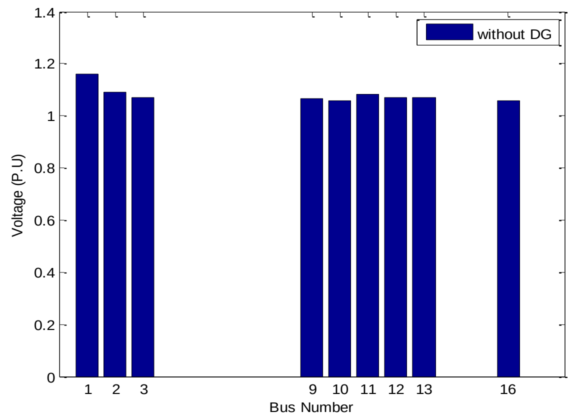

Figure1.4: shows the Voltage stability of power system without Distributed generation.

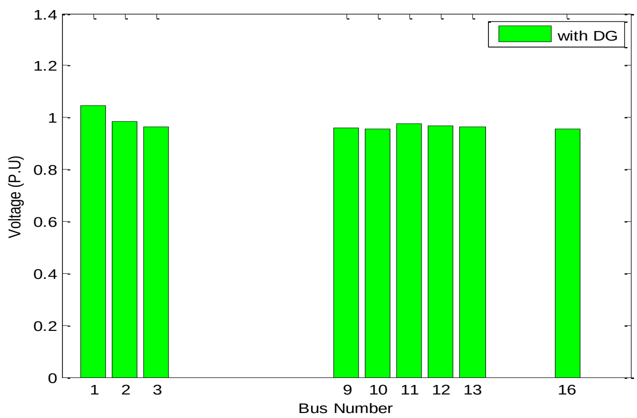

Figure1.5: Per-Unit Voltage of power system with Distributed generation

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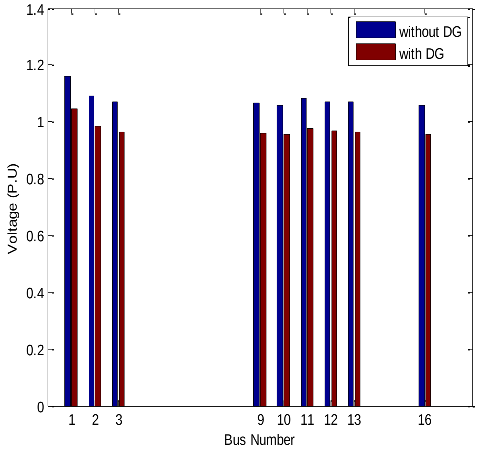

Figure1.6: Comparison of per-unit Voltage with and without Distributed generation

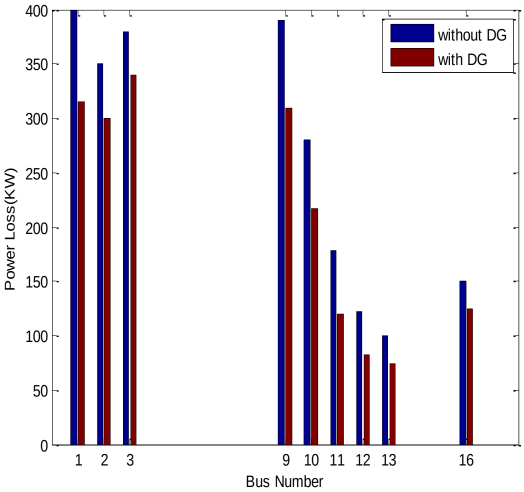

Figure1.7: Comparison of power Loss with and without Distributed generation

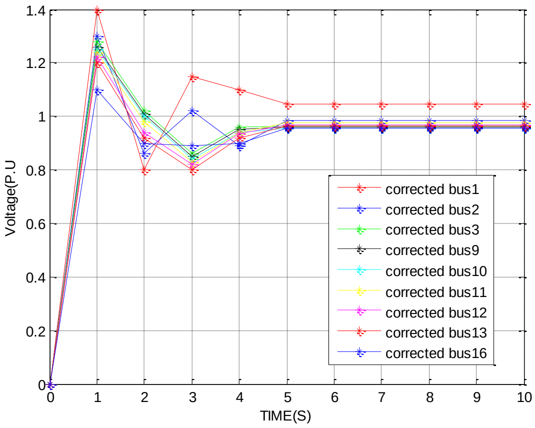

Figure1.8: Voltage stability of power system with Distributed generation

VI. CONCLUSION

This paper discussed the use of Distribution Generation (DG) to optimize the power system at New Haven 33/11KV substation. The model of DG power system using MATLAB/SIMULINK to improve Power system performance was done by comparing the faulty per-unit voltage with and without DG system. From the result of the comparison, it wasobserved theinstability of per-unit voltage between 0 to 5 seconds and system stabilizes the per-unit voltage between 5 to 10 seconds. Therefore from the results, there was reduction of power Loss when DG was applied in the power system. The total power system Loss without and with DG are 2350KW and 1883KW respectively. Hence, the percentage of power system improvement was 11.03%. from the results, it was deduced that there was decrease in power Loss when DG was applied in the system model. Hence power system was improved when DG was introduced into the system.

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