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Voltage Stability Assessment on a Distribution System without Wind Turbine Generators Connected

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Abstract

This work investigates the healthiness of the Nigeria distribution grid (the test system) to accommodate the connection of wind turbine generators. The test distribution system is subjected to load-flow analysis; the program was developed in Matlab platform without wind turbine connection. This is necessary to know if the system voltages at each bus remain within specified limits and angle at each bus. The ability of a site to sufficiently accommodate wind generation does not only depend on wind speeds but its ability to interconnect to the existing grid. That is, it is not enough to say that the wind turbines should be connected to the grid just because there are sufficient wind speeds to drive the wind turbine, but the wind turbine generators must be able to connect with the existing grid (which must be healthy enough to accommodate the wind turbine generator). The result shows that the voltage magnitude at each bus is within the specified limit which shows that the network is healthy without wind turbine generators connected. The findings in this research work will give much better insight to potential investors in wind power in Nigeria.

Keywords: Distribution, Grid, Load-Flow, Nigeria, Voltage Stability, Wind Turbine

1. Introduction

The crucial role of energy in the economic, social and political advancement of any nation cannot be over-emphasized. Nigeria is endowed with abundant energy resources. Despite this, the country is still in short supply of electrical power. Only about 40% of the nation's over 170 million inhabitants have access to grid electricity¹. Even this insufficient electricity supply to the consumers that are connected to the grid is erratic. There is therefore the need to harness renewable energy potentials, which

are emission free and available at no costs, for reliable power supply in this country. Nigeria is known to have high potentials for wind power. Report have shown that some offshore or coastal areas from Lagos State through Ondo, Delta, Rivers, Bayelsa to Akwa-Ibom states have potentials for harvesting strong wind energy throughout the year. Also, detailed wind speed measurements and data carried out in some hilly areas in Nigeria have shown excellent wind potentials for implementation of wind farms in those areas. In the country, where the wind

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power prospect is estimated to be moderately high, this Wind Energy Conversion (WEC) has not been connected to the (distribution) grid.

It can be seen from equation 1.1³⁻⁶ that the wind turbine power output is a function of the wind speed. If the wind speed is moderately high, the turbine power output should also be reasonably high.

$$P_{ae} = \frac{1}{2} \rho \pi R^2 V_{eq}^3 C_p(\theta_{pitch}, \lambda) \quad 1.1$$

Where P_{ae} is the aerodynamic power extracted from the airflow [Watt],

ρ is the air density [typically 1,225Kg/m³]

C_p is the power coefficient which depends on the pitch angle θ_{pitch} [in degrees] and on the tip speed ratio.

$\lambda = \frac{\omega_{rot} \cdot R}{V_{eq}}$ which is the ratio between the blade tip speed $\omega_{rot} \cdot R$ and the equivalent wind speed V_{eq} [m/s²].

R is the rotor radius and ω_{rot} is the rotor speed.

Equation (1.1) shows that the power which a particular wind turbine can extract from wind is a cubic function of the wind speed. But it is very important to state here that it is not just enough to say that the wind turbines should be connected to the grid just because there are sufficient wind speeds to drive the wind turbine, but the wind turbine generators should be able to (without disturbing its normal operation) connect with the existing grid. That is, the existing (distribution) grid must be healthy enough to accommodate the new generation. In this case, the stability and reliability studies must be carried out whenever wind power is to be connected to the power system to predict severe consequences (if any) on the power system. In this research work, the static stability assessment on the test distribution grid is considered using the load-flow analysis when the wind turbine generators are not connected. This is necessary to ascertain if the existing distribution system is healthy to accommodate the wind generators.

2. Materials and Methods

The Load-flow study was carried out on the test distribution system to ascertain if the grid network is healthy enough to accommodate the new generation. Load-flow analysis on distribution systems has not received much attention unlike the transmission systems. This is because distribution system has some peculiar characteristics. The following, according to⁷⁻⁹ are the characteristics of a typical distribution system:

- Radial or weakly meshed topologies
- High R/X ratio of the distribution line
- Unbalanced operation and loading conditions
- Non-linear load models and dispersed generation
- Multiphase and unbalanced operation
- Unbalanced distribution load.

The conventional load-flow methods of Newton-Raphson and Fast-decoupled methods cannot be used for the solution of a distribution system because of high R/X ratio of its lines, its radial nature and unbalanced operation in distribution system. These conventional load-flow methods used for distribution network may not be efficient, may not provide accurate result and the solution may even fail to converge¹⁰⁻¹⁴. There are three categories of algorithms developed for solution of radial distribution systems are as follows:

- Modified Newton-Raphson, Fast-decoupled and Gauss-Seidel methods
- Forward/backward sweep-based Methods
- Probabilistic load-flow methods.

The Forward/backward Method was used in this research work to carryout load-flow analysis on the test Nigerian distribution system when wind turbine genera-

tors are not connected to the grid, because of the following advantages^{15,16};

- Low memory advantage
- Easy programming
- More effective and computationally efficient
- Robust and excellent convergence characteristics

2.1 Description of the Test Distribution System

The test distribution system shown in Figure 1 is derived and drawn from the schematic diagrams collected from Power Holding Company of Nigeria (PHCN), Eko distribution business unit. The injection substation (33/11kV which is used in this research work) is located 9km away from the wind turbines (wind clusters). This location was chosen because of the availability of enough wind speed

in that location¹⁷ to drive the wind turbines. According to¹⁸, large wind-farms with high wind penetration (Off-shore) are normally connected to 33-kV distribution network from which 132kVis obtained via step-up transformer, while small-scale wind clusters (On-shore and or near shore) are normally connected to 11-kV distribution network and eventually to 33-kV network.

A balanced three-phase radial distribution network is assumed in this research work and so the network can be represented by its equivalent single-line diagram. The distribution lines are represented by their resistances and reactance in per unit. Line shunt capacitance is also negligible at the distribution voltage levels as found in most practical cases. From the schematic diagram obtained from PHCN, 132- / 33-kV transformers have ratings in the range of 30MVA to 60MVA depending on the location. The ratings of the transformers are determined by the load demand in that particular area. Also, 33-/11-

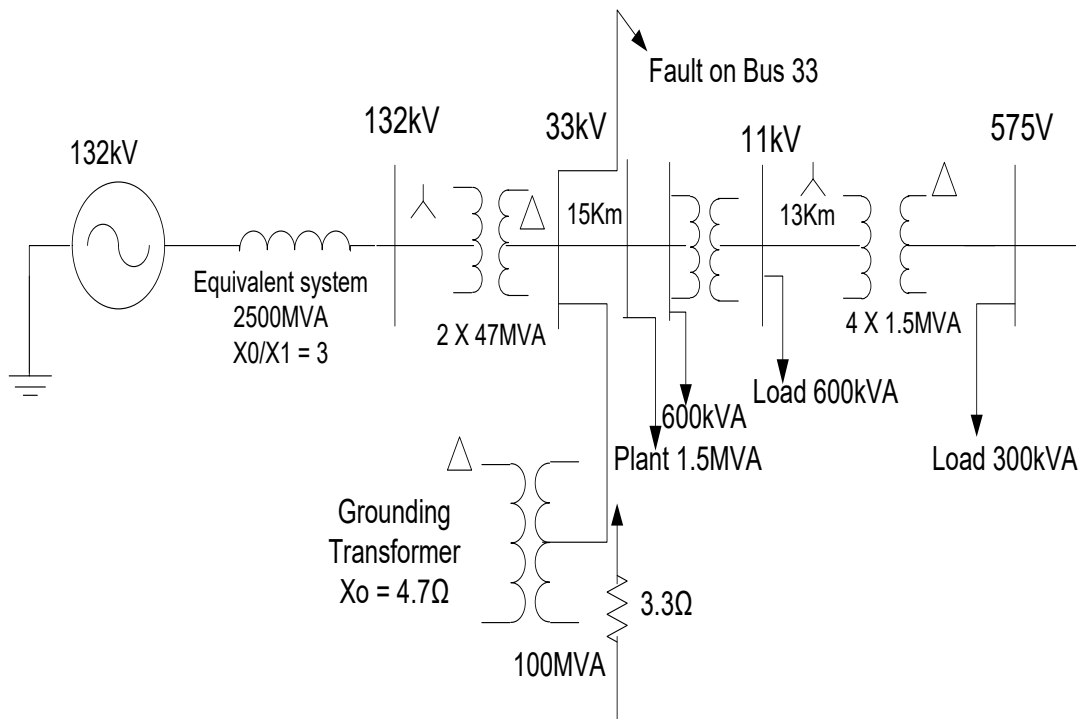


Figure 1. One-line diagram of the test system²⁰.

kV transformers are rated 15MVA. A 132- / 33-kV Transformer rated 47MVA was chosen for in this research work since it falls within the range given on the schematic diagram. Note that the model for this transformer is available in Simpower system software. The remaining feeders have Industrial and Residential loads connected to them. The total number of buses used here is six. The load-flow analysis is carried out on the test system when the wind turbine is not connected. This load-flow analysis is still very necessary even though the calculations of parameters at the Point of Common Coupling (PCC) and POC confirmed that a 6-MW turbine generator can be connected to the test distribution grid¹⁹.

2.2 Load-Flow Analysis without Wind Turbine Generator

As explained in section 2, the conventional load-flow solution algorithms such as Newton-Raphson, Gauss-Seidel and Fast-decoupled used for transmission system cannot be used in this test distribution system because of high R/X ratio of the distribution line and its radial nature. The method used in this work is Forward/Backward sweep algorithm. The solution algorithm of the method used here was written in MATLAB-based programme.

The major concern here is to determine the following:

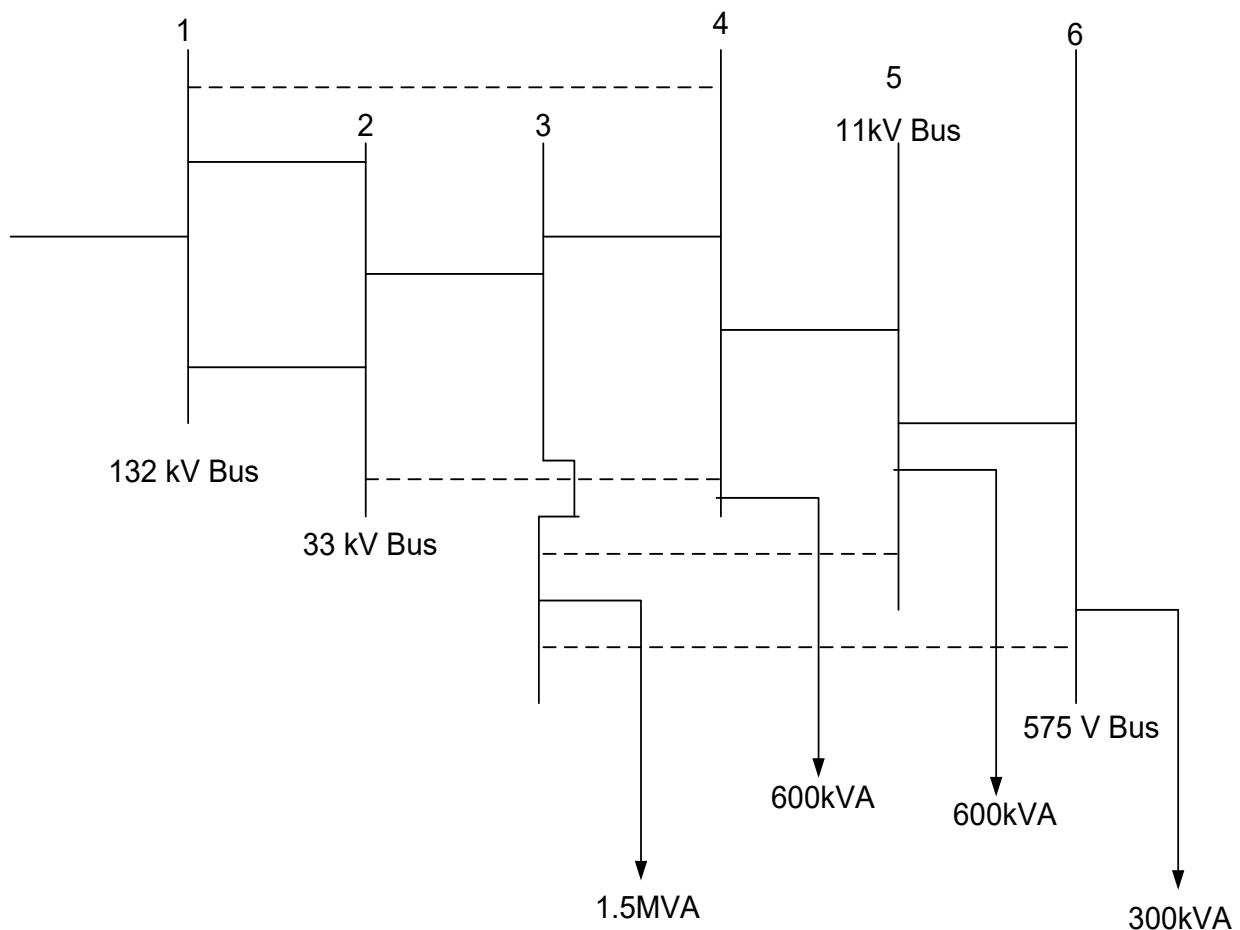


Figure 2. One-line diagram of the test distribution system showing the six buses and the loads supplied by four of them²⁰.

Table 1. Showing the distribution lines' parameters used in Figure 2²⁰

From Bus	To Bus	Resistance Ω/km	Reactance Ω/km
1	2	0.1630	0.0892
1	4	0.1630	0.0892
2	3	0.2660	0.0949
2	4	0.2660	0.0949
3	4	0.2660	0.0949
3	5	0.2660	0.0949
3	6	0.1630	0.0892
4	5	0.4110	0.1070
5	6	0.4110	0.1070

- the steady-state voltage magnitude and angle at each bus
- the total losses in the distribution lines.

Bus one (132-kV) is chosen as the slack bus. Bus two (33-kV) has no load connected to it. Bus three (33-kV) has a load of 1.5MVA connected to it. Bus four (33kV) has a load of 600kVA connected to it. Bus five (11kV) has a load of 600kVA connected and bus six (575V) has a load of 300kVA connected to it²⁰.

Buses three to six are PQ buses while bus one is the slack bus. The load power factor for the relevant PHCN network in Nigeria is 0.8747 lagging. This is the power factor value used in this research work.

The base MVA used is 100MVA. From the information given above, the reactive power components of the attached loads can be calculated. Figure 2 shows the one-line diagram of the test system with the buses and the load connected to each bus.

The line parameters used in Figure 2 are as given in Table 1.

3. Results and Discussion

The result of the load-flow is as shown below in Table 2. The minimum and maximum per unit voltage values were set in the load-flow program to 0.95 and 1.07 respectively. The base kV used here is 11kV.

From the results in Table 2, it can be seen that the test distribution network is within the set limit (minimum = 0.95 and maximum = 1.07). The least voltage magnitude is 0.9938 which occurs at bus 4 (33-kV bus). From the results table, the difference between the highest and low-

Table 2. The load-flow analysis results without wind turbine connection²⁰

Bus Number	Voltage magnitude V (p.u)	Voltage Angle(degree)
1	1.06000	0
2	1.0000	14.3360
3	1.0004	22.0859
4	0.9938	11.3344
5	0.9970	18.7528
6	1.0016	21.0763

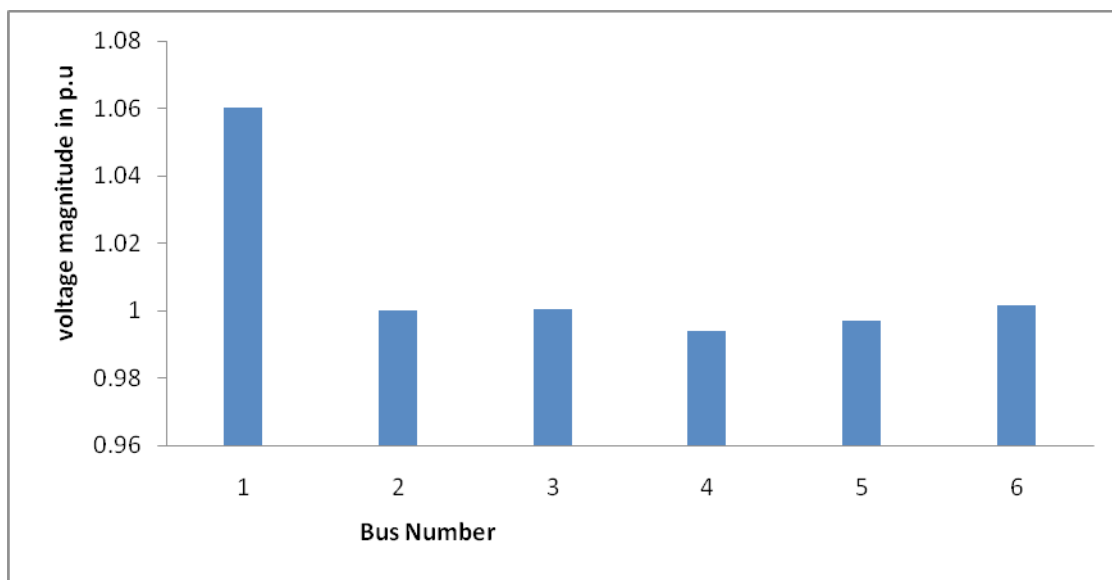


Figure 3. Column chart showing the results of the load flow.

est voltage is 0.0662 p.u. The total line loss is calculated to be 81.05kW.

The result shows that the distribution system is “healthy” since all the bus voltage magnitudes are within the specified limit values. The column chart for the result in Table 2 is as given in Figure 3.

The most important point to note here is that the voltage magnitude at each bus is within the specified limit. This shows that the network is healthy without wind turbine generators connected.

4. Conclusion

Load-flow study has been carried out on the test distribution grid to assess if the grid is healthy enough to accommodate the new generation (wind power). The result of the load-flow study shows that the voltage magnitude at each bus is within the specified limit, which means that the test distribution network is healthy without the wind turbine generators connected to it. Finally, this work ascertained that the test system is healthy and therefore the wind turbine can be connected to the grid.

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