Improvement of Electrical Power Load Demand and Stability in Electrical Power System with Incorporation of Wind Power Generation

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Abstract: - Nowadays, the penetration level of wind generation in power system is one of the most evolving among renewable generation (solar and hydro generation) with a least cost of installation to support the power system expansion planning. Thus, this study aimed to improve the Nigerian power system stability and meet the load demand from customers during contingency with application of wind power generators. The new generation location was obtained by converting one of the load buses on Nigerian 31-bus power system to generator bus and a new generator admittance matrix using Y bus matrix was formed. Swing equation was employed and the behavior of generator during contingency was determined. Then, the L-VSI for each new addition generation was obtained and used to optimally identify new location for the placement of the wind generator in the power system. Simulation was done in MATLAB R2023a. The generator damping ratio, total active power losses and total cost of the generator were determined. It was revealed that the result verified the accuracy of effective placement of wind generator in the power system to meet the load growth

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I. Introduction

Today, electric power demand is increasing than before due to the increasing number of consumers which may lead to overloads, loss of generation and constant power failure (Akwukwaegbu *et al*. 2021).This high demand of electricity has made the power management to operate power system closer to their limits which has affected the power system operation and subject it to system instability (Eseosa and Ike, 2015; Adepoju *et al*., 2017; Ajenikoko *et al*., 2019; Mohammed *et al*., 2019; Gupta *et al*., 2020).

However, stability of an electrical power system depends on the ability to continuously match the electrical output of generating units to the electrical load of the system. If for any reason the transfer impedance between the synchronous machine and an induction motor load increases, a voltage reduction will occur which causes the motor to slow down. This will cause an increment of current and reactive power flowing into the motors and a further voltage decrement (Anwar *et al.,* 2019). Therefore, to meet the high power demand during the disturbance, additional generation has to be planned (Damor *et al*., 2014; Roche *et al*., 2019; Okelola *et al*., 2019; Akwukwaegbu *et al*. 2021).

One of the most common technical solutions in dealing with the high demand of electrical power demand and to improve the system stability is the construction of new transmission lines, but the process is both time-consuming and costly, and may cause short and long-term disruptions to the environment. Thus, incorporation of power generators such as Thermo-Electric Generators (TEGs) and wind power generation bring great innovation to transmission expansion planning and in transmitting electrical power supply to customer (Martinek *et al*., 2013).

These generators convert mechanical power into three-phase electric power at lower voltage levels. Depending on the installed power system capacity of the generator, they are usually connected to the transmission grid at medium-voltage levels or rarely at high-voltage level. The power generation can be main activity producer and auto-producer plants, where data are available. Main activity producers generate electricity for sale to third parties as their primary activity while, auto-producers generate electricity wholly or partly for their own use as an activity supporting their primary activity. Both types of plants can be privately or publicly owned.

However, due to the power congestion normally occurring at power generation as a result of high load demand and non-optimal location of the generation units, these generator has been operated at their maximum capacity and this can result in instability problems such as network overloading, line tripping and subsequent blackouts.

For this reason, there should be a technical arrangement for power generation systems connection in a safe manner without any negative effects. Thus, the need for power generation expansion planning that will maximize the power generation operation and improve the network topology (physical connection between electrical nodes and feeder segments)

II. Materials and Method

The objective of this study is to improve the load supply of the Nigerian 31-bus transmission system shown in Figure 1 to meet the load growth and demand by customer. In order to meet the load demand and improve the load growth of the power system, new generator was added to the system load buses one at a time for a new generation expansion. This was done by converting load bus of the system to the generator bus making the number of the load buses to reduce by 1. Hence, the objective function is mathematically formulated as Equations (1) (Gbadamosi and Nwulu, 2021):

$$Of = optimize \cdot \left[P_{Load}\right] = \min \frac{\left[P_{Loss}\right] \times \left[P_{Gen}\right]}{XP_D} \tag{1}$$

where: X is the system transfer line reactance per phase, P_{load} is the system maximum load power, P_{loss} is the system loss vector, P_{Gen} is the generator ideal load for the system, Of is the objective function, P_D . is the total system power demand.

The objective function is subject to the following constraints in Equation (2) to (7) (Chen *et al.,* 2020).

$$P_{Gi}^{Min} = P_{Gi} \leq P_{Gi}^{Max} \qquad i = 1,2,.......Ng \tag{2}$$

$$0.95 p.u \leq V_i \leq 1.05 \qquad i = 1,2....N_b \tag{3}$$

$$N_g^{Min} \leq N_g \leq \left(N_{Lb}^{Max} - 1\right) \tag{4}$$

$$N_{Lb}^{Max} \leq N_{Lb} \leq \left(N_{Lb}^{Max} - 1\right) \tag{5}$$

where; P_{Gi} is the generator real power, V_i is the voltage magnitude at bus i , Ng is the number of generator, N_{Lb} is the numbers of load buses in the system.

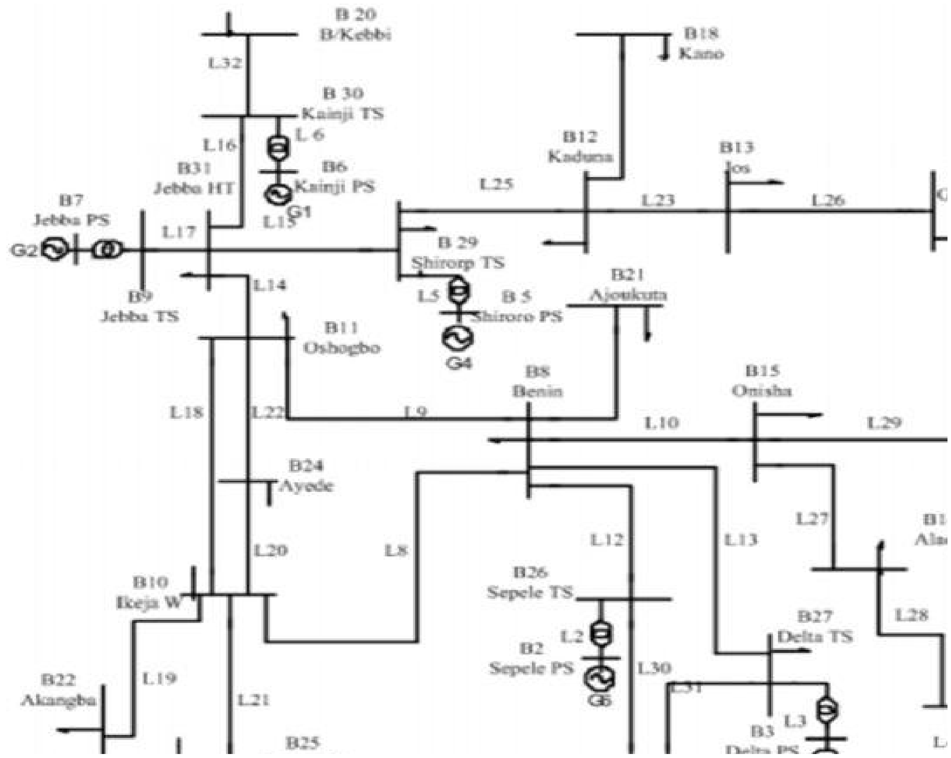

Figure 1: Nigerian 330 kV, 31 –Bus Transmission System [4, 5]

A. Incorporation of power Generator for System Improvement

The new generation location was obtained by converting one of the load buses in the Nigerian 31-bus power system to generator bus and a new generator admittance matrix using Y bus matrix was formed. This increased the power system generator buses with one (1) and reduced the load buses by one (1). Under steady state operating condition, for a given system, the network steady state performance equation is given by Equations (6) to (7) (Gunadin *et al*., 2020; Adebayo *et al.,* 2016; 2021; Adebayo and Sun, 2022):

$$[I_L]=[Y_{LG}]\cdot[V_G]+[V_{LL}]\cdot[V_L] \quad (6)$$

$$[I_G]=[Y_{GG}]\cdot[V_G]+[V_{GL}]\cdot[V_L] \quad (7)$$

where: $[I_G]$, I_L are the complex bus current injection vectors, $[V_G]$, $[V_L]$ are the complex bus voltage vectors and $[Y_{GG}]$, $[Y_{GL}]$, $[Y_{LG}]$, $[Y_{LL}]$ are the corresponding partitioned matrices of the bus admittance matrix.

The equivalent shunt admittance Y_G of generator node was calculated using Equation (8):

$$Y_{Gj}=\frac{1}{V_{Gj}}\left(\frac{-S_{Gj}}{V_{Gj}}\right)^{*} \quad (8)$$

where; $(*)$ is conjugate, S_G is the generator apparent power, V_G is the generator voltage

The equivalent shunt admittance in Equation (3.18) was added to the corresponding diagonal entries of Y-bus matrix. The generator voltage was updated as a function of load voltage using Equation (9).

$$V_G=[Y_{LG}][V_L] \quad (9)$$

The reactive power loss allocated to each load bus was calculated using Equation (10):

$$Q_{GLi}=\sum_{i=1}^{Ng}Q_G-Q_D \quad (10)$$

where Q_D is the net reactive power load demand at the generator buses

B. Application of Swing Equation with Contingency

With addition of generator bus to the Nigerian 31-bus transmission system, the generator load power of the power system varying by 50% to 90 % (acceptable minimum and maximum range of power generator) to compute the power system generator oscillation damping ratio. Swing equation was employed and the behavior of generator during contingency was determined using Equation (11).

$$\frac{H\partial^2 \Delta\delta}{\omega \cdot \partial t^2} = \Delta P_m - \Delta P_e \tag{11}$$

The change in the generator damping ratio was calculated using Equation (12):

$$\Delta K_{GDi} = \int_{0.03}^{0.05} \left(\Delta P_{GL} - \left| \Delta P_{ei} + \frac{H\partial^2 \Delta\delta}{\omega \partial t^2} \right| \right) \partial t \tag{12}$$

The system line loss and bus voltage based on the damping ratio was calculated using Equations (13) and (14), respectively.

$$L_{Lossi} = \sum_{i=1}^{N} \left(\frac{X_s}{V_i^2} P_{Li} + jQ_{Li} \right) + \Delta K_{Di} \tag{13}$$

$$\Delta V_{Gi} = \sum_{i=1}^{N} Y_{Gij} \left(\frac{X_S}{V_i^2} \right) + \Delta K_{Di} \tag{14}$$

where; $\Delta\delta$ is the variation of rotor angle δ, P_e is electrical power transmitted in the line, P_m is mechanical power obtained from the generator, V_i is the system voltage, Y_G is the element of generator bus admittance matrix, V_G is the generator voltage, $P_{L\,i}$ *and* Q_{Li} are active and reactive power loss, P_G are the generator active power, N is the number of bus

The L-VSI for each new addition generation was obtained using Equations (15) and (16).

$$L - VSI = \sum_{i=1}^{N} \left[w_1 \sum \left(\frac{Y_G X_S}{V_i^2} \right) + w_2 \sum \left(\frac{P_{Li} X_S}{V_i^2} + jQ_{Li} \right) + \Delta K_{Di} \right] \tag{15}$$

$$ff = \min \alpha\gamma(P_{Gbus}) + \beta \frac{F_{L-VSI}}{N_{bus}} \tag{16}$$

where; $\gamma(P_{Gbuss})$ is the objective function classifier error, F_{L-VSI} is the number of selected critical buses, and N_{bus} is the total number of features (buses). In addition, α, β are EO feature subsets which are in two factors where; $\alpha \in [0,1]$ and $\beta = (1-\alpha)$.

III. Results and Discussion

In this section, the simulation results of incorporation of wind power generator to improve the power system and meet the increase load demand at the contingency on Nigerian 31-bus power system are presented.

Table 1 presents the selected buses for the placement of wind generator on Nigerian 31-bus at 50% loading. With inclusion of wind generator on the power system at 50% loading, three (3) vertical wind generators were placed on buses 5, 11 and 21 one at a time with corresponding generator size and cost value of 2.5 MW and $370 per kW; 2.0 MW and $3000 per kW; 3.0 MW and $4500 per kW, respectively It was also observed that the value of voltage magnitude and damping ratio of these buses were improved, respectively. The voltage magnitude and damping ratio in these buses were 1.0000, 1.0056 and 1.0000 p.u.; 0.03, 0.03 and 0.04, respectively. However, bus 21 with L-VSI value of 0.57 is the most sensitive bus with higher value of L-VSI and was selected as new generator bus as to meet the increase in load demand of the power system at contingency.

Table 1: Improvement of Nigerian 31-Bus with Wind Generator at 50% Loading

From Bus	Voltage Magnitude (p.u)	Damping Ration	Optimized L-VSI	Wind Generator Size (MW)	Unit Cost ($/kW)
5	1.0000	0.3	028	2.5	3750
11	1.0056	0.3	0.26	2.0	3000
21	1.0000	0.4	0.57	3.0	4500

While, Figure 2 presents the comparison of total active power loses of the power system at 50% loading. The total active and reactive power loss in the system reduced to 332.32 MW (34.1 %) and 237.73 MVar (38.7 %) compared with contingency value of 504.77 MW and 387.61 MVar. respectively.

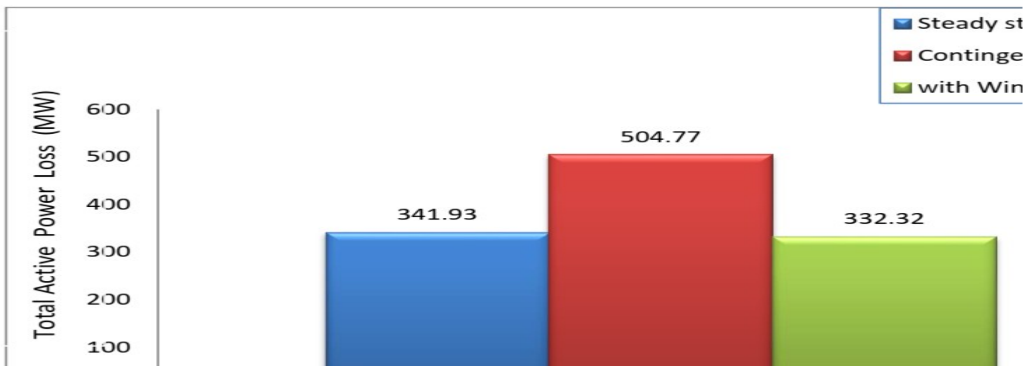

Figure 2: Comparison of Active Power Loss of Nigerian 31-Bus System at 50% Loading

Table 2 also presents the results of selected buses for the placement of wind generator on Nigerian 31-bus at 70% loading. The appropriate wind generator size and cost for the selected buses 5, 11 and 21 were 3.0, 2.0 and 3.0 MW; 4500, 3000 and 4500 $/kW, respectively. The damping ratios in these buses are 0.04, 0.03 and 0.04, respectively. The value of voltage magnitude and damping ratio of buses were also improved compared to contingency case. The damping ratios in these buses are 0.04, 0.03 and 0.04, respectively. However, buses 5 and 21 are the most sensitive buses with higher value of L-VSI value of 0.58 and 0.57, respectively and were selected as new generator buses to meet the increase in load demand of the power system. An appropriate vertical wind generator size and cost value of 3.0 MW and $4500 per kW each were placed in these buses.

Table 2: Improvement of Nigerian 31-Bus with Wind Generator at 70% Loading

From Bus	Voltage Magnitude (p.u)	Damping Ration	Optimized L-VSI	Wind Generator Size (MW)	Unit Cost ($/kW)
5	1.0000	0.04	058	3.0	4500
11	1.0050	0.03	0.26	2.0	3000
21	1.0000	0.04	0.57	3.0	4500

Figure 3 illustrates the comparison of total active power loses of the power system at 70% loading. The total active power losses in the power system were reduced to 340.93 MW compared with steady state and contingency without incorporation of wind generator values of 341.93 and 504.77 MW, respectively.

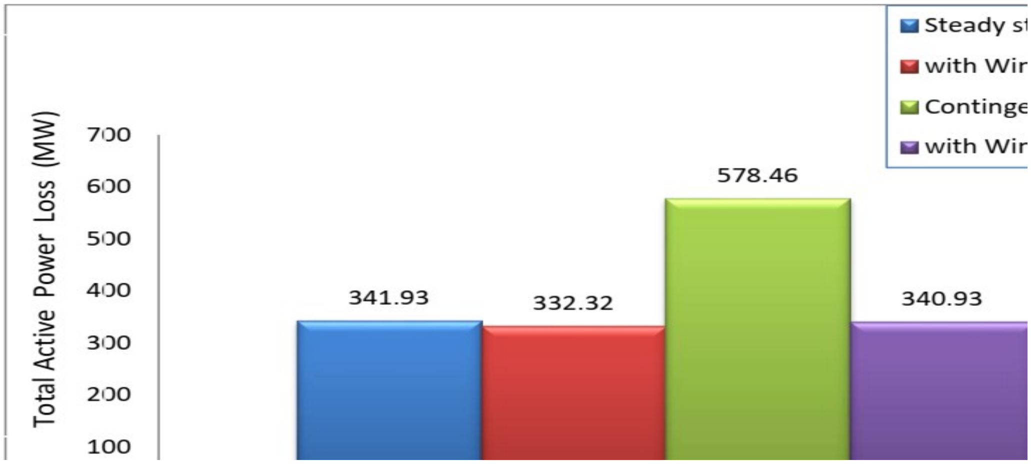

Figure 3: Comparison of Active Power Loss of Nigerian 31-Bus System at 70% Loading

Moreover, Table 3 presents the results of selected buses for the placement of wind generator on Nigerian 31-bus at 90% loading. An appropriate vertical wind generators size and cost value of 3.0 MW and $4500 per kW; 2.0 MW and $3000 per kW; 2.0 MW and $4500 per kW, respectively were placed in the selected buses 5, 11 and 21. The damping ratios in these buses are 0.04, 0.03 and 0.04, respectively. However, buses 5, 21 and 30 were selected as new generator buses in the power system. These buses have L-VSI value of 0.58, 0.57 and 0.54, respectively.

In addition, Figure 4 illustrates the comparison of total active power loses of the power system at 90% loading. The total active and reactive power loss in the system were reduced to 341.59 MW (50 %) and 256.59 MVar (49.3%) compared with contingency value of 684.52 MW and 505.68 MVar..

Table 4.20: Improvement of Nigerian 31-Bus with Wind Generator at 90% Loading

From Bus	Voltage Magnitude (p.u)	Damping Ration	Optimized L-VSI	Wind Generator Size (MW)	Unit Cost ($/kW)
5	1.0000	0.04	058	3.0	4500
11	1.0130	0.03	0.26	2.0	3000
21	1.0000	0.04	0.57	3.0	4500
30	1.0000	0.04	0.54	2.5	3750

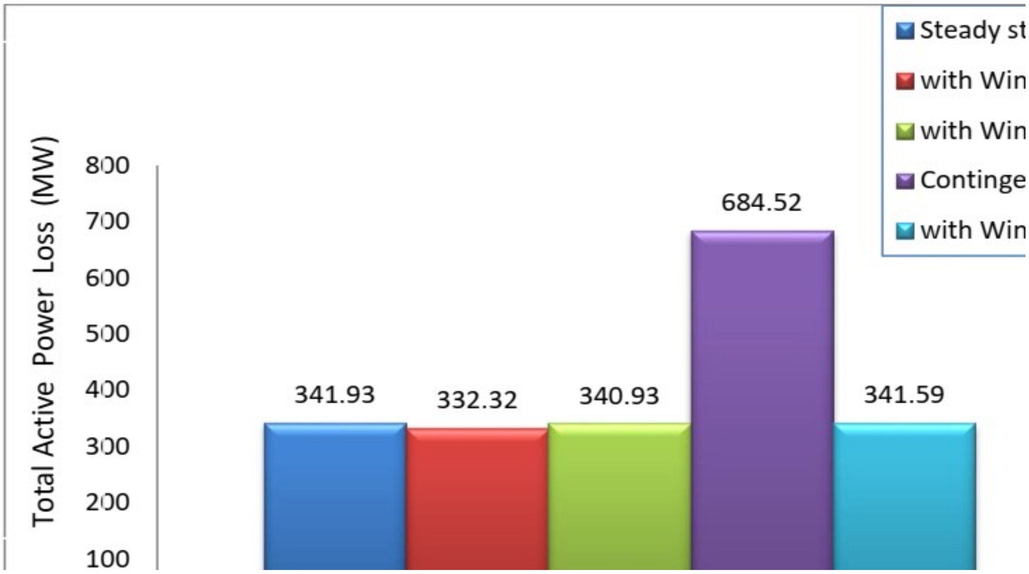

Figure 4: Active Power Loss of Nigerian 31-Bus System at 90% Loading with

IV. Conclusion

This research paper has successfully presented the application of wind power generator for improvement of electric power system to meet the load growth in power system as to provide effective solution for the reliable functioning of the power system during disturbance. The approach was implemented on Nigerian 31-bus transmission system. It can be concluded from the results that, inclusion of wind generator on the power system improved the system electricity generation. It was revealed that the voltage magnitude and damping ratio of the power system were improved, respectively. The active and reactive power in the system was also improved tremendously, while the system power loss reduced to barest minimum. The results verified the accuracy of the optimal placement of the wind generator in meeting the electrical load growth during contingency. Thus, the study would help the Independent System Operators (ISO) to coordinate, monitor and control voltage instability in electric power system.

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