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Characterization of the Nigerian 46 Bus 330kv Transmission Grid Power Network using Continuation Power Flow Technique

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ABSTRACT

The Continuation Power Flow (CPF) has proved to be a viable tool for the determination of power system stability and the identification of weakest buses in a multi-bus network. In this paper, load flow based on Newton Raphson's method is performed on the Nigeria 46 bus 330kV grid power transmission network to determine the value of the network variables (voltage magnitude and angle, real and reactive power flow and losses) during normal operating conditions. CPF is then performed to determine the weakest buses. The load flow and the CPF studies are all implemented in PSAT/Matlab. The power transmission network is also modeled in PSAT/Matlab. By ranking the voltage magnitudes of the determined weakest buses in ascending order, the optimum locations for placement of compensating devices on the network are determined. The buses with voltages below 0.95 after CPF are categorized as weak buses while the bus with the lowest voltage becomes the weakest bus. Result showed that the optimum locations for series compensation are at Yola-Gombe line and Adamawa-Mayobelewa line. The Yola bus with the lowest voltage magnitude of 0.4675pu is the weakest bus.

Keywords: Continuation Power Flow, Load Flow, Voltage Stability, Weakest Bus

1. Introduction

Over the years, multi-bus inter-connected, power networks have continued to suffer instabilities due to constraints associated with the dynamic nature of power networks. Rapid population growth, commercialization and industrialization especially in developing countries like Nigeria are further stretching the power networks beyond its stability limits. The new global trend in power sector restructuring has seen most power networks across the world undergo deregulation/privatization the operational logistics and constraints associated with deregulated powers systems has in no small way contributed to the challenges of instabilities (Pawan, Dharmendra & Sudhir, 2018).

Poor generation, aged equipment, weak transmission infrastructure etc. are some of the many technical challenges faced by the Nigeria 330KV transmission grid networks (Ayodele et al, 2011). This exposed the Nigerian 330KV transmission grid network to faults, various forms of instabilities and cascaded blackouts. The ugly power situation has impacted negatively on social and economic lives of the people. This work is therefore targeted at identification of weak buses and determination of optimum location of series compensation devices on the Nigerian 46 bus 330kV transmission grid network.

2. Theory of Work

In CPF, a system is deemed to have voltage stability if all the buses possess a voltage magnitude of value within the IEEE acceptable limit of 0.95pu to 1.05p (Olabode, 2017). In the criteria for voltage stability, the network is deemed unstable if at least one bus falls outside the above stated limit after the performance of continuation load flow studies.

To determine the weakest buses, the voltage magnitude of the buses is ranked in ascending order (starting from lowest to the highest) (Mohammed, Arif & Tarek, 2014). The buses with voltages below 0.95 are categorized as weak buses while the bus with the lowest voltage becomes the weakest bus. Identifying the weakest buses is key to effective reactive power compensation in the network for the network's overall voltage stability improvement. The method of CPF involves firstly, the reformulation of power flow equations. This is done by infusing a load parameter into these equations.

2.1. System Design

Injected powers can be written for the i^{th} bus of an n-bus system as follows:

$$P_i = \sum_{k=1}^{n} |V_i|\,|V_k|(G_{ik}cos\theta_{ik} + B_{ik}sin\theta_{ik}) \quad (1)$$

$$Q_i = \sum_{k=1}^{n} |V_i|\,|V_k|(G_{ik}sin\theta_{ik} - B_{ik}cos\theta_{ik}) \quad (2)$$

$P_i = P_{Gi} - P_{Di}, Q_i = Q_{Gi} - Q_{Di}$

The subscripts G and D represent generation and load demand respectively on the related bus. For a load change to be simulated, a load parameter λ is infused into demand powers P_{Di} and Q_{Di}.

$$P_{Dio} = P_{Dio} + l(P_{Dbase}) \quad (3)$$

$$Q_{Dio} = Q_{Dio} + l(Q_{Dbase}) \quad (4)$$

The subscripts G and D represent generation and load demand respectively on the related bus.

The initial load demands on i^{th} bus are denoted P_{Dio} and Q_{Dio}, $P_{\Delta base}$ and $Q_{\Delta base}$ are given quantities of powers selected to scale λ accordingly. After an appropriate substitution of new demand powers in Equations 3 to 4, new set of equations can be denoted thus:

$$F(\theta, V, \lambda) = 0 \quad (5)$$

The symbol, θ represents vector of the bus voltage angles and V denotes the vector of bus voltage magnitudes. The base solution for λ=0 is arrived at through power flow. Consequently, the continuation and parameterization processes are applied.

Prediction Step

This step involves the process of using linear approximation by taking an adequately sized step in a tangential direction to the solution path. Hence, Equation (4) is differentiated on both sides.

$$F_\theta d_\theta + F_v d_V + F_\lambda d_\lambda = 0 \qquad (6)$$

In matrix form:

$$\lfloor F_\theta \; F_V \quad F_\lambda \rfloor \begin{bmatrix} d_\theta \\ d_V \\ d_\lambda \end{bmatrix} = 0 \qquad (7)$$

Since there is an addition of an unknown variable λ to load flow equation, Equation 7 can only be solved by inclusion of one more equation. This is achieved by addition of continuation parameter. That is the process of setting one of the tangent vector components to +1 or -1. This induces a non-zero value on the tangent vector thereby making the Jacobian nonsingular at the critical point. Therefore, Equation 7 becomes:

$$\begin{bmatrix} F_\theta F_v F_\lambda \\ e_k \end{bmatrix} \begin{bmatrix} d_\theta \\ d_v \\ d_\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ \mp 1 \end{bmatrix} \qquad (8)$$

where e_k is the appropriate row vector with all elements equal to zero except the kth element equals 1. Initially, λ is taken as the continuation parameter. On repetition of the process, the state variable that has the largest rate of change is chosen as the continuation parameter owing to the nature of parameterization. The tangent vector can therefore be found by solving Equation 8. Hence the predication can be made thus:

$$\begin{bmatrix} \theta \\ V \\ \lambda \end{bmatrix} = \begin{bmatrix} \theta_0 \\ V_0 \\ \lambda_0 \end{bmatrix} + \sigma \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} \qquad (9)$$

The step size, σ is selected so that the solution so predicted is within the radius of convergence of the corrector. The subscript '0' identifies the value of the state variable at the beginning of the predictor step. If it is not satisfied, a smaller step size is chosen.

Correction Step:

In correction step, the correction of the predicted solution is achieved through the use of local parameterization. The initial set of equation is increased by one equation that specifies the value of state variable chosen and it results in:

$$\begin{bmatrix} F_\theta & F_V & F_\lambda \\ & x_k - \eta & \end{bmatrix} = [0] \qquad (10)$$

where x_k is the state variable selected as continuation parameter and η is the predicted value of this state variable. By applying a marginally modified Newton-Raphson power flow method Equation (10) can be evaluated.

Parameterization

The selection of continuation parameter is very crucial in continuation power flow technique. It should be noted that the continuation parameter is simply the state variable that has the greatest rate of change. At first step, there are visible changes in the bus voltages and angles as a result of small load. This is why λ is selected as continuation parameter initially. Selection of continuation parameter is observed after each correction step. This is because the solution approaches the critical point when the load beefs up after a few steps leading to increment in the rate of change of bus voltage and angle. If the parameter is increasing, +1 is used; if it is decreasing, -1 is used in the tangent vector in Equation (8). The continuation power flow is stopped when critical point is reached.

Critical point is the point where the loading has maximum value. After this point it starts to decrease. The tangent component of λ is zero at the critical point and negative beyond this point. Therefore, the sign of dλ shows whether the critical point is reached or not.

Continuation Method without Parameterization

Parameterization is necessary to ensure the non-singularity of Jacobian matrix in power flow equations, nevertheless the continuation equations of the corrector step can be shown nonsingular at the collapse point.

This technique involves the application of continuation power flow without altering continuation parameter. In the entirety of prediction and correction steps, load parameter λ is selected as continuation parameter. In order to obtain a non-singular Jacobian by this technique, the step size σ is reduced as the solution approaches to critical point.

2.2 System Implementation

The bus and line data of the Nigeria 46 bus 330kV transmission network obtained from Transmission Company of Nigeria (TCN) was used for performing load flow CPF on the test network. To perform load flow and CPF studies on the test network in PSAT environment, a Simulink model of the 46 bus 330kV Nigeria Transmission network is first implemented in PSAT/Simulink platform. The model is then configured to reflect the line and bus data of the test network. PSAT extracts the bus and line data from the Simulink model when loaded and then uses the information to compute the values of the required variables (voltage angle and voltage magnitude, passive power and active power in the lines, and passive power/active power losses. The implemented Simulink model of the test network is presented in Figure 1 while the results of the load flow and CPF are presented in Figures 2 and 3 respectively.

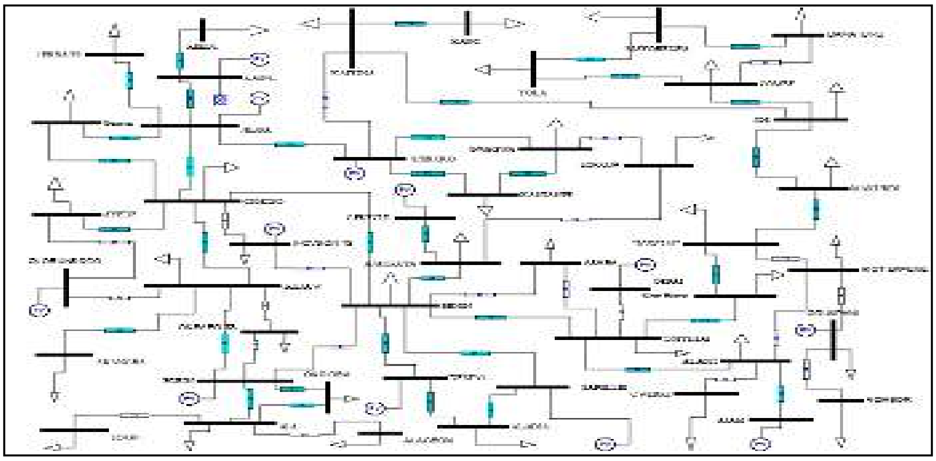

Figure 1: PSAT model of the 46 bus 330kv Nigeria transmission network

3. Results and Discussion

From Figure 2, it can be observed that Yola (0.895pu), Gombe (0.897pu), Mayobelewa (0.905pu) and Damaturu (0.904pu) buses recorded a voltage magnitude that is below the acceptable IEEE standard of 0.95pu. This suggests that the network has voltage stability issues and the above-named buses could be the weakest buses. However, continuation load flow is the standard tool for determining if a network has voltage stability or not and which buses are the weakest ones.

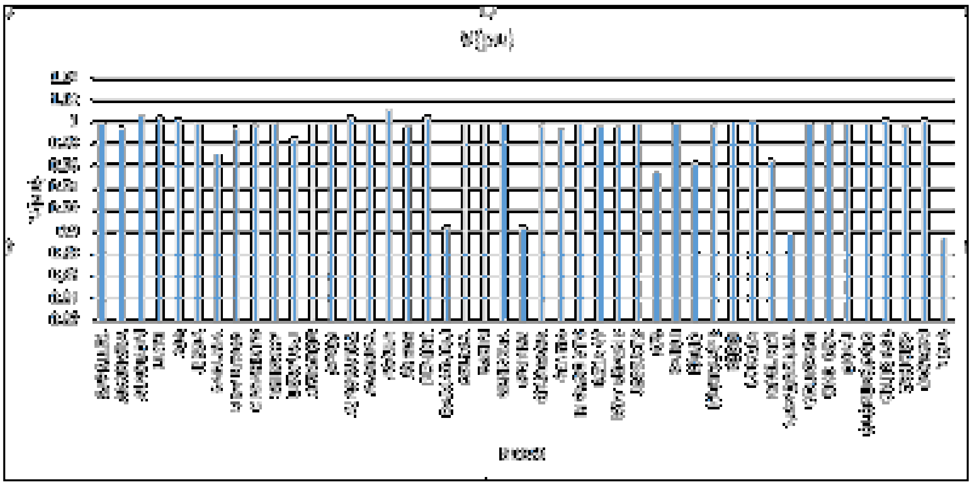

Fig 2: Voltage profiles of all buses of the test network after load flow

Figure 3 presents the voltage magnitude of the Nigeria 46 bus 330kV transmission network after CPF studies. Continuation Power Flow overcomes the challenge of non-convergence at the critical point (near the nose point) experienced with conventional load flow techniques like Newton Raphson's method.

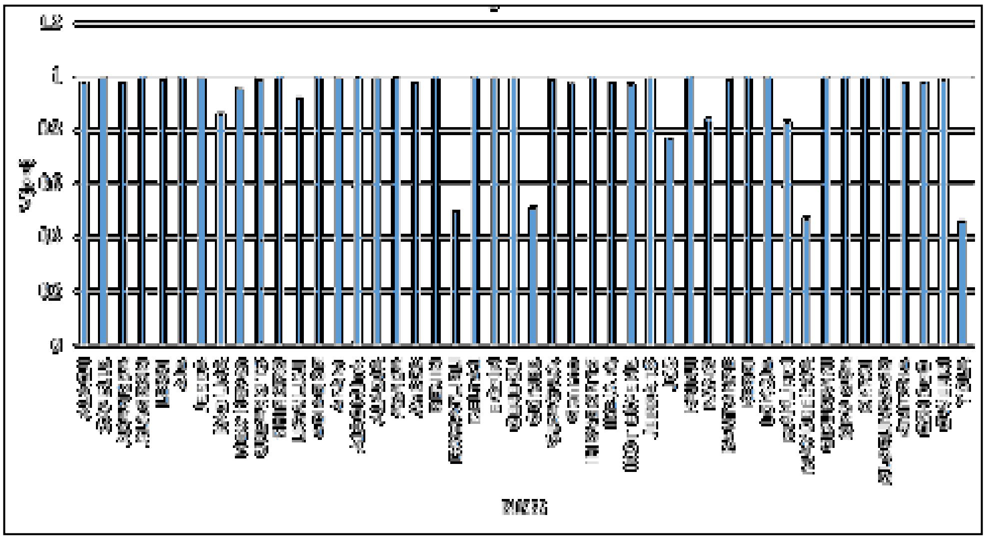

Fig 3: Voltage profiles of all buses of the test network after continuation load flow

CPF is also able to stretch the network close to its stability limit unlike the conventional load flow techniques. This makes it a perfect tool for determining whether a network is stable or not as it relates to voltage. The rule is that if at least one bus has a voltage magnitude less than 0.95pu after running continuation load flow, the system is considered unstable with regards to voltage. Also, to identify the weakest buses, a ranking of all the buses with voltage less than 0.95pu is done as presented in Table 1. The bus with lowest voltage is considered the weakest buses.

Table 1: Ranked voltage magnitude from continuation load flow showing weakest buses

Buses	V (pu)
Yola	0.46753
Mayobelwa	0.47655
Damaturu	0.50778
Gombe	0.51145
Jos	0.7739
Makurdi	0.83247
Kano	0.84368
Kaduna	0.86468
Ugwuaji	0.92426

From Table 1, it can be seen that seven buses fell below the acceptable value of 0.95pu. Yola bus with the lowest voltage magnitude of 0.4675pu is the weakest bus in the network. Yola is followed by Mayobelewa, Damaturu and Gombe in the ranking. Two lines in the network of the four weakest buses in table 1 (Yola-Gombe and Damaturu-Mayobelewa) were identified as the optimum location for connecting series compensation.

4. Conclusion

Load flow studies performed on the Nigeria transmission grid network revealed that only about four buses had voltage magnitude violation in the network (below 0.95pu). However, on performing CPF studies, the network was confirmed unstable and 9 weak buses revealed. Using ranking method, the weakest buses were identified and the optimum location for series compensation identified.

It is obvious from the result that Continuation Power Flow is an effective technique in voltage stability analysis, identification of weak buses and determination of optimum location for connecting series compensators.

References

Ayodele, T. R., Ogunjuyigbe, A. S., and Oladele, O. O., (2016). Improving the Transient Stability of Nigerian 330kv Transmission Network Using Static Var Compensation Part I: The Base Study. *Nigerian Journal of Technology (NIJOTECH).*

Mohammed, A., Arif, B., and Tarek, B., (2014). Weakest Buses Identification and Ranking in Large Power Transmission Network by Optimal Location of Reactive Power Supports. *TELKOMNIKA Indonesian Journal of Electrical Engineering* 12(10), 7123-7130

Olabode, O. E., (2017). Comparative Application of Load Tap-Changing Transformer (LTCT) and Shunt Capacitor for Voltage Profile Enhancement on Nigerian 330kV, 24-Bus Transmission System. *International journal of scientific and technical research in engineering (IJSTRE)* www.ijstre.com 2(1).

Pawan, C. T., Dharmendra, k. S. and Sudhir, P. (2018). Restructuring and Deregulation of Power System -A Review. *International Journal of Current Research* 10(6), 70474-70478