Convergence Problems Of Contingency Analysis In Electrical Power Transmission System

Taofik Adekunle Boladale *taboladale@lautech.edu.ng*
Works Department,
Ladoke Akintola University of Technology.
Ogbomoso, 210214, Nigeria.

Gafari Abiola Adepoju *gaadepoju@lautech.edu.ng*
Facuty of Engineering/ Electronic and Electrical Department
Ladoke Akintola University of Technology.
Ogbomoso, 210214, Nigeria

Abstract

Contingency analysis is a tool used by power system engineers for planning and assessing power system reliability. The conventional analytical method which is mathematical model based, is not only tedious and time consuming in view of the large number of components in the network but always left some critical components unassessed due to non-convergence of the power flow analysis of such, hence the contingency analysis of such system could not be said to be completed.

In this work, contingency analysis of line components of a standard IEEE-30 Bus and real 330-kV Nigerian Transmission Company of Nigeria (TCN) network (28Bus) systems were investigated using Radial Basis Function Neural Network (RBF-NN) which is artificial intelligence based.

The contingency analysis was carried out by solving the non-linear algebraic equations of steady state model for the standard IEEE-30 Bus and TCN-28 Bus power networks using Newton-Raphson (N-R) power flow method. RBF-NN method was used for the computation of Reactive and Active performance indices (PI_R and PI_A) which were ranked in order to reveal the criticality of each line outage. Simulation was carried out using MATLAB R2013a version. The non-converged lines in both systems were reinforced and re-analysed. The results of contingency analyses of the reinforced systems show more robust systems with complete line ranking.

Keywords: Contingency Analysis, Analytical method, RBF-NN method, Active and Reactive Performance Indices, Ranking .

1. INTRODUCTION

The electrical power system network comprises of Generating stations, Circuit Breakers, Transformers, Transmission lines and the likes, all of which have different operating limits. These limits determine to a large extent the reliability of the network. The degree however is much worse in third world countries where poor planning, inadequate financing and lack of good maintenance culture are the order of the day.

The challenges of ensuring the security of Power system is therefore an enormous task that must be contended with and the effect of weather (Storms, Earthquake, Tornadoes and so on), human factors (sabotage, terrorism, illegal Building constructions just to mention a few) and bad Political structures (corruption, nepotism and favouritisms) especially in developing countries are not helping the already worsen situations. The major focus of power system Engineers is how to ensure that the outages are minimised in terms of frequencies of occurrence and durations of power outages. Since the outages cannot be completely avoided, a contingency arrangement must be put in place in order to minimise the effect of shutdown resulting from the power outage (Onohaebi, 2009).

In order to have a reliable network, continuous monitoring of the system where parameters are continuously checked and adjusted as may be required from time to time through the use of telemetry system or by a Supervisory Control and Data Acquisition (SCADA) equipment is therefore required. The continuous checks and balances required in order to have a stable and reliable system is therefore termed the contingencies control strategies. This however, involves knowing the operating limits of each integral component of the network prior to and after the occurrence of the contingency.

Contingency analysis is therefore time consuming and cumbersome since the operating limit of individual components must be known. The most common approach of Contingency analysis is to carry-out the power (load) flow analysis and compute performance indices following each possible outage. However, in view of the cumbersomeness of the power network and the rigorous calculations and time involve; the use of conventional approach is found to be limited and ineffective especially on online real life systems (Shahnawaaz and Vijayalaxi, 2014). Amit (2011) and Naik (2014) have therefore recently researched into the utilisation of the proficiency of artificial intelligence for contingency analysis of small standard IEEE systems. This research work therefore considers implementation of the radial basis function neural network (RBF-NN) on medium size power transmission systems and to establish its application on real life power system, using 330kV Nigerian transmission system as a case study.

Contingency analysis is conventionally carried out using either contingency selection (ranking) or screening methods. Contingency ranking is achieved using Performance Indices while screening is better achieved using fast and approximate network solution (Ejebe *et. al.*, 1998). Contingency screening (or selection) is therefore an important task which help to minimise the rigorous and tasking computation, due to the complexity of the network and helps to determine the most severe contingency as well as the degree of severity.

Generally, the Contingency analysis applies the Kirchorff Current law (Nodal Analysis) to calculate the current injection into various buses of the power system network (Kusic, 2009); however the most accurate methods are based on AC Power (load) flow computation which are solved by iteration techniques (Maghrabi *et al*, 1998). The AC Power (load) flow are Gauss Seidel, Newton Raphson (N-R) and Fast decoupled load flow, Gauss Seidel ought to be the most accurate but its use is limited to small systems due its slow rate of convergence. N-R method on the other hand has the largest convergence rate but it requires large computer memory while Fast Decoupled method is the least accurate of the three (Adejumobi *et al.,* 2013). The speedy convergence advantage of N-R method irrespective of the system size prompted its choice in this work.

Artificial neural networks in simple feed-forward topology is used in the formulation of Radial basis function network and for Contingency analysis it is usually combined with Unsupervised learning. The merits of both according to Boudour and Hellal (2004); are high rate of convergence even on complex mapping problems, simple structure, fast and efficient training process and absence of local minimal problem. It also has the capability of accommodating newer data without any need for retraining. These reasons prompted the choice of Radial basis function neural network (RBF-NN) for this work and its representation in simplest form is shown in Figure1.

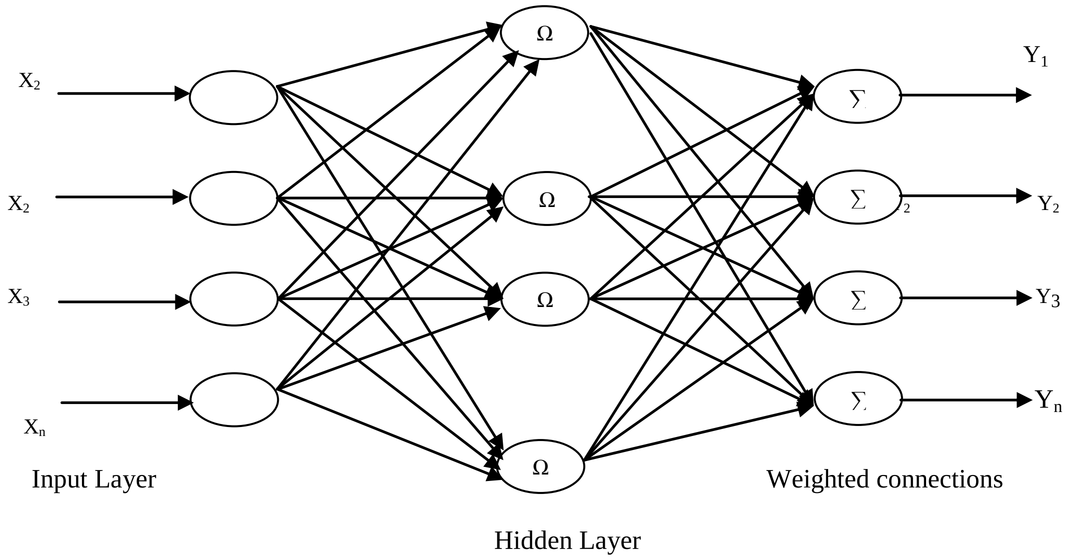

FIGURE 1: Radial basis function (Artificial) neural network (RBF-NN)
General Structure (Andrej *et. al*., 2011).

2. RESEARCH METHODOLOGY

The contingency analysis was carried out by solving the non-linear algebraic equations of steady state model for the standard IEEE-30 Bus and TCN-28 Bus power networks using Newton-Raphson (N-R) power flow method. RBF-NN method was used for the computation of Active and Reactive performance indices (PI_A and PI_R), with the data generated from Analytical method. Simulation was carried out using MATLAB R2013a version. The non-converged lines in both systems were noted for reinforcement using additional lines of the same parameters, the contingency analyses of the reinforced systems were then carried out.

2.1 Analytical Method

The conventional analytical method of carrying out contingency analysis involve; simulation of contingency (outage), performing power (load) flow and computing the performance indices following each contingency. Contingency Analysis of the IEEE-30 Bus Standard system and 28 Bus of Transmission Company of Nigeria (TCN) system, using Newton-Raphson (N-R) load flow analysis and Analytical method reported by Ejebe *et al.,* (1998) which was used to determine the system performance indices as expressed in equations 1, 2 and 3**.**

2.1.1 Active Power Performance Index

Active Power performance Index (PI_A) is a function of power flow limit violation of line and it is given by equation 1 as:

$$PI_A = \sum_{i=1}^{N_L}\left(\frac{W}{2r}\right)\left(\frac{P_i}{P_{i(\max)}}\right)^{2r} \qquad 1$$

where

P_i = Active (MW) power flowing on line i prior to the line outage.

$P_{i\,(\max)}$ = the maximum active power (MW) capacity of line *i* and it is given by DC load flow analysis as:

$$P_{i(\max)} = \frac{V_i \times V_j}{X_{ij}} \qquad 2$$

V_i = voltage at Bus i after the completion of the N-R load flow analysis

V_j = voltage at Bus j after the completion of the N-R load flow analysis and

X_{ij} = the reactance of the line connecting lines i and j.
N_L = is the number of transmission lines in the system under consideration
W and r are real non negative weighting factor and exponential penalty factor respectively.
W = 1 and r = 2 are said to be adequate for 14Bus system (Javan *et. al*, 2011).

It should be noted that according to Javan *et. al*, (2011); the Active power performance (PI_A) has a small value when all the line flows are within their limits and has a high value when any line(s) is (are) overloaded for a given state of the power system.

2.1.2 Reactive Power Performance Index

The Reactive Power performance Index (PI_R) is a function of Bus voltage limit violations and it is given by:

$$PI_R = \sum_{i=1}^{N_{LB}} \frac{W}{2r} \left(\frac{2\left(|V_i| - |V_{i(av)}| \right)}{V_{i(\max)} - V_{i(\min)}} \right)^{2r} \qquad 3$$

where
V_i = Voltage at bus i
$V_{i(\max)}$ and $V_{i(\min)}$ are the maximum and minimum voltage limits.

$$V_{i(av)} = \frac{V_{i(\max)} + V_{i(\min)}}{2}$$

N_{LB} = No of load Buses in the system.
W = Weighting coefficient
r = Order of the exponent

It should be noted that the voltage range used is +10% and -10% according to Transmission Company of Nigeria (TCN), Osogbo) as reported by Onojo *et. al.,* (2013), hence at slack/ nominal voltage of 1.0p.u, there will be a violation if either the $V_{i(\max)}$ or $V_{i(\min)}$ is above 1.05p.u or below 0.95p.u (1.10p.u or 0.9p.u in Transmission Company of Nigeria's case) respectively. Reactive power performance index (PI_R) is therefore an indication of the severity of the contingency (outage) on a particular line and if it is greater than zero, the corresponding contingency is recognised as critical or insecure otherwise it is said to be Secure.(Javan *et. al.*, 2011).

A Matlab based code was deployed for the actualisation of this Analytical method using the flow chart of Figure 2.

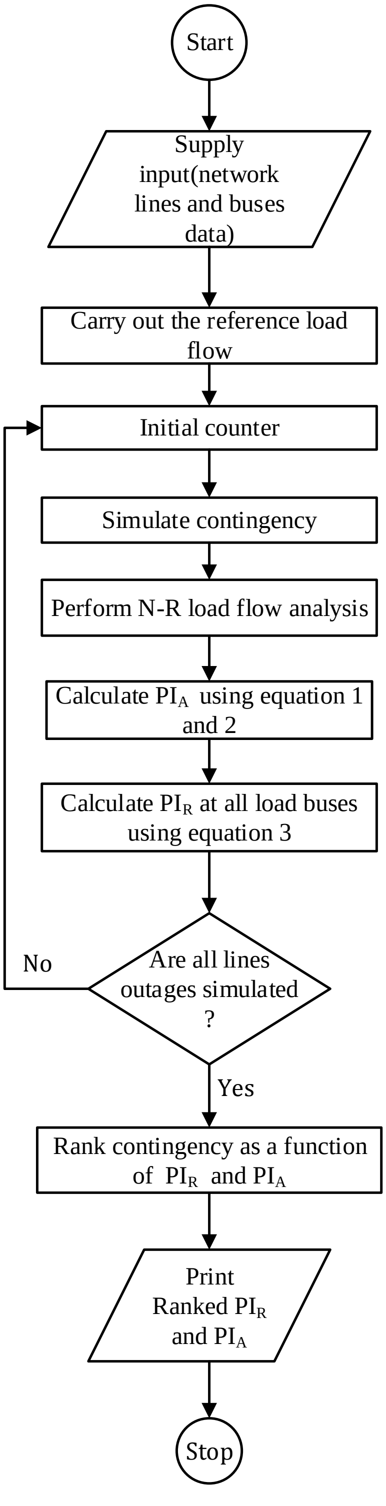

Figure 2: Flow Chart for Contingency Analysis Using Analytical Method

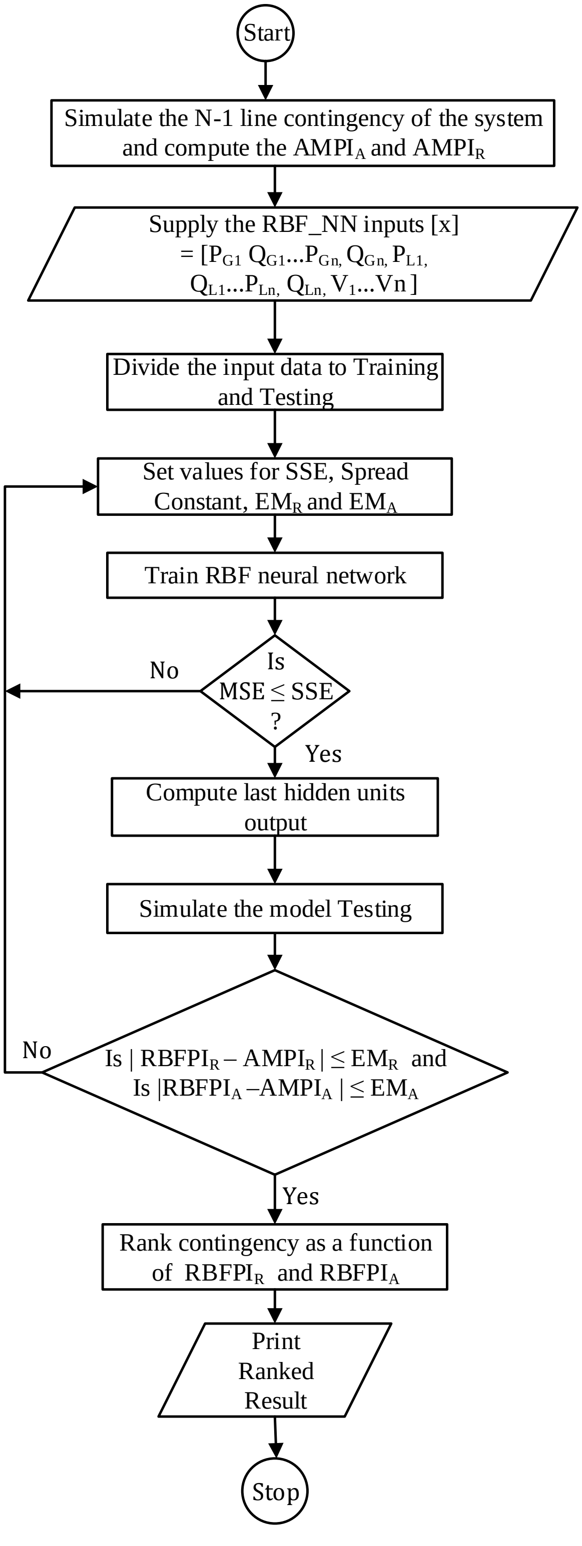

Figure 3: Flow Chart for Contingency Analysis Using RBF-NNl Method

2.2 RBF-NN Method

The contingency analysis using Analytical method in view of the large number of components in the power system, is slow hence the use of Radial Basis Function Neural Network with the flow chart in Figure 3 was used in this study. The procedure of RBF-NN method involves feeding the result of load flow following each contingency into the developed RBF-NN algorithm to compute and rank the performance indices.

Contingency Analysis of the IEEE-30 Bus Standard system and TCN-28 Bus of Nigerian system, using Newton-Raphson (N-R) for load flow analysis and RBF-NN prediction method to determine the performance indices were carried out. This was achieved using Matlab code based on the flow chart in Figure 3 which was based on the general structure of RBF-NN in Figure 1 with the determination of hidden neurons based on an algorithm called Growing and Pruning algorithm reported by Javan *et al*, 2011. The statistical data used for each system is as shown in Table 1.

S/No	Power Systems	No. of Lines	Error Goal	Spread Constant	MSE	SSE	Correlation Coefficient (R)
1	IEEE-30 Bus (Normal)	41	1.00E-03	15	1.001	1.0005	0.8914
2	IEEE-30 Bus (Improved)	44	1.00E-04	15	1.0331	1.0005	0.7496
3	TCN-28 Bus (Normal)	52	1.00E-03	20	0.006	0.0778	0.945
4	TCN-28 Bus (Improved)	53	1.00E-04	20	0.0081	0.0902	0.9727

TABLE 1: The statistical data of RBF-NN Method.

The Line diagram of TCN-28 system is as shown Figure 4 while that of standard IEEE-30 Bus could be easily gotten online via www.ieee.org.

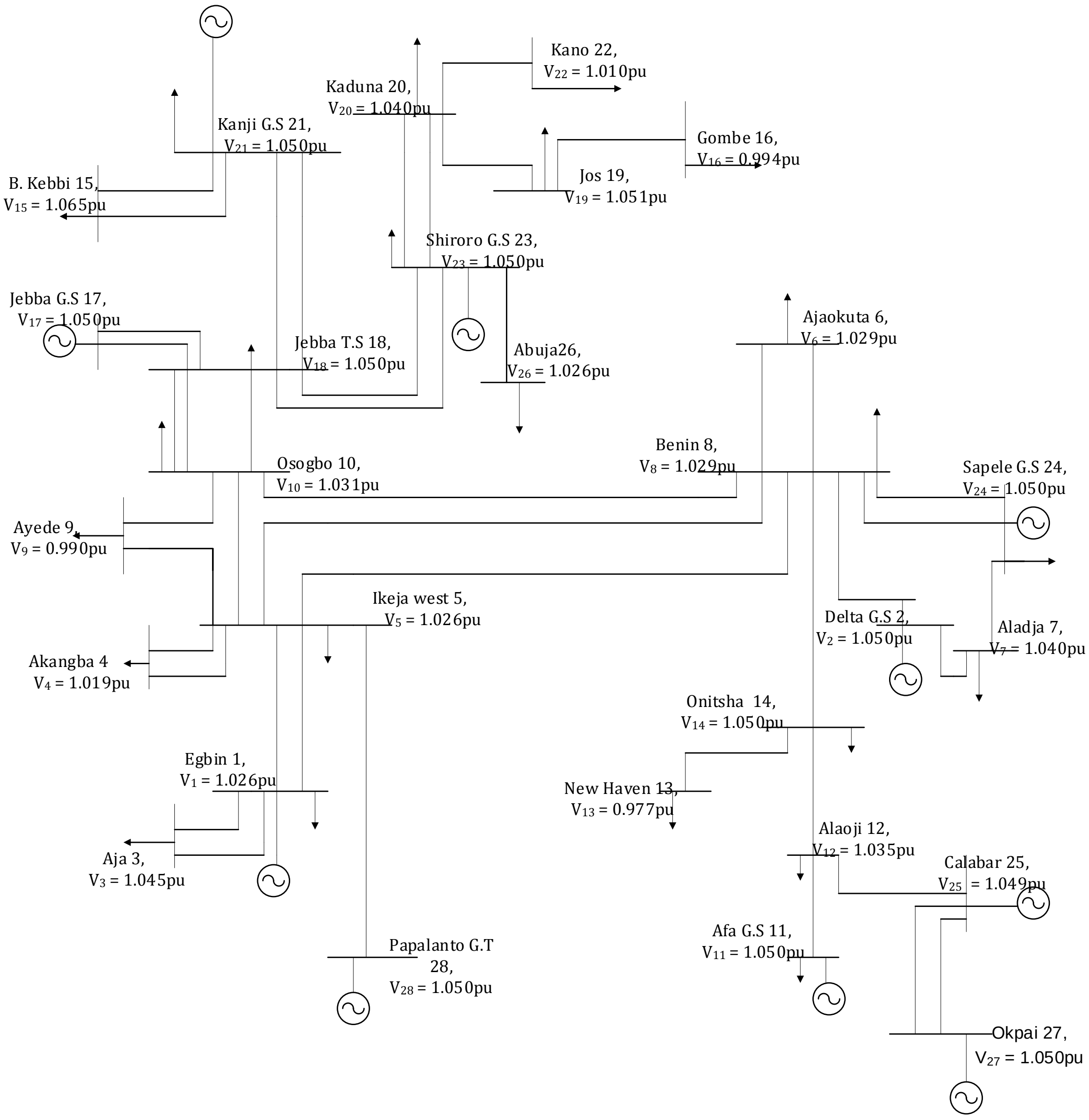

Figure 4: TCN – 28 Bus Nigerian System Pre-contingency Load Flow
(Source: TCN , 2013)

3. RESULTS AND DISCUSSION

The simulation of Contingency analysis of the two systems were carried using RBF-NN method with normal data and improved system data and the result are presented as follows;

3.1 Standard and Improved IEEE-30 Bus Systems

Upon the implementation of the RBF-NN method for the Standard IEEE-30 Bus system, Lines 13, 16 and 34 were found not to have converged as shown in Figures 4a, these lines were ranked as 39th, 40th and 41st most critical lines respectively hence they were regarded as the least critical lines while the three most critical lines are Lines 36, 37 and 38; based on the fact that they have largest number of voltage violations ranging from 1.082 to 0.861pu. These results were found to be in agreement with the reports of Mario and Carlos, 2003 and Sarika *et. al.*, 2013. The non-convergence of the above lines was however an indication of their criticality to the functionality of the system hence outage of any of those three lines could lead to instability and eventually the shutdown of the system. They were therefore reinforced with lines of the same parameters.

The simulation of this improved System gives the result ranked in Figures 4b., where the most critical line is 39 (the initial line 36) and the least critical line 15 (former line14).

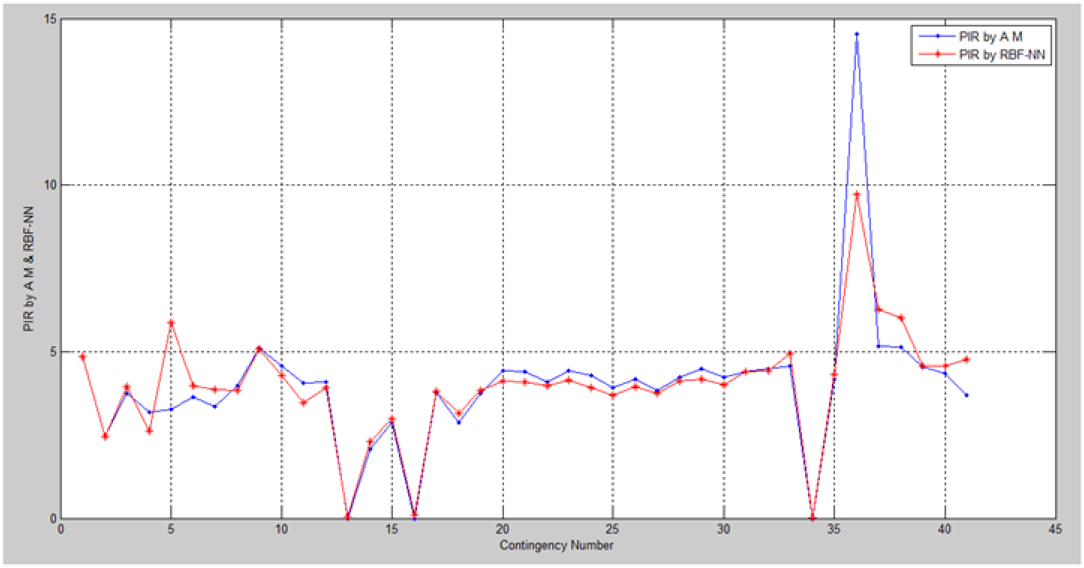

FIGURE 4a: Contingency Analysis Ranking of Standard IEEE-30 Bus System using Reactive performance indices.

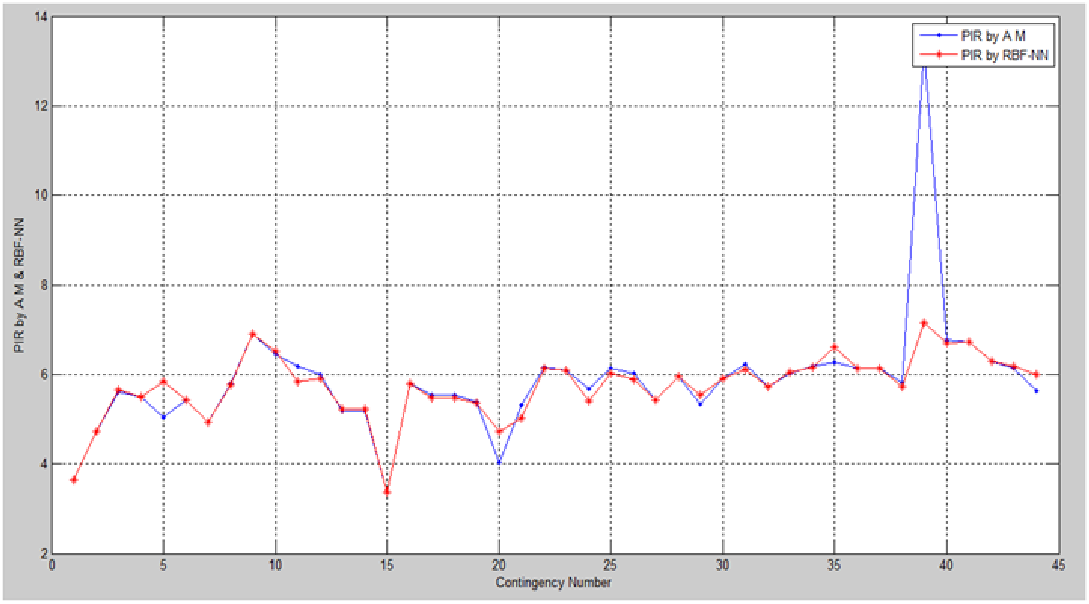

FIGURE 4b: Contingency Analysis Ranking of Improved IEEE-30 Bus System using Reactive performance indices.

3.1 Standard and Improved TCN-28 Bus Systems

Also the implimentation of the method on the real Nigerian transmission TCN-28 Bus System gives the resulting Reactive and Active performance indices shown in Figure 5a(I and II) respectiely; which indicated that line 31 did not converge, hence was considered to be the least critical line. Upon reinforcement, line 31 and the incorporated line 32 were still ranked to be the least critical lines as far as voltage violation is concerned but this was found not to be so based on power violation, since the most critical line was line 20 as against the initial line 31 in the standard TCN-28 Bus system. The change in the most critical line from 31(in normal system) as against to line 20 (in improved system) is an indication of imperfect ranking going by the contingency analysis of the normal system. This is shown in Figure 5b (I and II). Also, the least critical line after the reinforcement were lines 29 and 30.

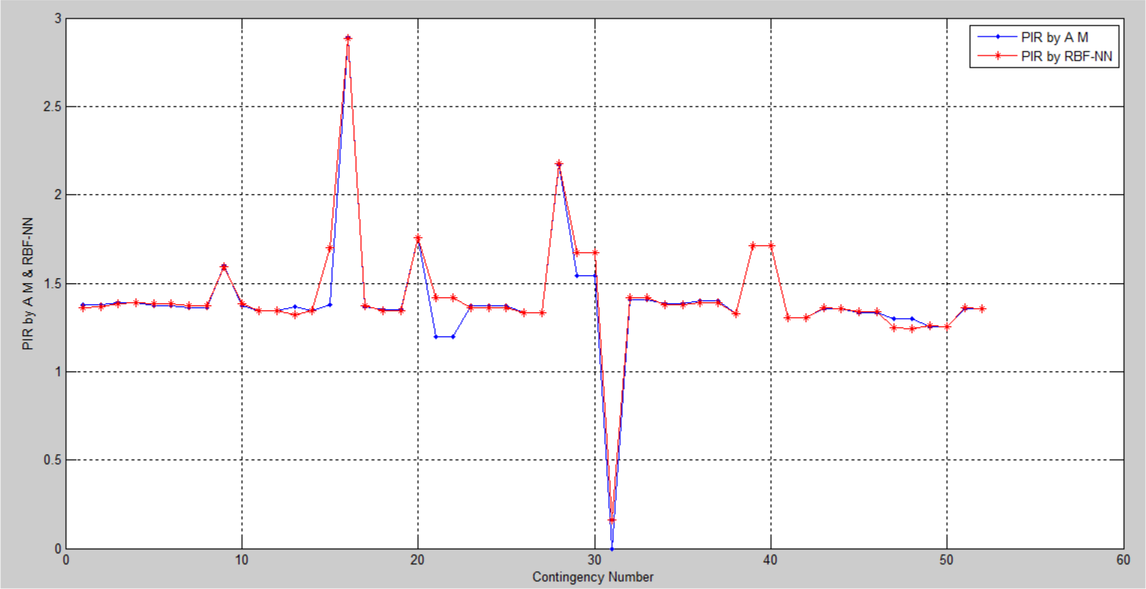

FIGURE 5a(I): Contingency Analysis Ranking of Standard TCN-28 Bus System using Reactive performance indices.

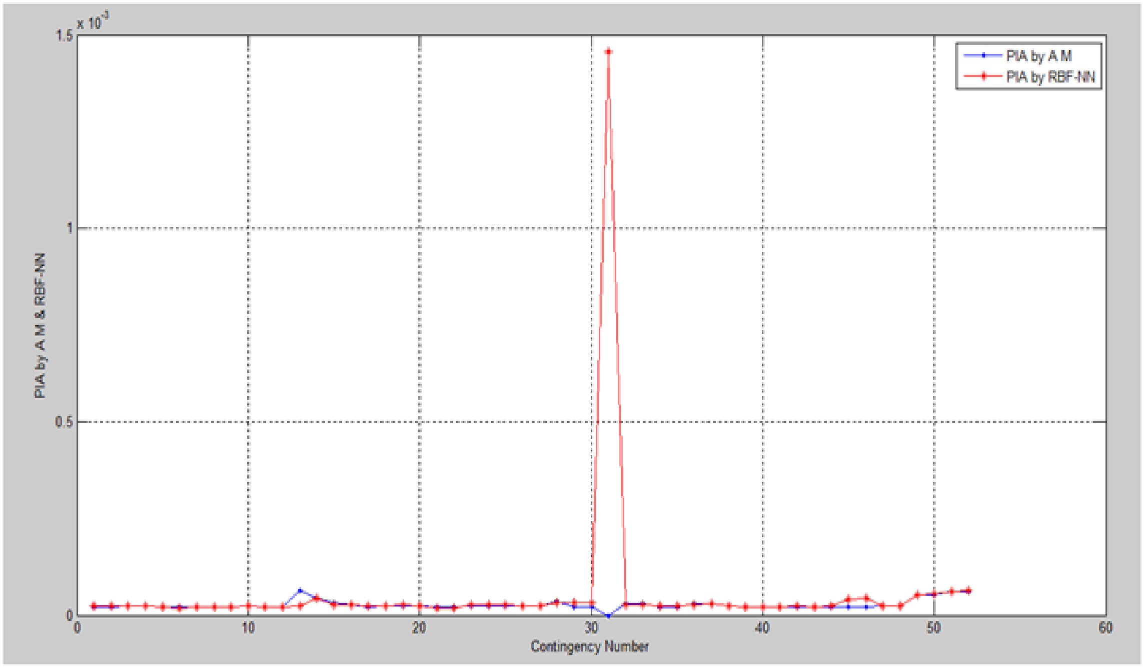

FIGURE 5a(II): Contingency Analysis Ranking of Standard TCN-28 Bus System using Active performance indices.

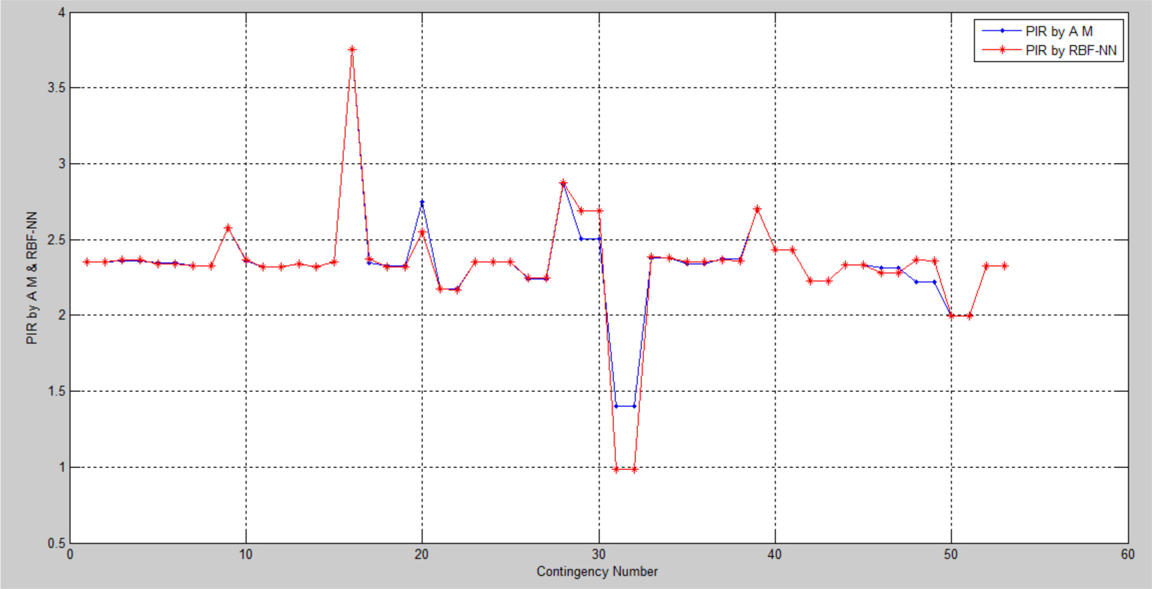

FIGURE 5b(I): Contingency Analysis Ranking of Standard TCN-28 Bus System using Reactive performance indices.

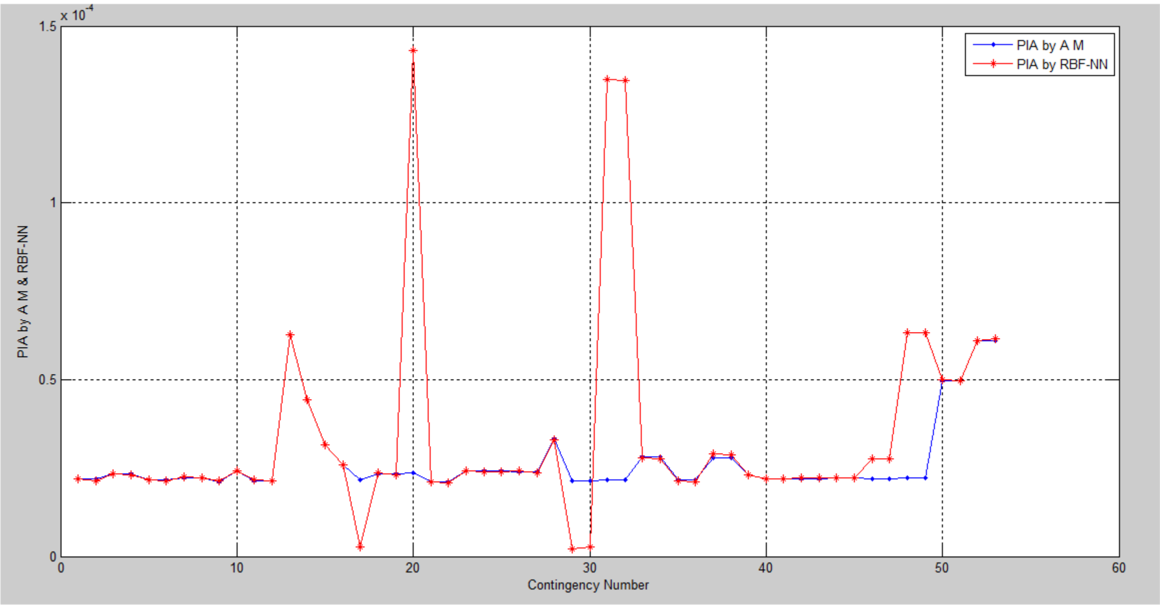

FIGURE 5b(II): Contingency Analysis Ranking of Standard TCN-28 Bus System using Active performance indices.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

This research investigated the proficiency of artificial intelligent; radial basis function neural network for revealing the effect of non-convergent power flow on the contingency analysis of electrical power systems by predicting the Active and Reactive performance indices and ranking both in ascending order to show the severity of the transmission lines outages based on power and voltage violations respectively. The contingency analysis of lines with non-convergent power flow which were ranked least were reinforced and their criticality as far as the stability of the system either as a result of voltage or power flow violations is concerned were revealed.

Following the above findings it could be concluded that, non-covergency of some of the lines of any power system will definitely affect the contingency analysis of such system as any outage of the non convergent line(s) could lead to the instability and shutdown of such system since either the voltage or power of the particular neighbouring components could be easily driven beyond the operating limits.

Consequently in order to appropriately analysed any system with such non-convergent line(s), reinforcing such will give the true picture of system.

Lastly, incorporation of parallel line(s) in real power systems such as TCN-28 Bus system will improve the stability property of the system aside providing additional capability of power transmission.

4.2 Recommendation

This research work concentrate on N-1Line contingency, multiple components contingency with RBF-NN especially on large real systems should be considered in future work.

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