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Development of a Hybridized Model for Detection of Voltage Collapse in Electrical Power Systems

Ganiyu Adedayo Ajenikoko Sulaiman Oni
Department of Electronic and Electrical Engineering, Ladoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Nigeria

Abstract
Voltage collapse is an occurrence in power systems that are heavily loaded, faulted and have reactive power shortages. It is a system instability involving large disturbances (including rapid increase in load or power transfer) and usually associated with reactive power deficits. Numerous power system blackouts in the past indicates/shows that enough researches have not been done to solve the problem of voltage instability and the resultant voltage collapse. This research paper therefore develops a hybridized sensitivity based voltage collapse prediction index model for detection of voltage collapse in electrical power systems. Sensitivity based method and the voltage collapse prediction index method were hybridized using the linearized basic power flow equations. Newton-Rapson technique was employed to solve the linearized power flow equation to compute the changes in real and reactive powers with respect to change in voltage magnitudes and voltage phase angles. The stressed version of the standard IEEE 24 bus system was used as an input parameter for the computation.Load shedding technique was then embarked on to find the weak bus for load shedding and the required generation reduction to maintain power balancing while buses having an unstable voltage profile were selected using the developed model. Bus number 3 had the least voltage magnitude of 1.018 p.u before stressing while bus number 16 recorded the highest voltage magnitude of 1.082 p.u even though the voltage magnitudes of these two buses were 0.623 p.u and 0.4611 p.u respectively after being stressed. The least and highest loads after shedding with the sensitivity based method were 0.11925 p.u and 0.6214 p.u respectively while the least and highest loads after shedding with the VCPI method were 0.1368 p.u and 0.6148 p.u respectively. With the hybridized sensitivity based VCPI model, the least and highest loads after shedding were 0.2068 p.u and 0.6314 p.u respectively confirming the efficiency of the HSBVCPI model.The total load demand met by the system with the hybridized model was higher compared to that of the sensitivity based method and the VCPI method. The power generated after the multi-stage load shedding by the sensitivity based method, VCPI method and the hybridized model were 2.12 p.u, 3.05 p.u and 3.65 p.u respectively showing that the power balance equations were satisfied since the total generation was greater than the total demand. The hybridized model improves better the voltage profiles of many of the load buses as compared to the other two methods. Bus numbers 4, 5, 12 and 15 were selected for load shedding with the hybridized model since all the load buses had loads less or equal to their loadability margin, hence, all the buses have satisfied the loadability condition. Even though, the VCPI method perform better than the sensitivity based method in detecting voltage collapse, the hybridized model performs best in term of detection of power system voltage collapse and load shedding implementation.
Keywords: Voltage Collapse, Sensitivity, Voltage Collapse Prediction Index (VCPI), Voltage Instability, Load Shedding, Power Balance, Newton-Raphson technique.

I. Introduction

Voltage collapse is the process whereby the sequence of events accompanying instability of voltage leads to a low unacceptable voltage profile in a major part of the power system (Badru and Carson, 2000; Musa, 2015). Voltage collapse can also been seen as an aftermath of voltage instability in electrical power systems (Althowibi and Mustafa, 2010; Chayapathi, Sharath and Anitha, 2013; Mohamed, 1998).

A voltage collapse represents a unique arrangement with very slow dynamics with a specified time domain within the range of a few seconds to some minutes. Voltage collapse has to do with disturbances in a power system network where the voltage magnitude becomes uncontrollable. The voltage decline is monitors at the beginning of the collapse and difficult to detect (Zambroni de Souza, First and Isabella, 2011). A sudden increase in the voltage decline leads to the end of the collapse scenario. It becomes difficult to distinguish this phenomenon from transient stability where voltage also decreases in a similar manner to voltage collapse. The actual cause may only be revealed by a very careful post-disturbance analysis (Glavic and Van, 2011; Manohar, Siva and Gowri, 2012; Moghavvemi and Omar, 1998).

Static methods are usually employed due to the quasi-static nature of the system. It also provides a clear information about the voltage stability problems and can take closer computational time.

Voltage instability can be caused by some of the following (Arthit, Nadarajah and Kwand, 2006; Schlueter, 1998; Goh, Chua, Lee, Kok and Goh, 2015):

i. Characteristics of the load.
ii. Reactive power limits of generator

iii. Transmission lines and transformer's parameters.
iv. The inability of the power system to meet demands for reactive power in the heavily stressed system to keep voltage in the desired range.
v. Action and coordination of the voltage control devices.
vi. Characteristics of the reactive power compensation devices.

Improvement of Voltage Instability

The following methods can be used to improve the voltage instability in power systems (Chayapathi, Sharath and Anitha, 2013; Glavic and Van, 2011; Musa, 2015).

i. Reactive power compensation
ii. Generator AVRs
iii. Under-load taps changers
iv. Load shedding during contingencies.

II. Materials and Methods

Development of Sensitivity Based Voltage Collapse Prediction Index (SBVCPI) Model

The following sequential systems were taken in the development of the SBVCPI model:

i. Selection of a system that is vulnerable to voltage collapse as input test system.
ii. Development of the sensitivity based model.
iii. Development of the voltage control prediction index (VCPI) model.
iv. The sensitivity based model and the VCPI model were hybridized using the linearized basic power flow equations
v. Solution of the linearized power flow equation using Newton-Raphson technique.
vi. Computation of the changes in real and reactive powers with respect to the change in voltage magnitude and voltage phase angle.
vii. Use of the stresses version of the standard IEEE 24 bus system as input parameter for the computation.
viii. Load shedding technique was performed to identify the weak buses and the required generation reduction to maintain power balancing.
ix. Selection of buses with unstable voltage profiles.
x. Power balance equation was used to detect the absence of voltage collapse.

a. The Sensitivity Based Model Development

In this approach, the voltage to reactive load sensitivity was calculated which expressed the slope of a curve, where the voltage was given as a non-linear function of reactive power at the same bus. When the critical voltage was approached, the number increased to an infinite value. The sensitivity value is valid only in the close vicinity of the actual voltage as a result of the non-linearity in the network behaviour. The linearized power flow equations were used to compute the changes in real and reactive powers with respect to change in voltage magnitudes and voltage phase angles.

The linearized power flow equation is:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{Q\theta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad (1)$$

where $\Delta P, \Delta Q, \Delta\theta\ and\ \Delta V$ are incremental changes in real power, reactive power, voltage phase angle and voltage magnitudes respectively.

As ΔP approaches zero, the sensitivity of voltage to reactive power at a load bus becomes

$$\frac{\Delta V}{\Delta Q} = J_R^{-1} = \left(J_{QV} - \left(J_{Q\theta} J_{PV} J_{P\theta}\right)\right)^{-1} \quad (2)$$

J_R^{-1} is the reduced V-Q Jacobian matrix. The i^{th} diagonal element of the reduced Jacobian matrix is a measure of the sensitivity at the i^{th} bus.

b. Voltage Collapse Prediction Index (VCPI) Model

VCPI is a useful indicator that accurately predicts the points of voltage collapse and determines the voltage stability allocation for each bus and indicates closely, how far the bus is from its collapse point. It is derived from the basic load flow equation:

$$S_K = V_K^* I_K^* \quad (3)$$

Where S_K = complex power at bus K.

V_K = voltage phasor at bus K.

I_K = current phasor at bus K.

Separating equation (3) above into real and imaginary parts;

$$f_1(V_K,\delta)=|V_K|^2-\sum_{\substack{m=1\\m\neq K}}^{N}|V_m^1||V_K|Cos\delta_K \tag{4}$$

$$f_2(V_K,\delta)=|V_K|^2-\sum_{\substack{m=1\\m\neq K}}^{N}|V_m^1||V_K|Sin\delta_K \tag{5}$$

Using the Newton-Raphson technique to determine the unknowns, equations (4) and (5) were solved to compute the VCPI of K^{th} bus.

Thus,

$$VCPI=\left|1-\frac{\sum_{\substack{m=1\\m\neq K}}^{N}V_m^1}{V_K}\right| \tag{6}$$

The VCPI values determine the proximity to voltage collapse at a bus. VCPI values vary between 0 and 1. i.e $0\le VCPI\le 1$

If VCPI = 0, the bus is stable.

If VCPI = 1, the bus is unstable.

c. Load Shedding Technique

This involves multi-stages. It is otherwise called a multi-stage load shedding. The technique was employed when the probability of voltage collapse was high and detected. The essence of load shedding is to find the weak bus for load shedding and the required generation reduction to maintain power balancing. Buses having an unstable voltage profile were selected using the two voltage collapse detection methods. A multi-port network model was then formed to determine the weak bus where load shedding was required.

Detection of unstable buses for multi-port network modelling differs in both the VCPI method and sensitivity-based approach. Only the voltages of unstable load buses were selected to determine the weak bus in the VCPI method unlike all the load buses that were considered for selecting the weak buses when voltage instability was detected in the load bus.

The flow chart for a multi-stage load shedding is shown in Figure 1.

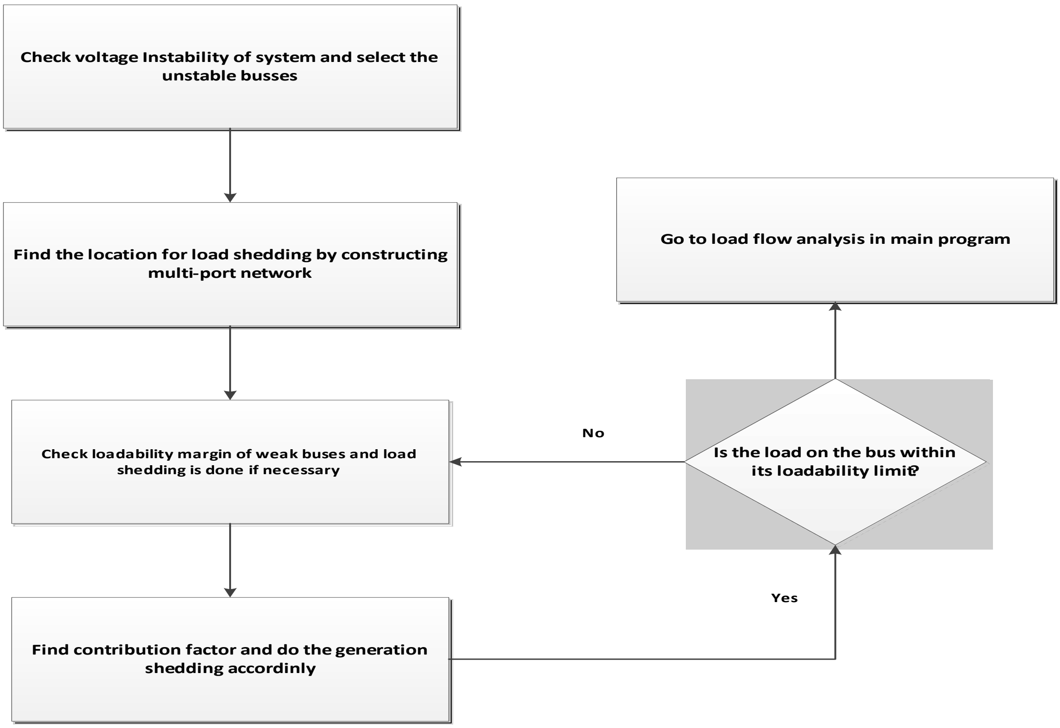

Figure 1: Flowchart for multi stage load shedding.

d. The Flowchart for the Hybridized Model

The flowchart for the steps involved in the development of the Hybridized Sensitivity Based Voltage Collapse Prediction Index (HSBVCPI) is shown below in Figure 2.

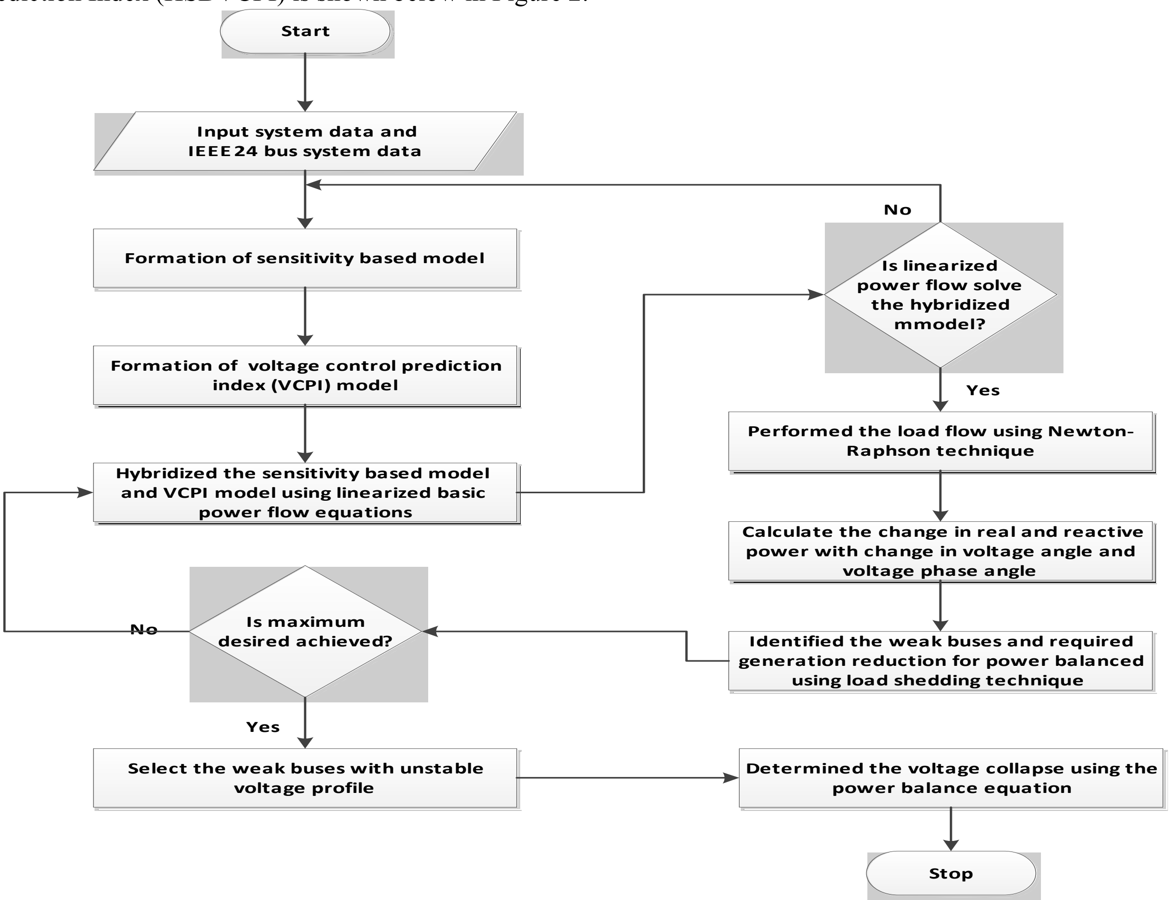

Figure2: Flowchart for the hybridized Model

III. Discussion of Results

The voltage magnitudes of the buses before stressing the PQ buses is shown in Figure 1. The voltage magnitude fluctuates as the bus number advances. Thus, the voltage magnitudes for buses 1,2,3,4,5 and 6 are 1.05 p.u,1.035p.u,1.018p.u,1.021p.u,1.031p.u and 1.05p.u respectively. In addition, voltage magnitudes of 1.042p.u, 1.071 p.u, 1.082 p.u,1.0413 p.u and 1.0212 p.u correspond to buses 14,15,16,17 and 18 respectively. The total load demand before stressing the PQ buses is 3.25p.u.

Figure2 illustrates the voltage magnitudes of the stressed buses. After stressing the PQ buses, the voltage magnitudes fluctuate along the bus numbers. Thus, at bus numbers 1,2,3,4,5,6,7,8,9,10, the voltage magnitudes of the stressed buses are 1.0550 p.u, 0.7998 p.u,0.6230 p.u,0.6458 p.u, 0.6774 p.u, 0.6167p.u, 0.5924 p.u, 0.6458 p.u, 0.5324 p.u and 0.5249 p.u respectively. The total load demand of all the stressed PQ buses is 3.926 p.u which indicates that the stressed PQ buses have demanded additional 0.67 p.u load as compared to the total load demand of 3.25 p.u before the PQ buses were stressed.

Figure 3 shows the percentage reduction in the voltage magnitude. This varies and fluctuates as the bus number advances. The relationship between the voltage magnitudes of stressed buses and the voltage magnitudes before stressing is depicted in Figure 4. Observation reveals that the voltage magnitudes of the stressed buses reduced drastically as compared to the voltage magnitudes before stressing the PQ buses. Thus, before stressing the PQ buses, the voltage magnitudes of 1.05 p.u,1.035 p.u, 1.01 8p.u,1.025 p.u,1, 031 p.u and 1.05 p.u corresponds to voltage magnitudes of 1.0550 p.u,0.7998 p.u,0.6230 p.u,0.6458 p.u,0.6774 p.u and 0.6167 p.u respectively of stressed buses.

The voltage profile of the PQ buses with the sensitivity bused method is shown in Figure 5. The voltage magnitudes fluctuate along the bus numbers. Thus, at bus number 1,2,3,4,5 and 6, the voltage magnitudes with sensitivity based method are 1.03 p.u, 0.9689 p.u, 0.8888 p.u, 0.9061 p.u, 0.9083 p.u and 0.8918 p.u respectively – indicating a drastic change in the voltage profiles by stressing the loads. The voltage profiles for bus numbers 12,13,14,15,16 and 17 are 0.9068 p.u, 0.8941 p.u, 0.9489 p.u, 0.9385 p.u, 0.9128 p.u and 0.8314 p.u respectively. In this case, the voltage magnitude in bus 24 has also decreased to 0.816 p.u which is the most badly affected one. This is evident that the system is very near to voltage collapse which eventually indicates an occurrence of a black-out condition.

Figure 6 shows the voltage profile of the PQ buses with the voltage collapse prediction index. At bus numbers 1,2,3,4,5,6,7,8,9 and 24, the voltage profiles with the use of VCPI are 1.04 p.u, 0.9689 p.u, 0.8888 p.u, 0.9081 p.u, 0.9061 p.u, 0.8918 p.u, 0.9088 p.u, 0.9028 p.u, 0.9046 p.u and 0.8179 p.u respectively, which suggests a fluctuation pattern in the voltage profiles. The voltage magnitude in the bus number 24 has decreased to 0.8179 p.u, representing a 36.52% decrease. This is a clear evidence that the system approaches a voltage collapse condition with the occurrence of a total black-out condition at this time.

The voltage profile of the hybridized model is shown in Figure 7. The voltage magnitudes fluctuate accordingly without a definite pattern. With the hybridized model, voltage magnitudes of 1.05 p.u, 0.9788 p.u, 0.8988 p.u, 1.0081 p.u,, 1.0028 p.u,, 1.0379 p.u, 1.0111 p.u,, 0.9808 p.u, 0.9480 p.u, and 0.8190 p.u, were recorded for bus numbers 1,2,3,4,8,12,14,15, 20 and 24 respectively.

In the same vein, the voltage magnitude in bus number 24 has decreased to 0.8190 which is the most badly affected bus in this regard. In addition, this is an indication that the system is very near to voltage collapse and even a black-out condition is very prominent.

Figure 8 shows the relationship between the voltage profiles when the sensitivity-based method and when the hybridized model was used. Voltage magnitudes of 1.03 p.u, 0.9083 p.u, 0.8870 p.u,, 0.9311 p.u, 0.9093 p.u, and 0.8126 p.u, were recorded on bus number 1,5,10,15,20, 21 and 24 respectively with the sensitivity-based method. These correspond to voltage magnitudes of 1.05 p.u, 1.0061 p.u, 1.0379 p.u, 0.9480 p.u, 0.8418 p.u, and 0.8190 p.u along bus numbers 1,5,10,20 and 24 respectively. This clearly shows that the voltage magnitudes on bus number 24 has drastically decreased indicating its nearness to voltage collapse with an occurrence of a prominent black-out.

The correlation between the voltage profile with VCPI method and with the hybridized model is shown in Figure 9. The voltage magnitude for the two approaches fluctuate accordingly. With the VCPI method, the voltage magnitude at bus number 2,4,6,8,10,12 and 24 are 0.9689 p.u,, 0.9081 p.u,, 0.8918 p.u,, 0.9028 p.u,, 0.9379 p.u, 0.9111 p.u, and 0.812 p.u, respectively while these bus numbers correspond to voltage magnitudes of 0.9788 p.u,,1.0081 p.u,, 0.9918 p.u, 1.0028 p.u,,1.0379 p.u, 1.0111 p.u, and 0.8190 p.u, respectively.

Figure 10 shows the voltage profile when the three methods; sensitivity-based method, VCPI method and the hybridized model were compared.

The voltages profile of the PQ buses does not follow a definite pattern when the sensitivity-based method, VCPI method and the hybridized model were used. The voltage magnitude of the PQ buses fluctuates accordingly.

At bus numbers 4,8,12,16,20 and 24 the voltage magnitudes are 0.9061 p.u, 0.9028 p.u, 0.9068 p.u, 0.9128 p.u, 0.9093 p.u, and 0.8126 p.u, respectively when the sensitivity-based method was used. In the same vein, the voltage magnitudes corresponding to these six buses when the VCPI method was used are 0.9081 p.u, 0.9028 p.u, 0.9111 p.u, 0.9156 p.u, 0.8356 p.u, and 0.8179 p.u, respectively. For the hybridized model, the voltage magnitude of these six buses are 1.0081 p.u, 1.0028 p.u, 1.0111 p.u, 0.9187 p.u, 0.8418 p.u, and 0.8190 p.u, respectively.

In this case, the voltage magnitudes of the PQ buses at bus number 24 has decreased to 0.8126 p.u, 0.8179 p.u, and 0.8190 p.u, respectively with the use of the sensitivity based method, VCPI method and the hybridized model. This shows that bus number 24 is very close to voltage collapse which was accompanied by a pronounced system black-out.

Figure 11 illustrates the initial loads of the PQ buses after load shedding. The initial loads fluctuate throughout the bus numbers. Bus number 16 recorded the highest initial load of 0.9843 p.u with a least initial load of 0.1648 p.u recorded on the bus number 21 with the use of sensitivity based approach. Thus, the initial loads on bus numbers 3,8,9,12 and 24 are 0.9521 p.u, 0.9796 p.u, 0.7214 p.u, 0.3141 p.u and 0.3757 p.u, respectively after load shedding.

The loadability limit of the PQ buses after load shedding is shown in Figure 12. The loadability limits at bus numbers 3,8,9,12,20 and 24 are 0.7121 p.u, 0.7191 p.u, 0.6912 p.u, 0.8321 p.u, 0.1945 p.u and 0.2565 p.u respectively which indicates that all the loads on the PQ buses are within their loadability limits.

Figure13 illustrates the variation of the load after shedding using sensitivity-based approach. Thus, the loads of the PQ buses after shedding using the sensitivity-based method are 0.5218 p.u, 0.4916 p.u, 0.6214 p.u, 0.1495 p.u and 0.25645 p.u at bus numbers 3,8,9,20 and 24 respectively. With this approach, the least load after shedding was 0.13355 p.u on bus number 12 while the highest load after shedding was 0.6148 p.u recorded on bus 9.

Figure 14 illustrates the loads of the PQ buses after shedding using the VCPI method. The loads fluctuate accordingly down the buses. At bus numbers 3,8,9,12,20 and 24, the loads after shedding were 0.5126 p.u,, 0.6148 p.u, 0.5092 p.u, 0.4192 p.u, 0.1368 p.u and 0.19685 p.u respectively. Observation reveals that in some of the selected PQ buses, the load increases after shedding with the use of VCPI method compared to when the sensitivity-based method was employed.

Figure 15 illustrates the loads on the selected PQ buses after shedding when the hybridized model was used. At selected PQ buses 3,8,9,20,21 and 24, the loads after shedding with the hybridized model are 0.5163 p.u, 0.6226 p.u, 0.6314 p.u, 0.2371 p.u, 0.24016 p.u and 0.20687 p.u respectively. In this case, the loads increase for the selected PQ buses compared to when the VCPI method was used.

The relationship between the loads of the PQ buses when using sensitivity-based method, VCPI method and hybridized model is illustrated in Figure 16. At the selected PQ buses 3,8,9,12,20 and 24, the load after shedding using the sensitivity based method are 0.5218 p.u, 0.4916 p.u, 0.6214 p.u, 0.6010 p.u, 0.1495 p.u and 0.25645 p.u respectively as compared to the VCPI method that recorded load magnitude of 0.5126 p.u, 0.6148 p.u, 0.5092 p.u, 0.4192 p.u, 0.1368 p.u and 0.19685 p.u for the same selected PQ buses. In addition, when the hybridized model was used, the load after shedding are 0.5163 p.u, 0.6226 p.u, 0.6314 p.u, 0.5108 p.u, 0.2371 p.u and 0.20687 p.u for the selected PQ buses 3,8,9,12,20 and 24 respectively.

The hybridized model improves better, the voltage profiles of many of the PQ load buses as compared to the sensitivity based and VCPI methods. The total amount of load shed with the sensitivity-based method was greater than that of VCPI method. In this case, the total load shed with the use of the VCPI method was lesser. With the hybridized model, the total load demand met by the system after the load shedding is higher. The power generated after the multi stage load shedding by the sensitivity-based method, VCPI method and the hybridized model were 2.12 p.u, 3.05 p.u and 3.65 p.u respectively. The values obtained for power demand and generation in each method show that the power balance equation was satisfied since the total generation is greater than the total demand.

The buses selected for load shedding with the hybridized model were 4,5,12 and 15 since all load buses had loads less or equal to their loadability margin, hence all the buses have satisfied the condition for loadability. Even though the VCPI method performs better than the sensitivity-based method in detecting the voltage collapse in power system, the hybridized model performed best in terms of detection of power system voltage collapse and load shedding implementation.

Three methods; sensitivity-based method, VCPI method and the hybridized model have been used to compare their performance in terms of detecting voltage collapse vulnerability of buses and the implementation of the prevention techniques. The hybridized model gave the best performance compared to the method of improving the stressed system which is highly vulnerable to voltage collapse where power balance is met and loads on all buses are within their limits of loadability.

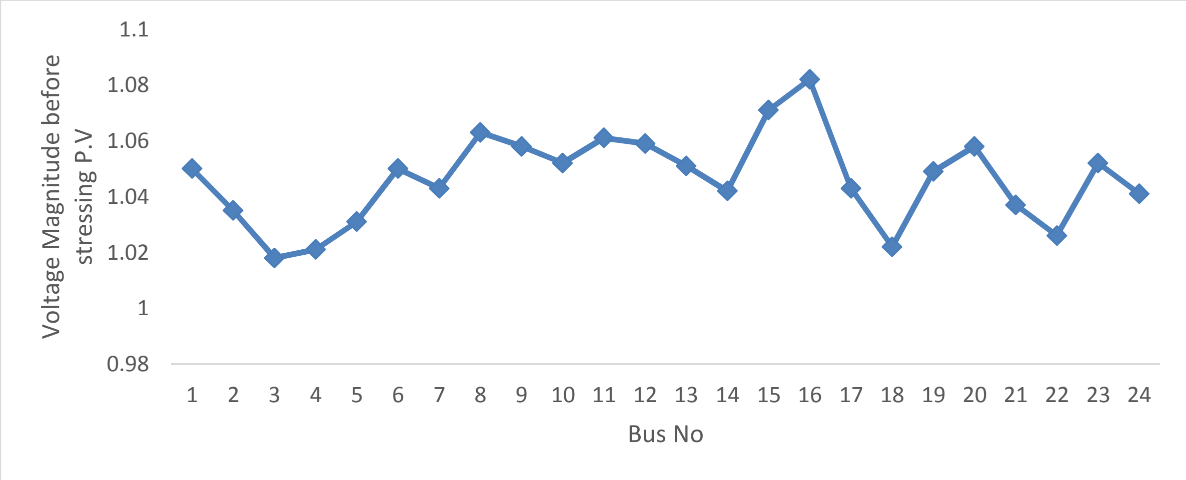

Figure 1: Voltage magnitude before stressing

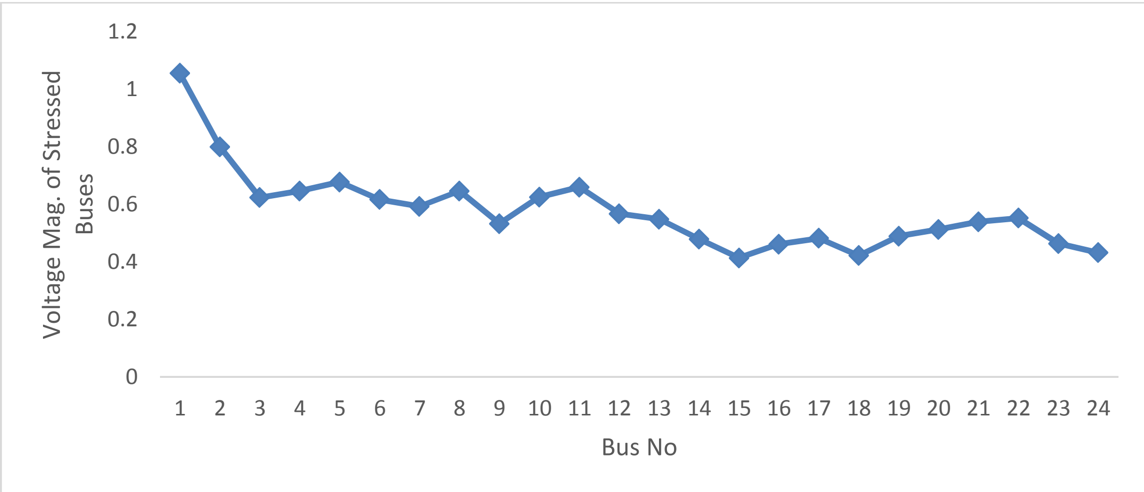

Figure 2: Voltage magnitude of stressed buses

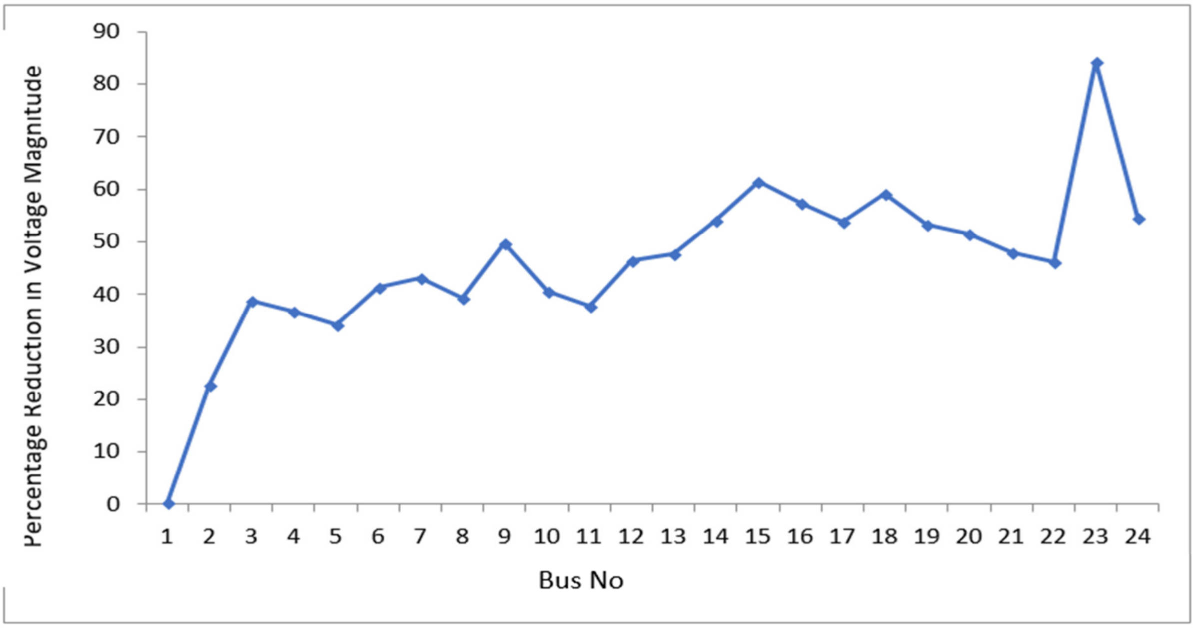

Figure 3: Percentage reduction in voltage magnitude

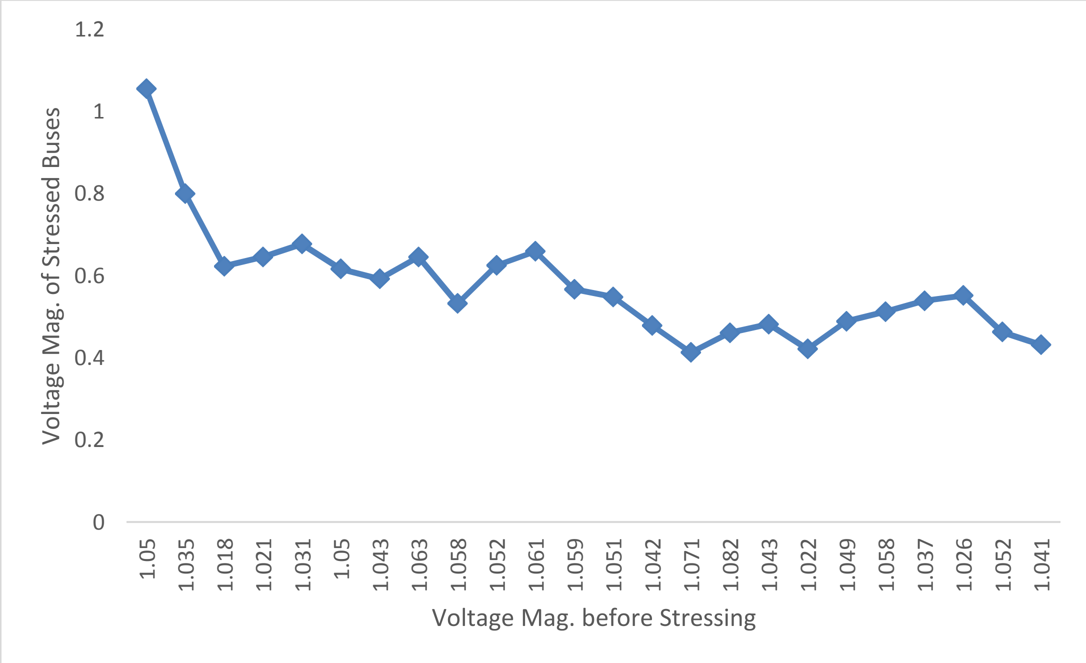

Figure 4: Voltage magnitude of stressed buses versus voltage magnitude before stressing.

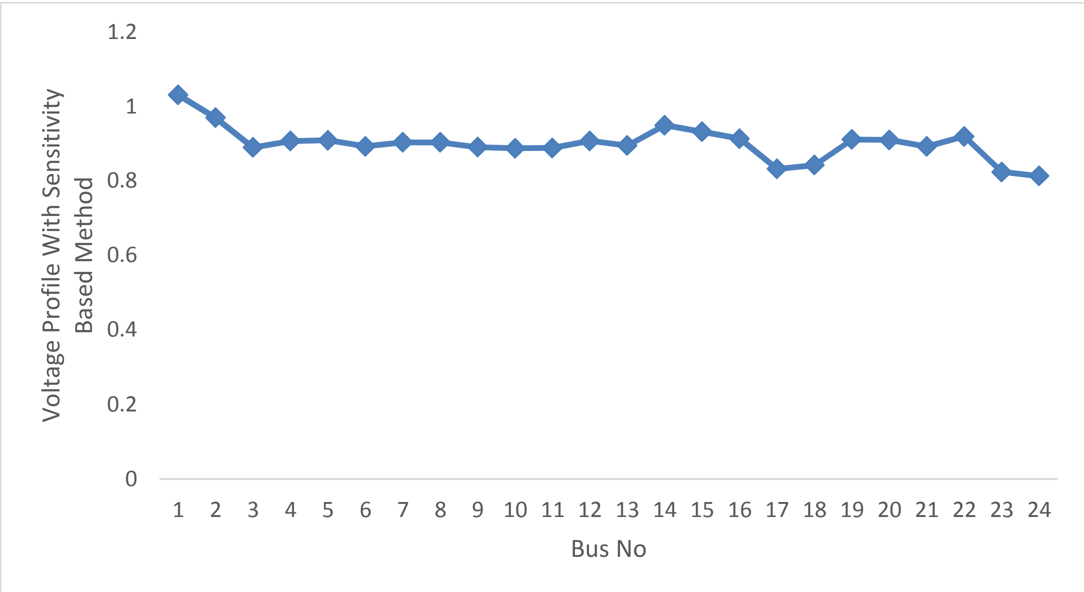

Figure 5: Voltage profile with sensitivity based method

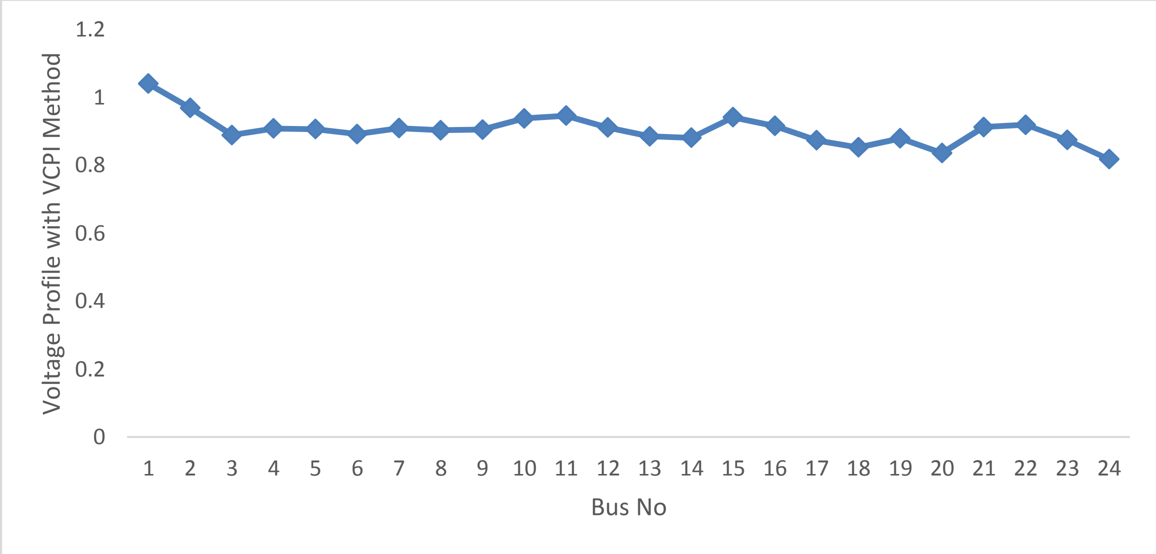

Figure 6: Voltage profile with VCPI method

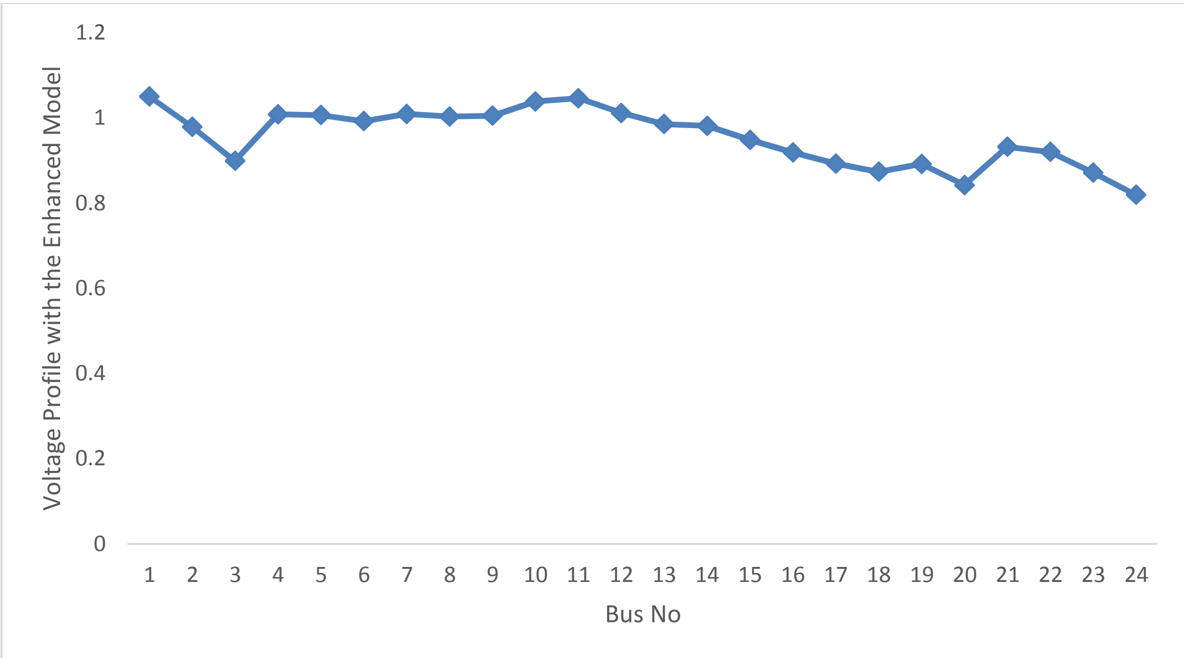

Figure 7: Voltage profile with the enhanced model

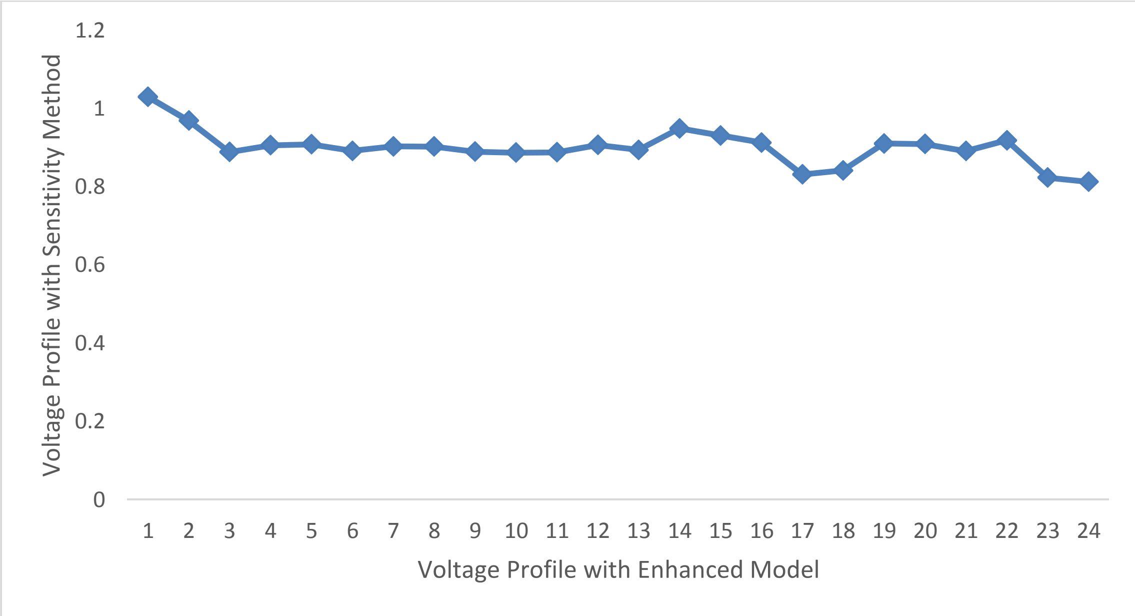

Figure 8: Voltage profile with sensitivity method versus voltage profile with enhanced model

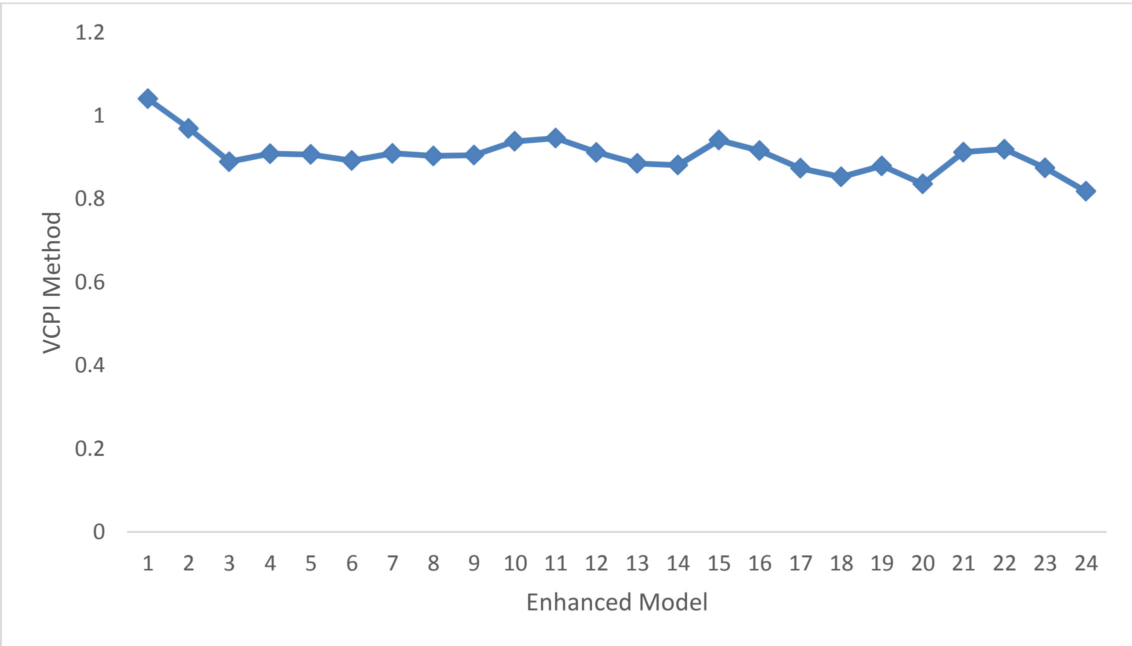

Figure 9: Voltage profile with VCPI method versus profile with enhanced model

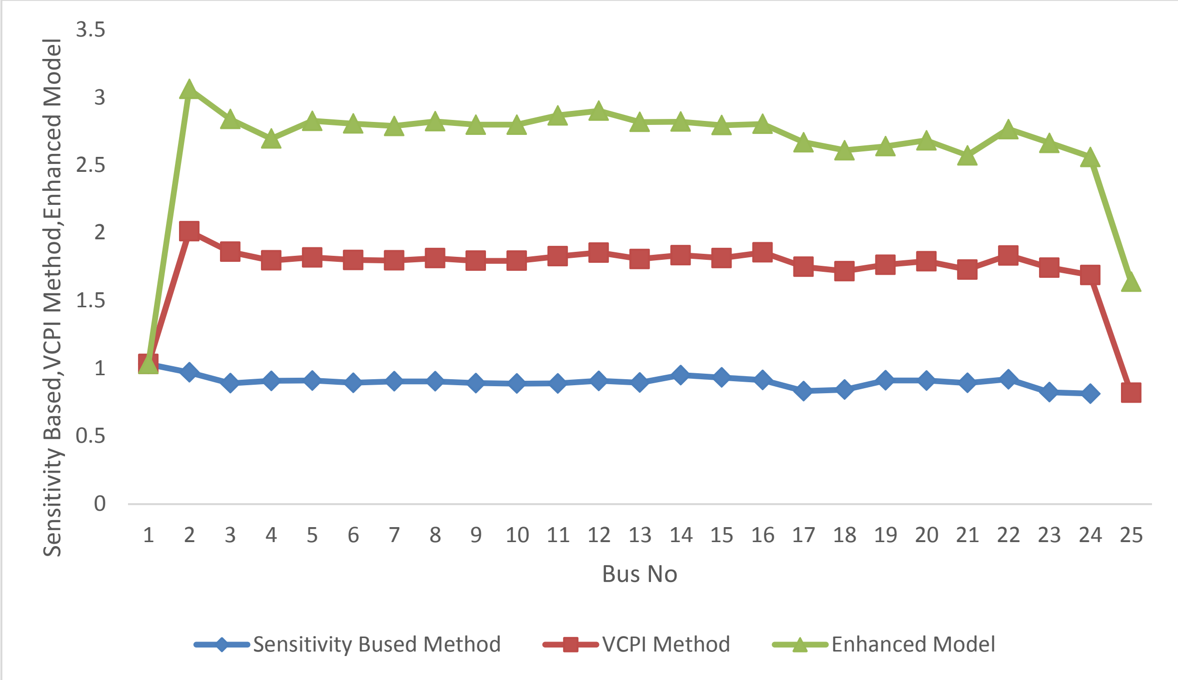

Figure 10: Voltage profile with sensitivity based method, VCPI method and enhanced model

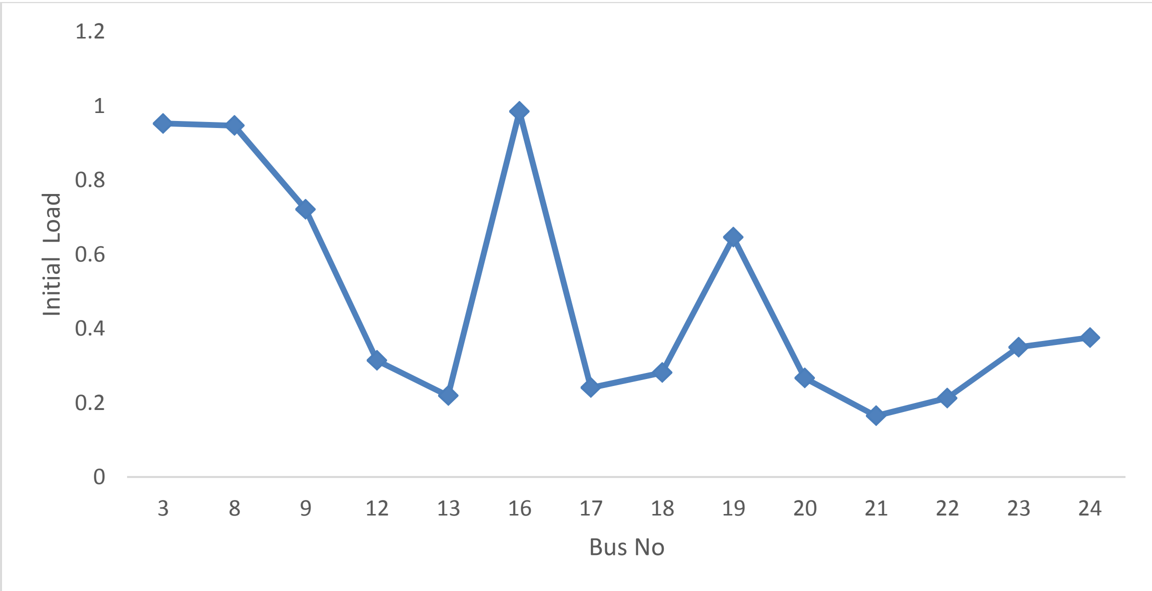

Figure 11: Initial load after load shedding

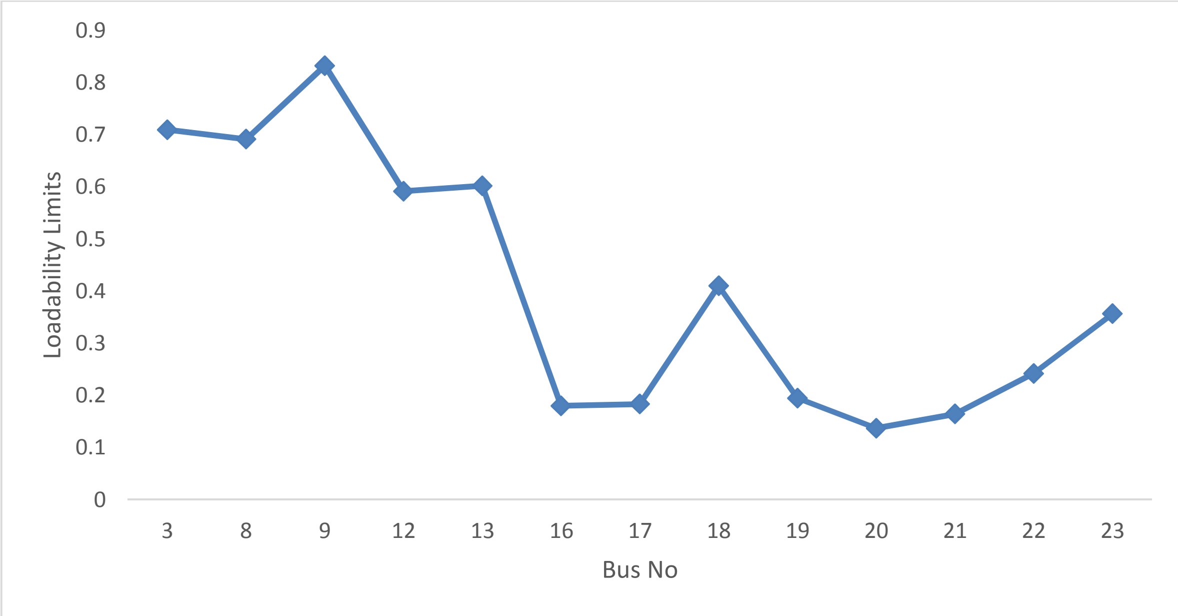

Figure 12: Laudability limit after shedding

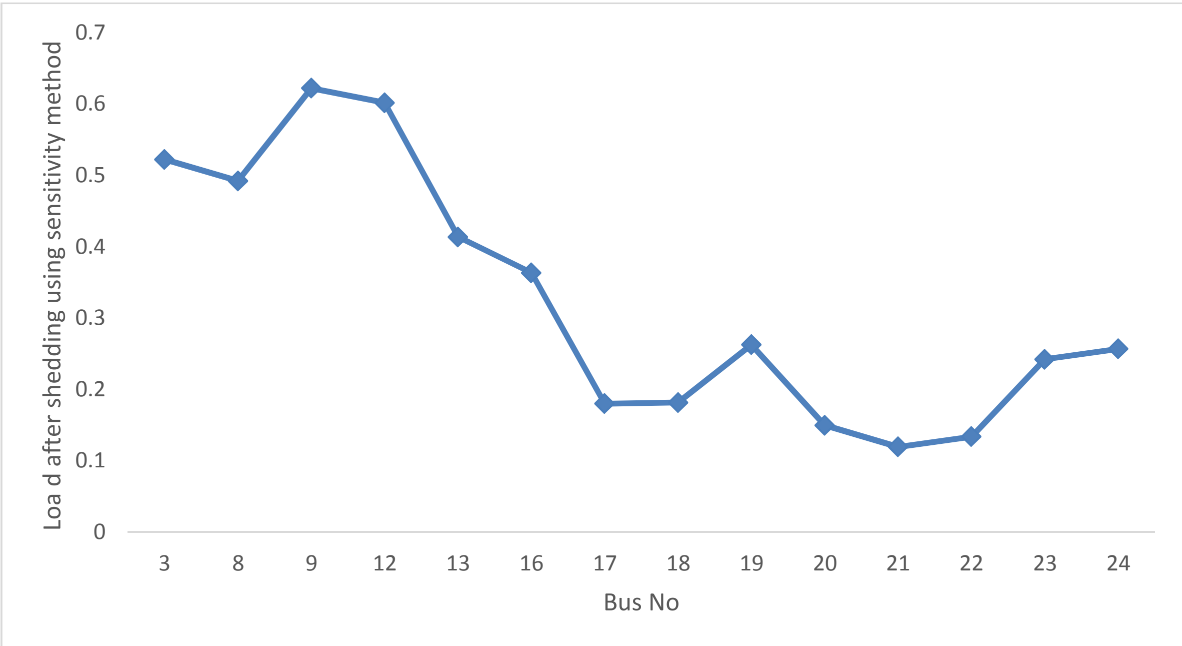

Figure 13: Load after shedding using sensitivity method

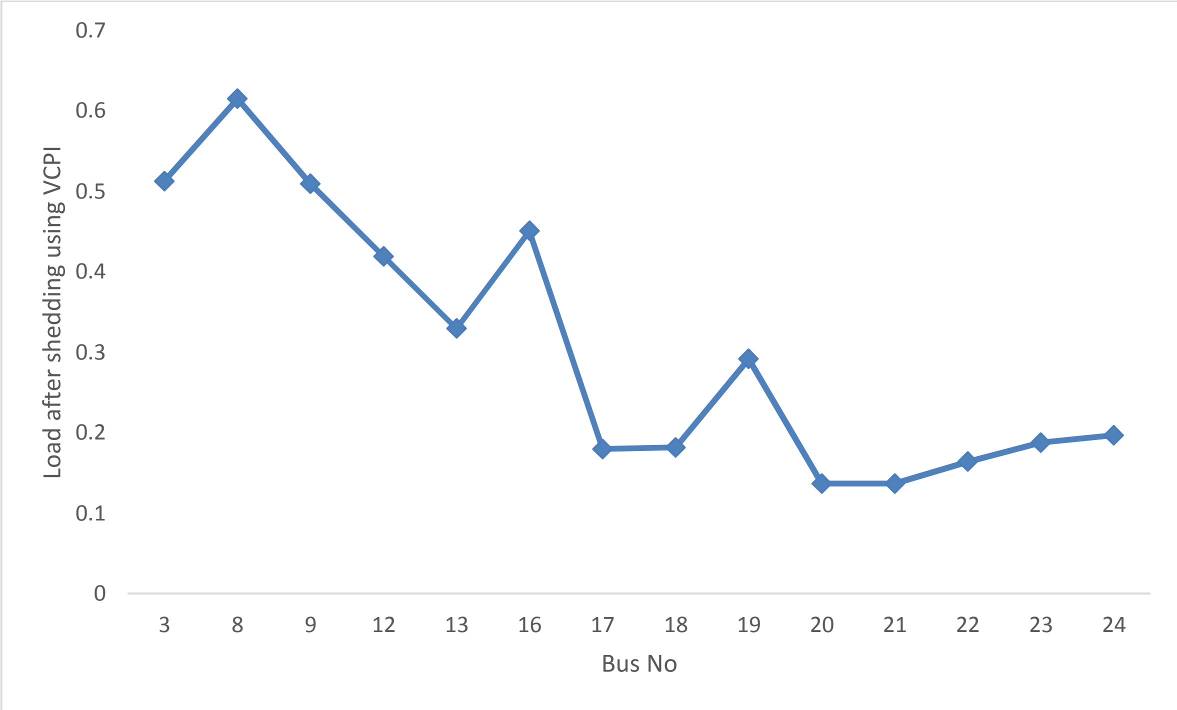

Figure 14: load after shedding using VCPI method

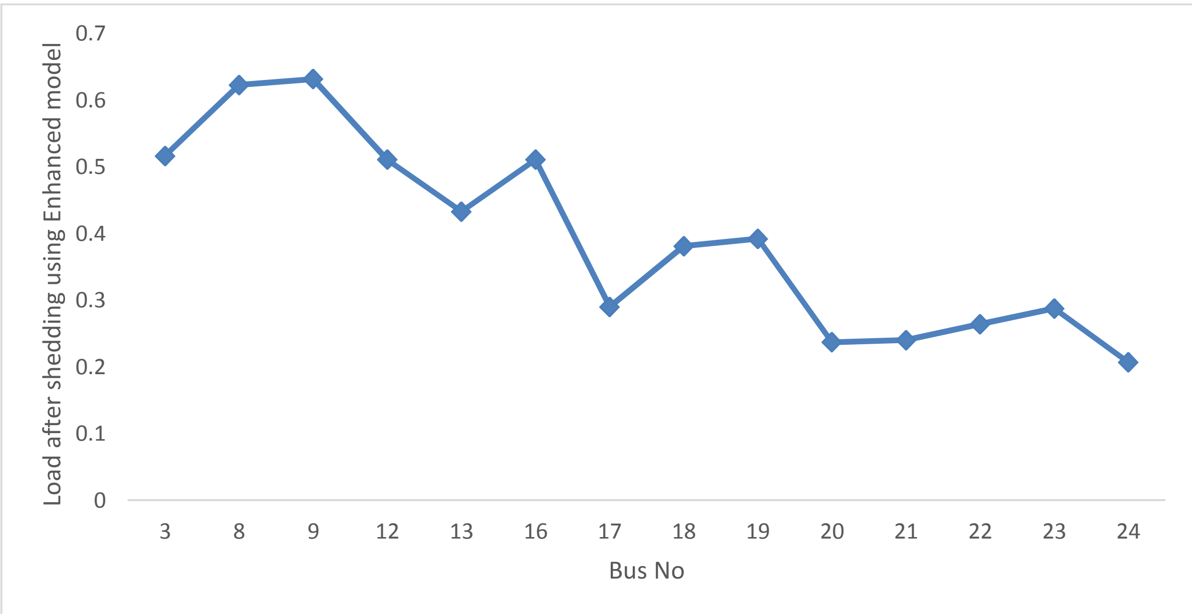

Figure 15: Load after shedding using hybridized model

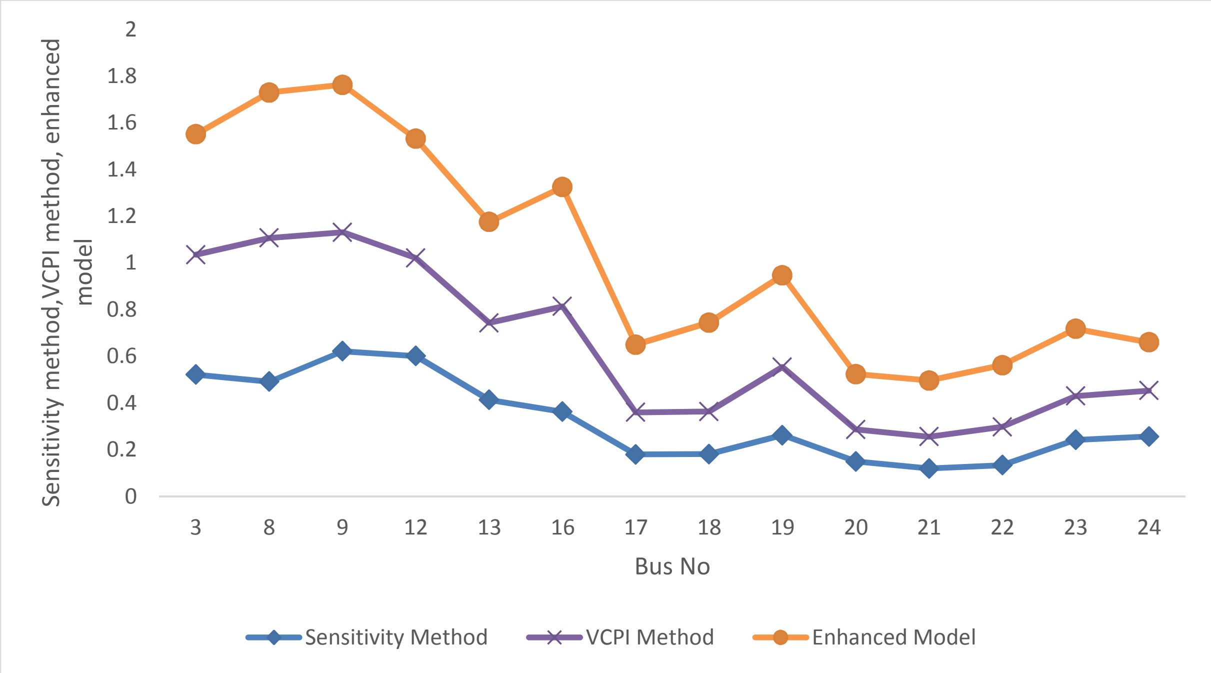

Figure 16: Load after shedding using sensitivity method, VCPI method and hybridized model

IV. Conclusion

A hybridized sensitivity based voltage collapse prediction index model has been developed for detection of voltage collapse in electrical power systems. Bus number 3 had the least voltage magnitude of 1.018 p.u before stressing while bus number 16 recorded the highest voltage magnitude of 1.082 p.u, even though, the voltage magnitudes of these two buses were 0.623 p.u and 0.4611 p.u respectively after being stressed.

With the sensitivity based method, the least and highest loads after shedding were 0.11925 p.u and 0.6214 p.u respectively while the least and highest loads after shedding with the VCPI method were 0.1368 p.u and 0.6148 p.u respectively. With the hybridized sensitivity based VCPI model, the least and highest loads recorded after load shedding were 0.20687 p.u and 0.6314 p.u respectively, thus confirming the efficiency of the HSBVCPI model.

The hybridized model perform best compared to the sensitivity based method and the VCPI method in terms of detection of power system voltage collapse and implementation of load shedding.

V. References

[1] Althowibi, F.A and Mustafa, M.W. (2010). Voltage stability calculations in power transmission lines: indications and allocations. IEEE International Conference on Power and Energy, 390-395.
[2] Arthit, S.Y, Nadarajah, M and Kwand, Y.L. (2006). A maximum loading margin method for state voltage stability in power systems. IEEE Transactions on Power Systems, 21(2): 799-808.
[3] Badru, H.C and Carson, W.T. (2000). Voltage stability analysis –V-Q power flow simulation versus dynamic simulation. IEEE Transactions on Power System. 5(4): 1354-1359.
[4] Canizares, C.A. (1995). On bifurcations voltage collapse and load modeling. IEEE Transactions on Power Systems, 10(1): 512-522.
[5] Chayapathi, V, Sharath, B and Anitha, G.S. (2013). Voltage collapse mitigation by reactive poer compensation at the load side (IJRET). International Journal of Research in Engineering and Technology, 2(9): 251-257.
[6] Dobson, I. (1992). Observations on the geometry of saddle node bifurcation and voltage collapse in electrical power systems. IEEE Transactions on Circuits and Systems 1. Fundamental Theory and Applications, 39(3): 240-243.
[7] Glavic, M and Van, T.C. (2011). A short survey of methods for voltage instability detection. IEEE Power and Energy Society General Meeting, USA, 1-8.
[8] Goh, H.H, Chua, Q.S, Lee, S.W, Kok, B.C and Goh, K.C. (2015). Comparative study of line voltage stability indices for voltage collapse forecasting in power transmission systems. Journal of Applied Engineering, 3(6): 210-219.
[9] Hasani, M and Parniani, M. (2005). Method of combined static and dynamic analysis of voltage collapse in

voltage stability assessment. In Proceedings of the International Conference on Power Systems Operations and Planning-VI (ICPSOP), 103-108.
[10] Manohar, R, Siva, S and Gowri, T. (2012). Literature review on voltage stability phenomenon and importance of FACTS controllers in power system environment. Global Journal of researches in Engineering, 12(3): 25-29.
[11] Moghavvemi, M and Omar, F.M. (1998). Technique for contingency monitoring and voltage collapse prediction. IEEE Proceeding on Generation, Transmission and Distribution, 145: 634-640.
[12] Mohamed, A.G. (1998). A static voltage collapse indicator using line stability factors. Journal of Industrial Technology. 7(1): 73-85.
[13] Musa, H. (2015). An overview on voltage stability indices as indicators of voltage stability indices as indicators of voltage stability for networks with distributed generation penetration. International Journal of Science, Technology and Society, 3(4): 214-219.
[14] Robbins, B.A, Hadjicostis, C.N and Dominguez-Garcia, A.D. (2013). A two-stage distributed architecture for voltage control in power distribution system. IEEE Transactions on Power System, 28(2): 1470-1482.
[15] Schlueter, R.A. (1998). A voltage stability security assessment method. IEEE Transactions on Power System, 13(4): 1423-1434.
[16] Zambroni de Souza, A.C, First, M and Isabella, F.B. (2011). Using PV and QV curves with the meaning of static contingency screening and planning. Electrical Power System Research, 81: 1491-1498.