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VOLTAGE STABILITY ASSESSMENT IN RADIAL DISTRIBUTION NETWORK USING VOLTAGE STABILITY INDICES

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Abstract
Increased power demand and constrained power resources have made assessment of voltage stability in power system networks necessary in these days to predict voltage instability in order to ensure safe and secure operation of power systems. Also, due to numerous factors the existing power system networks are forced to operate at its peak limit. Therefore, it is essential to assess the maximum voltage stability prior to occurrence of voltage collapse. This will be used as preliminary information by the operator to avoid complete interruption of power system. In this paper, numerous Voltage Stability Indices (VSI) are presented to assess the voltage stability of a Radial Distribution Network (RDN). VSIs are computed from the load flow solution data. The determined VSI also points out the most vulnerable lines or buses those are likely to get voltage collapse. Different VSIs are evaluated for IEEE 15, 33, 69 and 85 bus RDN with nominal and peak power demand. The obtained results have highlighted the importance of voltage stability prediction in RDN for initiating necessary action to avoid voltage collapse from being arising.

Keywords:
Voltage Stability, Voltage Collapse, Voltage Stability Indices, Radial Distribution Network

1. INTRODUCTION

The electrical power produced from the generating stations reach the consumer site with the help of transmission and distribution networks. The electrical demands of consumers are powered through distribution power network. Different distribution networks such as radial, mesh or loop and network were used to transfer the power to the consumers. However, due to simple structure radial distribution network is mostly preferred by the power utilities. In recent times, electrical power networks around the globe are operated at its peak limit majorly due to economic reasons. Such operating condition highly influences the scenario known as voltage instability. The presence of voltage instability causes the system voltage to slip beyond the acceptable limit and induce a scenario called blackout. Blackout in electrical power system is a condition at which the system voltage cannot restored to its specified limit. Moreover, blackout completely interrupt the power source and causes reliability problems.

It has been investigated and reported in [1], [2] that lack of real time data is the main reason for majority of blackouts occurred around the globe. Therefore, real time assessment and control are important for reliable and secure system [2]. This enables the system operators to perform the necessary preventive actions in order to evade the possibility of occurrence of voltage instability. Voltage stability assessment and control in transmission and distribution networks have been given more considerations in order to evade the occurrence of blackout.

The stability of a power system network is determined based on the magnitude of bus voltages. If the bus voltages are kept within the acceptable voltages under normal and abnormal (disturbance) operating condition, then the power system is said to be in voltage stability region [3], [4]. Reliable power systems need to be stable condition for utmost time. On the other side, voltage instability occurs when the bus voltages are not maintained within acceptable limit. Presence of voltage instability for a specified duration causes power system outage. However, occurrence of power system outage can be avoided by incorporating necessary protective schemes. The power system without proper protective scheme leads to voltage instability problem.

Various approaches were used by the researchers to assess the voltage stability of power system network; however estimation of distance towards voltage collapse greatly helps the operators to take the necessary corrective actions [5] [6]. The distance towards voltage collapse can be computed using a factor called Voltage Stability Indices (VSI) [7].

VSI is a scalar quantity which computes the stability of power system network. VSI is basically classified into Jacobian matrix VSI and system variable VSI. System based VSI is focused in this paper to assess the stability of distribution power network as it takes minimum computing time compared to Jacobian matrix based VSI. Moreover, it precisely helps to find the weaker bus or lines of power network.

In this paper, the voltage stability of different Radial Distribution System (RDS) is evaluated for nominal and peak demand cases. Furthermore, the weakest bus or lines of test systems are identified based on VSI.

The rest of the sections of this paper are organized as follows: The concept of voltage stability and VSI are presented in section 2. Formation of different VSI for radial distribution system is discussed in section 3. In section 4, detailed simulation results are presented for RDS. Finally, conclusion is presented in section 5.

2. VOLTAGE STABILITY AND VOLTAGE STABILITY INDICES

2.1 VOLTAGE STABILITY

Voltage stability in power system can be inferred as the ability to keep the bus voltage of the system at steady values under all operating conditions [8]. Also, it is the capability of power system to sustain a balance between power demand and power supply [9]. On the other side, a power system is considered to be voltage instable even if the voltage profile of single bus falls below an allowable limit [10]. Furthermore, lack of power system in delivering adequate reactive power to the load causes voltage stability [11]. Occurrence of voltage instability leads to an event called blackout which accounts for complete interruption of power supply.

Based on the duration of voltage instability sustains in power system, it is classified into short term and long term voltage instability. Short term voltage instability only last for few seconds, but long term voltage instability last for more than a minute. Usually, small perturbation in system load is the cause of short term stability problem and inadequacy in meeting required reactive power demand is cause of long term stability problem.

2.2 VOLTAGE STABILITY INDICES

Voltage stability indices (VSI) are the scalar quantity that outlines the state of voltage stability of power system networks. Furthermore, they point out the weaker bus or lines and measure the distance between the certain operating point and voltage collapse [12]. VSI helps the power system operator to implement a certain preventive actions.

VSI are categorized into Jacobian matrix based VSI and system variables based VSI [13]. Jacobian matrix based VSI determines the voltage stability margin and also computes the maximum loading point of a system. However, these VSI are not suitable for online measurement as they take more time.

On the other side, VSI based on system variable takes minimum computation time as they uses the power system variables such as bus voltages and line power flows. With ability to measure the stability at minimum computation time, these VSI are adopted for online monitoring and assessment.

3. VOLTAGE STABILITY INDICES

3.1 FORMULATION

In this section, four three types of VSI are implemented for a two bus radial distribution system shown in Fig.1. These VSI are line stability indices and are framed using power transmission concept for a single distribution line.

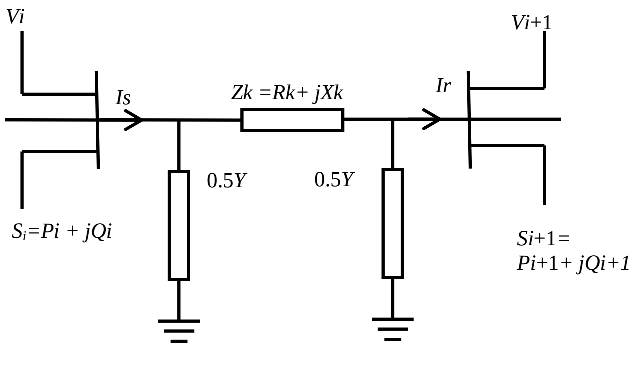

Fig.1. Two bus radial distribution system

Before framing VSI, following factors are considered. Let V_i and V_{i+1} be magnitude of voltage profile at sending end and receiving end buses respectively. P_i and Q_i be the corresponding real and reactive power at sending end bus. P_{i+1} and Q_{i+1} be the corresponding real and reactive power at receiving end bus. S_i and S_{i+1} be the apparent power of sending and receiving end buses respectively. Y be the shunt admittance of the line. R_k, X_k and θ_k be the corresponding resistance, reactance and impedance angle of a distribution line. Z_k be the impedance of a distribution line. I_s and I_r be the current at sending and receiving ends of a distribution line respectively.

3.2 STABILITY INDEX (SI)

The voltage stability of RDS is assessed by evaluating SI introduced by Charkravorty and Das [14] and the formulation of this index is presented in Vovos and Bialek [15]. The mathematical expression for VSI is given below:

$$SI_{i+1} = \{|V_i|^4\}-4\{P_{i+1}X_k-Q_{i+1}R_k\}^2-4\{P_{i+1}R_k+Q_{i+1}X_k\}|V_i|^2 \quad (1)$$

The buses of radial distribution network are said to be in a stable condition when $VSI_{i+1} > 0$.

3.3 NOVEL LINE STABILITY INDEX (NLSI)

Yazdanpanah-Goharrizi et al. [16] introduced a VSI to assess the line stability of power system network. The line with NLSI closer to unity refers the state of instability or voltage collapse. The mathematical expression obtained for NLSI is given in Eq.(2)

$$NLSI = \frac{P_{i+1}R_k + Q_{i+1}X_k}{0.25V_S^2} \quad (2)$$

3.4 FAST VOLTAGE STABILITY INDEX (FVSI)

A novel FVSI proposed in [17] was obtained from a line voltage stability index of a two bus system. FVSI below 1 for a line indicates stable condition. If FVSI approaches towards unity then buses will experience a sudden voltage drop. The expression for FVSI is presented in Eq.(3)

$$FVSI = \frac{4Z^2Q_{i+1}}{V_i^2X_k} \quad (3)$$

4. RESULTS AND DISCUSSION

In this paper, the stability of radial distribution system with nominal and peak demand is assessed by evaluating three different VSI. Referring to Eq.(1)-Eq.(3), to evaluate these VSI the following parameters are required: Line resistance, reactance and impedance, effective real and reactive power at all buses and voltage magnitude of all buses. Amongst these parameters, effective real and reactive powers and voltage magnitude at all buses need to be determined. Therefore, load flow analysis is essential in RDS. In this paper, backward forward sweep algorithm [18] is utilized to find the line flows and voltage profile of RDS.

4.1 IEEE 15 BUS RDS

IEEE 15 bus RDS comprises of 14 load buses, one swing bus and 14 branches. The test system includes total active and reactive power demand of 1226.4 kW and 1251.178 kVAr respectively under nominal condition. The single line diagram representation of this test system is illustrated in Fig.2. The required bus and line data for IEEE 33 bus RDS is referred from [19]. The voltage profile of IEEE 15 bus RDS with nominal and peak demand is obtained from load flow study and are shown in Fig.3. Referring to Fig.3, it is evident that voltage profile of test system reduced as the load gets increased. To illustrate peak load condition, the power demand is increased by a factor 1.6. The test system with nominal and peak loading conditions has a minimum voltage of 0.9445 p.u and 0.9081 p.u respectively.

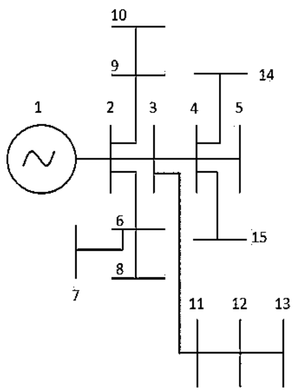

Fig.2. Single line diagram of IEEE 15 bus RDS

The Fig.4 and Fig.5 show different VSI computed for this test system with nominal and peak power demand. Test system has a minimum SI of 0.7958 and 0.6801 for nominal and peak demand respectively. Referring to Fig.4, bus number 13 is found to be the weaker bus as it has lowest SI value for both nominal and peak demand. Similarly, Fig.5 shows FVSI and NLSI of IEEE 15 bus RDS with nominal and peak demands. Based on the values of FVSI and NLSI, it is found that bus number 5 is weaker bus.

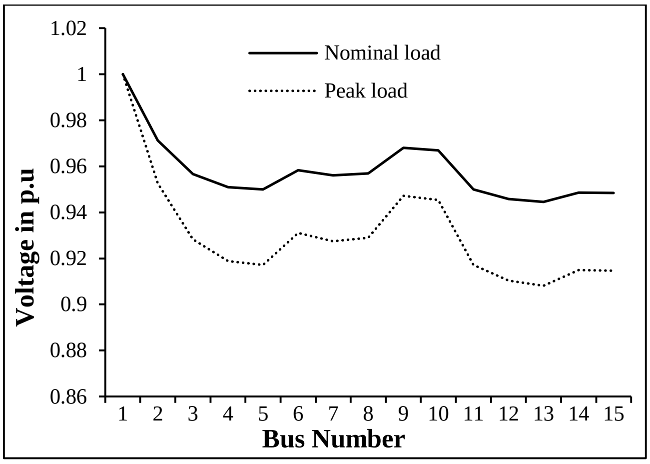

Fig.3. Voltage profile of IEEE 15 bus RDS

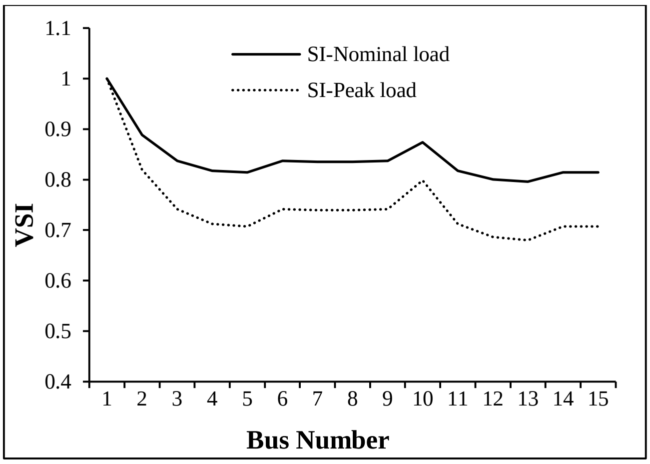

Fig.4. SI of IEEE 15 bus RDS

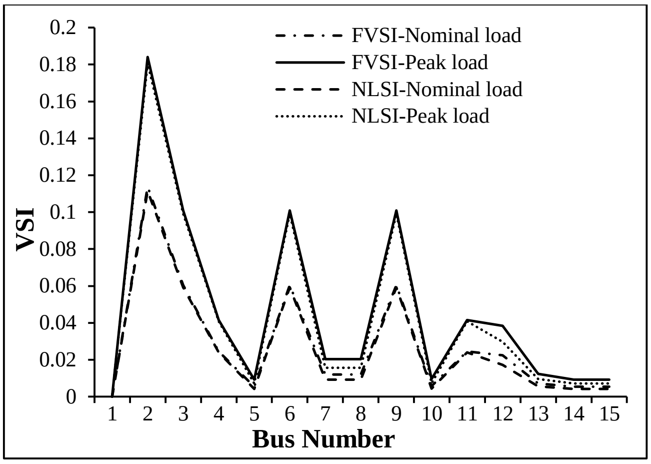

Fig.5. FVSI and NLSI of IEEE 15 bus RDS

4.2 IEEE 33 BUS RDS

IEEE 33 bus RDS comprises of 32 load buses, one swing bus and 32 branches. The test system has a total real and reactive power demand of 3720 kW and 2300 kVAr respectively under nominal condition. The single line diagram representation of this test system is illustrated in Fig.6. The voltage profile of IEEE 33 bus RDS with nominal and peak demand obtained from load flow study is shown in Fig.7.

For peak load condition, the power demand is increased by a factor 1.6. Referring to Fig.7, it is evident that voltage profile of test system gets reduced as the load increased. The test system with nominal and peak loading conditions has a minimum voltage of 0.9038 p.u and 0.8360 p.u respectively.

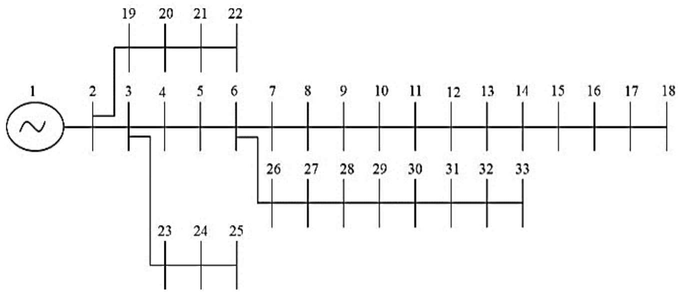

Fig.6. Single line diagram of IEEE 33 bus RDS

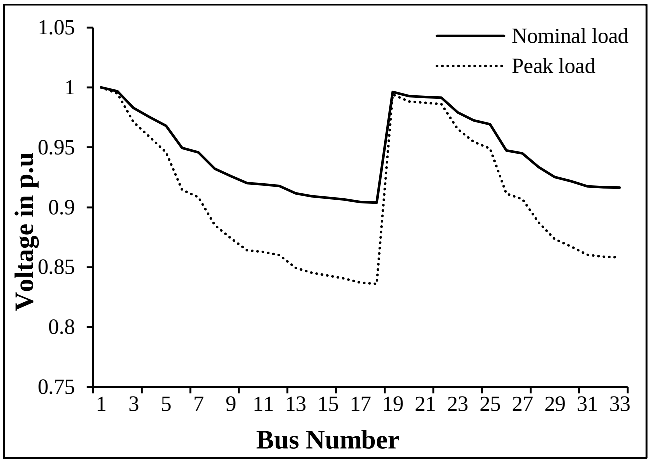

Fig.7. Voltage profile of IEEE 33 bus RDS

The Fig.8 and Fig.9 show different VSI computed for this test system with nominal and peak power demand. Test system has a minimum SI of 0.6672 and 0.4884 for nominal and peak demand respectively. Referring to Fig.8, bus number 18 is found to be the weaker bus as it has lowest SI value for both nominal and peak demand. Similarly, Fig.9 shows FVSI and NLSI of IEEE 33 bus RDS with nominal and peak demands. It is found that bus number 33 is a weaker bus of this test system according to the values of FVSI and NLSI.

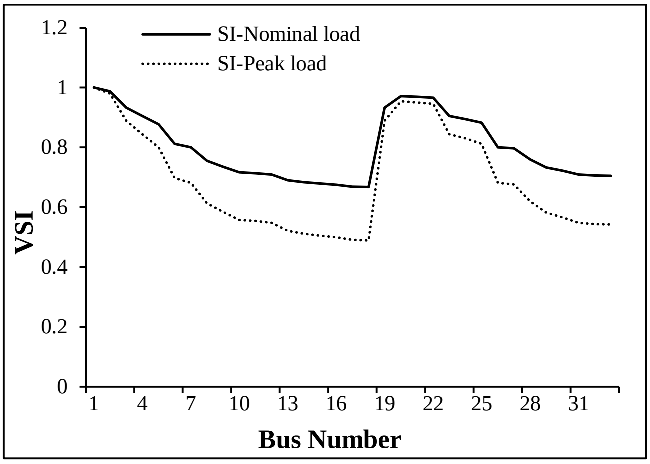

Fig.8 SI of IEEE 33 bus RDS

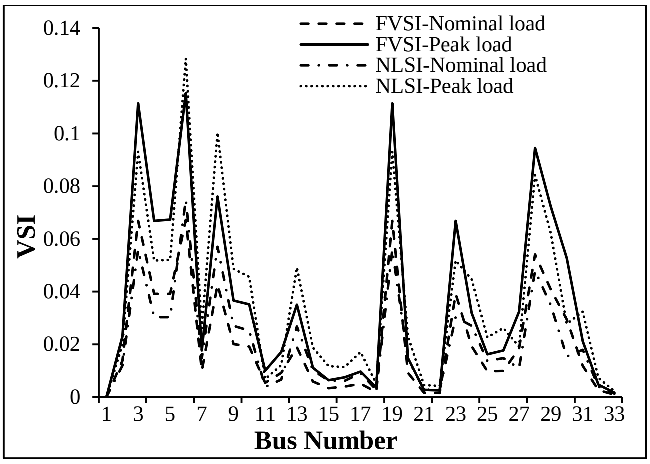

Fig.9 FVSI and NLSI of IEEE 33 bus RDS

4.3 IEEE 69 BUS RDS

IEEE 69 bus RDS comprises of 68 load buses, one swing bus and 68 branches. The test system has a total real and reactive power demand of 3800 kW and 2690 kVAr respectively. The single line diagram representation of this test system is illustrated in Fig.10. The voltage profile of IEEE 69 bus RDS with nominal and peak demand obtained from load flow analysis is shown in Fig.11. Referring to Fig.11, it is evident that voltage profile of test system gets reduced as the load increased. The test system with nominal and peak loading conditions has a minimum voltage of 0.9092 p.u and 0.8445 p.u respectively.

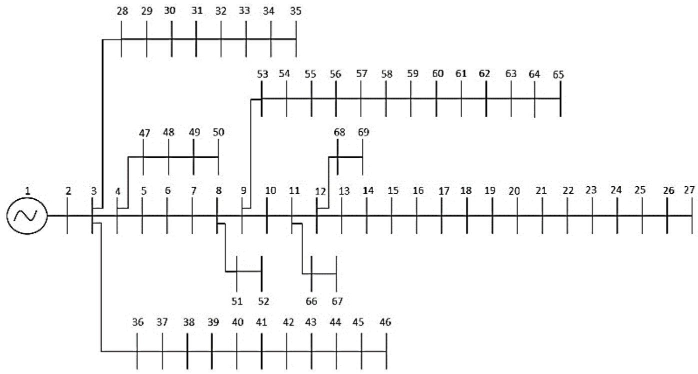

Fig.10 Single line diagram of IEEE 69 bus RDS

The Fig.12 and Fig.13 show different VSI computed for this test system with nominal and peak power demand. Referring to Fig.12, bus number 65 is found to be the weaker bus as it has lowest SI value for both nominal and peak demand. Test system has a minimum SI of 0.6832 and 0.5085 for nominal and peak demand respectively. Similarly, Fig.13 shows the variation of FVSI and NLSI for IEEE 69 bus RDS with nominal and peak demands. It is found that bus number 2 is a weaker bus of this test system according to the values of FVSI and NLSI.

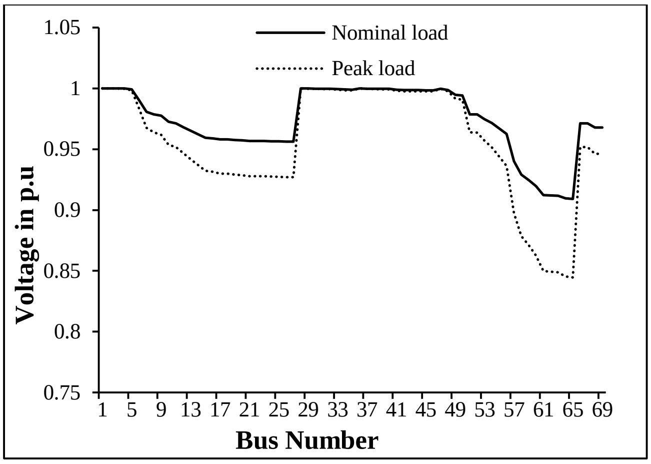

Fig.11. Voltage profile of IEEE 69 bus RDS

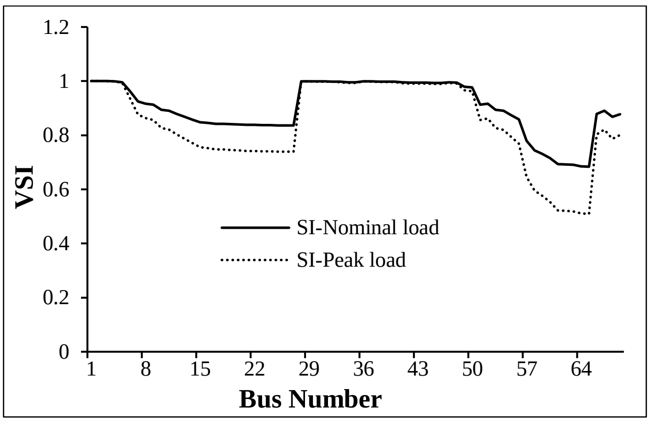

Fig.12. SI of IEEE 69 bus RDS

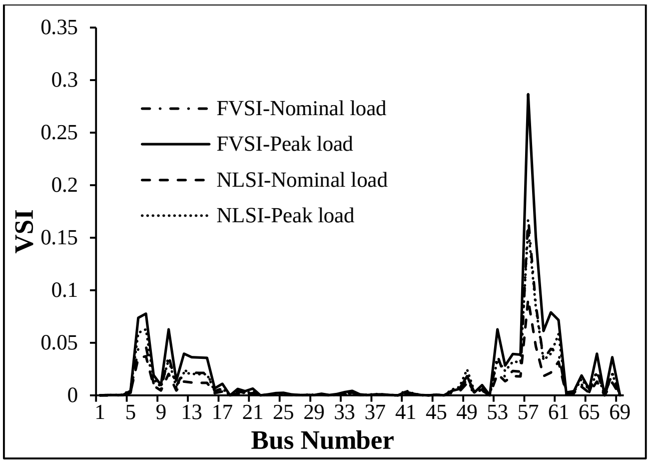

Fig.13. FVSI and NLSI of IEEE 69 bus RDS

4.4 IEEE 85 BUS RDS

IEEE 85 bus RDS comprises of 84 load buses, one swing bus and 84 branches. The single line diagram representation of this test system is illustrated in Fig.14. The voltage profile of IEEE 85 bus RDS with nominal and peak demand obtained from load flow study is shown in Fig.15. Referring to Fig.15, it is evident that voltage profile of test system gets reduced as the load increased. The test system with nominal and peak loading conditions has a minimum voltage of 0.8713 p.u and 0.8021 p.u respectively.

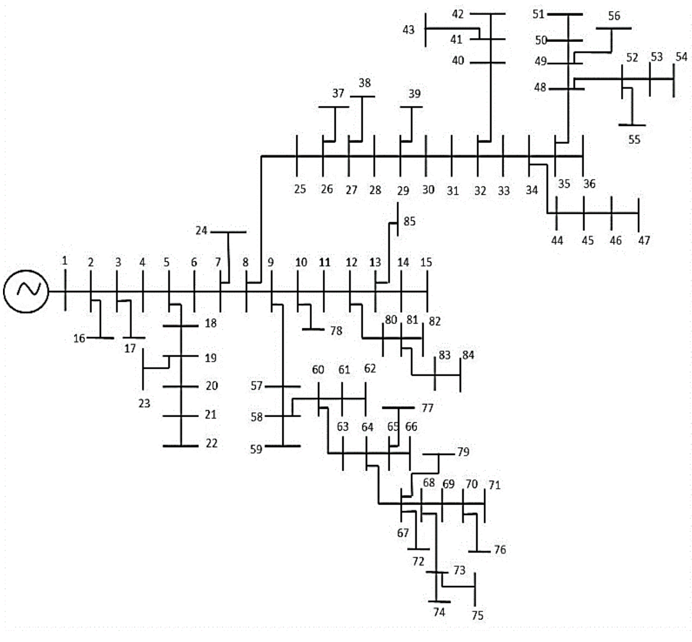

Fig.14. Single line diagram of IEEE 85 bus RDS

The Fig.15 and Fig.16 show different VSI computed for this test system with nominal and peak power demand. Test system has a minimum SI of 0.5763 and 0.3552 for nominal and peak demand respectively. Referring to Fig.8, bus number 54 is found to be the weaker bus as it has lowest SI value for both nominal and peak demand. Similarly, Fig.16 shows FVSI and NLSI of IEEE 85 bus RDS with nominal and peak demands. It is found that bus number 48 is a weaker bus of this test system according to the values of FVSI and NLSI.

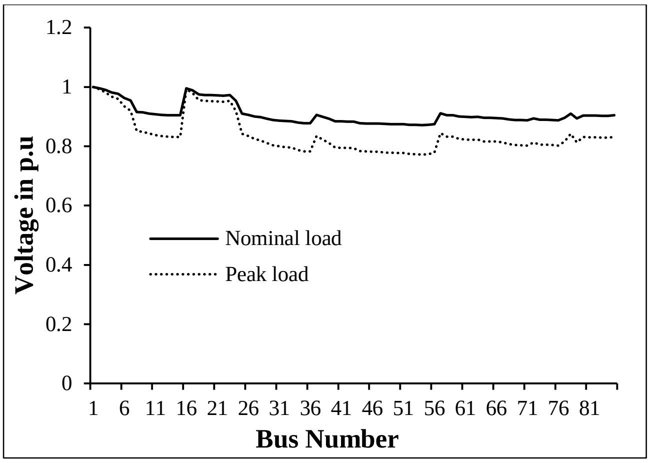

Fig.15. Voltage profile of IEEE 85 bus RDS

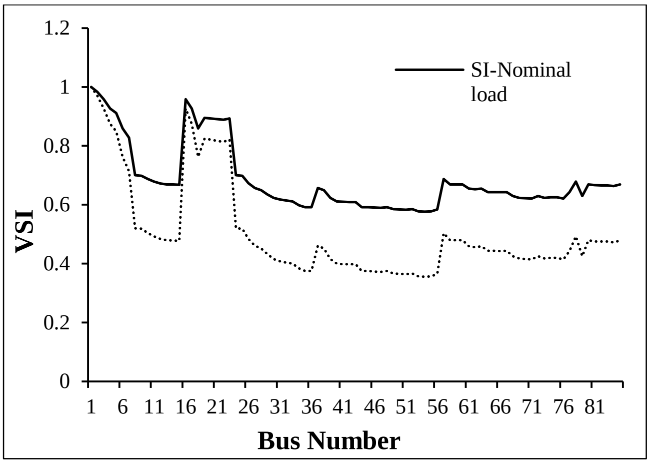

Fig.16. SI of IEEE 85 bus RDS

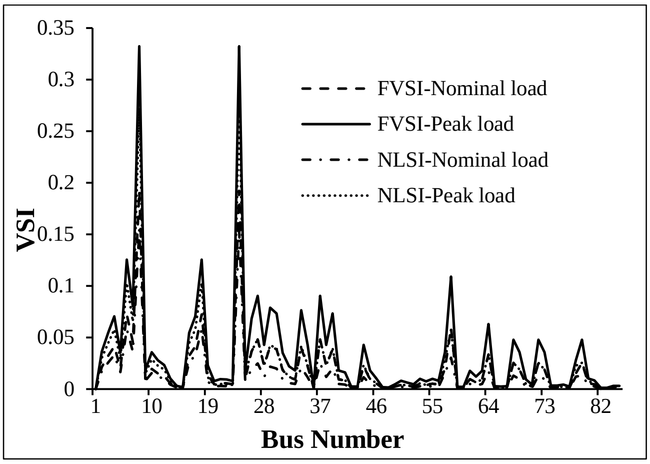

Fig.17. FVSI and NLSI of IEEE 85 bus RDS

5. CONCLUSION

In this paper, voltage stability of radial distribution system has been assessed for nominal and peak demand conditions by computing different voltage stability indices. The stability analysis was performed for IEEE 15, 33, 69 and 85 bus RDS. The impact of load variation on system voltage profile is studied for both test system. It was found that as the load on the test system is increased bus voltages are considerably reduced. Apart from assessing stability of the system, evaluation of different VSI helped to determine the weakest bus of test system that may induce voltage instability problem. The test results have highlighted that variation of power demand causes the system voltage to fall in progressive manner and induce voltage instability. Moreover, evaluation of VSI greatly helps to predict this unwanted event in well advance in order to initiate necessary corrective actions.

REFERENCES

[1] P. Pourbeik and P.S. Kundur, "The Anatomy of a Power Grid Blackout - Root Causes and Dynamics of Recent Major Blackouts", *IEEE Power and Energy Magazine*, Vol. 4, No. 5, pp. 22-29, 2006.

[2] J.W. Bialek, "Why Has it Happened Again? Comparison Between the UCTE Blackout in 2006 and the Blackouts of 2003", *Proceedings of IEEE Lausanne Power Tech*, pp. 1-5, 2007.

[3] P. Kundur, N.J. Balu and M.G. Lauby, "*Power System Stability and Control*", McGraw-Hill, 1994.

[4] A.M. Azmy and I. Erlich, "Impact of Distributed Generation on the Stability of Electrical Power System", *Proceedings of IEEE General Meeting on Power Engineering Society*, pp. 21-25, 2005.

[5] H. Goh, "Power Stability Monitoring based on Voltage Instability Prediction Approach through Wide Area System", *American Journal of Applied Sciences*, Vol. 11, No. 5, pp. 717-731, 2014.

[6] H. Goh, "Comparative Studies of Different Kalman Filter Implementations in Power System Stability", *American Journal of Applied Sciences*, Vol. 11, No. 8, pp. 1379-1390, 2014.

[7] J. Wen, "Optimal Coordinated Voltage Control for Power System Voltage Stability", *IEEE Transactions on Power Systems*, Vol. 19, No. 2, pp. 1115-1122, 2004.

[8] P. Kundur, N.J. Balu and M.G. Lauby, "*Power System Stability and Control*", 7th Edition, McGraw-Hill, 1994.

[9] P. Kundur, "Definition and Classification of Power System Stability IEEE/CIGRE Joint Task Force on Stability Terms and Definitions", *IEEE Transactions on Power Systems*, Vol. 19, No. 3, pp. 1387-1401, 2004.

[10] P. Kundur, J. Paserba and S. Vitet, "Overview on Definition and Classification of Power System Stability in Quality and Security of Electric Power Delivery Systems", *Proceedings of IEEE International Symposium on Quality and Security of Electric Power Delivery Systems*, pp. 457-464, 2003.

[11] A. Chakrabarti and S. Halder, "*Power System Analysis: Operation and Control*", 3rd Edition, PHI Learning, 2010.

[12] P.A. Lof, G. Andersson and D. Hill, "Voltage Stability Indices for Stressed Power Systems", *IEEE Transactions on Power Systems*, Vol. 8, No. 1, pp. 326-335, 1993.

[13] F. Karbalaei, H. Soleymani and S. Afsharnia, "A Comparison of Voltage Collapse Proximity Indicators", *Proceedings of IEEE International Conference on International Power and Energy*, pp. 1-8, 2010.

[14] M. Chakravorty and D. Das, "Voltage Stability Analysis of Radial Distribution Networks", *International Journal of Electrical Power and Energy Systems*, Vol. 31, No. 2, pp. 129-135, 2001.

[15] P.N. Vovos and J.W. Bialek, "Direct Incorporation of Fault Level Constraints in Optimal Power Flow as a Tool for Network Capacity Analysis", *IEEE Transaction on Power Systems*, Vol. 20, No. 4, pp. 2125-2134, 2005.

[16] A. Yazdanpanah Goharrizi and R. Asghari, "A Novel Line Stability Index (NLSI) for Voltage Stability Assessment of Power Systems", *Proceedings of International Conference on Power Systems*, pp. 165-167, 2007.

[17] I. Musirin and T.A. Rahman, "Novel Fast Voltage Stability Index (FVSI) for Voltage Stability Analysis in Power Transmission System", *Proceedings of International Conference on Research and Development*, pp. 341-346, 2002.

[18] M.H. Haque, "Efficient Load Flow Method for Distribution Systems with Radial or Mesh Configuration", *Proceedings of IEEE Conference on Generation, Transmission and Distribution*, pp. 33-38, 1996.

[19] N.C. Sahoo and K. Prasad, "A Fuzzy Genetic Approach for Network Reconfiguration to Enhance Voltage Stability in Radial Distribution Systems", *Energy Conversion and Management*, Vol. 47, No. 18-19, pp. 3288-3306, 2006.