International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Static Voltage Stability Analysis of IEEE 14 Test Bus System Using PSAT

R. Karthikeyan

SCSVMV University, Enathur, Tamilnadu
Email: kascs2007@gmail.com

ABSTRACT—

The complexity of the power system and level of power demand has increased leading to voltage instability problem across many power systems. Voltage instability is concerned with maintaining appropriate voltage level across all the buses in the power system . Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. In this paper the static voltage stability analysis of IEEE 14 bus system was analysed using Power system Analysis Toolbox. (PSAT)

Keywords— Modal Analysis, IEEE 14 Bus system, MATLAB (PSAT)

I. INTRODUCTION

The complexity of the power system has increased in response to the economic growth and continuously increasing power demand. Voltage instability has been given much attention by power system researchers and planners in recent years, and is being regarded as one of the major sources of power system insecurity. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. Static Voltage stability analysis is one of the major studies that is carried out during the planning and operation of the power system. The static voltage stability analysis uses a system condition or a snapshot to assess the voltage stability issues.

Several incidences of voltage collapse have been observed, in the past few decades, in different parts of the world. Some of the incidences of voltage collapse are:

- New York State Pool disturbance of September 22, 1970.
- Jacksonville, Florida system disturbance of September 22, 1977.
- Zealand, Denmark system disturbance of March 2, 1979.
- Longview, Washington area system disturbance of August 10, 1981.
- Western System Coordination Council (WSCC) interconnected system (North America) disturbance of July 2, 1996.
- Sri Lanka Power System disturbance of May 2, 1995.
- Northern Grid disturbance in the Indian Power System of December 1996.
- North American Power system disturbance of August 14, 2003.
- National Grid System of Pakistan disturbances of September 24, 2006.

National Scenario

- Northern Regional grid security violation, January 2001 leading to 1500mw loss in a generation.
- Northern Regional failure 23rd December 2000.
- Southern Regional grid failure on 13th October 1995.
- Western Regional Grid failure on 10th November 1995.
- Western Regional Grid failure on 9th December 1995.
- Sriperumpudur 400 kV substation disturbance in August 2006.

VOLTAGE STABILITY

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result occurs in the form of a progressive fall or rise of voltages of some buses.

VOLTAGE STABILITY ANALYSIS:

The analysis of voltage stability, for planning and operation of a power system, involves the examination of two main aspects:

- How close the system is to voltage instability (i.e. Proximity). When voltage instability occurs, the key contributing factors such as the weak buses, area involved in collapse and generators and lines participating in the collapse are of interest (i.e. Mechanism of voltage collapse).Proximity can provide information regarding voltage
- The mechanism gives useful information for operating plans and system modifications that can be implemented to avoid the voltage collapse

II. STATIC VOLTAGE STABILITY ANALYSIS

Static methods involve the static model of power system components. These methods are important when the power system is in operation and planning stages, to prepare an adequate perfect plan for meeting the power requirements during different types of contingencies arising during its operation.

The Modal analysis of the Jacobian matrix is used to analyze the static voltage stability Nima Amjady et al. (2008)[83] as given in the equation

$$\begin{bmatrix} \Delta P_{PQ,PV} \\ \Delta Q_{PQ} \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{Q\theta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V_{PQ} \end{bmatrix}$$

where,

$\Delta P_{PQ, PV}$ is the incremental change in bus real power

ΔQ_{PQ} is the incremental change in bus reactive power

$\Delta\theta$ is the incremental change in bus voltage angle

ΔV is an incremental change in bus voltage magnitude

The elements of the Jacobian matrix represent the sensitivities between nodal power and bus voltage changes. Power system voltage stability is largely affected by reactive power. Keeping real power constant at each operating point, the Q-V analysis can be carried out. Assuming $\Delta_{PPQ,PV} = 0$, it follows from the equation

$\Delta Q_{PQ} = [J_{QV} - J_{Q\theta}.J^{-1}_{P\theta}.J_{PV}].\Delta V_{PQ} = J_R.\ \Delta V_{PQ}$

and, $\Delta V_{PQ} = J^{-1}_{R.}.\Delta Q_{PQ}$

The Q-V modal analysis can be performed based on the inverse of the reduced Jacobian matrix (J_R^{-1}), and it represents the reduced V-Q Jacobian matrix. Therefore, the bus, branch, and generator participation factors are obtained. Moreover, the stability margin and the shortest distance to instability will be determined. In most cases, the system dynamics affecting voltage stability are quite slow. The static approach effectively analyzes most of the problems. It can examine the viability of a specific operating point of the power system. Also, the static analysis method provides information such as sensitivity or degree of stability and involves the computation of only algebraic equations. It is much more efficient and faster than dynamic approaches. The static analysis approach is more attractive than the dynamic method and well suited to voltage stability analysis of power systems over a wide range of system conditions.

Continuation Method

Continuation power flow-based voltage stability techniques are based on the reformulation of the load flow equation and application of predictor and corrector techniques with local parameterization to plot the trajectory of the PV curve. The continuation power flow method is used to analyze the power system where the load changes continuously from the base case to a critical point. This method yields accurate results and is used to determine the critical buses that may lead to voltage insatiability.

In Voltage Stability analysis using the power flow method, the Jacobian matrix becomes singular at the critical point also known as the stability limit. As a result, the power flow solutions near the critical point are prone to divergence and error. The Continuation Power Flow method is a powerful tool to determine the continuum of power flow solutions starting from the baseload until the steady-state voltage stability limit of the power system. Venkataramana Ajjarapu and Colin Christy (1991)[5]. As a result of this algorithm, divergence due to ill-conditioning is overcome at the critical point. In the method, the singularity in the Jacobian is avoided by slightly reformulating the power flow equations by applying a locally parameterized continuation technique (Fig.1.4).

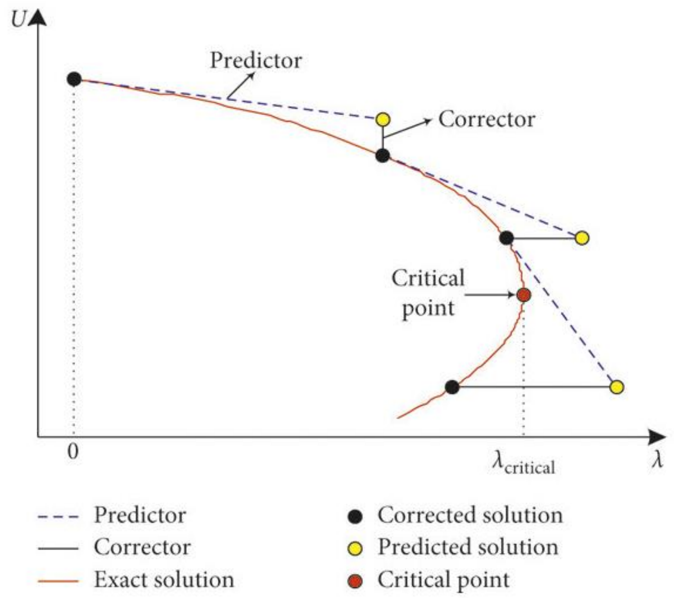


Figure 1.4 Continuation Power Flow Diagram

ALGORITHM FOR VOLTAGE STABILITY ANALYSIS USING MODAL ANALYSIS

Modal based voltage stability analysis of a power system is carried out by following the sequence of steps as listed below:

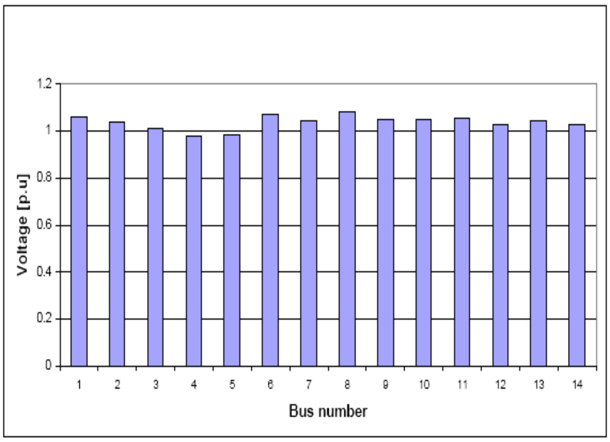
- The power flow analysis using Newton Raphson is carried out to determine the specific operating condition. The corresponding power flow Jacobian matrix and the reduced Jacobian matrix are obtained.
- The modal analysis on the reduced Jacobian Matrix is performed to determine the smallest Eigenvalue and its corresponding Eigenvectors. The bus, branch, and generator participation factors are evaluated based on the Eigenvectors.
- The Eigenvalue is an indicator of proximity to voltage instability. The Eigenvector provides information about the critical buses, branches, and generators that contribute to voltage instability.
- Generate the V-P curves at critical buses to identify the Voltage Stability Margin to implement the desired corrective action.

SIMULATION AND EXPERIMENTAL VERIFICATION

To demonstrate the significance of Modal analysis in evaluating the Voltage stability Analysis, an IEEE 14 test bus system as shown in the figure was selected. The IEEE 14-bus test system consists of five generators located at the bus no. 1, 2, 3, 6 and 8.There are a total of 14 buses of which bus 1 is considered the slack bus, buses 2, 3, 6, 8 are the PV buses, and buses 4, 5, 7, 9, 10, 11, 12, 13, and 14 totaling eleven constitute the PQ bus or load bus. There are 20 transmission lines in the test bus system.

Evaluation of the Voltage Profile of the Buses

As mentioned in the algorithm, first the Newton Raphson load flow program was executed to obtain the current operating condition. From the power flow result, the voltage profile at all the buses is obtained and is plotted as shown in the following bar chart.



Voltage profile of IEEE 14 Test Bus System

It can be observed from the above bar chart that the bus voltages at all the buses are within the acceptable voltage level of ± 5%.

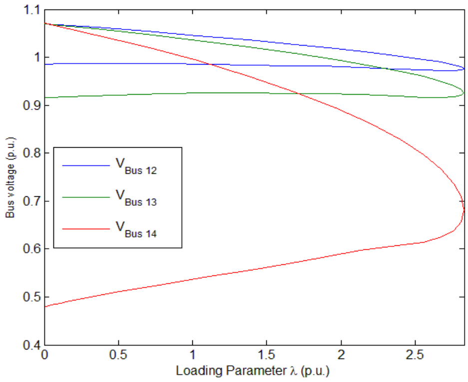
Evaluation of the Static Voltage Stability of the System using Eigenvalues

From the Newton Raphson load flow result the Jacobian matrix and the Reduced Jacobian Matrix J_R are evaluated. Since there are 14 buses of which there is one swing bus, 4 PV buses, and 9 PQ buses, there are 9 numbers of Eigenvalues in the reduced Jacobian matrix. The values of the Eigenvalue are given in the following table.

Eigenvalues of the Reduced Jacobian Matrix

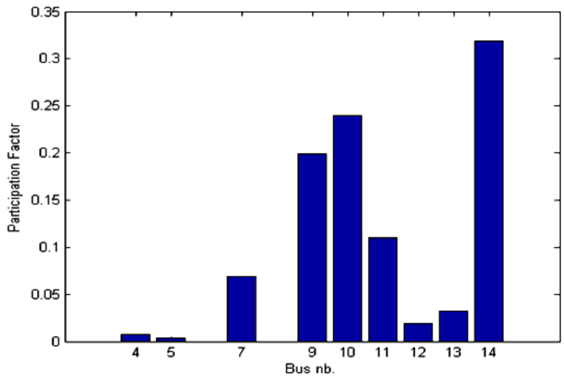
S. No.	1	2	3	4	5	6	7	8	9
Eigen value	65.1	39.2	21.6	18.8	16.2	11.2	2.69	5.52	7.59

From the above table , it is inferred that 2.69 is the smallest Eigenvalue indicating the proximity to voltage instability. The P-V curve for this load condition is plotted as shown in the following figure. The curve is plotted using the PSAT software. From the P-V curve, it is evident that the Voltage Stability Margin is 2.69 p.u.



Identification of the Weak Buses

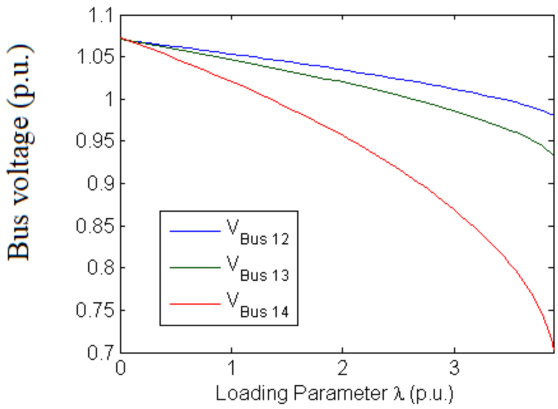
To identify the weak or the critical buses, the bus participation factor is evaluated by using the Eigenvectors. The participation factor and the corresponding buses are shown in the following figure:



It is inferred from Figure 3.4, that bus number 14 has the highest participation factor for this particular mode followed by bus 10, bus 9, and bus 11. The participation factor from other buses is comparatively low. So it is concluded that bus number 14 is the weakest bus and may contribute to making the system unstable.

MITIGATION OF VOLTAGE STABILITY BY INTRODUCTION OF SVC

To improve the voltage stability of the system, the Static Var Compensator is introduced in bus 14 which has been identified as the weak bus based on the Modal analysis. The SVC is capable of regulating the voltage profile by supplying as well as absorbing the reactive power. After the introduction of the SVC on the 14th bus, the P-V curves are plotted as shown in Figure 3.5.



It is observed from the P-V curve that the introduction of SVC at bus 14, has significantly improved the voltage profile at the weak buses, and also the voltage stability limit has been improved to 3.38 p.u.

1. Through the application of the Modal analysis, it has been identified that the IEEE 14 test bus system is stable as all the Eigenvalues are positive.
2. From the smallest Eigenvalue, 2.69 p.u is an indicator of the proximity to instability.
3. The evaluation of the Eigenvectors and the bus participation factor indicates that bus number 14 is the weakest bus since it has the highest participation factor of 0.345.
4. To improve the voltage stability margin, the SVC was introduced at bus number 14 and its introduction has improved the voltage profile significantly, at the same time the voltage stability margin has also improved from 2.69 p.u to 3.38 p.u thus improving the voltage stability of the system as a whole.

Conclusion:-

In this paper , the voltage stability analysis of IEEE 14 bus was carried out based on Static voltage stability analysis using Modal and Continuation power flow technique. Power system Analysis Tool Box (PSAT) on MATLAB 2014 was used for analyzing the voltage stability of the IEEE14 bus and it was identified that the system does not possess voltage stability. And the stability of the system was increased by integrating SVC.

REFERENCES

[1] Li X., Bao L., Daun X., He Y., Gao M., "Effect of FACTS Controller Small-Signal Voltage Stability", IEEE Power Engineering Society Winter Meeting, pp.2793-2799, 2000.

[2] Jafari M., Afsharnia S., "Voltage Stability Enhancement in Contingency Conditions Using Shunt FACTS Devices", IEEE EUROCON 2007, pp.1660-1665, 2007.

[3] Candelo J. E., Caicedo N. G., Aranda F. C., "Proposal for the Solution Voltage Stability Using Coordination of FACTS Devices", IEEE Transmission, Distribution Conference, pp.1-6, 2006.

[4] Kundur, P., "Power System Stability and Control", McGraw Hill, 1994.

[5] B. Gao, G. K. Morison, P. Kundur, "Voltage Stability Evaluation Using Modal Analysis," Transactions *on* power Systems, Vol. 7, No. 4. November 1992.

[6] B. Gao, G. K. Morison, P. Kundur, "Voltage Stability Analysis Using Static and Dynamic Approaches," IEEE Transactions *on* power Systems, Vol. 8, No. 3, August 1993.

[7] P. Pal, "*Voltage Stability Conditions Considering Load Characteristics*", IEEE Trans. on Power Systems, Vol. 7, No. 2, pp. 243-249, Feb. 1992.

[8] P. Kessel and H. Glavitsch, "*Estimating the Voltage Stability of a Power System,*‖ IEEE Trans. on Power Delivery, vol. 1, pp. 346-353, July 1986.

[9] C. D. Vournas, P. W. Sauer, and M. A. Pai(1996), "Relationships between voltage and angle stability of power systems", Electric Power Systems Research, vol. 18, no. 8, November 1996, pp: 493-500.

[10] Antonio C. Z. de Souza, Claudio A. Canizares, Victor H. Quintana (1996), "New Techniques to speed up voltage collapse computations using tangent vectors", IEEE Transactions on Power Systems, 1996.

[11] Scott Greene, Ian Dobson, Fernndo L. Alvarado (1997), "Sensitivity of the loading margin to voltage collapse concerning arbitrary parameters", IEEE Transactions on Power Systems, Vol. 12, No. 1, February 1997, pp:262-231.

[12] D.L.H. Aik; and G. Andersson (1998), "Use of participation factors in modal voltage stability analysis of multi-infeed HVDC system", IEEE Transactions on Power Delivery, Vol. 13, No. 1, January 1998, pp: 203 – 211.

[13] C. A. Canizares, "Calculating optimal system parameters to maximize the distance to saddle-node bifurcations," in *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, vol. 45, no. 3, March 1998, pp: 225-237.