2012 2nd International Conference on Power and Energy Systems (ICPES 2012)
IPCSIT vol. 56 (2012) © (2012) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2012.V56.9

Voltage Stability Analysis with Equal Load and Proportional Load Increment in a Multibus Power System

S.D.Naik [1+], M.K.Khedkar [2] and S.S.Bhat[3]

[1] Associate Professor RCOEM, Nagpur

[2] Vice Chancellor, SGBA, Amravati University, Amravati

[3] Associate Professor, V.N.I.T.Nagpur

Abstract. In heavily loaded systems, voltage stability limit is usually dominant and voltage instability is usually observed following large disturbance. In the deregulated environment the transmission systems are operating under more stressed condition due to increased transaction level associated with open access.This causes voltage instability. In recent years, abnormal voltage instability has occurred in several countries viz.France, Japan, USA. Sufficient attention to voltage stability in deregulated system is not paid as compared to angle stability. More attention is thus required to be paid to keep voltage profile and hold the voltage stability under control. There are various methods for voltage stability analysis in the literature. In this paper simple static voltage stability analysis is carried out for a multibus power system (26 Bus System) using proportional load increment and equal load increment on selected load buses. It is necessary to find the weak buses those are prone to voltage instability due to the required level of power transfer. Using modal analysis bus participation factors are found to identify weak buses. The effect of shunt compensation on minimum eigen value of Jacobian matrix, maximum system loadability and improvement of bus voltage profile is studied.

Keywords: Voltage stability, Shunt compensation, Reactive power, Modal analysis, Bus participation factor.

1. Introduction

The voltage stability is gaining more importance now a days with highly developed networks as a result of heavier loadings. Voltage instability may result in power system collapse. *Voltage stability* is the ability of power system to maintain steady acceptable voltages at all buses in the system under normal and abnormal conditions [1].*Voltage collapse* is the process by which the sequence of events accompanying voltage instability leads to a low unacceptable voltage profile in a significant part of the power system. When power system is subjected to a sudden increase of reactive power demand following a system contingency, additional demand is met by the reactive power reserves carried by the generators and compensators. If sufficient reserves are there, the system settles to a stable voltage level. However because of a combination of events it is possible that additional reactive demand may lead to voltage collapse.

In deregulated environment the power system usually operates under stressed condition [2].The heavily loaded systems are more prone to the voltage instability and the maximum loadability of the system is greatly affected. In recent years, abnormal voltage instability have occurred in several countries viz.France, Japan,USA.More attention is required to be paid to keep voltage profile and hold the voltage stability under control [2]-[3]. In this paper simple voltage stability analysis is carried out for a multibus power system (26 Bus System). The effect of shunt compensation on maximum loadability and minimum eigen value corresponding to critical mode is established for two cases of load increment viz.proportional load increase and equal load increase on selected load buses.

+ Corresponding author. Tel.: + (please specify); fax: +(please specify).
E-mail address: (please specify).

2. Static Voltage Stability and Modal Analysis

It is common to consider curves which relate voltage to active or reactive power. Such curves are referred to as V-P and Q-V curves. The transmission characteristics of interest are the relationship between the transmitted power, receiving end voltage and reactive power injection [4]-[5].

Fig.1 shows the variation of voltage as a function of total active power load at a bus in a power system consisting of many voltage sources and load buses. At the Knee of the curve, the voltage drops rapidly with an increase in load demand. The power flow solution fails to converge beyond this limit, which is indicative of instability [5]-[6].

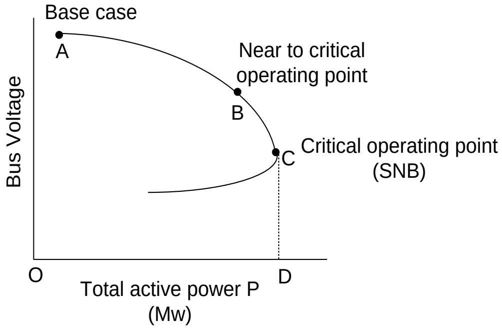


Fig. 1: V-P Curve.

2.1 Modal Analysis

The reduced Jacobian matrix of the system is given by

$$J_R=[J_{QV}-J_{Q\theta}J_{P\theta}^{-1}J_{PV}] \quad (1)$$

Voltage stability characteristic of the system can be identified by computing eigen values and eigen vectors of reduced Jacobian matrix J_R given by equation

$$J_R=\xi\Lambda\eta \quad (2)$$

Where ξ = Right eigenvector matrix of J_R

η = Left eigen vector matrix of J_R

Λ = Diagonal eigen value matrix of J

From equation

$$J_R^{-1}=\xi\Lambda^{-1}\eta \quad (3)$$

We get

$$\Delta V=\xi\Lambda^{-1}\eta\Delta Q \quad (4)$$

Each eigen value λ_i and corresponding right and left eigen vectors define the i th mode of Q-V response.

Finally the relationship between modal voltage and modal reactive power for the buses is given by

$$v_i=q_i/\lambda_i \quad (5)$$

Where,

v_i =Vector of modal voltage variations

q_i = Vector of modal reactive power variations

λ_i = eigen value corresponding to mode i

2.2 Saddle Node Bifurcation and Static Voltage Stability

Equation (5) suggests that,

- If q increases and v increases or vice versa then $\lambda_i > 0$, which means that i th modal voltage variation and i th modal Q variation are along same direction indicating voltage stability.
- If q increases and v decreases or vice versa then $\lambda_i < 0$, which means that i th modal voltage variation and i th modal Q variation are in opposite direction indicating voltage instability.

When the system reaches the voltage stability critical point, modal analysis is helpful in finding voltage critical areas and the elements which participate in this mode. There are two voltage solutions before saddle node bifurcation point SNB for certain loading as shown in Fig.1.The upper voltage solution corresponds to normal behavior of the system and represents stable system. The lower voltage solution represents unstable solution. At saddle point SNB only one voltage solution occurs. Thus the system can be loaded up to SNB, which is called as critical or maximum loadability point. The critical load for static voltage stability is given by distance OD in Fig.1.The SNB occurs due to slow and gradual increase in loading and may result in static voltage instability At SNB point, the sensitivity $\partial V/\partial P$ becomes infinity and Newton Raphson Load Flow Jacobian becomes singular. The minimum singular value of Jacobian indicates the distance between studied operating point and the steady state stability limit. In voltage stability studies, the minimum singular value of the Jacobian becoming zero corresponds to the critical mode of the system [7]. Voltage collapse and loadability computations are discussed in [8]-[9]. A new method CPFLOW for tracing power system steady state stationary behaviour due to load and generation variations is discussed in [10].

2.3 Bus Participation Factor (BPF)

It gives the information on how effective reactive power compensation at a bus is required to increase the modal voltage at that bus. It is given by,

$$P_{ki} = \xi_{ki}\ \eta_{ik} \tag{9}$$

Thus P_{ki} determines the contribution of λi of mode i to V-Q sensitivity at bus k. A bus with high participation factor indicates that it has large contribution to this mode. The size of bus participation in a given mode indicates effectiveness of remedial action applied at that bus. The advantage of modal analysis is that it clearly identifies groups of buses which participate in the instability so that reactive power compensation can be provided at less number of buses.

Local Modes: It indicates the buses with high participation factor that need high reactive power compensation.

Non Local Modes: It indicates large number of buses with small participation factor that needs small reactive compensation.

3. Methodology

1. Read the system data (Base Data).
2. Perform Load Flow Analysis.
3. Check for the divergence of load flow.
4. Increase the load on selected buses equally or in proportion to their original loading.
5. Distribute the increased load on the generators in proportion to their original generation.
6. Repeat step 2 above.
7. Identify the critical load when load flow diverges. Print the values of bus voltages, total critical load etc.
8. Find bus participation factors at critical load, in least stable mode. (Least stable mode corresponds to minimum eigen value of reduced Jacobian matrix).
9. Plot the nose curves (V-P curves) for selected buses.
10. Plot the variation of minimum eigen value with total load.
11. Identify the buses with low voltages at critical Load.
12. Insert the shunt compensation at low voltage buses and repeat step (2) above.
13. The strategy outlined above is applied to 26 bus power system of an electric company as shown in Fig.2 and voltage stability analysis is carried out.

4. Results

Following cases are studied and analyzed.

1. Base case with original data for the system.
2. Load variation till the critical load with equal load increment without additional shunt compensation.
3. Load variation till critical load with proportional load increment without providing shunt compensation.
4. Load variation till the critical load with equal load increment and with shunt compensation at the sensitive buses
5. Load variation till the critical load with proportional load increment and with shunt compensation at sensitive buses
6.

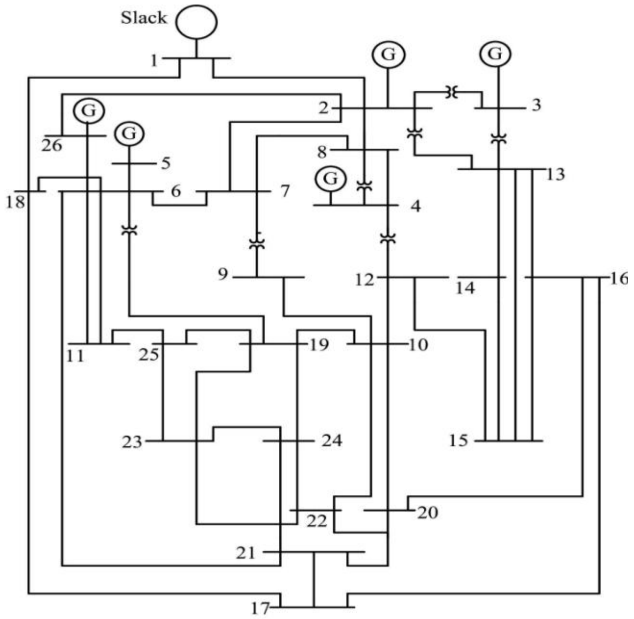


Fig. 2: 26 Bus Power System

Fig.3 to Fig.12 shows the bus voltages, bus participation factors-V curves and variation of minimum eigen value corresponding to critical mode for two cases viz. equal load increment and proportional load increment.

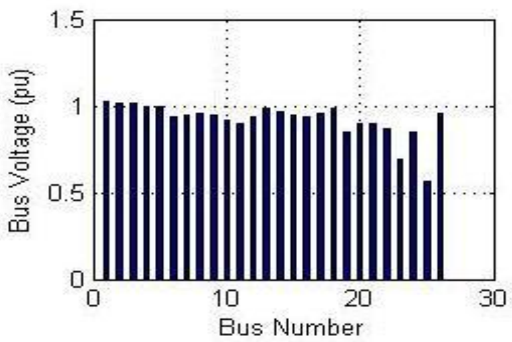


Fig.3: Bus Voltages for Equal Load Increment

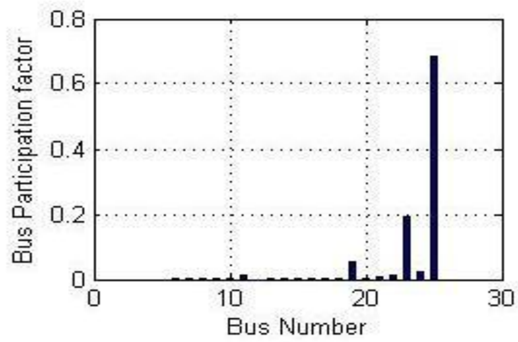


Fig.4: BPF for Equal Load Increment

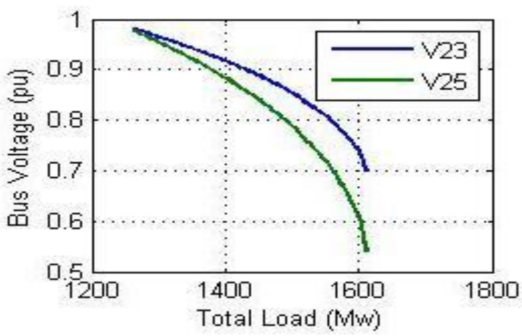


Fig.5: P-V Curves for Equal Load Increment

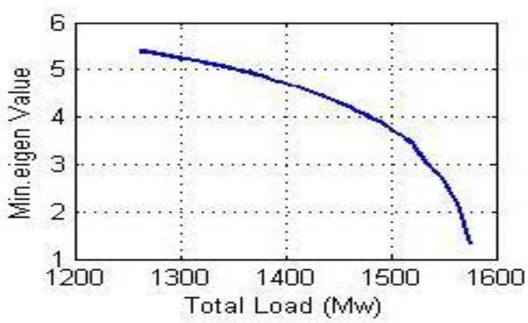


Fig.6: Min.eigen Value for Equal Load Increment

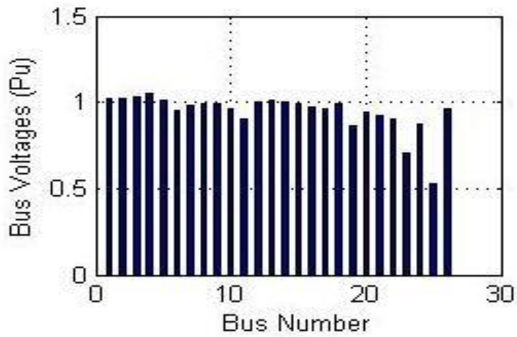


Fig.7: Bus Voltages for Proportional Load Increment

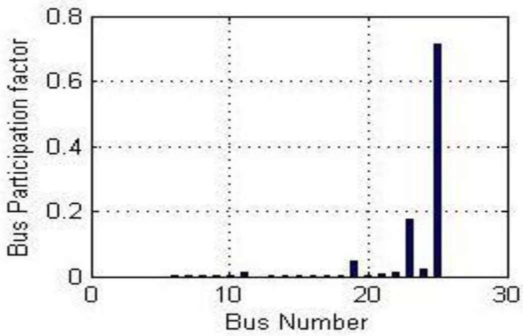


Fig.8: BPF for Proportional Load Increment

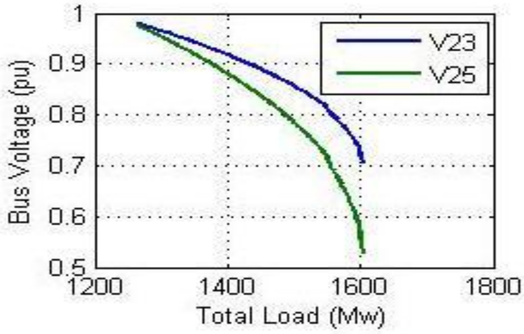


Fig.9: PV Curves for Proportional Load Increment

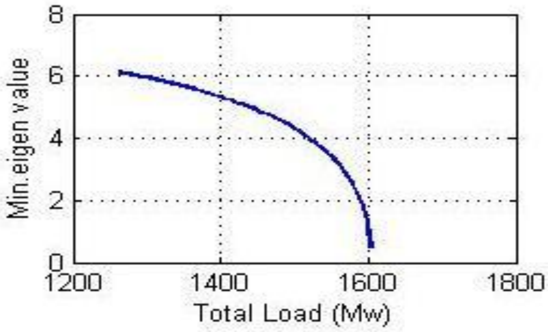


Fig.10:Min.eigen Value for Proportional Load Increment

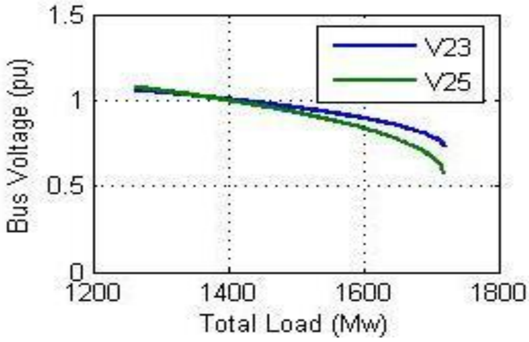
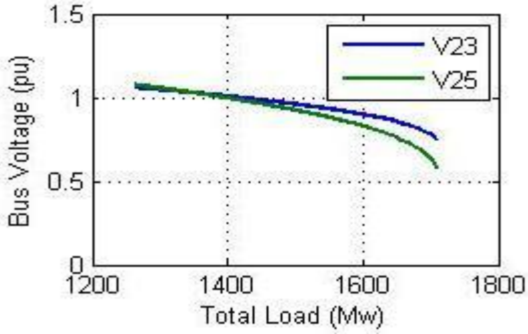


Fig.11: P-V Curves with Compensation
(For Equal Load Increment)



Fig, 12: P-V Curves with Compensation
(For Proportional Load Increment)

5. **Discussion**

1. In both the cases studied i.e. with equal load increment and with proportional load increment on selected buses 23 and 25, these bus voltages drops to very low values. The participation factors of these buses are found to high.
2. The shunt compensation of 60 MVAR is provided at buses 23 and 25 to increase their voltages for improvement of voltage stability.
3. By adding the shunt compensation it is possible to raise the bus voltages and the system loadability.
4. As the total load on the system increases, the minimum eigen value corresponding to critical mode reduces.

6. Conclusion

The driving force for voltage instability is usually loads. In response to the disturbance, power consumed by loads tends to be restored by combined action of distribution voltage regulators, tap changing transformers and thermostats Restored load increase the stress on high voltage network by increasing the reactive power consumption and causing further voltage reduction. Voltage collapse may occur when load dynamics attempt to restore power consumption beyond the capability of transmission network and the connected generation.

Voltage stability is threatened when a disturbance increases the reactive power demand beyond the sustainable capacity of the available reactive power resource. The aim of reactive power consumption is to improve the performance of power system by maintaining reactive power balance. The sources of reactive power are located close to the sinks of reactive power as possible. Finding the bus participation factors allow to decide the buses requiring additional shunt compensation to improve the voltage profile.

7. References

[1] Ajjarapu V, Christy C. "The continuation power flow: A tool to study steady state voltage stability" *IEEE Trans. On power systems,Vol.7,No.1,pp.416-423 Feb.1992*

[2] G.Hamoud,"Assesment of ATC of transmission system" *IEEE Trans. Power Systems*, vol. 15, No.1 pp. 27-32, Feb. 2000.

[3] Therry Van Cutsem "Voltage instability: Phenomena, Countermeasures and Analysis methods," Proceedings of *IEEE, Vol.88, No.2, pp.208-227, Feb.2000.*

[4] Prabha Kundur "*Power system stability and control*" TATA McGraw-Hill Edition, Power System Engineering Series

[5] Chowdhury B.H., Taylor C.W. "Voltage stability analysis: V-Q power flow simulation versus dynamic simulation" *IEEE Trans. On power systems, Vol.15, No.4, pp.1354-1359, Nov.2000*.

[6] Taylor C.W. "*Power System Voltage Stability*" McGraw-HILL International Editions, Electrical Engineering series J. Jones. (1991, May 10). *Networks*. (2nd ed.) [Online]. Available: http://www.atm.com

[7] Zhou Y.,Ajjarapu V.,"A fast algorithm for identification and tracing of voltage and oscillatory stability margin boundaries", Proceedings of IEEE,Vol.93,no.5,pp.934-946,2005.

[8] Souza De A., Canizares C.A.,Quintana V.H.,"New techniques to speed up voltage collapse computations using tangent vectors",IEEE Trans.on power systems,Vol.12,pp.1380-1387,1997.

[9] Canizares C.,A.Alvarado,"Point of collapse and continuation methods for large AC/DC power systems",IEEE Trans.on power systems,Vol.8,No.1,pp.1-8,1993

[10] Chiang H.D.,Flueck A.J.,Shah K.S.,Balu N.,"CPFLOW:a practical tool for tracing power system steady state stationary behavior due to load and generation variations",Ieee Trans.on power systems,PWRS-10,pp.623-634,1995.