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PARTICIPATION FACTOR IN MODEL VOLTAGE STABILITY ANALYSIS

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ABSTRACT

This Paper presents use of bus participation factor in modal voltage analysis. This Method is identifying the weakest bus in a distribution network. In heavily loaded systems, voltage stability limit is usually dominant and voltage instability is usually observed following large disturbance. More attention is required to be paid to keep voltage profile and hold the voltage stability under control. In this paper simple voltage stability analysis is carried out for IEEE 30 Bus System using Bus participation factor modal analysis. The method based on the Eigen value decomposition technique known as modal analysis, had been applied to the voltage stability analysis. In this method not only the critical Eigen values are use for evaluating the voltage stability of the system but also associated eigenvector. Thesis presents a bus participation factor corresponding minimum Eigen value is used to identify the weakest bus and SVCs are used to improve voltage profile.

Keywords – Participation Factor, Eigen value, Voltage stability, SVC

INTRODUCTION

Voltage stability and system security are of great concern to planning engineers in the electric power industry. The modern power system around the world has grown in complexity of large interconnection of the electric networks and power demand. The focus has shifted towards enhanced performance, reliable and clean power. Voltage stability is an important factor to be considered in power system operation and planning since voltage instability would lead to system collapse. The problem of voltage stability has been defined as inability of the power system to provide the reactive power or non-uniform consumption of reactive power by the system itself. Therefore, voltage stability is a major concern in planning and assessment of security of large power systems in contingency situation, especially in developing countries because of non-uniform growth of load demand and lacuna in the reactive power management side. The loads generally play a key role in voltage stability analysis and therefore the voltage stability is known as load stability [1].

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. Voltage levels and reactive power flow must be carefully controlled to allow a power system to be operated within acceptable limits. Keeping the voltage security in concern, power systems are provided with a lot of voltage controlling devices such as generators, tap changing transformers, shunt capacitors/reactors, synchronous condensers, and static VAR compensators etc. Either by the variation of load or by the variation of network configuration, a real time control employing those controlling devices is required to alleviate the problems that cannot be solved exactly [2].

Voltage stability assessment using modal analysis of the power flow Jacobian in the large power system has been presented in this thesis. In its basic form, the method evaluates the Eigen value of power flow Jacobian and reduced to an appropriate dimension, at the power operating point. The smaller Eigen value and its associated Eigen vector, known as the critical mode, determine the closeness of the system and the contribution of system elements, respectively, to the voltage instability. Participation factor obtained from the Eigen value identify the critical system location for implanting the most effective system. The ability of the modal method to reveal the proximity and mechanisms of voltage instability, participation factor with critical modes are used to find the most effective location to site a static var compensator (SVC) to enhance system voltage stability [3]. The whole work is solved on placement of SVCs using bus participation factors.

Participation factor are used with critical modes to demonstrate the close correspondence between the static and dynamic approach to analyse voltage instability [4]. In this Thesis modal analysis is performed on the power flow Jacobian to investigate system voltage stability. This work is reported that the critical mode contains modal information about the most severe disturbances to the system. Therefore, the objective of this work is to exploit further, the use of modal information of the critical mode in the voltage stability analysis of IEEE 30 bus system.

In this work, the IEEE-30 bus system is used so that the method can be applied to more number of buses configurations, and also to have a more illustrative case for the use of participation factors.

PROBLEM FORMULATION

Identification of weak bus

A Weak Bus is defined as that bus that experiences as significant voltage and Reactive power deviation for a small load change. The buses of the system which are weak in nature .i.e., (weakest voltage) that need reactive power compensation to improve voltage profile [1].

Q-V Modal Analysis

Modal analysis performed at the critical operating point provides the information regarding voltage instability prone buses and clearly identifies the generators and lines participating in the critical mode [5], [6].

This technique provides useful information about voltage stability critical areas and information about the best steps to enhance system stability.

Power system is modelled as follow

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 | J_2 \\ \hline J_3 | J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \tag{1}$$

Critical bus recognition is accomplished by applying modal analysis method on the system Jacobian matrix, hence

$$J_R = \left[J_4 - J_3 \times J_1^{-1} J_2 \right] \tag{2}$$

Where,

J_R is the reduced Jacobian matrix of the system.

we have,

$$\Delta V = J_R^{-1} \Delta Q \tag{3}$$

The matrix J_R and J_R^{-1} gives the sensitivities of relation between ΔQ and ΔV. Volta ge stability characteristic of the system can be identified by computing Eigen values and Eigen vectors of Reduced Jacobian matrix J_R given by equation, thus

$$J_R = \xi \Lambda \eta \tag{4}$$

Where,

ξ is the Right eigenvector matrix of J_R

η is Left Eigen vector matrix of J_R

Λ is Diagonal Eigen value matrix of J_R

From equation (17),

$$J_R^{-1} = \xi \Lambda^{-1} \eta \tag{5}$$

Substituting in equation (16)

$$\Delta V = \xi \Lambda^{-1} \eta \Delta Q \tag{6}$$

Or

$$\Delta V = \sum_i \frac{\xi_{ki} \eta_{ik}}{\lambda_i} \tag{7}$$

Where,

ξ_i = i^{th} column right Eigen vector

η_i = i^{th} row left Eigen vector

Each Eigen value λ_i and corresponding right and left Eigen vectors define the i^{th} mode of Q-V response. The V-Q Sensitivity at bus k in quantitative form is given by

$$\frac{\partial V_k}{\partial Q_k} = \sum_i \frac{\xi_{ki} \eta_{ik}}{\lambda_i} \tag{8}$$

Generally V-Q sensitivity is found for minimum Eigen value for application to static voltage collapse. Thus, in voltage stability study, the minimum singular value of Jacobian becoming zero corresponds to the critical mode of the system. It can serve as stability index which indicates the distance between the studied operating point and the steady state voltage stability limit. To get qualitative as well as quantitative information of voltage stability margin, the sensitivity is often found at critical point for any given change of parameters.

Since,

$\xi^{-1} = \eta$, put then equation (19) will be written as

$$\Delta V = \left(\eta^{-1}\Lambda^{-1}\eta\right)\Delta Q$$

$$\eta\Delta V = \left(\Lambda^{-1}\eta\right)\ \Delta Q$$

$$v = \Lambda^{-1}\ q \tag{9}$$

$$v_i = \frac{q_i}{\lambda_i}$$

Or $$q_i = v_i\ \lambda_i \tag{10}$$

Where,

v = Vector of modal voltage variations

q = Vector of modal reactive power variations

Λ^{-1} = A diagonal matrix

Modal analysis, calculation of Eigen values and Eigen vectors of the Jacobian matrix can be used to derive weak voltage nodes in the system. If an extended Jacobian matrix (where generators, loads etc. are modelled into the matrix) is used, the participation factors of the states in the models are presented with modal analysis [5], [6].

Bus Participation Factor

It gives the information on how effective reactive power compensation at a bus is required to increase the modal voltage at that bus [10]. It is given by,

$$P_{ki} = \xi_{ki}\eta_{ik} \tag{11}$$

Where,

P_{ki} : is the participation factor of the bus k in the i^{th} voltage variation mode.

ξ_{ki}, η_{ik} : is the k^{th} element of the right-column and left- row eigenvector, respectively associated with the i^{th} mode eigenvalue λ_i.

Physically, ξ_{ki} is a measure of the activity of bus k in the i^{th} voltage variation mode, η_{ik} is the weighting of the contribution of this activity, and so their product is a measure of net participation of bus k in the i^{th} voltage variation mode.

Thus, P_{ki} determines the contribution of λ_i 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. There are two modes:

1. **Local Modes:** It indicates the buses with high participation factor that need high reactive power compensation.
2. **Non Local Modes:** It indicates large number of buses with small participation factor that needs small reactive power compensation.

Bus participation factor in modal analysis indicates the contribution of the bus to the system instability. Bus with high participation factor are the firstly priority for the location of Load-Shedding [4], [5], [6].

VOLTAGE PROFILE IMPROVEMENT USING STATIC VAR COMPENSATOR

"Static Var Compensator is a shunt-connected static Var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage)." The Static Var Compensator (SVC) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system.

The reactive power is changed by switching or reactive power elements connected to the secondary side of the transformer. Capacitor bank is switched on and OFF by Thyristor valve (TSC). Reactor can be either switched (TSR) or controlled (TCR) by Thyristor valves [9].

- When system voltage is low, the SVC generates reactive power (SVC capacitive) and
- When system voltage is high, it absorbs reactive power (SVC inductive).

The SVC is in Reactive under low voltage conditions due to faults in the system. However, the clearing of the fault can result in temporary overvoltage due to load rejection, particularly under weak system conditions [1] ,[4], [7].

Case study and Results

Table: Result for 30-bus test system (without loading)

Sr. no.	Bus no.	Voltage(v)	Angle delta	P calculated	Q calculated
1	1	1.0600	0	0.1921	0.5875
2	2	1.0430	0.0018	-0.0082	-0.0677
3	3	1.0173	-0.0003	-0.5842	-1.7744
4	4	1.0457	-0.0003	0.9598	3.2272
5	5	1.0100	-0.0247	-0.0080	-0.1156
6	6	1.0071	-0.0001 -	-0.5202	-1.8800
7	7	1.0012	-0.0035	-0.0295	-0.0932
8	8	1.0100	-0.0041	0.0787	0.2418
9	9	1.0081	-0.0000	0.0000	-0.3942
10	10	1.0016	-0.0011	-0.0000	-0.0000
11	11	1.0820	-0.0000	0.0000	0.4266
12	12	1.0077	-0.0035	-0.0000	-0.7415
13	13	1.0710	0.0000	0.0000	0.5431
14	14	0.9992	-0.0025	-0.0000	0.0000
15	15	1.0000	-0.0013	-0.0000	-0.0000
16	16	1.0002	-0.0010	-0.0000	0.0000
17	17	0.9987	-0.0014	-0.0000	0.0000
18	18	0.9992	-0.0008	-0.0000	0
19	19	0.9987	-0.0012	-0.0000	0
20	20	0.9997	-0.0004	0	-0.0000
21	21	0.9989	-0.0008	-0.0000	0.0000
22	22	1.0002	-0.0002	-0.0000	0.0000
23	23	0.9996	-0.0002	-0.0000	0.0000

24	**24**	**0.9980**	**-0.0020**	**0.0000**	**0.0000**
25	**25**	**0.9995**	**-0.0001**	**-0.0000**	**0**
26	**26**	**0.9940**	**-0.0025**	**-0.0000**	**0.0000**
27	**27**	**1.0001**	**-0.0002**	**0.0000**	**-0.0000**
28	**28**	**1.0036**	**-0.0003**	**-0.0144**	**-0.1318**
29	**29**	**0.9975**	**-0.0019**	**-0.0000**	**0.0000**
30	**30**	**0.9881**	**-0.0146**	**-0.0000**	**0.0000**

Table: Eigen value

Sr. no.	**Load bus no.**	**Eigen value**	**minimum Eigen value**	**maximum Eigen value**
1	**3**	**273.8049**		**273.8049**
2	**4**	**198.3747**		
3	**6**	**215.5571**		
4	**7**	**143.3217**		
5	**9**	**109.3908**		
6	**10**	**84.3435**		
7	**12**	**83.1504**		
8	**14**	**81.1723**		
9	**15**	**5.7862**		
10	**16**	**7.4706**		
11	**17**	**70.1560**		
12	**18**	**14.3375**		
13	**19**	**62.6165**		
14	**20**	**61.2720**		
15	**21**	**23.8690**		
16	**22**	**24.0854**		
17	**23**	**28.5468**		
18	**24**	**29.5599**		
19	**25**	**32.8468**		
20	**25**	**36.0825**		

21	**27**	**54.3633**		
22	**28**	**5.7242**	**5.7242**	
23	**29**	**47.3530**		
24	**30**	**44.1520**		

Table : Participation Factor corresponding to the minimum Eigen value (5.7242)

Load Bus Number	Participation factor for 400 MW loading	Participation factor for 500 MW loading
3	**0.0024**	**0.0024**
4	**0.0022**	**0.0022**
6	**0.0015**	**0.0015**
7	**0.0013**	**0.0012**
9	**0.0004**	**0.0002**
10	**0.0022**	**0.0017**
12	**0.0035**	**0.0034**
14	**0.0164**	**0.0184**
15	**0.0066**	**0.0072**
16	**0.1806**	**0.1906**
17	**0.0307**	**0.0353**
18	**0.0001**	**0.0001**
19	**0.0031**	**0.0031**
20	**0.0025**	**0.0027**
21	**0.0433**	**0.0432**
22	**0.0350**	**0.0359**
23	**0.0488**	**0.0492**
24	**0.0106**	**0.0126**
25	**0.2129**	**0.2086**
26	**0.0541**	**0.0512**
27	**0.2100**	**0.2066**
28	**0.0107**	**0.0101**
29	**0.1212**	**0.1126**
30	**0.0000**	**0.0000**

Table: voltage at 400 MW loading with and without SVC

Sr. no.	Bus no.	Voltage without SVC	Voltage with SVC
1	**1**	**1.06**	**1.06**
2	**2**	**1.043**	**1.043**
3	**3**	**1.0157**	**1.0171**
4	**4**	**1.0079**	**1.0096**
5	**5**	**1.01**	**1.01**
6	**6**	**1.0064**	**1.0086**

7	**7**	**0.9964**	**0.9977**
8	**8**	**1.01**	**1.01**
9	**9**	**1.022**	**1.0256**
10	**10**	**1.0011**	**1.0074**
11	**11**	**1.082**	**1.082**
12	**12**	**1.0196**	**1.0223**
13	**13**	**1.071**	**1.071**
14	**14**	**0.9982**	**1.002**
15	**15**	**0.992**	**0.9967**
16	**16**	**1.0013**	**1.0056**
17	**17**	**0.9934**	**0.9991**
18	**18**	**0.9773**	**0.9827**
19	**19**	**0.9733**	**0.979**
20	**20**	**0.9791**	**0.9849**
21	**21**	**0.9792**	**0.9867**
22	**22**	**0.9873**	**0.9979**
23	**23**	**0.9788**	**0.9866**
24	**24**	**0.9686**	**0.9846**
25	**25**	**0.9636**	**0.999**
26	**26**	**0.9374**	**0.9737**
27	**27**	**0.9733**	**1.0202**
28	**28**	**1.0038**	**1.0099**
29	**29**	**0.9434**	**0.9919**
30	**30**	**0.9262**	**0.9756**

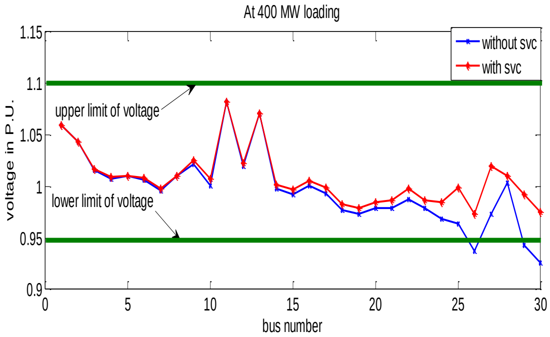

Fig: Voltage profile graph at 400 MW with and without SVC

Fig: show the graphs for bus voltages at 400 MW with and without SVC respectively. These results show that the voltage profile is improved using SVC. In these graphs green lines indicate the upper and lower limits of voltages. It is clear from the results that the voltages at bus number 25 and 30 are below the specified voltage range (0.95> V >1.1) and with the placement of SVC at the weak bus the bus voltages are brought with in the range. Also the amount of reactive power injection is found by the trial and error method.

CONCLUSION AND FUTURE SCOPE

CONCLUSION

In the large power system, this work presents a method which is very simple, easy to understand and easy to compute voltage stability. In this work, the bus participation factor has been used to identify the critical bus that contributes most to the voltage instability as the systems are continually stressed. The system has been tested using the IEEE-30 bus test system and the result shows that this method can correctly identify the critical bus for the placement of SVC.

Therefore, finding bus participation factor using modal analysis is the most effective methods for identifying the voltage weak area in the large system. System stress and parameters are improved by placing the shunt compensation like SVC.

FUTURE SCOPE

In future Optimizations techniques can be used to find optimal location and the optimal sizing of FACTS devices can be obtained by these soft computing techniques. Also both the objectives can simultaneously be fulfilled by the same.

Locating FACTS devices at different bus locations enhances the system stability as well as the significance amount of reduction in the active and reactive power losses can be achieved.

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