

Reactive Power Dispatch by Modal Analysis based on Contingency Ranking and Comparison with other Techniques

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ABSTRACT: Electrical energy has become an important part of our daily life and can be easily transmitted and received at reasonable cost and at high efficiency. Every electric or electronic device installed requires a steady supply of clean power for proper functioning. Power systems usually face various network contingencies. It is necessary to study the effect of contingencies on the system to provide suitable security and ensure improvement in system stability limit. An approach for optimized reactive power dispatch is proposed based on fuzzy expert iteration. The ability of Modal analysis is effectively used in the identification of weak bus to place Static VAR Compensators as a part of reactive power planning. A model to improve the stability margin of a system using Relative Electrical Distance (RED) is also presented. The results for a 25 bus system based on Modal analysis and comparison with other methods are discussed.

KEYWORDS: Fuzzy, Ranking, Modal Analysis, Reactive power, Schedule Power.

I. INTRODUCTION

In both developed and developing countries power is generated by integrated investor owned utilities. The interconnected transmission systems of electric utilities form a large power grid divided into multiple pools, each consisting of several closely located utilities operating in tandem to schedule generation of bulk power cost effectively. Latest technology has laid emphasis on the quality of AC power driving various electronic sub-systems, an integral part of a wide variety of cluster products. Based on one nation one grid policy of India the five region wise grids are interconnected to share the load based on the demand.

For the utilities having a share from the central generating stations located in the neighbouring systems a proper import/export over the interconnected tie-lines needs to be arrived at the planning stage as it is difficult to match the corresponding reactive flows as envisaged, visualised only after preliminary studies. This aspect is important in reactive power planning and it is essential to represent the neighbouring systems up to transmission level.

Electric power systems routinely experience abnormalities due to various contingency events. Over loading of network branches pose problem during line outage contingency. The bus voltages of the system reach unsatisfactory levels leading to voltage collapse. A proper security needs to be provided to overcome voltage collapse. It is also necessary to compute the effect of contingencies on voltage stability. This necessitates an implementable algorithm to compute the contingency ranking based on their severity level. Currently the contingency analysis draws considerable attention with respect to power system planning and operation. Evaluation of contingency ranking is one of the important criteria for online security assessment.

A model to improve the stability margin of a system using Relative Electrical Distance (RED) is presented. It is a fact that earlier power systems were self-sufficient islands generating power to meet the load demand with vast reserve margins, sufficient transmission system and reactive power capabilities [1]. The power systems developed using large

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interconnected grids [2] consider an integrated operation based on both technical and more importantly on economic viability.

II. POWER FLOW ANALYSIS

The Newton-Raphson method of power flow is adopted. Let 1, 2, ..., n indicate the total number of buses of the system, 1, 2, ..., g, indicate the number of generator buses and the remaining buses (n-g) represent the load buses. Real power generation at a given bus:

$$P_{Gi} = P_{Gschi} - P_{Li} \tag{2.1}$$

$$P_{Gimin} \geq P_{Gi} \geq P_{Gimax}$$

Where

$P_{Gi}, P_{Gschi}, P_{Li}$ are active power generation, schedule and load powers respectively at bus '1' in p.u.

Bus '1' is assumed to be the reference for initial calculation of voltage, magnitude and phase angles of other buses.

Linearized equations for real power with Newton-Raphson iteration can be written as:

$$[\Delta P] = [J_1][\Delta \delta] \tag{2.2}$$

$$[\Delta Q] = [J_2][\Delta V], \tag{2.3}$$

Where $J_1 = \frac{\partial P_i}{\partial \delta_{j+1}}$, $i=1,2,\dots,n$; $j=1,2,\dots,n$

$$J_2 = \frac{\partial Q_{ng+i}}{\partial V_{ng+j}}, i=1, 2, \dots, n; j=1, 2, \dots, n$$

$$\left. \begin{aligned} \Delta P^k &= P_{spe} - P_{cal} \\ \Delta Q^k &= Q_{spe} - Q_{cal} \\ \delta^{k+1} &= \delta^k + \Delta \delta \\ V^{k+1} &= V^k + \Delta V \end{aligned} \right\} \tag{2.4}$$

and 'k' is the iteration within the power flow solution.

The Jacobian matrix $[J_1]$ and $[J_2]$ elements are evaluated by differentiating real and reactive power with respect to voltage and angle while $\Delta \delta$ and ΔV are solved by iterative process.

III. VOLTAGE STABILITY L-INDEX

The authors Kessel and Glavitsch [KG86] have proposed L-index as an indicator to decide the stability of the system. The author has expressed that numerical value of L-index lies within a unity circle, ranging from '0' at no load to '1' implying static voltage stability limit. It is calculated for every load bus with maximum value of L-index considered as the weakest and close to voltage collapse. The stability margin is the distance of maximum L-index from the unit value, i.e. (1-L). This method though simple in numerical calculation yet explicitly expresses the desired information.

Consider a power system having n, g and s indicating number of buses, generator buses and number of Switchable VAR Compensators (SVC) buses respectively.

Also 1, 2, ..., t, the number of OLTC transformers.

For the given system operating condition, the voltage stability L-index [3] is computed using the equation:

$$L_j = \left| 1 - \sum_{i=1}^g F_{ji} \frac{V_i}{V_j} \right| \tag{3.1}$$

Where

$$j=g+1, g+2, \dots, n.$$

The terms within the sigma on the right hand side are complex quantities.

The term F_{ji} is taken from the Y-bus matrix formulated for load flow studies.

For a given operating condition,

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$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \tag{3.2}$$

Where $[I_G], [I_L]$ is the complex current,

$[V_G]$ and $[V_L]$ are the voltage vectors of generator and load buses and $[Y_{GG}], [Y_{GL}], [Y_{LG}]$ and $[Y_{LL}]$ represent the sub-matrices of the Y-bus matrix of the network. Also,

$$[I_G] = [Y_{GG}][V_G] + [Y_{GL}][V_L]$$

$$[I_L] = [Y_{LG}][V_G] + [Y_{LL}][V_L]$$

Rearranging the above equations:

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ Y_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \tag{3.3}$$

Where $[F_{LG}] = -[Y_{LL}]^{-1}[Y_{LG}]$

The L index equation for the j^{th} node can be written as F_{ji} , complex elements of $[F_{LG}]$ matrix.

There are two conditions to be fulfilled:

- (i) The index ' L_j ' should not exceed the maximum point limit of '1' at any load bus 'j'.
- (ii) The voltage stability indicator takes a value of $L = \max(L_j)$ for all load buses. L-index value close to '0' indicates a system with improved stability and '1' indicates the weakest bus, vulnerable to voltage collapse. When the above two conditions are met the limit of stability is reached.

IV. CONTINGENCY RANKING USING FUZZIFICATION FOR DIFFERENT KEY VARIABLES

In the conventional optimal method due to constraints being modelled rigidly, the solution obtained being incapable of representing the practical cases, necessitates an alternate approach with reasonable flexibility in modelling [4]. Normally membership functions represent the degree of input and output linguistic variables lying between 0 and 1. Fuzzy rules are IF-THEN statements used to formulate the conditional statements. The 'IF' part generally consists of more than one condition and can be combined together using logic operators. The 'THEN' part being the conclusion may contain more than one output. The key variables considered are the real power line loading, voltage magnitude of the load bus and voltage stability L-index. Each of these variables are categorized into five linguistic values and later transformed to fuzzy domain. The key variables assumed are transformed into membership degree by using the following membership function:

$$\mu = \frac{1}{1 + \left[\frac{k-a}{A}\right]^2} \tag{4.1}$$

'k' is the assumed variable, 'a' and 'A' are membership constants. Figures 4.1, 4.2 and 4.3 represent the membership functions for the variables considered.

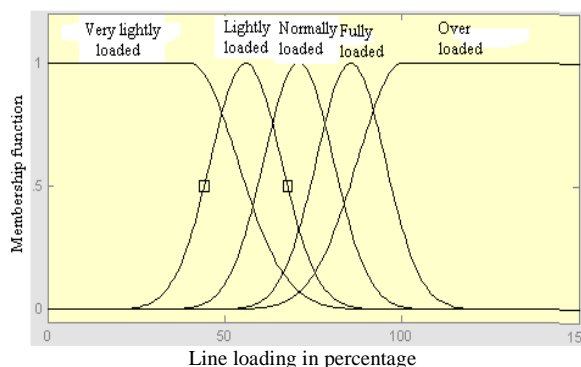


Figure 4.1 Membership function for line loading

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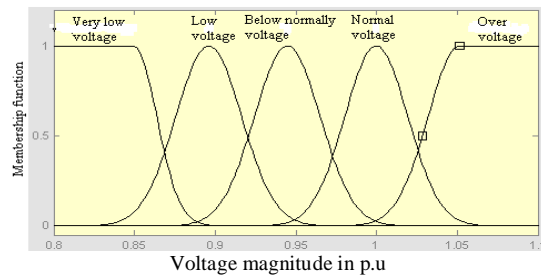


Figure 4.2: Membership function for load bus voltage

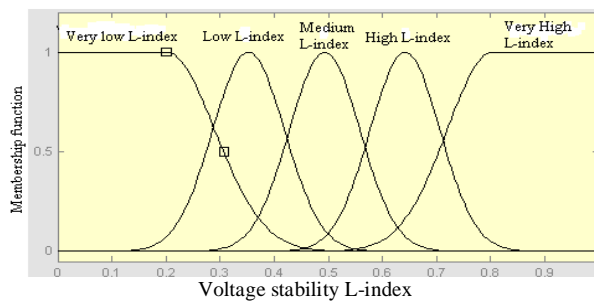


Figure 4.3: Membership function for voltage stability L-index

A.IV FUZZIFICATION OF INPUT AND OUTPUT VARIABLES

The state of a system is described by fuzzified key variables like, line loading, voltage profile and voltage stability L-index and for each, five linguistic values are assumed. Output variables are also fuzzified and five linguistic values are assumed. The fuzzy rule statement is given as ‘If X is A Then Y is B’ is applied to fuzzified variables and the corresponding fuzzy outputs in terms of linguistic values are shown in Table 4.1 respectively.

Sl. No	Input key variable	Output linguistic values(Severity indices)
1	VLL, LL, NL, FL, OL Very low, Lightly, Normal, Fully and Over loaded.	VLS, LS, BS, AS, MS Very less, Less, Below, Above and More severe.
2	VLV, LV, BNV, NV, OV Very low, Low, Below normal, Normal voltage and Over voltage.	MS2, AS, BS, LS, MS1 Very less, Above, Below Low and More severe.
3	VLI, LI, MI, HI, VHI Very low, Low, Medium, High and Very high L-index.	VLS, LS, BS, AS, MS Very less, Less Below, Above and More severe.

Table 4.1: Fuzzy rules for variables

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B.IV OVERALL SEVERITY INDICES (OSI) OF KEY VARIABLES

The post contingency of the line outage is obtained by rule-firing and the overall severity index of line loading is estimated by summing up all the severity indices. Assuming a suitable weightage factor the overall severity index is estimated using equation 4.1.

The membership function for post contingency variables of line loading, bus voltage magnitude and voltage stability L-index are used to calculate the network ranking and the overall severity index for a line contingency, is shown in Figure 4.4.

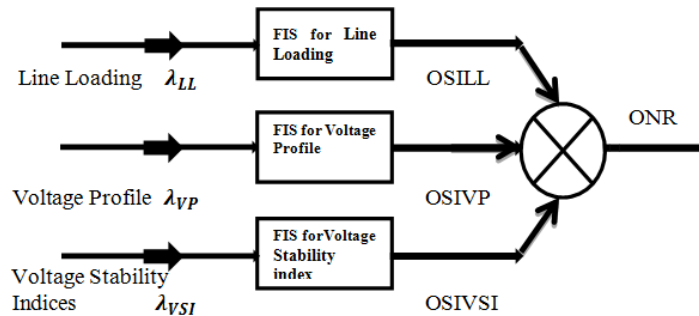


Figure.4.4 Composite criteria to determine overall network ranking

For a given contingency, the post contingency quantities such as line loading, voltage profile and voltage stability indices are combined together to obtain Fuzzy Inference System (FIS). The fuzzy inference is evaluated for each of the key variables using the fuzzy rules. Network Overall Severity Index (NOSI), the contingency ranking is the sum of overall severity index of line loading (OSI_{LL}), voltage profile (OSI_{VP}) and voltage stability indices (OSI_{VSI}) as given in equation 4.2. Overall Severity Indices of the line voltage is shown in Table 4.2.

$$NOSI = \sum(OSI_{LL} + OSI_{VP} + OSI_{VSI}) \tag{4.2}$$

Sl. No	Key variables	Overall Severity Indices of Key variables	λ_{LL} , transmittance coefficient
1	Line loading	$OSI_{LL} = \sum_{i=1}^{nl} \lambda_{LL} SI_{LL}$ SI_{LL} = Severity Index of Line Loading, 'nl' is the no. of transmission lines	$\lambda_{LL} = 0.20$ for VLS; 0.40 for LS; 0.50 for BS; 0.75 for AS; 1.00 for MS.
2	Voltage profile	$OSI_{VP} = \sum_{j=g+1}^n \lambda_{VP} SI_{VP}$ SI_{VP} =Severity Index of voltage profile.	$\lambda_{VP} = 0.20$ for MS2; 0.40 for AS; 0.60 for BS; 0.80 for AS; 1.0 for MS1.
3	Voltage stability L-index	$OSI_{VSI} = \sum_{j=g+1}^n \lambda_{VSI} SI_{VSI}$ SI_{VSI} = Severity Index of voltage profile, 'n' is the total number of buses and 'j' is the load bus	$\lambda_{VSI} = 0.20$ for VLS; 0.40 for LS; 0.60 for BS; 0.80 for AS; 1.0 for MS.

. Table 4.2: Overall severity indices of key variables

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V. ANALYSIS OF THE TEST SYSTEM

The proposed method based on fuzzy expert to determine contingency line outage ranking has been tested on a 25 bus practical Indian power system.

It has 4 generator buses (1-4) and 21 (5-21) load buses. The load is represented on the 220 kV side of 400kV/220kV system. The single line diagram, line data and bus data details are given in Appendix.

The system has been tested for line contingency and the computed severity indices of voltage profiles, voltage stability L-index and line loading are indicated in Table 5.1. Line outage contingencies are performed for all the lines of the system. For simplicity only 8 major line outages and the corresponding performance parameters are listed in Table 5.2. The overall ranking is the sum of all severity indices computed from the individual severity index. It is observed that severity indices are close to each other, indicating that severity of each variable is effectively the same on the system. Line outage L_{24-18} exhibits individual severity indices due to voltage profile, voltage stability L-index and line loading as 16.52, 13.24 and 15.95 respectively. The overall severity index value for line L_{24-18} is 69.54, considered as rank 1, implies that, if this line outage occurs the system experiences violation of stability limits and it may reach state 'in extremis'. Similarly for the line outage L_{22-23} the overall severity index value is 65.08, considered as rank 2. For each line outage the order of severity is shown in Table 5.1. The variations of performance parameters with respect to every line outage are shown in Figure 5.2.

Line Outage		SI_{VP}	SI_{VSI}	SI_{LL}	NOS I	rank
From Bus	To Bus					
22	23	14.96	11.87	15.30	65.08	2
22	18	14.12	10.94	12.75	56.94	3
17	24	11.12	9.86	10.20	46.48	7
24	18	16.52	13.24	15.95	69.64	1
23	20	13.20	10.50	13.25	56.83	4
15	16	13.60	11.04	12.55	56.02	5
24	16	10.08	9.76	10.70	46.59	6
18	20	9.88	10.23	9.65	44.24	8

Table 5.1. 25 Bus EHV System severity indices and network overall ranking

L. No	Line Outage		V_{min} (p.u)	L_{max}	MSV	P_{loss}	rank
	From Bus	To Bus					
1	22	23	0.7153	0.8192	0.4631	83.30	2
2	22	18	0.7517	0.7126	0.5204	80.10	3
3	17	24	0.8428	0.5380	0.5072	64.57	6
4	24	18	0.7011	0.8432	0.3042	93.03	1
5	23	20	0.7477	0.5957	0.5166	75.40	5
6	15	16	0.8298	0.5762	0.5452	82.41	4
7	24	16	0.8454	0.5112	0.6770	64.79	7
8	18	20	0.8576	0.5251	0.7573	61.86	8

Table 5.2. 25 Bus EHV System voltage magnitude, voltage stability index, MSV and transmission losses at each line outage

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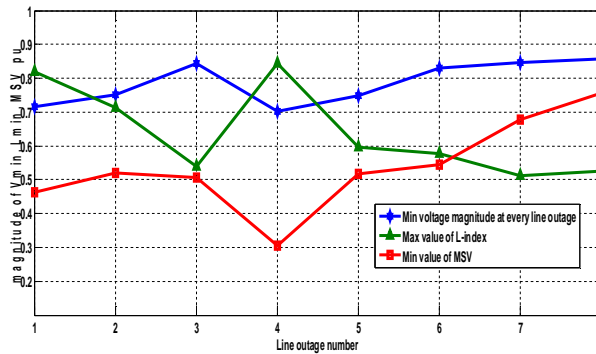


Figure 5.1. Variation of stability indices for each line outage

At any operating condition the system is voltage stable if there is an increase in voltage magnitude with increase in reactive power injection at the same bus and voltage unstable if there is a decrease in voltage magnitude with increase in reactive power injection at the same bus. The steady state linearized power system voltage equation may be expressed in the following form:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{Q\theta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad (5.1)$$

Where

ΔP , ΔQ , $\Delta\theta$ and ΔV indicate change in bus real power, reactive power injection, voltage angle and voltage magnitude respectively. The elements of the Jacobian matrix indicate the change in real and reactive power with respect to changes in bus angle and bus voltage. Voltage stability is affected by both real and reactive power at each operating point P and may be kept constant with voltage stability being evaluated by considering incremental change between Q and V. This gives the relation between the variation of Q and change in V and may be represented as Q-V curves [5]. The incremental change in reactive power and corresponding changes in voltage magnitude i.e. Q and V relationship is established considering different operating conditions.

Let $\Delta P = 0$;

$$0 = J_{P\theta} \cdot \Delta\theta + J_{PV} \cdot \Delta V \quad (5.2)$$

$$\Delta\theta = -J_{P\theta}^{-1} J_{PV} \cdot \Delta V \quad (5.3)$$

$$\Delta Q = J_{Q\theta} \cdot \Delta\theta + J_{QV} \cdot \Delta V \quad (5.4)$$

$$\Delta Q = [J_{QV} - J_{Q\theta} J_{P\theta}^{-1} J_{PV}] \Delta V \quad (5.5)$$

$$\Delta Q = J_R \cdot \Delta V \quad (5.6)$$

Where

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

$$\Delta V = [J_R]^{-1} \cdot \Delta Q \quad (5.7)$$

Where

J_R - reduced Jacobian matrix. This matrix relates the change in voltage magnitude with no change in reactive power.

J_R^{-1} - Inverse reduced Jacobian matrix.

The V-Q sensitivity is computed by solving the equation, $\Delta Q = J_R \cdot \Delta V$.

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Voltage stability of the system is analyzed by computing Eigen values and Eigen vectors from reduced Jacobian matrix

J_R .

Let the reduced Jacobian matrix be split into three matrices as:

$$J_R = \xi \Lambda \eta \quad (5.8)$$

Where

ξ, η, Λ indicates right, left and diagonal Eigen vector matrices of J_R respectively.

A.V. BUS PARTICIPATION FACTOR

The product of left and right Eigen vectors relates the participation of bus 'k' in mode 'i' and is given by:

$$P_{ki} = \xi_{ki} \eta_{ik} \quad (5.9)$$

Where

P_{ki} - Participation factor at bus 'k' at mode i.

ξ_{ki} is the right Eigen vector of bus 'k' and different 'i' modes of reduced Jacobian matrix.

η_{ik} is the left Eigen vector of bus 'i' and different 'k' modes of reduced Jacobian matrix. " P_{ki} ", determines the areas associated with each mode. The sum of all bus participation factors for each mode is equal to unity of normalized right and left eigenvectors. The size of the bus participation in a given mode indicates the vulnerability for voltage instability at that bus.

B.V. ESTIMATION OF REACTIVE POWER INJECTION (B_{SVC})

Normally the SVC can be viewed as a variable reactance with specified limits [1].

Figure 6.1 indicates variable susceptance connected to inject the reactive power at bus 'k'.

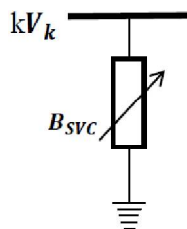


Figure 5.2. Variable shunt susceptance for injecting reactive power

The current injected into bus through SVC is:

$$I_{SVC} = jB_{SVC}V_k \quad (5.10)$$

Reactive power injected into bus 'k' is given as:

$$Q_{SVC} = Q_k = -V_k^2 * B_{SVC} \quad (5.11)$$

The variable shunt susceptance B_{SVC} is updated according to the following equation:

$$B_{SVC}^i = B_{SVC}^{(i-1)} + \left(\frac{\Delta B_{SVC}}{B_{SVC}} \right)^{(i)} * B_{SVC}^{(i-1)} \quad (5.12)$$

The new value indicates the total susceptance required to maintain the desired voltage magnitude.

VI. RESULT ANALYSIS

The bus participation factor for the lowest Eigen value indicates a weak voltage bus. Maximum numerical value of bus participation factor indicates a very weak bus and assigned rank 1 and is more susceptible to voltage collapse. Injection

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of required value of reactive power at the weak bus will improve the stability of the system, measured in terms of the performance parameters as discussed earlier.

The Eigen values obtained for reduced Jacobian matrix is shown in Table 6.1. It is to be noted that all the Eigen values are positive, indicating that the system is voltage stable. The most vulnerable load bus for voltage collapse is estimated from participation factor corresponding to least Eigen value load bus. The bus with highest value of participation factor is considered as the most critical bus vulnerable to voltage collapse and is found suitable for placing SVC. In this case, the least Eigen value is $\lambda = 2.2845$ and the corresponding participation factors are computed using equation (6.8). The maximum bus participation factor is 0.1169 occurring at bus 8. Hence bus-8 has the highest contribution to voltage collapse and is assigned rank 1, and also an ideal location for placing SVC. Ranking order based on bus participation factor for all buses is shown in Table 6.2.

load bus no.	Eigen values 'λ'	load bus no.	Eigen values 'λ'
5	234.6738	16	63.5623
6	215.2490	17	65.0261
7	191.7652	18	43.6196
8	188.6269	19	2.2845
9	141.0157	20	8.0329
10	126.3469	21	9.6668
11	120.1200	22	10.7972
12	111.4474	23	18.0137
13	107.3790	24	15.4520
14	82.5596	25	16.2523
15	68.5248		

Table 6.1 Eigen values of reduced Jacobian matrix

load bus number	bus participation factor	critical bus index ranking
5	0.0062	19
6	0.0594	7
7	0.0469	11
8	0.1169	1
9	0.0480	10
10	0.0662	5
11	0.0332	15
12	0.0558	8
13	0.1044	3
14	0.1117	2

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15	0.0006	21
16	0.0051	20
17	0.0105	17
18	0.0519	9
19	0.0428	12
20	0.0372	13
21	0.0162	16
22	0.0780	4
23	0.0361	14
24	0.0071	18
25	0.0657	6

Table 6.2. Participation factors and critical bus indices for the least Eigen value ($\lambda = 2.2845$)

An optimal value of static VAR compensator is computed using equation (6.11). Before placing SVC at bus 8, the minimum voltage $V_{\min} = 0.8576$ occurs at bus 13 and after placing SVC at bus 8, $V_{\min} = 0.9182$ occurs at bus 7. The MSV after placing SVC at bus 8 has improved from 0.7573 to 0.8554 and maximum value of voltage stability index L_{\max} from 0.5251 to 0.4368. Similar analysis has been made when SVC is placed at two different weak buses i.e rank 1 and rank 2 buses. After placing an optimized SVC value at these two weak buses, $V_{\min} = 0.9524$ at bus 5. The MSV improved from 0.7573 to 0.8896 and L-index from 0.5251 to 0.4095, as shown in Table 6.3. The variation of voltage magnitude at load buses after placing SVC at critical bus 8 is shown in Figure 6.1.

voltage profile	base case load flow results (p.u)	VAR injected at bus-8	VAR injected at Buses 8 & 14
V_5	0.9227	0.9448	0.9524
V_6	0.8793	0.9500	1.0473
V_7	0.8624	0.9182	0.9609
V_8	0.8615	1.0617	1.0618
V_9	0.9121	0.9775	1.0049
V_{10}	0.9159	0.9944	1.0188
V_{11}	0.9761	1.0514	1.0653
V_{12}	0.9631	1.0674	1.0856
V_{13}	0.8576	1.0162	1.0371
V_{14}	0.8907	1.0678	1.0959
V_{15}	0.9714	0.9791	0.9818
V_{16}	0.9469	0.9681	0.9755
V_{17}	0.9908	1.0302	1.0387
V_{18}	0.9262	1.0038	1.0280

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V_{19}	0.9030	0.9713	1.0660
V_{20}	0.8943	0.9479	0.9891
V_{21}	0.9458	0.9858	1.0344
V_{22}	0.8859	1.0061	1.0427
V_{23}	0.9335	0.9973	1.0242
V_{24}	0.9708	0.9989	1.0087
V_{25}	0.8751	0.9462	1.0441
P_{Loss} , MW	61.8551	57.5156	55.5067
number of under voltages	16	4	Nil
V_{min}	0.8576	0.9182	0.9524
L_{max}	0.5251	0.4368	0.4095
MSV	0.7573	0.8554	0.8896

Table 6.3: Results showing SVC Placement at bus 8 and buses 8 & 14

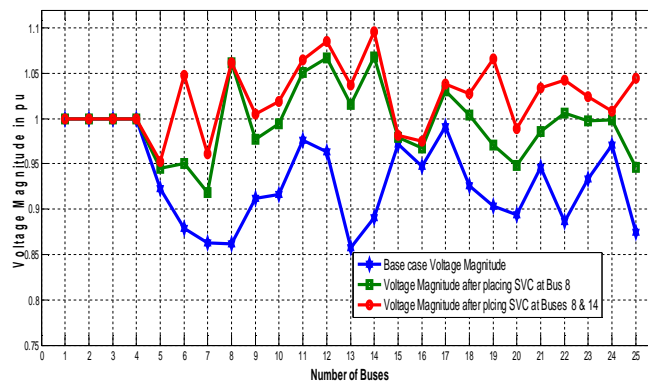


Figure 6.1 Voltage magnitudes before and after placing SVC

VII. REACTIVE POWER DISPATCH USING FUZZY APPROACH UNDER NORMAL CONDITION

The basic load flow result shows that 15 load buses are under voltage and $V_{min}=0.8640$. The performance parameter values are $L_{max}=0.5199$, $MSV=0.7481$, and $P_{loss}=61.0149$ MW. The reactive power is controlled by changing the position of control variables based on fuzzy inference. Load flow results shows that at every iteration there is an improvement in voltage profile as shown in Table 7.1. The control variables like generator excitation, transformer settings and switchable VAR compensators are operated as per the fuzzy output: the settings of control variables. At the end of 4th iteration, no bus experiences under voltage and the corresponding values are tabulated.

All controlling devices are operated based on the fuzzy [6] inference and final settings of the same are shown in Table 7.2. The voltage variation at each iteration with respect to the operation of controlling devices is shown in Table 7.3. The variation in voltage magnitude at every iteration at each load buses is shown in Figure 7.1.

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No. of iteration	No. of under voltage buses	Min voltage at load buses V_{min}	Max Stability index L_{max}	MSV	Power Loss MW
Base case	15	0.8640	0.5199	0.7481	61.0149
1 st	7	0.9244	0.4479	0.8497	55.4848
2 nd	4	0.9469	0.4235	0.8718	54.3592
3 rd	1	0.9489	0.4200	0.8770	54.0552
4 th	0	0.9501	0.4181	0.8794	53.9162

Table 7.1: Improvement in voltage profile and Stability parameters at each iteration

Controller	Initial setting	Final controller settings
V1	1.0000	1.0125
V2	1.0000	1.0250
V3	1.0000	1.0125
V4	1.0000	1.0125
T16-5	1.0000	0.9875
T22-13	1.0000	0.9875
T18-10	1.0000	0.9875
T19-6	1.0000	0.9875
T23-9	1.0000	0.9875
T20-7	1.0000	0.9750
T14-8	1.0000	1.0125
S5	5.0	25.0
S6	5.0	20.0
S7	5.0	30.0
S8	5.0	25.0

Table 7.2: Final settings of the controlling devices

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Load Buses	Initial Voltages (p.u)	Voltage magnitude in p.u			
		1st	2nd	3rd	4th
5	0.9266	0.9666	0.9725	0.9777	0.9781
6	0.8820	0.9367	0.9469	0.9489	0.9501
7	0.8691	0.9260	0.9494	0.9540	0.9578
8	0.8687	0.9300	0.9572	0.9596	0.9609
9	0.9165	0.9686	0.9775	0.9800	0.9814
10	0.9204	0.9734	0.9830	0.9851	0.9862
11	0.9797	1.0223	1.0387	1.0401	1.0408
12	0.9677	1.0196	1.0393	1.0410	1.0419
13	0.8640	0.9244	0.9504	0.9528	0.9542
14	0.8975	0.9676	0.9938	0.9961	0.9974
15	0.9721	0.9894	0.9909	0.9915	0.9916
16	0.9495	0.9749	0.9796	0.9826	0.9829
17	0.9929	1.0222	1.0340	1.0350	1.0354
18	0.9306	0.9708	0.9801	0.9822	0.9832
19	0.9064	0.9454	0.9542	0.9561	0.9573
20	0.8996	0.9402	0.9494	0.9528	0.9554
21	0.9484	0.9781	0.9838	0.9853	0.9863
22	0.8915	0.9370	0.9486	0.9510	0.9523
23	0.9378	0.9762	0.9849	0.9873	0.9886
24	0.9729	0.9989	1.0038	1.0053	1.0058
No of under voltage buses	15	7	4	1	0

Table 7.3: Voltage Improvement at every iteration

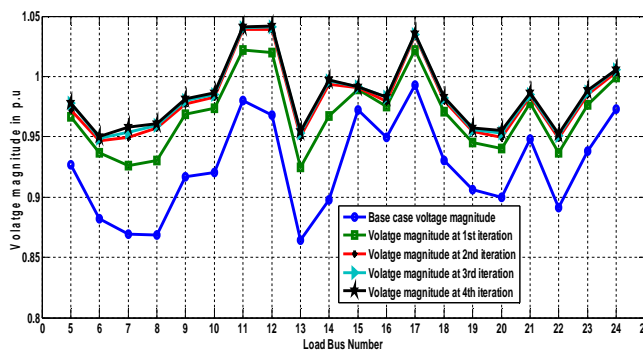


Figure 7.1 Voltage magnitude variations at every iteration at each load buses

VIII. REAL POWER SCHEDULING TO IMPROVE POWER SYSTEM STABILITY MARGIN –UNDER NORMAL CONDITIONS

Whenever a critical fault occurs, proper control should be exercised to arrest the system deterioration. With the liberalization of electricity market, sharing of transmission network to meet various load demands and losses are common. In this section the approach RED [8] is used to compute real power generation schedule to meet the load

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demand. An economical power transmitting contract agreement can be entered into by transferring power with the cheapest generator. However, in view of generation-load location and transmission systems, this may not always be the desired contract, as the selection based only on commercial terms may sometimes lead to transmission congestion.

The most economical way to select a generator schedule in Mega-Watt (MW) is presented while ensuring contracts resulting in minimal loss. The RED approach relates the distances between the generator and load buses. With this information, the Desired Generation Schedule (DGS) [9] can be arrived at, with real power flows being traced for the load of each generator and also sharing of the losses. The power contracts formed based on DGS will ensure voltage stability and also result in minimization of transmission losses.

A.VIII RESCHEDULING REAL GENERATION UNDER NORMAL CONDITIONS

Base load flow is performed and from the admittance matrix, $[F_{LG}]$ is computed. The F_{LG} in complex form calculated for the 25 bus system is shown in Table 8.1. All the elements of the $[F_{LG}]$ matrix are complex ([10]-[12]) quantities and the sum of real part of each row is close to 1.0. The real part of each row is used to compute the desired load shared by each generator. Thus the matrix emphasizes the relative contribution to reschedule the generation to meet the load on the network. The real part of $[F_{LG}]$ is denoted as $[D_{LG}]$ matrix.

Load Bus No	G ₁	G ₂	G ₃	G ₄
5	0.5535 + 0.0006i	0.0789 + 0.0004i	0.3335 - 0.0050i	0.0857 + 0.0006i
6	0.1349 + 0.0036i	0.0838 - 0.0004i	0.1771 - 0.0010i	0.6770 - 0.0071i
7	0.1713 + 0.0037i	0.0789 - 0.0000i	0.2249 - 0.0023i	0.5963 - 0.0063i
8	0.2166 + 0.0044i	0.2237 - 0.0075i	0.2843 - 0.0034i	0.4008 - 0.0040i
9	0.2769 + 0.0042i	0.1156 - 0.0007i	0.3633 - 0.0061i	0.3488 - 0.0055i
10	0.2945 + 0.0039i	0.1322 - 0.0011i	0.3864 - 0.0073i	0.2911 - 0.0036i
11	0.1826 + 0.0049i	0.5131 - 0.0100i	0.2397 - 0.0013i	0.1680 - 0.0016i
12	0.1931 + 0.0046i	0.4598 - 0.0098i	0.2535 - 0.0021i	0.2209 - 0.0027i
13	0.2193 + 0.0041i	0.1819 - 0.0016i	0.2879 - 0.0039i	0.4293 - 0.0076i
14	0.2119 + 0.0042i	0.2894 - 0.0069i	0.2782 - 0.0034i	0.3553 - 0.0049i
15	0.8413 - 0.0046i	0.0286 + 0.0010i	0.1209 + 0.0017i	0.0310 + 0.0011i
16	0.5535 + 0.0006i	0.0789 + 0.0004i	0.3335 - 0.0050i	0.0857 + 0.0006i
17	0.1689 + 0.0055i	0.5752 - 0.0108i	0.2218 + 0.0001i	0.1027 + 0.0008i
18	0.2945 + 0.0039i	0.1322 - 0.0011i	0.3864 - 0.0073i	0.2911 - 0.0036i
19	0.1346 + 0.0036i	0.0836 - 0.0003i	0.1767 - 0.0010i	0.6755 - 0.0071i
20	0.1713 + 0.0037i	0.0789 - 0.0000i	0.2249 - 0.0023i	0.5963 - 0.0063i
21	0.0919 + 0.0033i	0.0515 + 0.0004i	0.1207 + 0.0004i	0.7911 - 0.0074i
22	0.2213 + 0.0042i	0.1488 - 0.0019i	0.2905 - 0.0039i	0.4515 - 0.0071i
23	0.2769 + 0.0042i	0.1156 - 0.0007i	0.3633 - 0.0061i	0.3488 - 0.0055i
24	0.3579 + 0.0047i	0.1111 + 0.0001i	0.4697 - 0.0089i	0.1207 + 0.0004i
25	0.1350 + 0.0036i	0.0839 - 0.0004i	0.1772 - 0.0010i	0.6777 - 0.0073i

Table 8.1 F_{LG} of system under normal conditions

The $[D_{LG}]$ matrix shown in Table 8.2 is the relative proportion of generation contribution to load buses. For example, the load bus 19, closer to Generator 4, receives 67.55% of real power contribution from Generator 4, 13.46% from generator 1, 8.36% from generator 2 and 17.67% from generator 3 respectively. The new real power generation schedule of each generator is indicated in Table 8.2.

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Load bus No	G ₁ (p.u)	G ₂ (p.u)	G ₃ (p.u)	G ₄ (p.u)
5	0.5535	0.0789	0.3335	0.0857
6	0.1349	0.0838	0.1771	0.6771
7	0.1714	0.0789	0.2249	0.5963
8	0.2166	0.2238	0.2843	0.4008
9	0.2769	0.1156	0.3634	0.3488
10	0.2945	0.1322	0.3865	0.2911
11	0.1827	0.5132	0.2397	0.1680
12	0.1931	0.4599	0.2535	0.2210
13	0.2194	0.1819	0.2879	0.4294
14	0.2120	0.2895	0.2782	0.3553
15	0.8413	0.0286	0.1209	0.0310
16	0.5535	0.0789	0.3335	0.0857
17	0.1690	0.5753	0.2218	0.1027
18	0.2945	0.1322	0.3865	0.2911
19	0.1346	0.0836	0.1767	0.6755
20	0.1714	0.0789	0.2249	0.5963
21	0.0919	0.0515	0.1207	0.7912
22	0.2214	0.1488	0.2905	0.4515
23	0.2769	0.1156	0.3634	0.3488
24	0.3580	0.1111	0.4698	0.1207
25	0.1350	0.0839	0.1772	0.6777

Table 8.2 [D_{LG}] under normal conditions

The actual real power contribution from each generator is obtained by multiplying the load demand at each bus to entries of [D_{LG}] matrix by using equation 8.1. The new real power generation schedule is obtained by summing up all column entries of the matrix and the computed values are shown in Table 8.3. The Real Power Generation Schedule (RGS) for each generator can be obtained from equations (8.1) and (8.2).

$$[G_i]_{i=g} = D_{LGj} * P_{Lj} \tag{8.1}$$

G_i is the generation contribution to each load buses and P_{Lj} is the actual real power demand at each load bus.

The new real power generation schedule is estimated by:

$$[RPG]_{i=g} = \sum_{i=1}^g G_i \tag{8.2}$$

All the generators are rescheduled to the values shown in Table 8.3. Load flow is performed and overall system performance is computed.

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Load bus No.	Contribution of Generator 1 G ₁ (MW)	Contribution of Generator 2 G ₂ (MW)	Contribution of Generator 3 G ₃ (MW)	Contribution of Generator 4 G ₄ (MW)
5	238	34	143	37
6	38	23	50	190
7	55	25	72	191
8	39	40	51	72
9	33	14	44	42
10	18	8	23	17
13	99	82	130	193
15	656	22	94	24
25	5	3	7	27
Real Power Generation Schedule [RPG] MW	P _{G1} = 1181	P _{G2} = 252	P _{G3} = 614	P _{G4} = 793

Table 8.3 RPG values without considering losses of the system

B.VIII OVERALL SYSTEM PERFORMANCE PARAMETERS

Initially generators are scheduled for G₁=1820 MW, G₂=160 MW, G₃=350 MW and G₄=520 MW and after load flow: G₁=1698, G₂=160 MW, G₃=350 MW and G₄=520 MW and total generation is 2728 MW. Each generator is rescheduled to new real power generation, and load power contributed by each generator obtained by summation is: G₁=1181MW, G₂=252 MW, G₃=614 MW and G₄=793 MW as shown in Table 8.3. Again load flow is performed and new real power generation of each generator is, G₁=1052.14, G₂=252.21, G₃=613.78 and G₄=793.16 respectively as shown in Table 8.4. Now, total generation is 2711.30 MW. The difference of generation with and without RPG is equal to 16.7 MW. The effect of new real power generation schedule indicates considerable improvement in the stability parameters like MSV, P_{loss}, V_{min}, L_{max}, $\sum V_e^2$ and $\sum L_f^2$ as shown in Table 8.4.

Generation, P _g (MW)	Without RPG				With RPG			
	G ₁	G ₂	G ₃	G ₄	G ₁	G ₂	G ₃	G ₄
	1698	160	350	520	1052.14	252.21	613.78	793.16
Total Generation(MW)	2728				2711.29			
Transmission Loss	67.9264 MW				51.2856 MW			
% Loss	2.49%				1.89%			
V _{min} (p.u)	0.8427 (Bus:13)				0.8524 (Bus:25)			
L _{max}	0.5513 (Bus:8)				0.5362 (Bus:8)			
MSV	0.7171				0.8797			
$\sum V_e^2$	0.2215				0.1852			
$\sum L_f^2$	4.4502				4.4232			

Table 8.4 Overall system performance parameters under normal operation without transmission losses.

C.VIII EVALUATION OF RPG CONSIDERING TRANSMISSION LOSSES

The earlier RPG value calculated was merely based on Relative Electrical Distance [RED] without considering the transmission losses. Now, using equation 8.1, the real power generation rescheduling is done based on relative electrical distance considering transmission losses as shown in Table 8.5. The new real power generation schedule computed is G₁=1161.91 MW, G₂=242.09 MW, G₃=596.55 MW and G₄=772.26 MW. The voltage profile and voltage

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stability L-index after load flow is shown in Table 8.6. The voltage magnitude appreciably improved in all the buses and so also the performance parameters: V_{min} = 0.8428 to 0.8581, L_{max} = 0.5513 to 0.5354 and P_{loss} = 67.9264 to 51.1503. After setting new generation schedule, load flow is performed and as a result the real power generation are G_1 = 1100.24 MW, G_2 = 242.1 MW, G_3 = 596.55 MW, G_4 = 772.26 MW and total real power generation of 2711 MW as shown in Table 8.7.

Load bus No	Generator 1 G_1	Generator 2 G_2	Generator 3 G_3	Generator 4 G_4
5	236.5626	33.7142	142.5339	36.6094
6	38.3534	23.8320	50.3525	192.5358
7	54.7252	25.2066	71.8355	190.4735
8	36.0220	37.2108	47.2823	66.6656
9	31.9230	13.3292	41.8952	40.2151
10	17.0568	7.6556	22.3836	16.8595
13	91.4265	75.8365	119.9995	178.9634
15	650.6730	22.0996	93.4835	23.9956
25	5.1682	3.2114	6.7851	25.9445
Required Generation Scheduling [RPG], MW	P_{G1} = 1161.91	P_{G2} = 242.09	P_{G3} = 596.55	P_{G4} = 772.26

Table 8.5: L-Index and bus voltage with and without RPG considering transmission losses

Load Bus No:	Without RPG		With RPG	
	Bus Voltage (p.u)	L-Index	Bus Voltage (p.u)	L-Index
5	0.9180	0.3145	0.9334	0.3076
6	0.8576	0.4483	0.8582	0.4456
7	0.8517	0.4604	0.8579	0.4543
8	0.8470	0.5514	0.8628	0.5355
9	0.9010	0.3733	0.9194	0.3633
10	0.9045	0.3521	0.9240	0.3424
11	0.9686	0.2017	0.9802	0.1981
12	0.9533	0.2697	0.9672	0.2637
13	0.8428	0.5508	0.8581	0.5354
14	0.8769	0.4720	0.8933	0.4586
15	0.9695	0.0913	0.9782	0.0907
16	0.9423	0.2070	0.9572	0.2035
17	0.9862	0.1213	0.9942	0.1199
18	0.9149	0.3180	0.9343	0.3097
19	0.8879	0.3437	0.8884	0.3413
20	0.8842	0.3542	0.8900	0.3499
21	0.9373	0.2059	0.9348	0.2052
22	0.8717	0.4471	0.8858	0.4362
23	0.9228	0.3043	0.9407	0.2971
24	0.9656	0.1466	0.9787	0.1449
25	0.8532	0.4604	0.8538	0.4578

Table 8.6: L-Index and bus voltage with and without RPG considering transmission losses

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D.VIII OVERALL SYSTEM PERFORMANCE PARAMETERS CONSIDERING TRANSMISSION LOSSES

Overall system performance parameters, obtained for new real power scheduling considering transmission losses are also shown in Table 8.7.

Generation P_g in MW	Without RPG				With RPG			
	G ₁	G ₂	G ₃	G ₄	G ₁	G ₂	G ₃	G ₄
	1698	160	350	520	1100.24	242.1	596.55	772.26
Total Generation(MW)	2727.93				2711.15			
Transmission Loss of system	67.9264 MW				51.1503 MW			
Percentage, P_{loss}	2.49%				1.89%			
V_{min} (p.u)	0.8428 (bus 13)				0.8538 (bus 25)			
L_{max}	0.5513 (bus 8)				0.5354 (bus 8)			
MSV	0.7171				0.8719			
ΣV_g^2	0.2216				0.1830			
ΣL_r^2	4.4502				4.3986			
Max bus angle δ	-36°				-22°			

Table 8.7: Overall system performance parameters with transmission losses

It can be observed that there is not much variation in performance parameters after considering the transmission losses. A graph of voltage magnitude versus load bus number is plotted as shown in Figure 8.1.

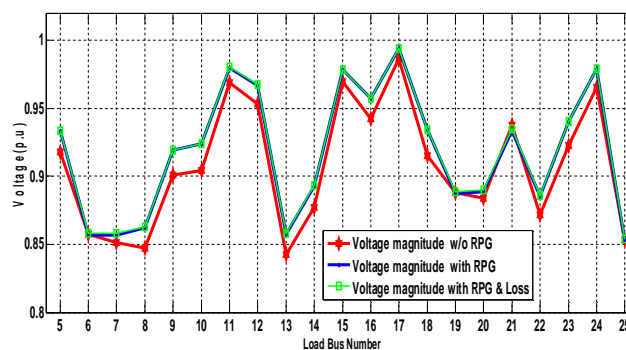


Figure 8.1 Voltage profile and its variation with and without RPG

IX. CONCLUSION

Network ranking using fuzzy approach under contingency of line outages is obtained. Modal analysis is applied for determining weak buses of the system for effective placement of SVC based on the least Eigen values and bus participation factors. The results obtained are compared with other methods like reactive power optimization by operating controlling devices like SVC, excitation voltage of generators and transformer tapping based on voltage deviations, voltage stability L-indices of load buses, Minimum Singular Value (MSV) and real power rescheduling based on Relative Electrical Distance (RED). In RED approach the Required Power Generation Schedule (RPGS) meets the load demand and also results in reduction of transmission losses. Results obtained for a 25 buspower system network shows that the proposed method reduces system power losses as well as improves the performance parameters.

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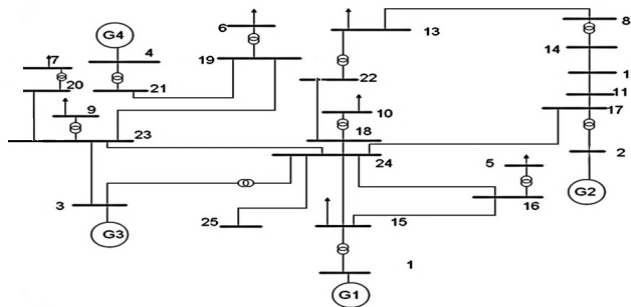
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REFERENCES

- [1] P.R. Bijwe, D.P. Kothari, and L.D. Arya, "Alleviation of line overloads and voltage violations by corrective rescheduling", IEE Proceedings-C, Vol. 140, No. 4, July 1993, pp.249-255.
- [2] Begovic, M, and A.G. Phadke, "Control of Voltage Stability Using Sensitivity Analysis", IEEE Trans. on power systems, Vol.7, No.1, 1992, pp.114-123.
- [3] Bansilal, D. Thukaram, K. Parthasarathy, "Optimal reactive power dispatch algorithm for voltage stability improvement," Int. Journal of Electrical Power and Energy Systems 18 (7) (1996) 461-468.
- [4] Bansilal, Thukaram D., Parthasarathy K., "An expert system for alleviation of network overloads," Electric Power Systems Research 40 (1997) 143-153.
- [5] B. Marques and Taranto, "A Knowledge - based system for supervision and control of regional voltage profile and security," IEEE Tr. On Power Systems, Vol.20, No.4, February.2005, pp 400-407.
- [6] Aydogan Ozdemir and Chanan Singh, "Fuzzy Logic Based Mw Contingency Ranking against Masking Problem", Power Engineering Society Winter Meeting, IEEE, Vol.2, 28 Jan - 1 Feb. 2001, pp.504-509.
- [7] Gao, B, G. K. Morison, and P. Kundur, "Voltage stability evaluation using modal analysis", IEEE Transactions on Power Systems, Vol.7, No.4, November 1992, pp.1529-1542.
- [8] P.A. Lof, G. Andersson, D. Hill, " Voltage dependent reactive power limits for voltage stability studies", IEEE Trans. on power systems, Vol. 10, No. 1, Feb. 1995, pp. 220-228.
- [9] Mansour, Y, W. Xu, F. Alvarado and C. Rinzin, "SVC Placement Using Critical Nodes of Voltage Instability", IEEE Trans. on Power Systems, Vol.9, No.2, May 1994, pp.757-763.
- [10] T. K. P. Medicherla, R. Billinton, and M. S. Sachadev, "Generation rescheduling and load shedding to alleviate line over loads-analysis", IEEE Trans. on PAS, Vol.98, No.12, 1979, pp .1876-1884.
- [11] Medicherla TKP, Billington R, and Sachadev MS. "Generation rescheduling and load shedding to alleviate line overloads - system studies", IEEE Trans. PAS 100 (1) (1981); 36-42.
- [12] Conejo A.J, Milano F, Garacia Bertrand R," Congestion management ensuring voltage stability ", IEEE Transaction Power system, Vol.21, No.1, Feb. 2006,pp.357-364

APPENDIX



Single line diagram of 25 bus Indian equivalent system

Table : 25-Bus EHV System (Actual data)	
Number of generators	4
Number of transformers	11
Number of transmission lines	16
Number of loads	8
Number of shunt compensators	5
Number of reactors	17
P-load (peak, MW)	2620
Q-load (peak, MVAR)	980