Journal of Thi-Qar University Special number Vol.5 March/2010

Computer Aided Voltage Stability Analysis in Power Systems

By

Dr. Mohammed J. Khami — *Assist. Prof.*, *Basrah Technical Institute*, *Foundation of Tech. Education*

Dr. Baqer T. Atiyah — *Lecturer*, *Nassiriyha Technical Institute*, *Foundation of Tech. Education*

Dr. Kadhem M. Hashem — *Assist. Prof.*, *Education College*, *Thi-Qar University*

Abstract:

The current paper aimed to present a computer simulation method to know the power system state which may be in case of voltage collapse, voltage instability or voltage stability by using eigenvalue analysis as well as identifying the weaken nodes in that power system using eigenvector analysis which is used to find the participation factor. The high participation factor values lead to the weaken nodes in the power system that required to treatment by installing shunt capacitors in those locations to improve the power system performance and reduce the losses power. The simulation results obtained by tested the proposed method on 30-bus, 30 lines distribution system and the satisfied results are obtained. The simulation results showed the efficiency and flexibility of proposed algorithm. Proposed algorithm has been implemented using MATLAB language version (7.5).

المستخلص

يهدف البحث الحالي الى تقديم طريقة محاكاة حاسوبية لمعرفة حالة منظومة القدرة والتي يمكن ان تكون في حالة أنهيار الفولتية أو في حالة أستقرار أوعدم أستقرار الفولتية بأستخدام تحليل (eigenvalue) بالأضافة الى تحديد النقاط الأضعف في المنظومة والتي بحاجة الى معالجة بأستخدام تحليل (eigenvector) الذي يستخدم لأيجاد معامل الأشتراك. قيم معامل الأشتراك العليا تشير الى النقاط الأضعف في المنظومة والتي يتطلب معالجتها بتنصيب متسعات التوازي في تلك العقد لتحسين أداء المنظومة وتقليل الخسائر فيها.

وللحصول على نتائج عملية المحاكاة تم اختبار الطريقة المقترحة على منظومة توزيع قدرة كهربائية مؤلفة من (30) عمومي توصيل و (30) خط نقل وتم استحصال النتائج التي بينت كفاءة ومرونة الطريقة المقترحة. طريقت المحاكاة المقترحة بنيت بأستخدام برامجيات MATLAB-7.5.

1: Introduction:-

The electrical networks need to be utilized ever more efficiently. The transfer capacity of an existing distribution network needs to be increased without major investments but also without compromising the security of power system. The more efficient use of distribution network has already led to situation in which many power systems are operated more often and longer closed to

voltage stability limits. A power system stressed by heavy loading has a substantially different response to disturbances from that of a non-stressed system. The potential size and effect of disturbances has also increased. When a power system is operating closer to a stability limit, a relative small disturbance may cause a system upset. In additional, larger area of the interconnected system may be affected by a disturbance.

Voltage stability is a problem in power systems which are heavily loaded, faulted or have storage of reactive power. The nature of voltage stability can be analyzed examining the production, transmission and consumption of reactive power. The problem of voltage instability is mainly considered as the inability of the network to meet the load demand imposed in terms of inadequate reactive power support or active power transmission capability or both [1].

At times generator overloading due to excessive reactive power generation is one of the most common and serious causes of voltage instability. Low voltage at load buses is another cause that is likely to result in voltage stability problems [2]. In the system where sufficient reactive power generation is not available locally to regulate voltage and maintain the reactive power balance is more prone to voltage instability. By undertaking reactive power injections in potentially reactive short area by switching capacitor bank or other regulating devices (SVCs, etc.) it is possible to steer the system to a safer state [3],[4].

In general, the voltage collapse can be mitigated in preventive way or corrective way. The aim of preventive control is to prevent voltage instability before it actually occurs.

1.1: Related Works:

Tiranuchit and Thomas [5] presented a control strategy against voltage instabilities utilizing minimum singular value of the load flow Jacobean as voltage security index. One of the disadvantages of using the minimum singular value index is the large amount of CPU time required in performing singular value decomposition. Overby and DeMarco [6] developed energy based controller sensitivities for voltage security enhancement. Closed form expression for Lyapnov type energy functions has been used to derive the sensitivities of this function with respect to controls. Static voltage stability control has also been attempted by Begovic and Phadke [7] using sensitivity analysis. Effect of allocation and amount of reactive power support on voltage stability margin has been discussed. Mansour et al. [8] used modal analysis as a tool for SVC placement to prevent voltage instability. System participation factors for critical modes are used to determine most effective location for enhancement of voltage using shunt compensations. Bansilal et al. [9] presented a reactive power dispatch for voltage stability margin improvement using L-index and non-linear least squares optimization algorithm. S. Chauhan and M. P. Dave [10] present a methodology to improve the voltage instability of power system. The method is based on sensitivity techniques. First stage involves calculation of sensitivity of target output with respect to input features in terms of connection weights and outputs at intermediate layers of trained network. Second stage deals with sensitivity of input features with respect to control parameters.

1.2: Research Aim:

The aim of this paper is to present an efficient computer simulation method to analyze voltage stability and identifying the weaken nodes in distribution power system depending on eigenvalue and participation factor. Then the weaken nodes can be manipulating later by one of reactive power compensation methods to realize the minimum acceptable value of voltage in system buses. The power-Flow solution which is applying in this research use Newton-Raphson power flow method.

2: Study of Voltage Stability:-

The methods for studying voltage stability are used to find the operation state, the voltage stability margins and limits and to study the system variation and element responses. The voltage stability study can be connected using analytical or monitoring methods:-[3]

2.1: Analytical Methods:-

These methods allow a detailed study for the variables, parameters and elements behavior of the power system, in order to find design solutions and operation criteria that allow the system to work far from the instability point. Each of these methods uses a mathematical technique, which is implemented in a computational tool with a great number of nodes, lines and loads. These methods are based on conventional power flows, progress power flows and dynamic analysis.

2.2: Monitoring Methods:-

These methods are based on data measurements of the power system variables such as voltages, current, active power, reactive power and vector angles, to find the operation state, voltage stability limit and margin as well as the critical nodes of the system. They can be used as a tool for the on-line and off-line voltage stability detection and prediction.

***3: Solution of Voltage Stability:-*[11]**

3.1: Reactive Compensation:-

These techniques are based on the compensation of reactive power to the system, from power generation source, transmission lines, transformer, and load nodes. The line compensation can be carried out with a constant value of reactive power, called static compensation using switched element to increase the voltage at the nodes: also, a variable compensation can be carried out, controlled by power electronic devices as FACTS; this is called dynamic compensation and is used to respond during transitory and small signal variations that occur in the power system due to disturbances.

3.2: Control of Elements:-

These techniques are used to avoid voltage instabilities and collapse in the power system by controlling elements that change the operation condition as protection relays, current limiters and TAP changers.

3.3: System Changes:-

These techniques are based on the entrance of elements or the shedding of loads to avoid voltage instability in the system. They are used to increase the power transmission capacity and to alleviate the power system overloads. These Methods are divided in undervoltage, shedding and system configuration changes.[12]

3.4: Mixed:-

This is a technique based on the combination of the above mentioned techniques to create a voltage stability prevention and correction scheme using different elements.

4: Sensitivity Method for Voltage Stability Analysis:

A bifurcation called the saddle-node bifurcation is of special interest. It is connected to the singularity of the power-flow Jacobin matrix:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{q\theta} & J_{qV} \end{bmatrix} \times \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \qquad (1)$$

Where the change in active and reactive power are related to changes in angle and voltage. If the Jacobin matrix is singular (non-invertible), the system has reached a point where it has no solution i.e. a saddle node bifurcation. The minimum singular value or the smallest eigenvalue of the Jacobin matrix can be used as distance or proximate indicator to this limit. If the Jacobin matrix models the power flow equations, this singularity will coincide with the point of maximum load ability. But if load behaviors etc. are included (extended Jacobin matrix) the singularity will indicate the point of collapse. If $\Delta P = 0$, the relation between voltage change and reactive power change can be written as:[13]

$$\Delta Q = \left\lfloor J_{qV} - J_{q\theta} \times J_{P\theta}^{-1} \times J_{PV} \right\rfloor \times \Delta V = J_R \times \Delta V \qquad (2)$$

The matrix J_R is used as state space matrix in the analysis. Efficient algorithm as in [10] has been developed to calculate the minimum singular value for the reduced matrix J_R which can be used as a voltage stability index.

5: Specified of Weak Nodes in Power System:

Modal analysis, calculation of eignvalues and eigenvectors of the Jacobin matrix can be used to drive weak voltage nodes in the system. [14]

The minimum eigenvalues, which become close to instability, need to be observed more closely. The appropriate definition and determination as to which node or load bus participates in the selected mode become very important. This necessitates a tool, called the participation factor, for identifying the weakest nodes or load buses that are making significant contribution to the select mode.

If ϕ_i and Γ_i are the right- and left-hand eignvectors, respectively, for the eignvalue λ_i of the matrix J_R , then the participation factor measuring the participation of the K^{th} bus in i^{th} mode is define as:- [15]

$$P_{ki} = \phi_{ki}\,\Gamma_{ki} \qquad (3)$$

For all the small eignvalues, bus participation factors determine the area close to voltage instability. Equation (3) implies that P_{ki} shows the participation of the i^{th} eigenvalue to the V-Q sensitivity at bus K.

6: Proposed Solution Method:-

The used procedure to determine whether the system reached the voltage stability or not and to specify the weak nodes in the test distribution system can be described as following:-

At the beginning, load-flow analysis will be performed by using full Newton-Raphson load flow method to obtain the voltage profile, total power losses and Jacobin matrix. The reduced Jacobin matrix J_R can be calculated from Jacobin matrix since;

$$J_R = \left| J_{qV} - J_{q\theta} \times J_{p\theta}^{-1} \times J_{PV} \right|. \qquad (4)$$

Then the eignvalue and eigenvector of reduced Jacobin matrix are calculated in order to specify the minimum eignvalue ($\lambda_{\min}$) which is used to know the system status which may be one of the following statuses:-

- **The system is voltage collapse if $\lambda_{\min}$ = 0.**
- **The system is instable from view of voltage stability if $\lambda_{\min}$ has a negative value.**
- **The system is stable from view of voltage stability if $\lambda_{\min}$ has a positive value.**

After that the participation factor can be calculated by right/left eignvector to determine buses with highest participation factors which refer to the weak nodes in test power system. Finally the optimal sizes of reactive power that injected in the weak nodes will be determined in order to reduce the power losses of tested power system. The proposed solution method programmed by using MATLAB Tool Box-Version 7.5. Figure (1) shows the flow chart of proposed solution method.

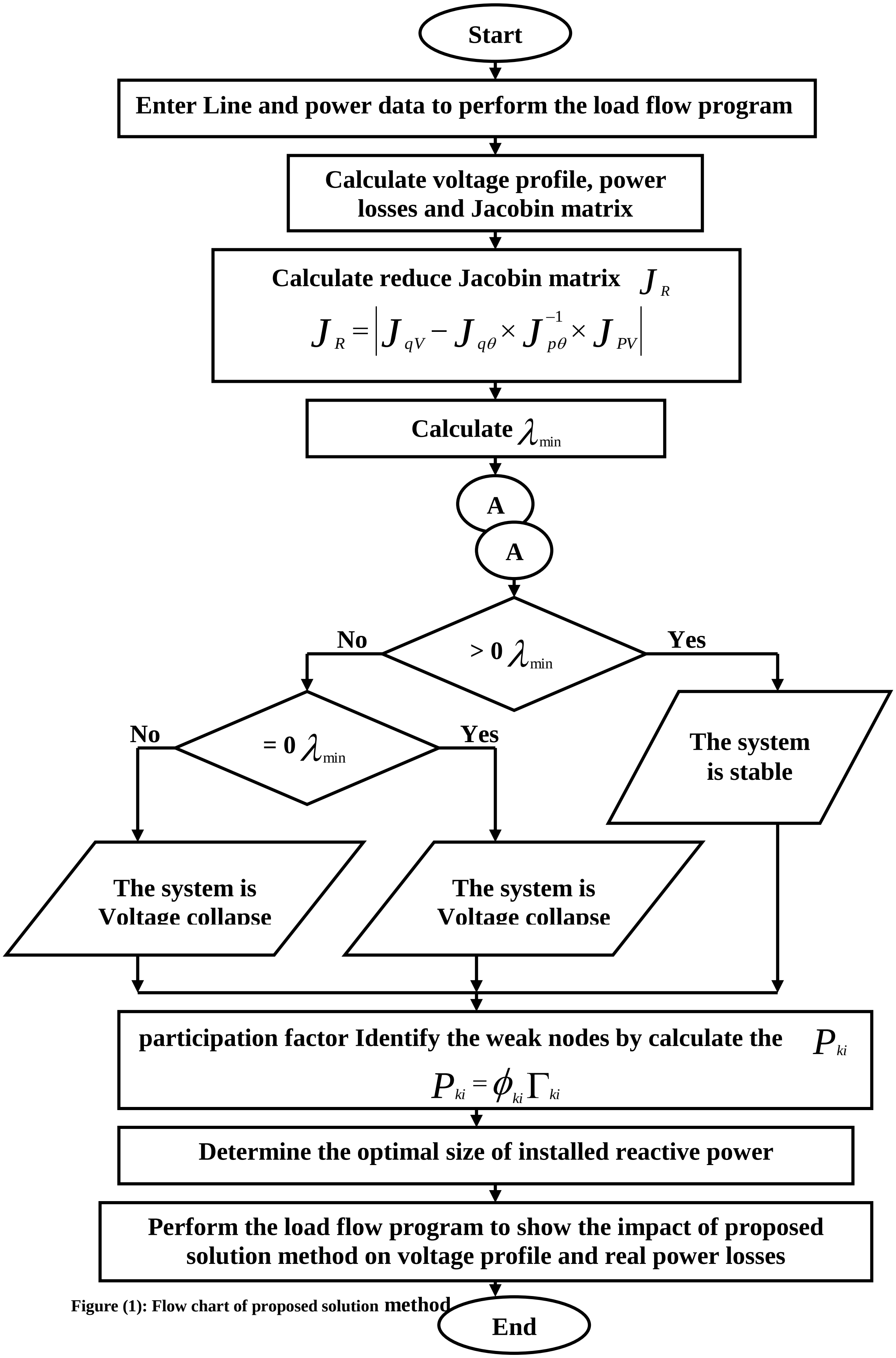

Figure (1): Flow chart of proposed solution method

7: Test System and Simulation Results:

The computer simulation of proposed algorithm tested on 30-bus, 30 lines distribution system taken from [16]. Figure (2) shows the one line diagram of test system, the test system is a 13.8Kv, 12KVA consisting of main branch and two laterals containing different number of load buses. Buses 1 to 17 lie on the main branch, the system also contains a loop connecting bus #18,19,20 and 21 to the main branch . Bus #1 represents the substation feeding the distribution system.

Table (1) shows the network data for this system. A feeder segment is modeled by the series combination of its corresponding resistance and reactance. Loads are represented as power sink where constant values of active power (P) and reactive power (Q) are assumed. Table (2) shows the corresponding P and Q for the loads connected to each bus.

After the Power-Flow program with Newton-Raphson method is implemented by using 7.5-MATLAB language, the Jacobin matrix and reduced Jacobin matrix (J_R) were computed to analyze the voltage stability through computing eigenvalues ,eigenvectors and participation factors, participation factor used to specified the weaken nodes which represents the suitable nodes to reactive power injection by installed shunt capacitors at this nodes. The final step represented by find the optimal sizes of reactive power which can be calculated by the value of MVAR gives the highest losses reduction and maintain the system constrains.

The eigenvalues and participation factor values are tabulated in Table (3), from this table we find the system is stable from view of voltage stability since all values of eigenvalues of load buses are positive and the buses 14, 15, 23, 24, 25, 27 and 29 represent the weaken nodes which is required to injected reactive power through it due to its highest participation factor values. The optimal sizes of injected reactive power are tabulated in Table (4).

Figures (3) and (4) show the voltage profile of test system before and after reactive power injection while the losses power reduction before and after injection process illustrated in Figure(5).

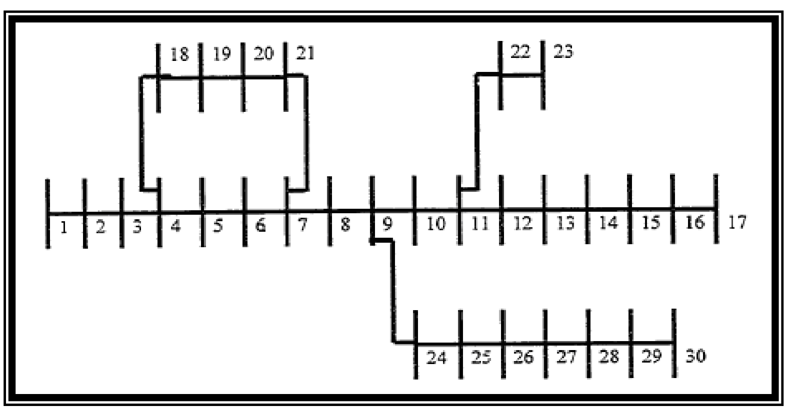

Figure (2): Single Line Diagram of Test Distribution System: [16]

Table (1): Test System Network Data: [16]

From Bus No.	To Bus No.	R(Pu.)	X(Pu.)	From Bus No.	To Bus No.	R(Pu.)	X(Pu.)
1	2	0.0967	0.0397	16	17	0.1359	0.0377
2	3	0.0886	0.0364	4	18	0.1718	0.0391
3	4	0.1359	0.0377	18	19	0.1562	0.0355
4	5	0.1236	0.0343	19	20	0.1562	0.0355
5	6	0.2598	0.0446	20	21	0.2165	0.0372
6	7	0.1732	0.0298	21	7	0.2165	0.0372
7	8	0.2598	0.0446	11	22	0.2598	0.0446
8	9	0.1732	0.0298	22	23	0.1732	0.0298
9	10	0.1083	0.0186	9	24	0.1083	0.0186
10	11	0.0866	0.1488	24	25	0.0866	0.1488
11	12	0.1299	0.0223	25	26	0.1299	0.0223
12	13	0.1732	0.0298	26	27	0.1299	0.0223
13	14	0.0866	0.1488	27	28	0.1299	0.0223
14	15	0.0433	0.0074	28	29	0.1732	0.0298
15	16	0.1483	0.0412	29	30	0.0866	0.1488

Table (2): Test System Load Data: [16]

Bus #	P (KW)	Q (KVar)	Bus #	P (KW)	Q (KVar)
1	0	0	16	145.5	130
2	300	280	17	60	35
3	0	0	18	360	335
4	1200	1170	19	1200	1100
5	100	80	20	200	190
6	112.6	105.2	21	114	81
7	400.4	300	22	50.3	30.5
8	75	54	23	80	65
9	130	122	24	28	20
10	280	190	25	1500	1380
11	145	104	26	140	100
12	145	104	27	1114	910
13	80	50.5	28	326	218.6
14	118	115.5	29	426	318.6
15	700	630	30	300	280

Table (3): Eigenvalue and participation factor Values

Bus No.	Eigenvalue	Participation Factor	Bus No.	Eigenvalue	Participation Factor
2	399.998	0.00859	17	12.322	0.00979
3	374.551	0.00725	18	45.685	0.00172
4	277.412	0.00412	19	84.625	0.00233
5	83.111	0.00212	20	61.512	0.00464
6	43.744	0.00166	21	41.814	0.00548
7	281.325	0.00391	22	53.945	0.00621
8	265.212	0.00264	**23**	**26.215**	**0.21838**
9	255.272	0.00224	**24**	**28.655**	**0.12221**
10	79.911	0.00198	**25**	**30.099**	**0.29485**
11	119.899	0.00450	26	58.527	0.00312
12	111.850	0.00653	**27**	**201.012**	**0.01551**
13	103.914	0.00033	28	43.555	0.00144
14	**39.333**	**0.10243**	**29**	**162.318**	**0.02463**
15	**19.544**	**0.03459**	30	10.385	0.00775
16	5.221	0.01182			

Table (4): Optimal Sizes of Injected Reactive Power

Bus No.	14	15	23	24	25	27	29
Optimal Size (Mvar)	0.9	0.75	1.2	1.35	1.2	1.2	0.45

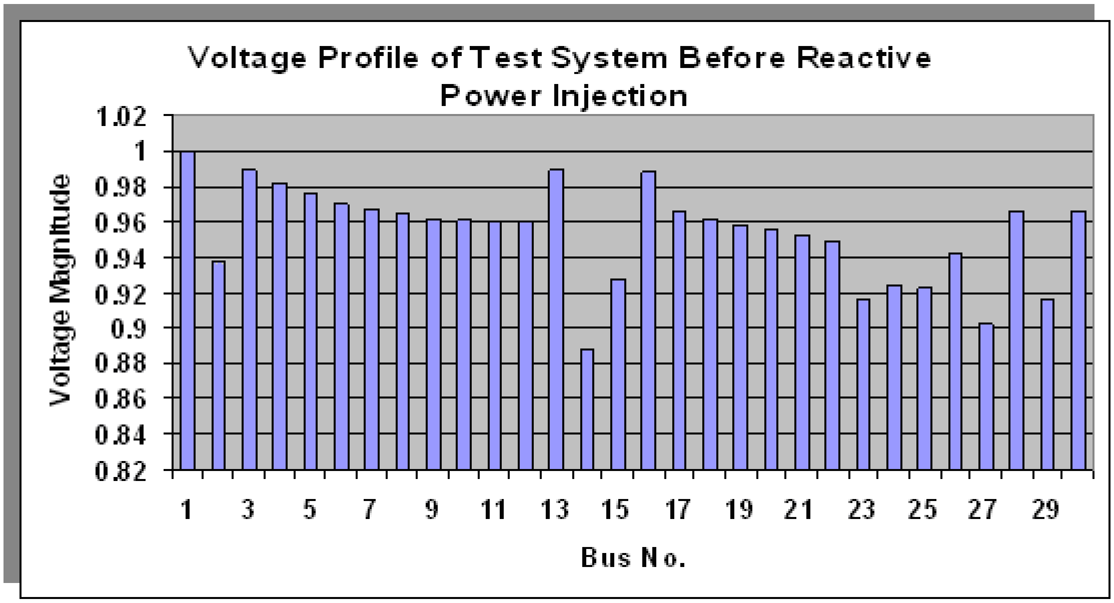

Figure (3): Voltage Profile before Reactive Power Injection

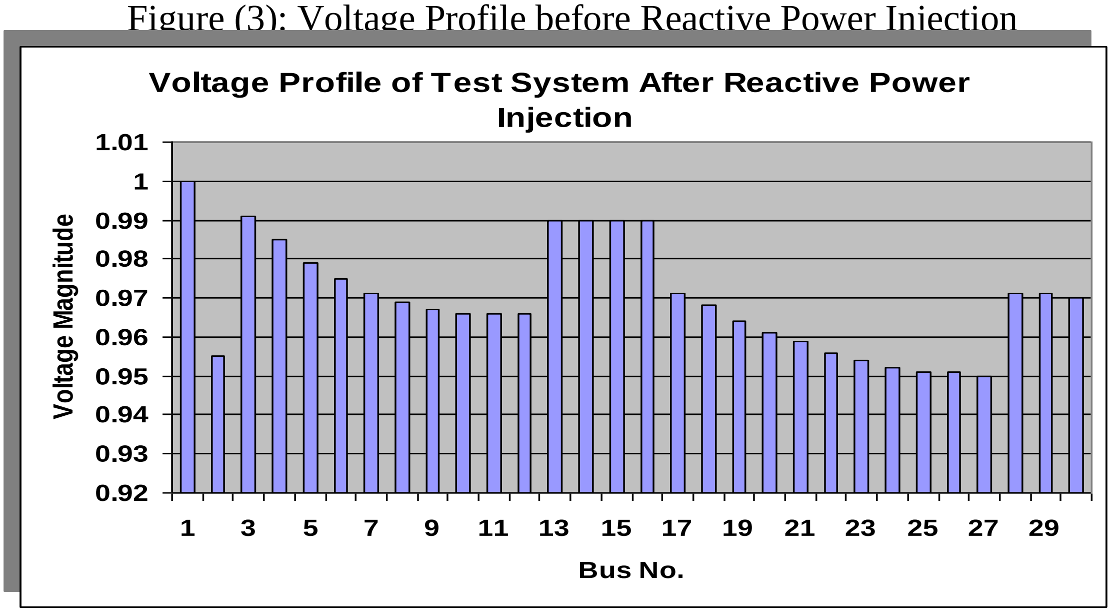

Figure (4): Voltage Profile after Reactive Power Injection

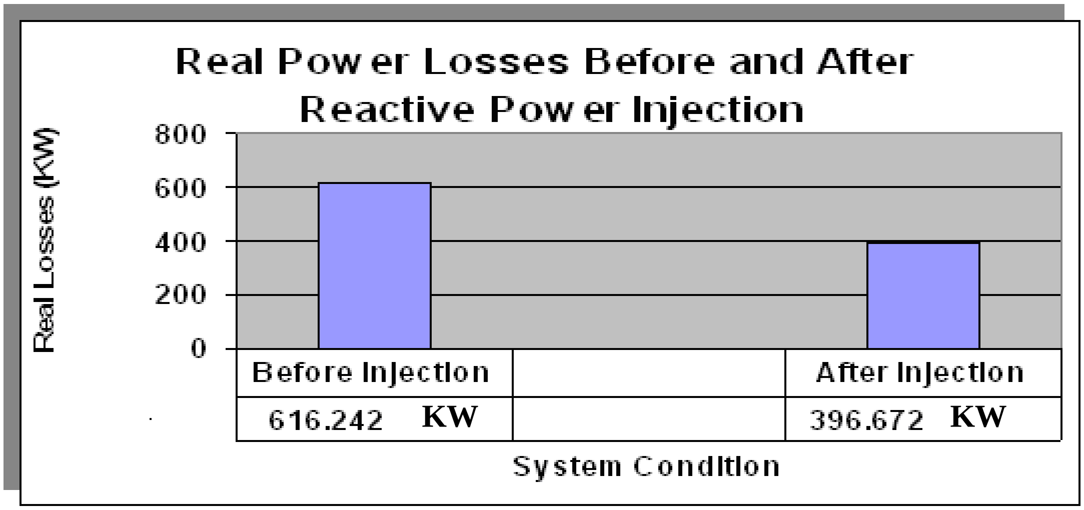

Figure (5): Real Power Losses before and after Reactive Power Injection

8: Conclusion:-

This paper reported an iterative method to know the power system status from view of voltage stability and determine the shunt Var compensation required for maintaining voltage stability of a power system by using eigenvalue analysis and participation factor. The employed of participation factor is an effective manner in reducing the total number of alternative examined points to find the optimal locations of shunt capacitors installation. The voltage stability analysis and Var calculations were carried out on 30-bus, 30 lines power system and the results are presented.

9: References:-

[1] C W Taylor. "*Power System Voltage Stability*", Mc Graw-Hill, 1993.

[2] S. Chauhan, M.P. Dave," *Sensitivity based voltage instability alleviation using ANN*", Electrical Power and Energy Systems ,2003.

[3] J. E. Candelo , N. G. Caicedo andF. Castro-Aranda, , "*Proposal for the Solution of Voltage Stability Using Coordination of Facts Devices*", 2006 IEEE PES Transmission and Distribution Conference and Exposition Latin America, Venezuela, 2006

[4] Li, Karnal, "*Optimal coordinated voltage control of power systems*", Journal of Zhejiang University SCIENCE A, 2006.

[5] Tiranuchit A, Thomas RJ.,"*A posturing strategy against voltage instabilities in electric power systems*",IEEE Trans Power System 1988; 3(1):87-93.

[6] Overbye TJ, Demarco CL.," *Voltage security enhancement using energy based sensitivities*", IEEE Trans Power System, 1991.

[7] Begovic MM, Phadke AG.," *Control of voltage stability using sensitivity analysis*", IEEE Trans Power Syst 1992;7(1): 114-23.

[8] Mansour Y, Xu W, Alvarado F, Rinzin C.," *SVC placement using critical modes of voltage instability*," IEEE Trans Power Syst. 1994.

[9] Bansilal, Thukaram D, Parthasarthy K. ,"*Optimal reactive power dispatch algorithm for voltage stability improvement*", Electr Power Energy Syst 1996;18(7):461-8.

[10] S.Chauhan and M. P. Dave," *Sensitivity Based Approach for Voltage Instability Alleviation using ANN*", IE (I) Journal-EL, Vol 84, 2004.

[11]: Vournas, C.D and krystianous, M.,"*Load TAP changers in emergency and preventive voltage stability control*", IEEE transactions power systems, vol.19, No.1, Feb, 2004.

[12]: Verbic, G and Gubina, F,"*A new concept of voltage collapse protection based on apparent power losses*", Eighth IEE International confer. on developments in power syst. protection, Vol. 2, Apr. 2004.

[13] IEEE/CIGRE ,"*Join Task Force on Stability Terms and Definition. Definition and Classification of Power System Stability*", IEEE Transection on Power System, Vol.19, No.2, 2004.

[14] Stefan Johanssonm, "*Long-Term Voltage Stability in Power Systems*", PHD Thesis, School of Electrical and Computer Engineering, Chalmers University of Technology, Sweden, 1998.

[15] G. Verghes, "*Selective Modal Analysis with Application to Electric Power Systems*", Part II, IEEE Transactions on Power apparatus and Systems, Vol. PAS 101, No. 9, 2002.

[16] Al-Mohammad,Ali Hasan Yasin, "*Optimal Capacitor Placement in Distribution Systems Using Heuristic Technique*", M.sc. Thesis, King Fahad University of Petroleum and Minerals, 1999.