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VOLTAGE STABILITY ASSESSMENT OF POWER SYSTEM BY COMPARING LINE STABILITY INDICES

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***Abstract* –In planning and security assessment of power systems, voltage stability improvement is a challenging problem. The power demand is increasing by the consumers and we have power sources also restricted, so that the systems need to operate to its maximum ability. It is very important thing in voltage stability to find the maximum ability margin to voltage collapse point, So that an early notification can be received to avoid interruption of power system. This paper compares the several line stability indices. These voltage stability indices are used to identify the proximity of voltage instability and also give information about weak load buses. All these method has been implemented on IEEE 39 bus test systems, where their performances of these indicator is explored over both stable and unstable region, by varying the load at a particular bus and gradually increasing the load in all load buses. So that essential control activity can be taken.**

***Index terms* - line voltage stability, voltage collapse, fast voltage stability index, voltage collapse proximity index**

I. INTRODUCTION:

DUE to increase in demand for electricity and operation nearer to the stability limits. Hence it is necessary to improve system stability and security in modern power network. For that we need a regular control of the system stability and security in modern power network. For that regular control of the system status and fast identifying proximity to voltage collapse point is a significant requirement. This information will be useful for the operations to take action or automate control action to prevent voltage collapse. Many methods and techniques are available for voltage stability analysis. Some of these methods are based on PQ and QV curve [1], Modal analysis [2], Singular value decomposition [3], Sensitivity method [4] and Continuous power flow [5].

On other hand, numbers of static voltage stability indices are widely used for identifying the voltage instability. These methods grouped into two types. Bus voltage indices are used to identify weakest bus in system such as L index [6], Voltage Stability index (VSI) [7], improved VSI [8]. In case of line indices are used to identify the most critical line like Fast VSI [9], Line stability (L_{mn}) [10], Voltage Collapse Proximity Indicator (VCPI) [11] and the Line voltage factor (L_{qp}) [12].

II. PROPOSED METHOD

The most traditional method is PV & QV curve. In this method, when system load increases gradually, necessary recalculate power flow until the nose of PV curve reach. The distance between the voltage collapse and the current operating point is used as voltage stability criterion [13], [17]. But this method requires a lot of computations for large complex network. From the QV curve method, operators can identify maximum reactive power that can be removed or added to weak bus before reaching voltage instability limit. The problem in QV curve is not known which buses of the curve to be generate. When load increase in one bus nearby buses also will be in stressed so results may misleading. Some method depend on the power flow jacobian matrix minimum magnitude of the Eigen value and minimum singular value of jacobian matrix have been used as an indicator of voltage stability [14]-[15]. These indices are not accurately estimate the collapse point because they indicate a very non-linear character near that point.

In this VQ sensitivity method, whether system is stable or unstable can be identified. Because of the non-linear nature of the VQ relation, the magnitudes of VQ sensitivity

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for various system situations do not furnish a direct measure of the proportionate degree of stability. Continuation power flow was taking up as a static voltage restraint in multi contingency model. These methods are moderately accurate but frustrate by taking longer computational time. Jacobian matrix based voltage stability indicator can calculate the maximum loadability limit or voltage collapse point but more amount of computing time will be taken, so they are not suitable for on-line assessment. System variables based Voltage stability bus indices use the parameters of the admittance matrix and system variable like bus voltage or power flow through lines, requires less calculation and therefore suitable for online. It gives better results in transmission radial network than in interconnected networks. System variable based voltage stability line indices are easy to calculate, small computational cost, and good for control purposes [18]-[22]. This type identifies weakest line in the network. By ranking critical line, we can judge in which place we can connect FACTS controllers. Christo Ananth et al.[16] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

This work is focused on different line stability method will be highlighted and results obtain from simulating on IEEE 39 bus bar test system will be discussed.

III. VOLTAGE STABILITY INDICES FORMULATION

In this paper five different types of line stability L_{mn} index, Fast voltage stability indices (FVSI), L_{qp} index, Voltage collapse proximity index (VCPI power) and voltage collapse proximity index(VCPI losses) are implemented and calculation are performed by using MATLAB.

A. Line stability index (L_{mn})

A single line in an interconnected network is shown below in Fig [1]

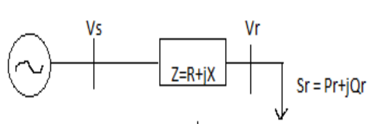

Fig [1] Single line diagram of transmission line

The line stability (L_{mn}) can be reproduced as in equation (1)

$$L_{mn} = \frac{4Q_r X}{[V_s \sin(\theta-\delta)]^2} \quad (1)$$

Where, V_s and V_r are the sending and receiving end voltages respectively. δ_s and δ_r are the phase angle at sending and receiving buses.

$$\delta = \delta_s - \delta_r$$

Z- line impedance; R-line resistance; X-line reactance; θ-line impedance angle; P_r-active power at receiving end; Q_r-reactive power at receiving end. The line of L_{mn} index is nearer to 1, gives the information that corresponding line close to their instability. To maintain secure system, all the line value of L_{mn} index should be bring to less than one.

B. Fast voltage stability index (FVSI)

The Fast voltage stability index, (FVSI) proposed in [17] is based on a concept of power flow through a single line. The voltage stability index is calculated for the interconnected transmission line by (2)

$$FVSI = \frac{4 Z^2 Q_r}{V_r^2 X} \quad (2)$$

Where, Z - Line impedance; X - Line reactance; Q_j - Reactive power flow at receiving end; V_i - Sending end voltage. The line of FVSI index approaching unity indicates instability. There is any sudden voltage drop system will lead to collapse indicated by FVSI index reaches unity.

C. Line stability factor (L_{qp})

The L_{QP} index is obtained using the same concept as (1) and (2).

$$L_{QP} = 4\left(\frac{X}{V_r^2}\right)\left(\frac{X}{V_r^2}P_r^2 + Q_r\right) \quad (3)$$

Where, X - Line reactance; P_i - Active power at receiving end; Q_j - Reactive power flow at receiving end; V_i - Sending end voltage. L_{qp} index value should be maintained less than unity for a secure operation.

D. Voltage collapse proximity indicators(VCPI)

Voltage collapse point indicators (VCPI) proposed in reference [11] are based on the concept of maximum power transferred through a line.

$$VCPI(power) = \frac{P_r}{P_{rmax}} \quad (4)$$

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$$VCPI(loss) = \frac{Q_r}{Q_{rmax}} \quad (5)$$

The maximum power ($P_{r\,(max)}$ and $Q_{r\,(max)}$) at receiving end can be obtained from the equation (6) and (7)

$$P_{r(max)} = \left(\frac{V_S^2}{Z}\right)\left(\frac{cos\phi}{4\,cos^2\left(\frac{\theta-\phi}{2}\right)}\right) \quad (6)$$

$$Q_{r(max)} = \left(\frac{V_S^2}{Z}\right)\left(\frac{sin\,\phi}{4\,cos^2\left(\frac{\theta-\phi}{2}\right)}\right) \quad (7)$$

The values of VCPI (power) and VCPI (losses) increases slowly when power flow through transmission line increases. When the power flow reaches maximum value of VCPI will be unity, the voltage collapse occurs. The VCPI values varies from zero (no load condition) to unity (voltage collapse).The value of power flow transferred by transmission lines increases, the value of VCPI (power) and VCPI (losses) also increases. When the index reaches unity system will be collapse. The value of VCPI varies from zero (no-load condition) to unity (voltage collapse).

IV. RESULT AND DISCUSSION

To check and identify the effectualness and the achievement of the proposed method, the standard IEEE 39 bus as shown in Fig [2] are used as the test systems. In IEEE 39 bus have 10 generators, 30 load buses and 46 transmission lines.

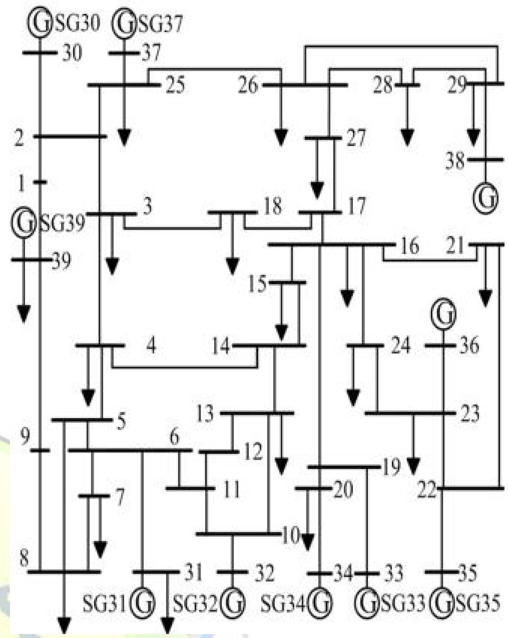

Fig [2] IEEE 39 bus test network

Using MATLAB, the results was carried out. In this simulation, to investigate the effect of reactive loading on five indices three load buses are chosen randomly. The reactive load at buses 26, 23 and 6 are increased gradually from the base case till their maximum loadability. Each and every load increases, L_{mn} index, FVSI index, L_{qp} index, VCPI (power) and VCPI (loss) were calculated for each line. With respect to increase in load, line with the highest index will be treated as the critical line. Any further increase in load will make the line to have index greater than unity and will result the whole system to an unstable condition. The different voltage system indices have been manipulated for the system under base case loading and its values are shown in Table [1].

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TABLE [1]
Line stability indices for IEEE39 bus test system with base case loading

Load (pu)	Line	L_{mn}	FVSI	L_{qp}	VCPI (power)	VCPI (loss)
Q26 =0.058	26-27	0.036	0.058	0.032	0.068	0.068
	26-28	0.013	0.023	0.014	0.022	0.022
	26-29	0.03	0.019	0.016	0.021	0.021
	26-25	0.015	0.022	0.017	0.025	0.025
Q23 = 0.05	23-36	0.032	0.055	0.025	0.051	0.051
	23-22	0.022	0.013	0.023	0.014	0.014
	23-24	0.023	0.015	0.021	0.016	0.016
Q 6 = 0.01	6-31	0.012	0.014	0.022	0.015	0.015
	6-11	0.014	0.012	0.024	0.013	0.013
	6-7	0.015	0.01	0.021	0.011	0.011
	6-5	0.011	0.012	0.022	0.014	0.014

Fig [3] shows the critical lines of the IEEE 39 bus test system for the line stability (L_{mn}). For example, the line between buses no 6 to 31 is most critical line referred to bus no 6. Same way line between buses 23 & 31 and 26 &27 is most critical lines of bus 23 and 26.

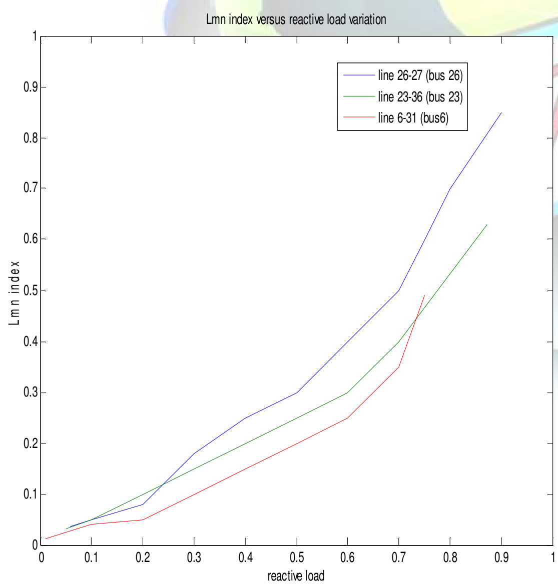

Fig [3] L_{mn} versus reactive load variation for IEEE 39 bus test system.

Fig [4] shows the critical lines of the IEEE 39 bus test system for the Fast voltage stability index (FVSI).

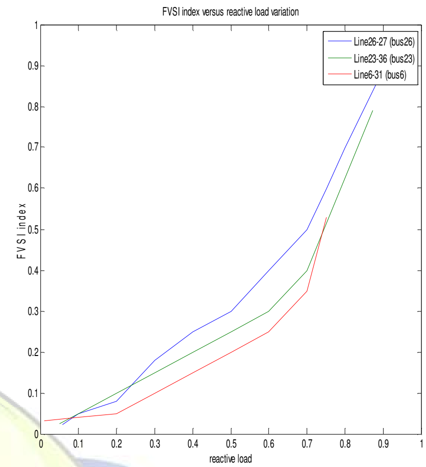

Fig [4] FVSI index versus reactive load variation for IEEE 39 bus test system.

Fig [5] shows the critical lines of the IEEE39 bus test system for the line stability factor (L_{qp}).

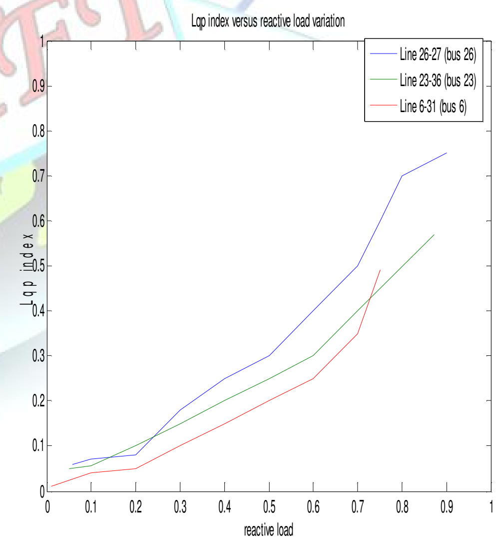

Fig [5] L_{qp} index versus reactive load variation for IEEE 39 bus test system.

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Fig [6] shows the critical lines of the IEEE 39 bus test system for the Voltage collapse point indicator (VCPI (power)).

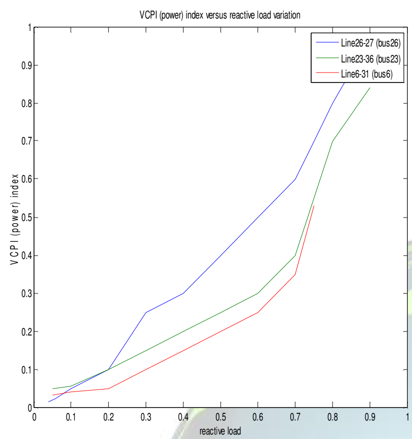

Fig [6] VCPI (power) index versus reactive load variation for IEEE 39 bus test system.

Fig [7] shows the critical lines of the IEEE 39 bus test system for the Voltage collapse point indicator (VCPI (loss)).

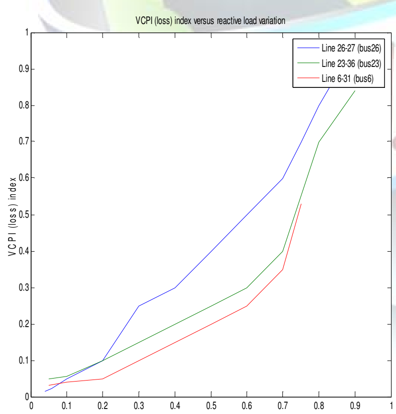

Fig [7] VCPI(loss) index versus reactive load variation for IEEE 39 bus test system.

The maximum permissible reactive load applied to particular three buses and corresponding to all line stability indices is calculated shown in table 2. From the table 2 line 26-27 at 26 bus is the most critical line as the result are shown as per different types of line indices. In this comparison it shows away that VCPI index show closest to unity at point of bifurcation. Same load condition, FVSI, L_{mn} index gives consistent result, but L_{qp} index find to be much lesser with other methods. Also same way line 23-36 at bus 23 is most critical line as it gives highest value of indices for given load ability of bus.

TABLE [2]
Line stability indices for IEEE39 bus test system with heavy loading condition

Load (pu)	Line	L_{mn}	FVSI	L_{qp}	VCPI (power)	VCPI (loss)
Q26= 0.957	26-27	0.82	0.89	0.76	0.968	0.968
	26-28	0.74	0.83	0.72	0.86	0.86
	26-29	0.64	0.75	0.63	0.85	0.85
	26-25	0.65	0.76	0.66	0.83	0.83
Q23= 0.872	23-36	0.63	0.79	0.57	0.84	0.84
	23-22	0.68	0.73	0.64	0.73	0.73
	23-24	0.61	0.66	0.59	0.67	0.67
Q6 = 0.738	6-31	0.49	0.53	0.44	0.54	0.54
	6-11	0.57	0.64	0.48	0.67	0.67
	6-7	0.48	0.54	0.45	0.58	0.58
	6-5	0.46	0.57	0.45	0.64	0.64

Using line stability indices weak bus in the system also identifies by consider the maximum load at particular bus. As a result, the bus 26 has smallest maximum loadability; it is review to be critical unstable bus.

V. CONCLUSION

The simulation results of IEEE 39 bus test system exhibit the workability and successfulness of the line stability indices. Using this method it was determine that critical line with respect to weak bus of the system. The simulation results indicate that bus 26 is observed to be a weakest bus. In this paper compares the different line stability indices and gives the information that VCPI performance is best then by following methods FVSI, L_{mn} and last is L_{qp} index. In future work, using optimization techniques calculate reactive power to be injected to bring back to stable condition.

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