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Prediction of Voltage Stability by Using L – Index in Power System

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Abstract—The prediction of voltage stability experiences sizable anxiety in the safe operation of power system. As power systems grow in their size and interconnections, their complexity increases. Hence, power system voltage stability and voltage control are emerging as major problems in the day to day operation of stressed power system. In this paper investigation of voltage stability index for voltage stability assessment has been discussed. At a normal operating condition L- index gives information about system state. There are so many indicators which predict the system condition. The objective of this paper is to develop a fast and simple method, which can be applied in the power system to estimate the voltage stability margin. Thereby an indicator is derived from the static power flow and Kirchhoff's-Laws, which is aimed at detection of the voltage instability. This voltage stability index can work well in the static state as well as during dynamic process. It can also be used to find the vulnerable spots of the system. IEEE-14 bus system is used for test set.

Keywords- *Voltage stability, , Voltage collapse, voltage stability indicator, L-index.*

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I. INTRODUCTION

Voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all buses under normal conditions and after being subjected to a disturbance. The transmission networks need to be utilized ever more efficiently. The transfer capacity of an existing transmission network needs to be increased without major investments but also without compromising the security of the power system. System stability is a significant factor, which needs to be taken into consideration for the period of the development and operation of electrical power systems in order to avoid voltage collapse and subsequent incomplete or full system blackout. From the voltage stability analysis point of view, system operators need to know not only the harshness of their system but also the mechanism that reason voltage instability.

Voltage instability is mainly associated with the inability of the power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to disturbances such as gradual load increase or outages of critical lines or generating units. The general characteristic of voltage instability is that the voltage level at different locations slightly changes after the disturbance but abruptly declines near to the collapse point. The system operator needs performance indices either in on-line or off-line modes to determine how close the system is to the collapse point and what the control actions should be carried out in that event[1].

Power system stability is essentially the capability of the power system to maintain equilibrium with system variables in an acceptable range after being subjected to a wide range of disturbances no matter how small or large. The size of the disturbance influences the method of analysis and prediction of the stability. The L-index gives sufficiently accurate as well as practical means of the assessment, and can express the stability analysis in simple and operator friendly way.Here, for assessment of voltage stability; IEEE 14 bus test set is being used. The most critical bus of the system is identified by running the power flow with NR method using MATLAB.

II. VOLTAGE STABILITY INDICATORS

A. Voltage Stability Index

System operators would always like to know how far the network is from voltage collapse point for smooth and reliable operation of power system. Voltage stability index is formulated which assess the state of a distribution system from the view point voltage collapse [4]. It is based on a simple solution of quadratic equation r_1+jx_1 between bus i and bus i+1 of the radial distribution system may be represented by an equivalent circuit model as shown in fig.[1].

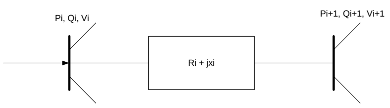

Figure 1. Voltage Stability Index.

$$L_i = \frac{4\sqrt{((P_{i+1}^2 + Q_{i+1}^2)(r_i^2 + x_i^2))}}{V_i^2} \le 1$$

The system is closed to the voltage collapse when the value of voltage stability index approaches unity. On the other hand, more the value of the indicator close to zero, the system is more stable. Any interconnected network can be reduced to an equivalent two bus network by keeping the sending end voltage constant and considering Ps and Qs as total and reactive power generation respectively connected with receiving end active and reactive load, P_R and Q_R respectively by an equivalent

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impedance of $r_{eq}+j_{eq}$. Voltage stability level of the interconnected system can be measured using proposed VSI and thereby appropriate action may be taken if the value of index would become nearer to unity [4, 5].

B. Fast Voltage Stability Index

Fast voltage stability index (FVSI) is formulated in this study as the measuring instrument in predicting the voltage stability condition in the system [4]. The proposed index made used the same concept as the existing ones (Moghavemmi and Omar, 1998 and Mohamed et al., 1989) in which discriminate is set to be greater or equal than/to zero to achieve stability. The mathematical formulation is very simple that could speed up the computation. The condition of voltage stability in a power system can be characterized by the use of voltage stability index referred to line. The value of FVSI that is evaluated close to 1.00 indicates that the particular line is closed to its instability point which may lead to voltage collapse in the entire system. To maintain a secure condition the value of FVSl should be maintained well less than 1.00. The quadratic equation for the receiving bus is given by

$$FVSI = \frac{4Z^2 Q_j}{V_i^2 X}$$

C. Voltage Stability L – index

The L – index is a quantitative measure for the estimation of the distance of the actual state of the system to the stability limit. The value of L – index is computed for each load bus in the system. The L – index varies in a range between 0 (no load) and 1 (voltage collapse). Considering a system where N_B is total number of buses, with N_{PV} generator bus and N_{PQ} remaining load buses [8]. By using the load flow results, the L-index is computed as…

$$VSEI = L - index = \max\left\{ L_j = \left| 1 - \sum_{i=1}^{N_{PV}} F_{ji} \frac{V_i}{V_j} \right|, j \in N_{PQ} \right\}$$

The value F_{ji} are the elements of sub matrix F_{LG} as obtained from Y-bus matrix.

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

Where $[I_G]$, $[I_L]$ and $[V_G]$, $[V_L]$ represents the complex currents and bus voltages respectively; where $[Y_{GG}]$, $[Y_{GL}]$, $[Y_{LG}]$ and $[Y_{LL}]$ are corresponding portion of network Y-bus matrix.

III. Case Study

A single line diagram of the IEEE 14-bus standard system extracted from [9]. It consist of five synchronous machines, two of them are providing both active and reactive power at bus 1 and 2. The other generator at bus 3, 6 and 8 are basically synchronous condensers; the base total loading level of the system is 259 MW and 73.5 MVar.

IV. RESULTS AND DISCUSSION

The L-index varies in the range of 0 (for no load) to 1 (voltage collapse point). The index was implemented using MATLAB. Results are obtained for IEEE14-bus.Table-1 shows results for base case of IEEE14-bus test set are as follows:

Table-1: Base case

Bus no.	L - index
4	0.0297
5	0.0202
7	0.0377
9	0.0664
10	0.0634
11	0.0361
12	0.0239
13	0.0318
14	0.0768

It can be seen from table that the order of the worst load buses with the largest L-indices. Now the load is increased and different values of the L-indices are derived. Similarly different buses are given load individually and L-index results are tabulated.

Table: 2 Change in L-index at various buses for Load Variation at Bus 4

Bus No.	Base Case	Plus 10%	Plus 20%	Minus 10%	Minus 20%
4	0.0297	0.0317	0.0337	0.0277	0.0257
5	0.0202	0.0215	0.0227	0.019	0.0178
7	0.0377	0.0385	0.0394	0.0368	0.036
9	0.0664	0.0673	0.0681	0.0656	0.0647
10	0.0634	0.0641	0.0648	0.0627	0.062
11	0.0361	0.0364	0.0368	0.0357	0.0354
12	0.0239	0.0239	0.024	0.0238	0.0238
13	0.0318	0.0319	0.032	0.0317	0.0316
14	0.0768	0.0773	0.0778	0.0762	0.0757
Max.	*0.0768*	*0.0773*	*0.0778*	*0.0762*	*0.0757*

Table: 3 Change in L-index at various buses for Load Variation at Bus **5**

Bus no.	Base case	Plus 10%	Plus 20%	Minus 10%	Minus 20%
4	0.0297	0.0299	0.0301	0.0295	0.0293
5	*0.0202*	*0.0206*	*0.0209*	0.0199	0.0196
7	0.0377	0.0377	0.0378	0.0376	0.0375

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9	0.0664	0.0665	0.0666	0.0664	0.0663
10	0.0634	0.0634	0.0635	0.0633	0.0632
11	0.0361	0.0361	0.0361	0.036	0.036
12	0.0239	0.0239	0.0239	0.0239	0.0239
13	0.0318	0.0318	0.0318	0.0318	0.0318
14	0.0768	0.0768	0.0769	0.0767	0.0767
Max.	*0.0768*	*0.0768*	*0.0769*	*0.0767*	*0.0767*
L-max Bus no.	14	14	14	14	14

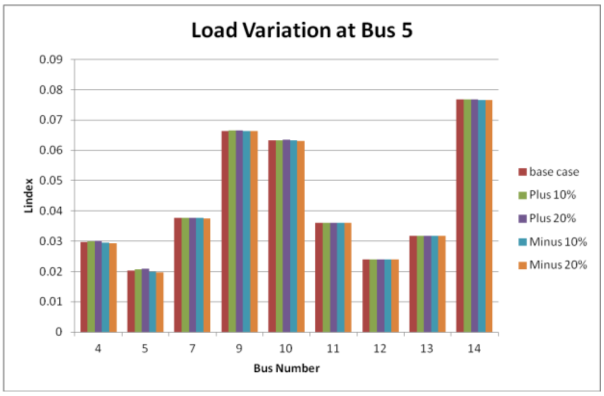

Figure 2. L-index at various buses for Load Variation at Bus 5.

Figure 2 shows the variation in L-index of different buses with respect to base case and load variation at bus no. 5. It is clearly observed that bus number 14 is the weakest bus in the system.

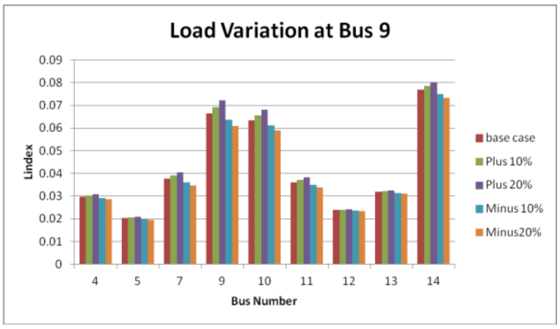

Figure 3. L-index at various buses for Load Variation at Bus 9.

The variation in L-index of different buses with respect to base case and load variation at bus no. 9 is shown in fig.3.

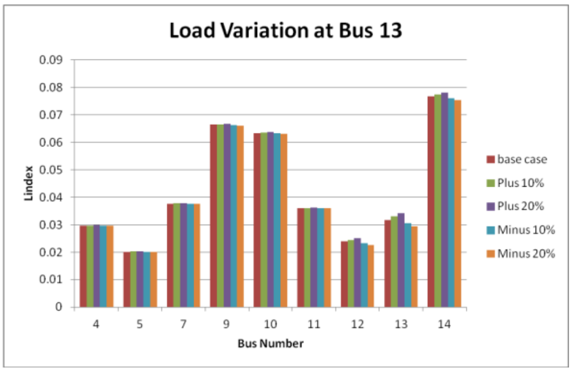

Figure 4. L-index at various buses for Load Variation at Bus 13.

Fig.4 shows the variation in L-index of different buses with respect to base case and load variation at bus no. 13.

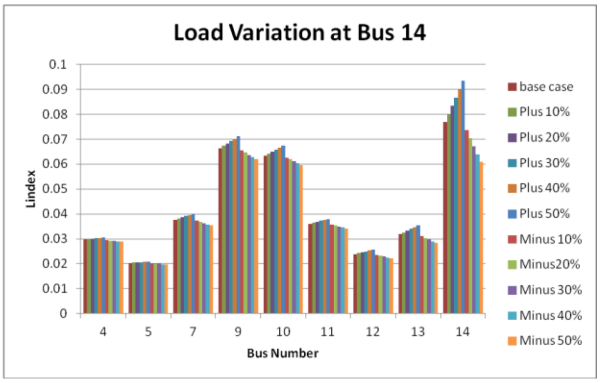

Figure 5. L-index at various buses for Load Variation at Bus 14

The variation in L-index of different buses with respect to load variation at bus number 14 is shown Fig. 5. It is clearly observed that bus number 14 is the weakest bus in the system.

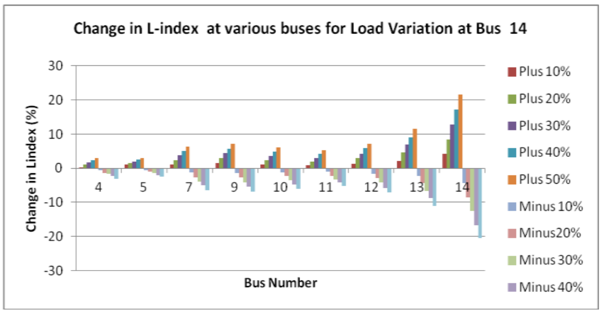

Figure 6. % Change in L-index at various buses for Load Variation at Bus 14

Fig. 6 shows the % variation in L-index of different buses with respect to base case value and load variation at bus number 14.

Bus no	Base case	Increasing load at all load buses simultaneously				
		+10%	+20%	+30%	+40%	+50%
4	0.0297	0.0328	0.0359	0.0391	0.0423	0.0456
5	0.0202	0.0224	0.0245	0.0266	0.0288	0.031
7	0.0377	0.0411	0.0446	0.0481	0.0517	0.0553

9	0.0664	0.0722	0.0782	0.0842	0.0904	0.0966
10	0.0634	0.0689	0.0744	0.0801	0.0859	0.0918
11	0.0361	0.0391	0.0423	0.0455	0.0487	0.052
12	0.0239	0.026	0.0282	0.0305	0.0327	0.035
13	0.0318	0.0347	0.0376	0.0405	0.0435	0.0465
14	0.0768	0.0837	0.0909	0.0981	0.1055	0.1131

Table: 4 Change in L-index at various buses for increasing load at all load buses simultaneously.

Table 4 shows the variation in L-index of different buses when all the load buses suffer from gradual incremental in load. It is clearly observed in this case that bus number 14 is the weakest bus in the system. From above all various loading strategy bus number 14 is found as the weakest bus in the system.

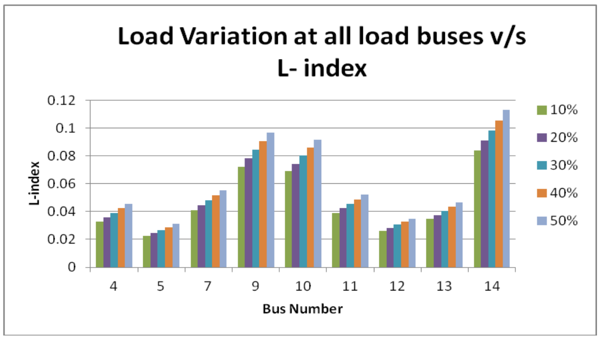

Fig. 7 Change in L-index when Load Variation at all Buses

V. CONCLUSION

This work has discussed the formulation of L-index. The higher values for L-indices are indicative of most critical buses and thus maximum of L-indices is an indicator of proximity in the system to represent voltage collapse. Results were carried out on IEEE 14-bus system. The voltage stability index, L-index is simple to compute and it provides a quantitative means to review the voltage stability of the system at any given operating point. Voltage stability indices are calculated and voltage instability is observed for various loading conditions. When the system voltage is stable, these indices are close to zero and when move towards 1 as system is gradually moving towards critical point. Using L-index, the weakest bus is identified. Performance evaluation is carried out under different loading conditions using MATLAB.

VI. FUTURE SCOPE

This work is useful for static voltage stability analysis. Future work can be done on dynamic voltage stability analysis by considering generator dynamics and dynamic load model. The improvement in voltage stability by various reactive power compensation devices can be observed.

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