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Identification of Critical Lines in a Power System Using a New Line Based Voltage Stability Index (NLBVSI)

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Abstract:
Now a days the power demand on the power system is increasing day by day. Hence, the power systems are operating at their maximum loadability limits due to limited power sources available. In other words it can be said that the power systems are operating under stressed conditions. Due to the above scenario the problem of maintaining voltage stability become a major issue. For stable operation of power systems, continuous monitoring of voltage stability is required. This paper presents a new line based voltage stability index for continuous monitoring of voltage stability. Critical transmission lines and proximity of voltage instability in a power system is identified using the above index.The proposed work is demonstrated on IEEE 14 and 30 bus systems. The results are compared with existing indices for showing its accuracy. All the simulations in this work are carried out through MATLAB 2014a.

Keywords: ***voltage stability analysis, voltage collapse, NLBVSI, FVSI, Lmn, critical line.***

1. INTRODUCTION:

The increase in power demand has forced the power system network to operate closed to its stability limit. This phenomenon is continuously becoming an issue which requires a voltage stability analysis to be properly conducted especially at the planning stage. According to Cutsem [4], voltage stability is defined as the characteristic for a power system to remain in a state of equilibrium' at normal operating conditions and to restore an acceptable state of equilibrium after a disturbance. It is generally categorized into two categories namely the dynamic and static. The static voltage stability analysis is widely accepted in the foregoing papers although the dynamic voltage instability has been the one that causes a lot of interruptions. The reason being is that, the dynamic analysis dealt with the non-linear load and rather difficult to model them. Static voltage stability analysis is conducted by assuming the system is operating in the steady state [5].

Several articles have been published in the literature in the area of voltage stability using Single Line Power Flow (SLPF) concept[2]. Moghavvemi et al. derived a line stability index (L*mn*) [6],Musirin et al. proposed a Fast Voltage Stability Index (FVSI) [1], using the same concept as L*mn*. Mohamed et al. developed the line stability factor (L*QP*) [7].Based on the maximum power and power loss in a line, Moghavvemi et al. derived four Voltage Collapse Proximity Indicators [8]. Line Voltage reactive power index (VQI*line*) [9] was developed by Althowibi et al. and Kanimozhi et al. derived an index NVSI for line voltage stability estimation [10]. In some of the above indices, the effect of active power change, angle difference between two buses and shunt components of the lines are neglected but not all these effects in a single through in single index.

This paper presents a new line based voltage stability index (NLBVSI) for assessment of voltage stability and it is derived based on the concept of single line power

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flow (SLPF). This index includes the effect of shunts which are neglected in most of the indices and effect of angle between two buses. The proposed index is tested on three standard IEEE test systems [12] and compared with some existing indices.

2. PRPOSED INDEX FORMULATION:

Considering limitations of existing voltage stability indices, a New Line Based Voltage Stability Index *(NLBVSI)* is proposed to assess the voltage stability of the power systems. The proposed index is derived from a voltage quadratic equation. The proposed index is based upon *ABCD* parameters of transmission line which include line charging capacitance and resistance of line that are neglected by existing voltage stability indices and the angle between two buses is also included. Therefore, the proposed index assesses the voltage sensitivity precisely under all the conditions and indicates the closeness of the system to voltage collapse point. From the fig.1 the receiving end power equation can be written as

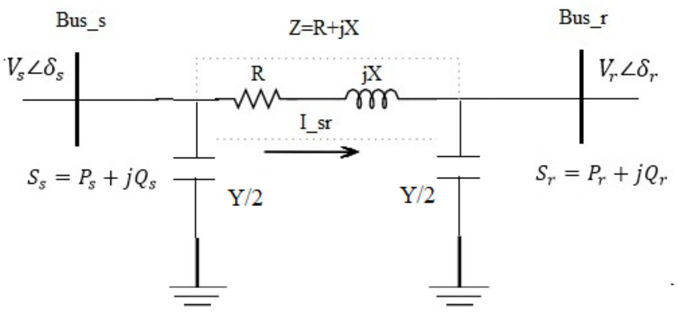

Fig.1 : single line diagram of pi section transmission line

$$S_r = V_r I_r^* \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

But, the sending end voltage/current of a line can be related to receiving end voltage/current using *ABCD* parameters in the following way

$$V_s = AV_r + BI_r \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$I_s = CV_r + DI_r \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Here,

$$A = 1 + \frac{ZY}{2} = A\angle\alpha$$

$$B = Z = B\angle\beta$$

$$C = Y\left(1 + \frac{YZ}{4}\right)$$

$$D = A = 1 + \frac{ZY}{2}$$

From equation (2),

$$I_r = \frac{V_s - AV_r}{B} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

By substitute equation (4) in equation (1),

$$S_r = V_r\left(\frac{V_s - AV_r}{B}\right)^* \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

From equation (5), by comparing real and imaginary parts on both sides the active and reactive power components can be written as

$$P_r = \frac{V_s V_r \cos(\beta-\delta)}{B} - \frac{AV_r^2 \cos(\beta-\alpha)}{B} \quad \ldots..(6)$$

$$Q_r = \frac{V_s V_r \sin(\beta-\delta)}{B} - \frac{AV_r^2 \sin(\beta-\alpha)}{B} \quad \ldots\ldots..(7)$$

From equation (7), the voltage quadratic equation can be written as,

$$=> \; Q_r B = V_s V_r \sin(\beta-\delta) - AV_r^2 \sin(\beta-\alpha)$$

$$=> AV_r^2 \sin(\beta-\alpha) - V_s V_r \sin(\beta-\delta) + Q_r B = 0$$

To get the real roots for V_r, the discriminant is set greater than or equal to zero, i.e.

$$(V_s \sin(\beta-\delta))^2 - 4A\sin(\beta-\alpha)\, Q_r B \geq 0$$

$$=> (V_s \sin(\beta-\delta))^2 \geq 4ABQ_r \sin(\beta-\alpha)$$

$$\therefore \frac{4ABQ_r \sin(\beta-\alpha)}{(V_s \sin(\beta-\delta))^2} \leq 1$$

The proposed index is

$$NLBVSI = \frac{4ABQ_r \sin(\beta-\alpha)}{(V_s \sin(\beta-\delta))^2}$$

The line that exhibits NLBVSI closed to 1.00 impliesthat it is approaching its instability point. If NLBVSI goesbeyond 1.00, one of the buses to the connected to theline will experience a sudden voltage drop leading tosystem collapse.

3. SIMULATION RESULTS ANALYSIS:

The proposed index has been rigorously tested on IEEE 14-bus and IEEE 30-bus systems [11] under various operating conditions and the application results are compared with those obtained by indices *L mn*[6] , *FVSI* [1] . The N*LBVSI index* for different lines is computed under various operating and system conditions. The value of proposed index increases from zero towards unity. When the system is close to voltage collapse; the proposed index is close to 1. Lines whose index value is near to unity are termed as critical lines. Above this loading voltage collapse occurs. The test results for various operating and system conditions are presented in following section.

3.1 IEEE 14 bus system:

In this system weak bus is identified based on maximum loadability at a bus. According to [3] bus 14 is the weak bus. Both P and Q loads are changed randomly at that bus until one of the lines reached to one. From fig. 2 line 17 is the critical line which is connected between bus 9 and bus 14. From fig. 3 it is clear that proposed index showing its accuracy. Critical line bus voltages and angles are shown clearly in fig. 4 and 5 respectively.

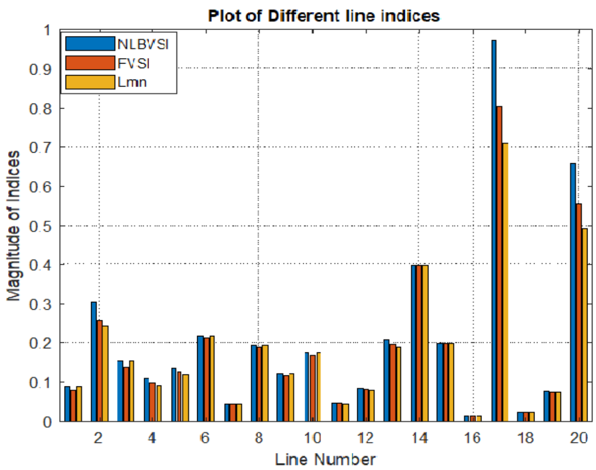

Fig. 2. Critical line identification graph

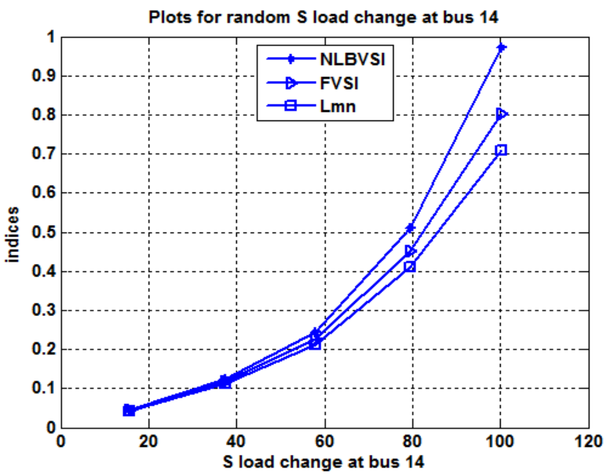

Fig. 3. Plot of different indices

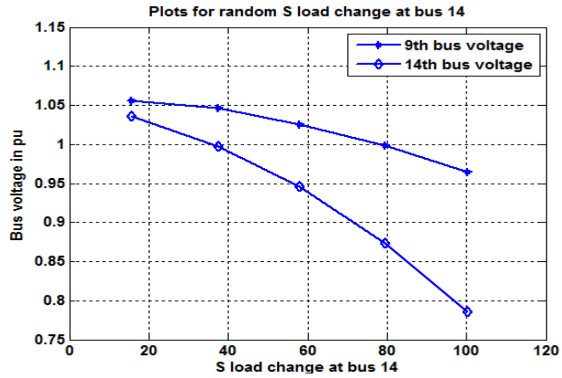

Fig. 4. Variation of critical line bus voltages.

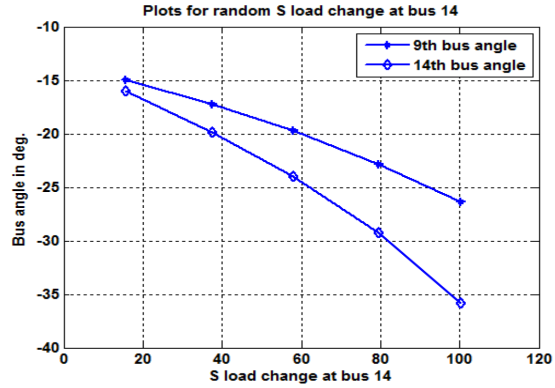

Fig. 5. Variation of critical line bus angles

3.2 IEEE 30 bus system:

In this system weak bus is identified based on maximum loadability at a bus. According to [3] bus 30 is the weak bus. Both P and Q loads are changed randomly at that bus until one of the lines reached to one. From fig. 6 line 38 is the critical line which is connected between bus 27 and bus 30. From fig. 7 it is clear that proposed index showing its accuracy. Critical line bus voltages and angles are shown clearly in fig. 8 and 9 respectively.

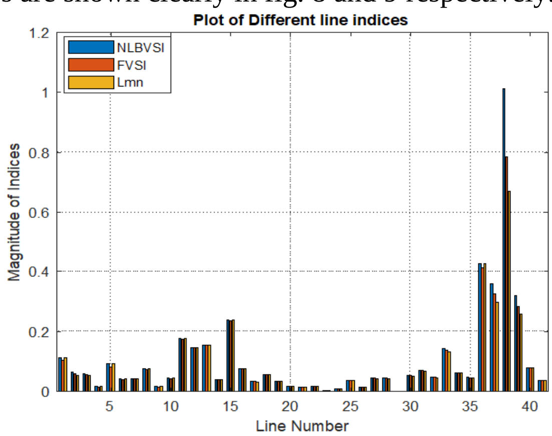

Fig .6. Critical line identification graph

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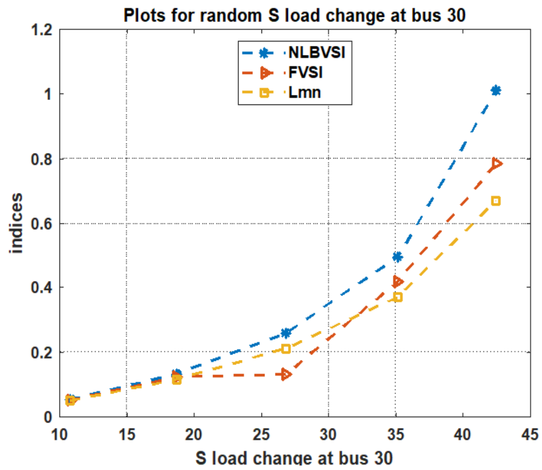

Fig. 7. Plot of different indices

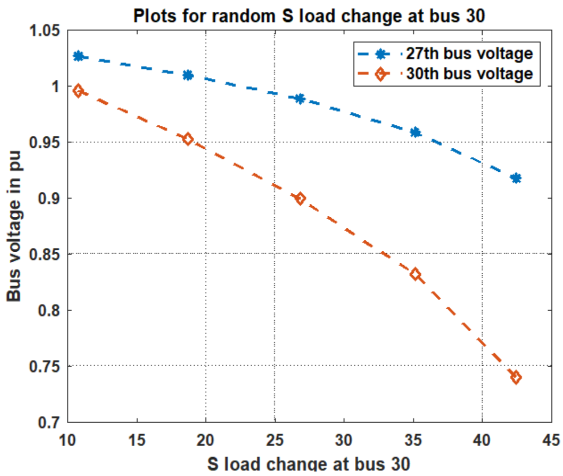

Fig. 8. Variation of critical line bus voltages.

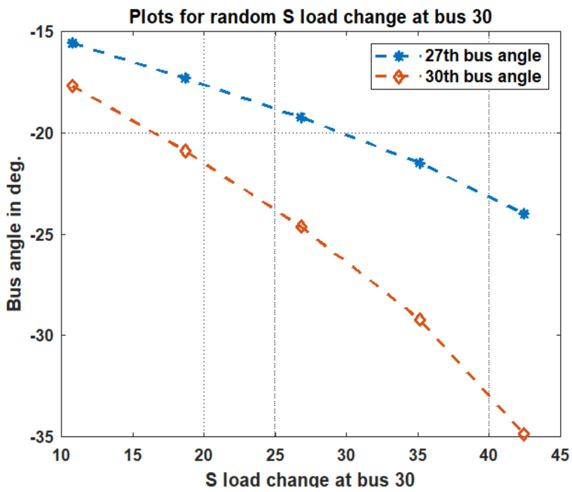

Fig. 9. Variation of critical line bus angles

4. CONCLUSION:

A New Line Based Voltage Stability Index (NLBVSI) is proposed in this work. This index is tested on two standard IEEE test systems. The obtained results are compared with existing indices and from the results it can be concluded that the proposed index is more effective than remaining indices. This is due to the fact, that the proposed index is based upon transmission line parameters; therefore it accounts line charging capacitances and resistances which is normally neglected by many voltage stability indices.

5. References:

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APPENDIX:

Standard IEEE bus test systems data is taken from [12], Newton Raphson load flow method in rectangular co-ordinates is used for load flow analysis.

Fast Voltage Stability Index:

$$FVSI = \frac{4Z^2 Q_r}{V_s^2 X}$$

Lmn:

$$L_{mn} = \frac{4XQ_r}{(V_s \sin(\theta - \delta))^2}$$

Where, Z = line impedance, Qr= reactive power available at receiving end bus, X= line reactance, Vs= sending end bus voltage, $\boldsymbol{\theta}$ = impedance angle, δ = angle between two buses of a line.