A Novel Line Stability Index (NLSI) for Voltage Stability Assessment of Power Systems

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Abstract: - The management of power systems has become more difficult than earlier because power systems are operated closer to security limits, environmental constraints restrict the expansion of transmission network, the need for long distance power transfer has increased and fewer operators are engaged in the supervision and operation of power systems. Voltage stability has become a major concern in many power systems and many blackouts have been reported, where the reason has been voltage instability.

This paper presents a novel line stability index (NLSI) referred to a line initiated from the voltage quadratic equation at the sending and resaving end of a representation of a 2-bus system. The line index in the inter-connected system in which the value that is closed to one indicates that the line has reached its instability limit which could cause sudden voltage drop to the corresponding bus caused by the active and reactive load variation. The proposed index consider both active and reactive power to investigate the voltage stability because this index provides more precise results than those which consider only reactive power. To indicate the ability of proposed index, NEW ENGLAND 30 bus is utilized and simulation results show good conformity with the other stability index that proposed in literature.

Key-Words: - Voltage stability index, Maximum permissible load, NLSI factor.

1 Introduction

Although power production, transmission and distribution are unbundled there still exist common interests for these companies: power system adequacy and security. The adequacy of production and transmission capacity is maintained in the long-term and is related to power system planning. The security of power system is a mandatory public good necessary for confidence in the power market. In order to maintain a secure system, the system operator needs to have at his disposal various services called ancillary services from generation and major customers.

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. The more efficient use of transmission network has already led to situation in which many power systems are operated more often and longer close 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.

Methods to understand the voltage instability phenomenon and quantify the stability indices have been reported in works [1, 2, 3, 4, and 5]. In [6] a voltage instability phenomenon and quantify the stability indices has been discussed whose value changes between zero (no load) and one (voltage collapse). The indicator incorporates the effect of all other loads in the system on the evaluation of index at individual load buses. The overall voltage stability of the system could be identified by the largest value of the index evaluated amongst all the load buses. This indicator can also be used as a normalized quantitative measure, for estimation of the voltage stability margin from operating point. Another method have been proposed in conducting the voltage stability analysis such as the P-V and Q-V curves, modal analysis[7], artificial neural networks [8], neuro-fuzzy networks [9], reduced Jacobian determinant, energy function methods[10] and sensitivity analysis [11]. Line stability indices [12, 13] can be used to evaluate the on-line voltage stability condition since they can be evaluated without having to turn off the generators.

This paper presents the development of a novel line stability index (NLSI) referred to a line which is capable in determining the point of voltage collapse, weak bus in the system and the most critical line in an inter-connected system. The direction of voltage and index profile was studied by increasing the active and reactive power until the load flow solution fails to give any results. NLSI was calculated for each line in the system as active and reactive load increased. The calculated NLSI could be used in determining the weakest bus and criticalness.

2 DERIVATION OF VOLTAGE STABILITY INDEX

Voltage stability and contingency analyses are two important procedures to be conducted especially, when voltage security assessment is discussed. Although voltage stability can be categorized in to two namely static and dynamic; however, static voltage stability analysis is commonly performed on a system and the results are indicative in determining the voltage stability condition of a system. In this research, static voltage stability and contingency analyses are performed based on the line voltage stability index termed as NVSI.

The mathematical formulation for the voltage stability index is derived by first obtaining the current equation through a line in a 2 bus system. Fig.1 illustrates the two-bus power system model.

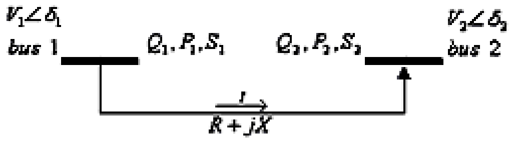

Fig. 1: two bus power system model

From the figure and taking bus 1 as the sending bus and bus 2 as the receiving bus we have these definitions as follows:

By choosing the sending bus as the reference ($\delta_1 = 0, \delta_2 = \delta$), then the power equation at bus 2 is as follows;

$$S_2 = V_2 \times I^* \quad (1)$$

The quantity of I given by;

$$I = \frac{V_1\angle 0 - V_2\angle\delta}{R + jX} \quad (2)$$

Where, V_1, V_2 are the voltages of the sending and receiving buses respectively. R, X are resistance and reactance of line respectively.

With substituting equation (2) in equation (1) we can obtain these following equations;

$$V_1V_2 \sin\delta - RQ_2 + XP_2 = 0 \quad (3)$$

$$V_2^2 - V_1V_2\cos\delta + RP_2 + XQ_2 = 0 \quad (4)$$

The quadratic equation for the receiving bus is given by;

$$V_2 = \frac{V_1\cos\delta \pm \sqrt{V_1^2\cos^2\delta - 4(P_2R + Q_2X)}}{2} \quad (5)$$

Where, P_1, Q_1 are the active and reactive power at the sending buses respectively. P_2, Q_2 are the active and reactive power at the receiving buses. δ is angle difference between the sending and receiving buses.

To obtain real value for V_2, the discriminate of equation (5) must be grater than or equal to zero. There for we can obtain this statement;

$$\frac{PR + QX}{0.25V_1^2\cos^2\delta} \le 1 \quad (6)$$

Since the difference in the angle between the sending bus and the receiving bus δ, is normally very small, therefore,

$\cos\delta \approx 1$

Taking the i as the sending bus and the j as the receiving bus, the novel line stability index (NLSI) can be expressed as,

$$NLSI_{ij} = \frac{R_{ij}P_j + X_{ij}Q_j}{0.25V_i^2} \quad (7)$$

Where, R_{ij}, X_{ij} are the resistance and reactance between sending and receiving buses. Q_j, P_j are the reactive and active power at receiving bus. V_i is voltage at sending bus.

Any line in the system that exhibits NLSI closed to unity indicates that the line is approaching its stability limit hence may lead to system violation. Therefore, NLSI has to be maintained less than unity in order to maintain a stable system. To comprise the other methods with describe index that discussed above, some index which have been used for investigation of voltage stability by previous articles will be describe in the next section of this paper.

3 LINE STABILITE INDEX AND FACTOR

Mohamed, in reference [14] derive four line stability factor termed as LQP, LPP, LPN and LQN based on the power equation in a transmission system. LQP is chosen for comparison since it indicates the line voltage stability with respect to changes in reactive power. The expression for LQP is given by;

$$LQP = 4\left(\frac{X}{V_i^2}\right)\left(\frac{X}{V_i^2}P_i^2 + Q_j\right) \qquad (8)$$

LQP must also be maintained less unity to achieve system stability.

Also, the line stability indexes are another indexes which indicate voltage stability of a power system. Some of these kinds of indexes are mentioned as follows:

Moghavvemi [12] proposed a line stability index based on the power equation in a π model transmission system. The index is given by;

$$L_{mn} = \frac{4Q_r x}{\left[|V_s|\sin(\theta - \delta)\right]^2} \qquad (9)$$

L_{mn} has to be maintained less than unity to ensure a stable system.

In [16] fast voltage stability index (FVSI) is developed according to quadratic equation for a receiving bus in a power system. The index is given by;

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \qquad (10)$$

Any line in the system that exhibits FVSI closed to unity indicates that the line is approaching its stability limit. Therefore, FVSI has to be maintained less than unity in order to maintain a stable system.

3 Result and Discussion

In order to investigate the effect of increasing reactive power on NLSI factor and indicating the critical line, three buses are considered. The reactive power of bus 7, 15, 30 gradually increased from basis quantity until the load flow equation diverged. This is the maximum power that a bus can supply before voltage instability happened. NLSI for each line of system is obtained according to increase of load. The line that has largest index is introduced as the critical line. The voltage collapse happens if the index exceeds one as load increases. The curves show in Fig.2 to Fig.4 illustrate this phenomenon. This figures show voltage of each bus according to increase in reactive power of bus (also index of each line correspond to bus). For this simulation the limitation of reactive power in each power station has been considered. The largest value of NLSI indicates the most critical line. For example line 18 is the critical line that connects to bus 15. Consequently, for the bus 7 it is clear that line 2 is the most critical line. Also line 38 is the critical line of bus 30. According to horizontal axes of curves (reactive power) it could be deduced that the

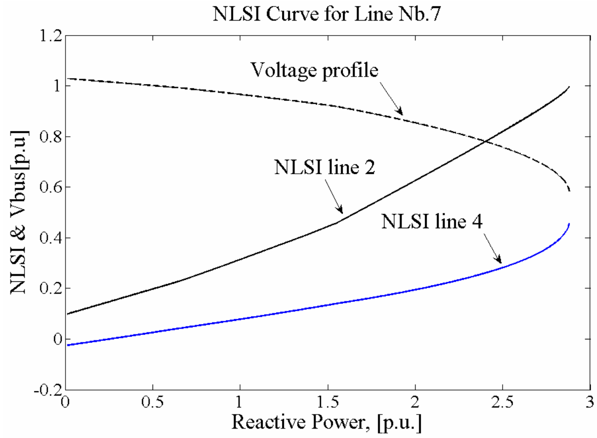

Fig. 2: voltage profile of 7 bus and NLSI index of its lines.

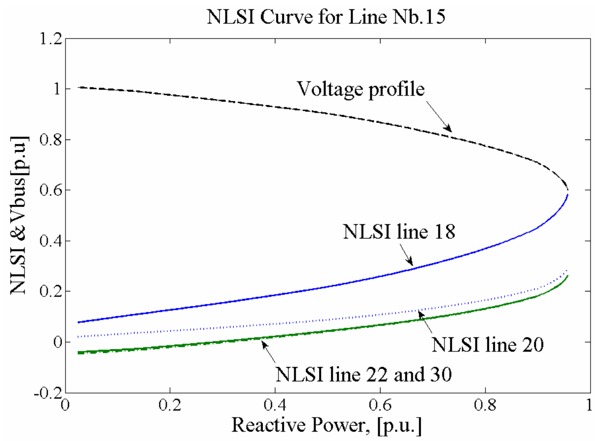

Fig. 3: voltage profile of 15 bus and NLSI index of its lines.

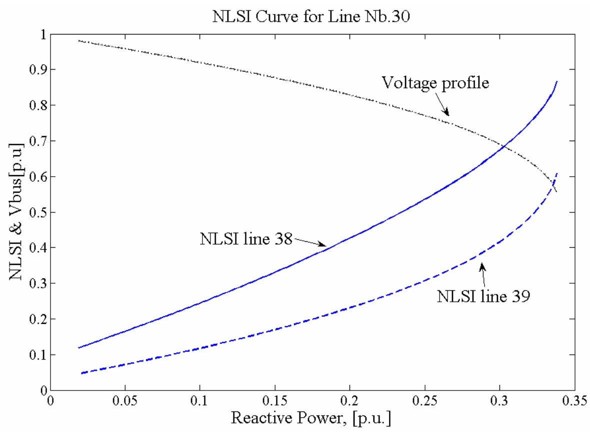

Fig. 4: voltage profile of 30 bus and NLSI index of its lines.

maximum increase power for bus 7, 15 and 30 before voltage collapse happens, are 2.88 p.u, 0.9575 p.u and 0.3397 p.u respectively. As can be seen, by increasing the reactive power than the cited values, the NLSI index exceeds one. So the power system fell into the voltage collapse.

In order to provide a comparative study the stability of power system investigated with FVSI, LQP and Lmn indexes. The results show in Table 1 and compared with the NLSI index. As it can be seen NLSI has good compatibility with other indexes.

Table 1: comparative study

Load	Voltage	Line No.	NLSI	Lmn	FVSI	LQP
Q_7= 2.88	V_7=0.584	2	0.9964	0.998	1.0049	0.9842
		4	0.4574	0.5232	0.5478	0.4895
Q_{15}= 0.9575	V_{15}=0.603	18	0.5829	0.6246	0.6489	0.5245
		20	0.2916	0.4594	0.5157	0.2331
		22	0.2617	0.3653	0.3889	0.3157
		30	0.2634	0.3468	0.3649	0.2936
Q_{30}= 0.523	V_{30}=0.562	38	0.9007	0.9262	0.9808	0.817
		39	0.6544	0.698	0.7304	0.5841

4 Conclusion

In this paper we propose a new line index for investigation of voltage stability in power system. This new index in many cases is more accurate than previous indexes that indicate voltage collapse in power systems (because of consisting both active and reactive power).

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