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Improvement of integrated transmission line transfer index for power system voltage stability

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ABSTRACT

With the increased loading of transmission lines, the voltage stability problem has become a critical issue for most power system planners and operators. Some important studies related to the voltage stability indices used in the electric power systems are first sorted. Then, a new approach for voltage stability is developed to find the weak lines in this paper. The new method is based on the practical line ABCD parameters, the power factor of receiving end, and the power angle between the sending end and the receiving end. This concept of integrated transmission line transfer index (ITLTI) is derived for a radial transmission system and later applied to a large system. However, ITILI index has a more integrated content and should be a better solution for on line voltage stability evaluation. The new ITLTI index and other existing techniques are demonstrated and compared with numerical studies by IEEE 14-bus test system, using gradually increase reactive load.

Introduction

Voltage stability problem is one of the major topics in power system planning and operation. Voltage stability is required by a power system to keep voltage in an acceptable range at all nodes under normal condition or after a disturbance [1]. By definition, the voltage instability indicates a voltage dip, surge, or interruption by a disturbance. As power systems grow to become more and more complex, with economical and environmental constraints, voltage instability will become a serious problem. During the last decades, the voltage stability problem arouses intensive consideration by several large-scare blackouts. Reports of major voltage stability incidents were found in Sweden, Germany, Japan, and in USA [2–5].

Voltage instability is a local phenomenon, but the consequences may be cross-country or nationwide. Researches of voltage stability can be basically classified into dynamic and static analysis. The static methods use the steady state model, like a power flow or a linearized dynamic model. Even take the uncertainty of system loads into account, and to determine the distribution of the stability by maximum entropy technique [6]. The dynamic analysis uses the transient stability model characterized by nonlinear differential and algebraic equations with generator's dynamics, and tap changing transformers, etc. [7]. The dynamic method is always time consuming to be used on line for the power system operators.

Whatever methods used, stability studies require a model of the power system. A good judgment of model is based upon how crucial is the actual operating point to the voltage stability limit to operators. Therefore, how to find a fast enough on line index has become an important task for most voltage stability studies. In this paper, voltage behavior has been studied using the static techniques. All practical operating statuses, including the line parameters, the power factor of receiving end loading, and the power angle between the sending end and the receiving end, are all taken into account, and an integrated transmission line transfer index (ITLTI) is derived.

This index provides reliable information for the critical margin of voltage instability for a power system. Usually, its value changes between 0 (no load) and 1 (voltage collapse). The existing voltage stability analysis, using various methods, will be highlighted and the results obtained from simulating on IEEE 14-bus test system will be compared with the new approach in this paper.

Existing voltage stability indices

The previously published indices used to examine the system stability are briefly described in this section.

P–V and V–Q curves

P–V curve is the most commonly used method for voltage stability. It is used to determine the load margin of a power system. The load is gradually increased and power flow re-calculated at

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each increment until the nose point of the PV curve is reached. The margin between the voltage collapse point (nose point) and the current operating point is defined as voltage stability margin [8].

V–Q curve computation is one of the earlier methods of voltage stability analysis. In addition to showing the sensitivity of the bus voltage to reactive power injection (or reactive load) at a bus, the curve also shows the reactive power margin at that bus, telling how much the system can be further stressed before it becomes "unstable".

For *P–V* and *V–Q* curves, have an improved impact on the voltage stability of the system than injecting a real power into the system, the computation of the voltage stability margin is time-consuming and that is why these methods cannot be used in on-line applications [8].

L index

L index is a quantitative estimation of the distance to stability limit developed by Kessel et al. [9]. The *L* index describes the stability of the system and is given by

$$L = \max_{j \in \alpha_L}\{L_j\} = \max_{j \in \alpha_L}\left|1 - \frac{\sum_{i \in \alpha_G}\overline{F}_{ji}\overline{V}_i}{V_j}\right| \tag{1}$$

where j, α_L is the set of consumer nodes and i, α_G is the set of generator nodes. F_{ji} is the sub-matrices of the hybrid (H) matrix generated from the Y-matrix by a partial inversion.

L_j is a local indicator that determines the bus from where collapse may originate. The L index varies in a range between 0 (no load) and 1 (voltage collapse).

Based on the quantitative voltage stability index L, genetic algorithm (GA) is used for optimization of the SMES location [10]. SMES is settled on the best site through GA optimization during the period of the voltage stability fault.

Modal analysis

To compute the smallest eigenvalue and associated eigenvectors of the reduced Jacobian matrix of the power system based on the steady state model is called modal analysis by Gao et al. [11]. If all the eigenvalues are positive, the system is considered to be voltage stable. If one of the eigenvalues is negative, the system is considered to be voltage unstable. A zero eigenvalue of the reduced Jacobian matrix means that the system is on the edge of voltage instability. The potential voltage collapse of a stable system can be predicted by the evaluation of the minimum positive eigenvalue which provides an evaluation to know how close the system is to voltage collapse. By using the bus participation factor, the weakest bus can be identified, which is also the greatest contributing factor for a system to reach voltage collapse. But modal analysis is very time waste and memory consuming in practice [11].

Line stability index L_{mn}

A line stability index based on the radial transmission line is derived by Moghavvemi et al. [12], in which discrimination of the voltage quadratic equation is set to be greater than or equal to zero to achieve stability. If the discrimination is smaller than zero, the roots become imaginary, meaning the cause of instability to the system. In Fig. 1, the line stability index L_{mn} can be defined as

$$L_{mn} = \frac{4XQ_j}{[V_i \sin(\theta - \delta)]^2} \tag{2}$$

where θ is the line impedance angle and δ is the voltage angle between the sending end and the receiving end.

If L_{mn} is close to 1, the line is close to instability point. To maintain a secure system, L_{mn} needs to be less than 1. This method was tested on the IEEE 24-bus reliability test system and has been found to be accurate and precise in voltage collapse prediction.

Line stability index FVSI

The line stability index FVSI proposed by Musirin and Rahman [13] is based on the concept of power flow. For a typical transmission line, the stability index is calculated by

$$\mathrm{FVSI}_{ij} = \frac{4Z^2Q_j}{V_i^2X} \tag{3}$$

where Z is the transmission line impedance, X is the transmission line reactance, Q_j is the reactive power monitored at the receiving end and V_i is the sending end voltage.

The transmission line with FVSI index closest to 1 will be the most critical line and may lead to the power system instability. The resulted FVSI can also be used to determine the weakest bus on the system. The most vulnerable bus in the system corresponds to the bus with the smallest maximum permissible load. This technique is indicative in predicting the occurrence of system collapse and hence necessary action can be taken to avoid such incident.

Line stability index LQP

LQP index is obtained using the same concept of the power flow as in [12,13] derived by Mohamed et al. [14], in which the discrimination of the power quadratic equation is set to be greater than or equal to zero. The LQP is obtained by

$$\mathrm{FVSI}_{ij} = \frac{4Z^2Q_j}{V_i^2X} \tag{4}$$

where X is the transmission line reactance, Q_j is the reactive power monitored at the receiving bus, V_i is the voltage on sending bus and P_i is the active power monitored at the sending bus.

To maintain a secure condition, LQP index should be maintained less than 1.

Line stability indices VCPI

The VCPI indices investigating the stability of each line in the power system are proposed by Moghavvemi and Faruque [15], and are based on the concept of maximum power transfer through a transmission line. We have

$$\mathrm{VCPI}(1) = \frac{P_R}{P_{R(MAX)}} \tag{5}$$

$$\mathrm{VCPI}(2) = \frac{Q_R}{Q_{R(MAX)}} \tag{6}$$

where the values of P_R and Q_R are obtained from conventional power flow calculations, and $P_{R(max)}$ and $Q_{R(max)}$ are the maximum active and reactive power that can be transferred through the transmission line. The VCPI indices vary from 0 (no load condition) to 1 (voltage collapse), and is found to be accurate in assessing the stressful status of the lines.

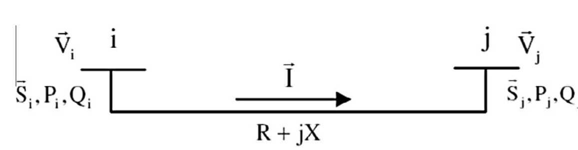

Fig. 1. Typical one-line diagram of transmission line.