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Voltage stability assessment in power systems using line voltage stability index☆

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ABSTRACT

The stressed operating conditions of transmission systems may lead to voltage collapse with consequent interruption in power supply. Therefore, it is necessary to continuously monitor the voltage stability of power system to avoid voltage collapse. In this paper, a line voltage stability index (*LVSI*) has been proposed to assess voltage stability state and stress condition of lines. The proposed index may be used to estimate the stability margin of the power system in terms of mega volt amp (MVA). The proposed index has been tested on IEEE 30-bus and IEEE 118-bus test systems under various operating conditions to evaluate its effectiveness.

1. Introduction

The environmental restrictions, deregulation policies, and high erection cost of transmission lines, compel the existing power systems to operate under stressed condition. Any slight disturbances at this state may cause voltage collapse [1–11]. Therefore; analysis of voltage stability is essential for a secure and reliable power system.

Voltage stability of a system can be analyzed by dynamic or static approaches. Dynamic stability analysis requires more computational time, whereas the static approach encapsulates snapshots of system at different time frames [12]. Therefore, system is at ease to be modelled and analyzed. Various static techniques are available in literature to analyze the voltage stability of a system. The significant outcomes of the early research work are based on repeated power flow using *PV* and *QV* curves [13–17]. But these methods require repeated power flow solution and therefore they are time consuming. For faster estimation of voltage stability of power systems,voltage stability indices based methods were developed. The voltage stability indices compute a numeric value from the power flow solution which indicates the voltage stability state of the system. The earlier indices were based on Jacobian matrix [18–20]. Indices based upon reduced Jacobian matrix were proposed in [21–23]. But these indices cannot accurately estimate the voltage collapse point because of non-linearity near the collapse point. Index based on artificial neural network (ANN) is suggested in [24] to address voltage security. However, this method becomes complex for large size power systems. The L-index developed in [25], is based on load flow solution. Nevertheless, the L-index based approach is inaccurate when loads are not constant-power type [26]. Line stability index (L_{mn}) index is proposed in [27] to assess the critical condition of lines. Line stability factor (*LQP*) index was developed in [28], is used for checking the voltage stability state of lines using load flow solution. Fast voltage stability index (*FVSI*) suggested in [29], was

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Nomenclature

P_R	Receiving end active power.
Q_R	Receiving end reactive power.
V_S	Sending end voltage.
V_R	Receiving end voltage.
A	Transmission line parameter.
X	Reactance of line.
R	Resistance of line.
Z	Impedance of line.
Y	Line charging admittance of line.
I	Current in transmission line.
θ	Impedance angle of line.
β	Angle part of transmission line parameter B.
δ	Phase angle difference between sending and receiving end voltages.
α	Angle part of transmission line parameter A.
λ	Load multiplication factor.
λ_{max}	Maximum loadability factor.
l	Maximum number of lines.
V_{Sj}	Sending end voltage of jth line.
V_{Rj}	Receiving end voltage of jth line.
A_j	Transmission line parameter of jth line.
β_j	Angle part of transmission line parameter B of jth line.
α_j	Angle part of transmission line parameter A of jth line.
δ_{SRj}	Phase angle difference between sending and receiving end voltages of jth line.

used to predict the voltage collapse point and contingency rankings of critical lines. The indices L_{mn} [27] and *FVSI* [29] do not consider real power flow of line for prediction of voltage stability and therefore they may give inaccurate results under certain operating conditions. The *LQP* [28] method employs simplified model of transmission line which ignores resistance of transmission lines. Moreover, indices proposed by [27–29] ignored the presence of line charging capacitance of transmission line network while deriving the equation of the indices [8]. It is to be noted, that line charging currents provide fairly good voltage support to the system under normal operating conditions. Therefore ignoring them may lead to erroneous prediction of voltage stability in certain cases. Moreover, the existing voltage stability indices are not able to translate voltage stability indices into mega volt amp (MVA) loading.

The shortcomings of existing indices discussed above, motivated the authors to develop a more accurate line voltage stability index *(LVSI)*. The index is based upon *ABCD* parameters of transmission system which incorporates the effect of shunt branch and line resistance parameters and more accurately reflect the power system parameters. The *ABCD* parameters of transmission lines are readily available, therefore, the proposed index provide a more accurate and faster tool of predicting voltage stability of power systems. The proposed index can also be used as online index to quickly estimate the voltage stability state. The voltage stability states of different lines is used to be monitored simultaneously and critical lines/buses can be identified using the proposed index. Control actions based upon the proposed index may help the system operator to maintain secure state of the power systems. Other useful application of proposed index is that it can be utilized to measure the available MVA margin of the system before the voltage collapse. The effectiveness of the proposed index has been investigated on standard IEEE 30- bus and IEEE 118-bus systems and their application results are compared with existing indices [27–29]. These existing indices are discussed in the following sections.

The remaining paper is organized as follows: Section 2 presents expressions of existing indices. The proposed index is derived in Section 3. In Section 4, simulation results and discussions are presented to validate the proposed methodology. Conclusions are given in Section 5.

2. Existing voltage stability indices

The status of stability in a power system can be assessed by voltage stability indices. For the sake of comparison the L_{mn}, *LQP* and *FVSI* are briefly discussed in the following sections.

2.1. Line stability index (L_{mn})

The stability index L_{mn} presented in [27] is based on the power flow in the line. It measures voltage stability for each line. Higher value of L_{mn} of a line is an indication of closeness to the instability. The root discriminant of voltage quadratic equation is set equal to zero, to acquire real roots of the voltage. If the discriminant is less than zero, the resultant roots will

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