Electrical Power and Energy Systems 81 (2016) 232–238

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A direct method for assessment of overall voltage condition of power system

Pankaj Mishra [a,*], T. Ghose [b]

[a] Department of Electrical & Electronics Engineering, Birla Institute of Technology, Mesra Off-Campus Deoghar, Jasidih, Deoghar, India
[b] Department of Electrical & Electronics Engineering, Birla Institute of Technology, Mesra, Ranchi, India

ARTICLE INFO

Article history:
Received 14 January 2015
Received in revised form 22 December 2015
Accepted 25 February 2016
Available online 9 March 2016

Keywords:
Voltage stability
Power loss
Two-bus equivalent network
Transmission line
Deregulation
Congestion

ABSTRACT

One of the reason of stressed power system being driven to voltage instability is the inverse relation between voltage and change in transmission line series loss. This work develops a technique for determining voltage stability of the system employing transmission line loss of a system. The equivalent two-bus model of network is used for assessing the voltage condition of the network. The main feature of technique is to avoid monitoring of individual buses or branches to assess the voltage stability. The objective of the work is to consider the total generation and total demand data available in the control center to predict the overall voltage stability of the system and thus it is suitable for real-time monitoring. The proposed voltage stability monitoring approach has been validated using IEEE 30 bus and Indian Utility 62 bus test system for different practical conditions.

Introduction

Voltage instability problem is experienced in power systems when system is under stressed condition due to high loading and at the same time system having shortage of reactive power. The open-access and deregulation of power system have increased the possibility of voltage instability in power networks.

Since last two decades the phenomenon of voltage stability has captured the attention of researchers. The researchers have defined and elaborated the phenomenon and the factors affecting it in details [1–4]. The vulnerability of a complex high loaded power system to voltage instability and thus the necessity of its estimation prior to its occurrence attract the researchers to develop its indicator. Some review works have enumerated the developments in this field [5–8].

Various methods have been suggested to predict the voltage stability of a power network, before it reaches the extreme state [2,9–17]. Some methods directly use the two-bus equivalent theory with network theorems while some involve repeated load-flow run. Recently, wide area measurement system (WAMS) and phasor measure unit (PMU) are used for online assessment of voltage stability condition of power system [18–22].

The techniques employing power flow solution, singularity of Jacobian matrix, loading margin, PV and QV curves, and optimal power flow are good enough for static voltage stability analysis, however, these techniques involve large numbers of data and may require running the load flow repeatedly, which restricts their use for real time monitoring of voltage stability conditions. Techniques based on PMU, WAMS and two-bus equivalent circuit, have already been proposed by authors for online monitoring of voltage stability. However these techniques assess voltage stability using phasor measurements of individual buses or branches. In recent years soft computing techniques have been used to solve various issues in power system. Fuzzy Logic, Artificial Neural Network and Neuro Fuzzy, to name a few, are some methods which have been utilized to solve both dynamic and static voltage stability issue of system. These techniques are fast and maintain accuracy, however, the training of neural network modules is extensive and for voltage stability assessment monitoring of several factors of various buses are required [23,24].

Innovative approaches for voltage stability analysis have been made by some researchers [16,25]. Concepts of global voltage stability margin (GVSM) and global voltage security indicator (GVSI) have also been introduced by some authors. The GVSM technique, applies the optimal power flow (OPF) method, for calculating the total loss in the system. But the large computational data and repeated OPF analysis restricts this method from being used in online monitoring of voltage stability. A simpler attempt has been

---

* Corresponding author. Tel.: +91 9470131287.
E-mail addresses: pankajmishra1306@gmail.com (P. Mishra), tghose@bitmesra.ac.in (T. Ghose).

http://dx.doi.org/10.1016/j.ijepes.2016.02.031
0142-0615/

made on calculating the GVSI but here also load flow solution is needed for calculating the line resistance and reactance of the equivalent circuit. A similar but more efficient attempt is made here in this work. Transmission line series loss based, simple and approximate, formulation has been derived and discussed, for getting real-time voltage signal for assessing the voltage stability condition. A two-bus equivalent representation of a multi-bus network has been used to derive the formula for voltage signal. Finally the method is verified using IEEE 30 bus test system and Indian Utility 62-bus test system.

Real and reactive power loss and node voltage

Before presenting the idea of the proposed work it is worth to discuss the phenomenon of voltage instability, under constrained situation. During heavily loaded condition the series-loss in transmission line accelerates the downfall of voltage. When the voltage decreases gradually, the industrial motor loads are thrown off, by under voltage relay at lower voltages, which leads to enhanced load bus voltage. In such situations, it is traditional to boost up the distribution voltage by transformer tap change, even though the transmission voltages of upstream nodes remain critical. This increases the bus loads again by reconnecting the industrial loads which results in the deterioration of reactive power position and the series reactive loss may increase tremendously, thus, depressing the load bus voltage of upstream nodes to an alarming level. In addition to this, the remote generator, along with local generators, tries to press more reactive power through the line, which further increases the series reactive loss resulting in voltage decline. Thus, in a heavily loaded line and depressed bus voltage, the reactive power demand increases and the transmission line series reactive loss is quite substantial which results in voltage collapse.

Thus it can be concluded that the transmission line losses have appreciable effect on progress of a system from normal or marginal voltage stability point to the voltage collapse point [4].

Series reactive loss and node voltage

Let us consider a simple two bus radial network. Since for long transmission lines the X/R ratio is very high so the line is purely reactive. Reactance X also includes series reactance of transformers in the line. The generator terminal voltage $E\angle 0$ is the e.m.f. at highly regulated bus which keeps the voltage at E. Let us consider S a constant MVA load, at voltage $V\angle\delta$ is drawn at the load bus, and Q_L be the series reactive loss occurring in line.

Then,

$$|Q_L| = |I^2 \times X| \tag{1}$$

where,

$$|I| = \left|\frac{S}{V}\right| \tag{2}$$

And therefore,

$$|Q_L| = \left|\frac{S}{V}\right|^2 \times |X| \tag{3}$$

The change in series reactive loss for a change in voltage is

$$\left|\frac{\partial Q_L}{\partial V}\right| = \frac{-2}{|V|^3} \times |S|^2 \times |X|$$

Assuming $|X|$ to be constant and for constant MVA load, we get.

$$\left|\frac{\partial Q_L}{\partial V}\right| \propto \frac{1}{|V|^3} \tag{4}$$

Thus, the change in series reactive loss increases sharply with any drop in transmission voltage.

Total series line losses and node voltage

Generally for long transmission lines X/R ratio is considered very high and the value of resistance for the line is neglected for analyzing most of the theoretical concepts. This assumption does not affect the validity of the result to a very large extent. However, in case of a stressed power system the resistive losses in the line cannot be neglected as the magnitude of the current is very high. Taking resistance into account, the series loss occurring in transmission line may have an approximate relation as developed in previous section for reactive loss.

As in Eq. (4), for any instant of operation, assuming MVA load (S) and line impedance to be constant, the change in MVA loss with voltage can be represented as

$$\left|\frac{\partial S_L}{\partial V}\right| \propto \frac{1}{|V|^3} \tag{5}$$

i.e. change in MVA loss increases sharply with any drop in voltage.

Proposed transmission loss based voltage stability analysis

Two-bus equivalent of a transmission network

In this paper, an equivalent model, having series impedance connecting two buses, has been used for voltage stability analysis. The two bus equivalent of a complex network has a generator bus, where all the generators of the network are clubbed having fixed terminal voltage i.e. the generator bus is considered as infinite bus. The second bus is considered as equivalent load-bus feeding the total demand of the network and the voltage of this bus is considered as V_{syst}. The branch connecting these two buses has series equivalent impedance calculated as follows:

Consider S_{GT} as the total MVA generation of all the generators of the original network at any operating time period, $E\angle 0$ as its terminal voltage, S_{DT} as the total demand for the same time period.

Then, total MVA loss occurring in the network can be represented as

$$S_{LT} = S_{GT} - S_{DT} \tag{6}$$

And equivalent current at the infinite bus is,

$$I_{eq} = \frac{S^*_{GT}}{E^*} \tag{7}$$

Hence, the equivalent impedance responsible for the loss is

$$Z_{eq} = \frac{S_{LT}}{|I_{eq}|^2} \tag{8}$$

The resulting equivalent network is drawn in Fig. 1.

Formulation of voltage stability signal

Eq. (8), can also be approximated as

$$S_{LT} = |I_{eq}|^2 \times Z_{eq}$$

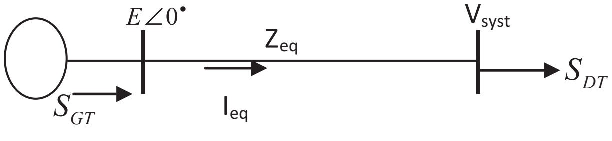

Fig. 1. Two-bus equivalent of complex network.