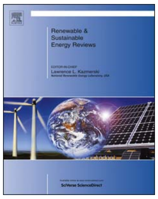
Renewable and Sustainable Energy Reviews 63 (2016) 1–12

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



A comprehensive review of the voltage stability indices

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ARTICLE INFO

Article history:
Received 6 May 2015
Received in revised form
8 November 2015
Accepted 3 May 2016

Keywords:
Voltage stability index
Voltage stability
DG placement
Weak line
Weak bus

ABSTRACT

Voltage stability assessment is a major issue in monitoring the power system stability. Different voltage stability indices (VSIs) have been proposed in the literature for voltage stability assessment. These indices can be used for distributed generation (DG) placement and sizing, detecting the weak lines and buses and triggering the countermeasures against voltage instability. This paper reviews the VSIs from different aspects such as concepts, assumptions, critical values and equations. The review results provide a comprehensive background to find out the future works in this field and select the best VSI for different applications like DG placement and sizing and voltage stability assessment.

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http://dx.doi.org/10.1016/j.rser.2016.05.010
1364-0321/

1. Introduction

Voltage instability, which is essentially a local phenomenon, has been the cause of many major blackouts in the world [1]. In [2], 12 blackouts have been studied from 1965 to 2005 and indicating that voltage instability had been a major incident in 7 cases. The term voltage collapse is also used instead of voltage instability and it is the process by which the sequence of events accompanying voltage instability leads to an abnormally low voltages or blackout in a large part of the power system [3].

Voltage stability has been defined by the IEEE power system engineering committee as follows: "Voltage stability is the ability of a system to maintain voltage so that, when load admittance is increased, load power will increase, and so that both power and voltage are controllable" [4]. The IEEE/CIGRE Joint Task Force provides another definition for voltage stability which is: "Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition" [3].

Voltage instability can be caused either by a failure of reactive power sources in producing enough reactive power or by a failure of power system lines in transmitting the required reactive power [5]. The reactive power can be supplied by generators and reactive power compensators such as shunt capacitors. The main incidents causing voltage instability are load increase, tripping of power system equipment (such as transmission lines, power transformers and generators), exceeding some generators reactive power limits and the malfunction of on-load tap changing transformers.

There are countermeasures to avoid voltage instability. The most important ones are [6]

1. Improvement of weak buses and lines at the planning step of power system (by distributed generation units or other voltage supporting equipment)
2. Load shedding, shunt capacitor switching
3. FACTS devices to extend the voltage stability margin (VSM)
4. Tap changer blocking

where load shedding is the last line defense.

One of the important applications of the voltage stability indices (VSIs) is identifying the weak lines and buses in the power systems [7–11]. In this case, the VSIs are used in offline/online mode, and the required data are obtained from the static analysis or phasor measurement units (PMUs). Then, the line/bus with a VSI closest to the critical value is selected as the weakest line/bus. This application of VSIs can be used in different cases such as, the placement and sizing of distributed generation (DG) units, capacitor allocation and the planning of power systems [12–16]. In the DG placement and sizing problems, the VSIs are used in two steps. In the first step, the weak buses and lines are selected to determine the candidate location for DG units. In the second one, the optimal location of DG units are determined to maximize the VSM where the VSM is calculated by the VSIs.

Another application of VSIs is triggering the countermeasures against voltage instability [17–19]. In this case, the indices must be used in real-time and the required data are provided by the PMUs which constitute a part of the wide area measurement system (WAMS).

Many indices have been proposed in the literature to assess the voltage stability [20–23]. Some indices are functions of the power system impedance but some others are independent of it and only need the voltage and current of buses. In practice, determining power system impedance is not possible with high precision due to the atmospheric effects and insufficient information about the power system. So, the performance of indices which are functions of power system impedance is always associated with error.

A comparison of the VSIs have been made in some papers [24–31]. Nevertheless, the overall characteristics, classifications and differences have not been precisely investigated. So, in this paper, the VSIs are reviewed by considering different aspects and views such as assumptions, concept, equations and critical values (CVs). The review results can be employed to understand the future works in this field and select the best VSI for different applications such as DG placement and sizing, voltage stability assessment, ranking the buses and lines according to the voltage stability and activating the countermeasures to control the voltage collapse.

The rest of this paper is organized in the following way: Section 2 examines the application of VSIs in DG placement and sizing. Section 3 discusses the characteristics of the voltage collapse point. Section 4 reviews the VSIs. In Section 5 the VSIs are classified and Section 6 concludes the discussions.

2. VSIs in DG placement and sizing

DGs are small-scale power generations (typically in the range from 3 kW to 10,000 kW) are used to improve the traditional electric power systems [32,33]. The DG technologies include small gas turbines, micro-turbines, fuel cells, wind and solar energy, biomass, small hydro-power, etc. [34]. Integrating DG units into the power systems has many benefits like improving voltage profiles and load factors, grid reinforcement, deferring or eliminating for system upgrades, reducing power losses and on-peak operating costs, and improving system integrity, reliability, and efficiency [13,35,36]. To achieve these benefits, an appropriate size and place must be selected where the DG units are installed. Installing these units in the inappropriate places may diminish the reliability of the system and may also lead to an increase in the system losses and costs [14]. Moreover, if several DG units are installed, optimal approach for the placement and sizing of DGs becomes more crucial in order to maintain the reliability and stability of the power system [35].

The problems concerning the DG placement and sizing can be divided into two groups in terms of their objective functions and each group consists of two steps. In the first step, the candidate location for DG units are determined and secondly the optimal