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Statistical method for on-line voltage collapse proximity estimation

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ABSTRACT

This paper is aimed to propose a reliable method for estimating the voltage collapse proximity through a model obtained using statistical techniques. In the model building process a database is required, therefore the Voltage Collapse Proximity Index (VCPI) is used to obtain previous readings for different contingencies and loading conditions. This analytical proposal could be combined with existing equipment in the power system control centers for future on-line applications. The proposed method is applied to the IEEE 14-bus test system and the 190-bus Mexican equivalent. Results indicate that the proposed strategy is a reliable choice.

Introduction

A power system may become vulnerable for several reasons: natural calamities, component failures, protection and control failures, information and communication failures, instability due to disturbances, human errors, inadequate security assessment procedures, sabotage, and missing or uncertain information in decision making [1]. Causes of instability that are internal to the civil infrastructure may be reduced by decreasing the probability and severity of occurrence through the improved engineering of related systems. On the other hand, causes of instability that are external to the infrastructure (e.g., different contingencies) may be reduced by decreasing the severity of occurrence by constructing defender restoration systems [2].

Power system stability involve the system changes in normal operation and changes in the working point caused by disturbances. Although, small signal security problems studied alterations of the power system in the presence of small changes in the electrical variables, for these reason power grid security include major changes commonly called contingencies [3].

Considering that is important the system monitoring to know when it is close to an unsafe zone, in this work is proposed a method to estimate the proximity to voltage collapse. Specifically, considering the most important smart grids characteristics, like provide information to power system control center, which fosters take decisions preventing voltage collapse.

Although several methods conducting to voltage stability analysis; accurate voltage collapse predictions and rapid voltage stability analysis providing reduction in computation time, which are needed to successfully prevent voltage collapses and blackouts.

Researchers have presented some alternatives for on-line predicting or analyzing voltage collapse. In [4] a forecasting-aided state estimator is employed to detect the proximity of a voltage collapse problem, taking into account system loads trends is proposed. The exact voltage collapse point is determined through the use of an extrapolation technique. Other approach is presented by [5], the method requires the voltage phasor and angle information at a bus and the network admittance matrix to evaluate the system voltage stability at a bus in the form of Voltage Collapse Prediction Index (VCPI). This is an impractical situation in a real power system because network configuration may change due to contingencies that modify the admittance matrix, requiring techniques to know the current state of the power grid.

In voltage security assessment an Artificial Intelligence-based techniques are applied in [6,7], where Neural Networks and Genetic Algorithms are used. Starting from the state estimation, a given set of mathematical indices is computed to represent a snapshot of the current electric system operating point. In [8] a method for use on-line voltage collapse predications, theoretically proven for finding voltage collapse point precisely and determining voltage stability. Other on-line application is presented in [9], applicable for large scale power systems, the contingencies are defined previously and collapse prediction is possible if the model knows

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the contingency, situation that is not always possible especially when simultaneous contingencies occur or in a complex power systems.

Several algorithms have been developed that make use of synchrophasor technology for online voltage stability monitoring [10–13], however, these methods assume that know the current network configuration, a situation which in most cases is not possible due to different faults that may occur in power grid.

Considering the above arguments, this paper proposes a consistent method to voltage collapse proximity estimation. The paper is presented in the following order. Section "Problem description" justifies the proposed method; Section "Voltage stability model and statistical overview" describes theoretic considerations, and Section "Proposal" presents our contribution; Section "Results of 190-bus Mexican equivalent power grid" shows the results of the method applied to 190-bus Mexican power grid equivalent; finally, conclusions are presented.

Problem description

Naturally, voltage stability is a dynamic process, although steady-state assessment the use of steady-state is accepted generally. Considering voltage stability theory, the use of static and dynamic methods must provide similar results, provided that the analysis is not made during a transitional phenomenon. Voltage collapse may happen on power systems which are heavily loaded, faulted and/or have reactive power shortages. In fact, voltage collapse often affects the entire power system, although it usually arises in one particular area. Maintaining a system voltage profile within an acceptable range in power system operations, may improve system security and reliability, and prevents system collapse [14–16]. Operation beyond acceptable range limits leads to voltage instability and ultimately to voltage collapse. Relevance of voltage collapse indices lies in the fact that they are useful tools for voltage collapse proximity estimation. But, it is necessary to use under on-line context. That means, know in real time all parameters required to quick index calculation.

Considering that voltage stability in a power system may be affected by different reasons, highlighting load changes and contingencies are predominant factors, the voltage stability index represents a computational advantage respect to Continuation Power Flow (CPF). Now to compare voltage stability behavior using CPF and the Voltage Collapse Prediction Index (VCPI), is presented the 14-Bus IEEE test system, see results in Fig. 1. The CPF is not used under real-time applications due to the following disadvantages:

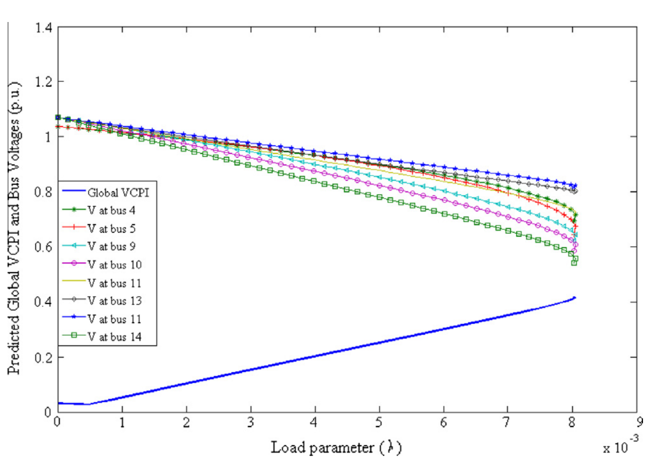

Fig. 1. Comparison between the Global VCPI prediction and CPF method.

(i) It requires long computing time and (ii) require load increment information (because it is no possible real-time load estimation) [17–19].

Researchers have presented some alternatives for on-line predicting voltage collapse, in [20] the method requires the voltage phasor, and angle information, and the admittance matrix to evaluate the system voltage stability in the form of VCPI. This is an impractical situation in a real power system because network configuration may change due to contingencies that modify the admittance matrix, requiring techniques to know the current state of the power grid. Other on-line application is presented in [9,21], applicable for large scale power systems, the contingencies are defined previously and collapse prediction is possible if the model knows the contingency, situation that is not always possible especially when simultaneous contingencies occur in a complex power systems.

Currently, it is relevant propose novel applications to power system monitoring, ensuring a safe operation, providing tools to prevent voltage collapse. In this way researchers have proposed different techniques that evaluate security conditions and so to identify corrective actions to maintain proper system operation. Specifically statistical methods present a promising alternative in which VCPI changes could be predicted with measurable on-line variables [22].

Voltage stability model and statistical overview

The conventional power flow model is generally expressed by equations as [22,23]:

$$\frac{d\boldsymbol{x}}{dt} = f(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{\lambda}) \quad (1)$$
$$0 = g(\boldsymbol{x}, \boldsymbol{y}.\boldsymbol{\lambda})$$

where $\boldsymbol{x}$ is the vector of state variables; $\boldsymbol{y}$ is a vector, and λ is a factor that change gradually, when power system is moving from an equilibrium point to another until reaching the collapse point are used equations,

$$P_{D,i} = P_{D0,i}(1 + k_{P,i}\lambda) \quad (2)$$
$$Q_{D,i} = Q_{D0,i}(1 + k_{Q,i}\lambda) = P_{D0,i}\tan(\varphi_i)(1 + k_{Q,i}\lambda)$$

where $P_{D,i}$ and $Q_{D,i}$ represent the active and reactive power demand at i-th bus, respectively, $k_{P,i}$ and, $k_{Q,i}$ are a constant that specify the rate of change in power generation when λ (load parameter) is varied; followed to calculation in power demand, as [17,22]:

$$P_{G,i} = P_{G0,i}(1 + k_{G,i}\lambda) \quad (3)$$

where $P_{G0,i}$ is the i-th initial active power generated; $k_{G,i}$ is the constant specifying the rate of change in generation when λ is varied.

Commonly, in steady-state analysis are used the following methods: modal analysis, direct method, optimization method, and continuation method [13].

Voltage stability indices

The security analysis in power grids usually divide voltage instabilities in two classes: the first one is due to electrical variables changes (e.g. power and voltage variations), and the other one is due to configuration changes (e.g. generators and transformers outages). The Voltage Collapse Proximity Index (VCPI) calculate voltage stability condition in each bus [20,24,25]. The VCPI index used the conventional power flow definition, and it calculated the injected power in each bus k. The calculation of this index requires the voltage phasor information of buses as well as the bus admittance matrix. The VCPI for the k-th bus is defined as,