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Voltage stability – Case study of saddle node bifurcation with stochastic load dynamics

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ABSTRACT

This paper presents an approach of analyzing power system voltage stability based on system potential. This framework provides a simple and better way of understanding voltage stability by visualizing the changes in topological structure of the system potential with respect to the change in power system loading. This paper also investigates the effect of random load variation in the power system stability. The stability margin index being studied is the Mean First Passage Time of the power system from the stable operating point to the closest unstable equilibrium point for small magnitude random load perturbations. The variation of MFPT for change in the loading of the system, Intensity and correlation time of the stochastic load are studied initially for an SMIB system.

1. Introduction

The dynamics of the power systems at any given time is governed by the difference between the mechanical power input and the electrical power demand at the load centers. The demand for electrical power is increasing in the load centers without proportionate increase in the transmission infrastructure due to the increased cost of construction, environmental concerns for building new transmission line and problems of right of way. This forces the power system operators to increase the loading in the existing transmission network and operate the power system closer to its maximum loadability limit [1]. Further small intensity uncontrollable random load perturbations are always present in the system [2]. This impresses the need to understand power system stability in a better way and to develop indices which provide the stability margin of the particular operating point of the power system considering stochastic load dynamics. Similar works on assessment of voltage stability margin using Neural network has been carried out in [3], using P–Q–V curve in [4] and using enhanced look ahead algorithms [5].

In this study, random load perturbation is modeled as the Gaussian white noise. White noise is characterized by the delta correlated autocorrelation function [6]. The white noise model of the power system loads can be validated by the fact that characteristic time of the system is much greater than the correlation time of the stochastic load [7]. The stability margin of power system with stochastic loads can be characterized with the help of Mean First Passage Time (MFPT) of the power system from the stable equilibrium point to reach the closest unstable equilibrium point when perturbed by the small load perturbation [8]. This index enables power system operator to understand the need to control and operate the power system at the most stable operating point for each load setting.

This paper also provides the easy and better way of understanding the effect of increased loading on the stability for Single Machine connected to Infinite Bus (SMIB) system by visualizing the change in the shape of the system potential. The counterpart of the system potential for multidimensional system are the energy functions. Voltage stability of multidimensional system can be explained as the change in the shape of the energy function with increased loading of the system as explained in chapter two of [9].

2. System potential

The mathematical model for any two dimensional system with displacement (x), damping (γ), potential energy ($U(x)$), parameters (λ) and the time dependent force ($\eta(t)$) is given by

$$m\frac{d^2x}{dt^2} = -\gamma(x,t)\frac{dx}{dt} - \frac{dU(x,\lambda,t)}{dx} + \eta(t) \quad (1)$$

Eq. (1) is the force balance equation of any two dimensional system. The force experienced by the system is equated to the summation of the friction force experienced by the system, force due

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