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Probabilistic tuning of Power System Stabilizers considering the wind farm generation uncertainty

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ABSTRACT

The increasing use of wind farms and the uncertainties in their generation levels have led to new challenges in system dynamic behaviors and Small Signal Stability (SSS). This paper proposes a probabilistic method to investigate the impact of the wind farm generation uncertainty on power system SSS, based on the Monte Carlo simulation. The proposed method is stochastic in contrast to conventional deterministic methods, which only analyze the system dynamic behaviors in one operating point. It determines several operating points, based on wind farm generation levels and calculates the Probability Density Function (PDF) of critical eigenvalues. Then, Genetic Algorithm (GA) is used to optimize the Power System Stabilizers (PSS) parameters. A case study is carried out on the IEEE 16-machine system to demonstrate the effectiveness and validity of the proposed algorithms. The results of probabilistic stability analysis are compared with those of deterministic analysis. It is shown that variation of the wind farm generation levels can cause the instability, even though the system is stable according to the deterministic analysis. Also, the time domain simulation results show how such tunings can effectively improve the SSS performance under the wind farm generation uncertainties.

Introduction

Due to various technical and non-technical concerns, renewable energy resources, especially wind farms, have received much attention during the recent decades [1]. The dynamic performance of a power grid is affected by the characteristics of the connected generators. While the conventional synchronous generators may present similar dynamic behaviors, wind farm dynamics is quite different. The wind farm generation capability relies on the environmental conditions such as wind speed. So, a wind farms has a variable generation level, depending on an uncertain wind speed. Therefore, if Wind Turbine Generator (WTG) contribution in the generation increases, some dynamic characteristics of power system performance such as Small Signal Stability (SSS) may change [2,3]. This is due to the fact that, the variation of the wind farm generation changes the system total power generation and therefore, the power generation and load consumption balance is disturbed. In this way, other generation units and loads would react which, in turn, cause the changes in the eigenvalues locations and system dynamic behaviors. So, the wind uncertainty should be accounted in SSS analysis procedure.

The traditional methods for SSS [4–6] are based on modal analysis, as a deterministic approach. A major drawback of traditional methods is the incapability of them in accounting with the stochastic behaviors of a power system, such as the wind speed uncertainty. In fact, continuous variation of the wind speed changes the wind farm generation level which can cause the movement of the eigenvalues to the right side of the $j\omega$ axis, making the system unstable.

The probabilistic SSS analysis is categorized into either the analytical or non-analytical methods. In analytical methods, Gram–Charlier expansion method [7] and the two point estimation method [8] can be used to achieve the Probability Density Function (PDF) of the eigenvalues. In fact, the eigenvalues are function of an uncertain parameter, and these methods are used to estimate the eigenvalues behaviors. Also, some improvement in analytical analysis is achieved in [9,10] and an analytical method is applied to study the effects of wind farm penetration on power system SSS in [11].

In terms of the latter, the Monte Carlo simulation as a non-analytical method is used for the probabilistic SSS. The Monte Carlo method generates a large number of random samples from the uncertain parameter's density function and estimates the PDF of

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desired output, such as the critical eigenvalues. This method is employed in [12,13], to study the effects of load and generation uncertainties on the probabilistic SSS analysis.

Improving the dynamic stability of a power system is essential for a secure operation. The Low Frequency Oscillations (LFO) may be observed due to various reasons. On the other hand, the variable dynamic behavior of a wind farm, arisen from the wind speed uncertainty, may highly affect such oscillations. Power System Stabilizer (PSS), as the most convenient tool, may be effectively employed to improve the LFO. Various tuning procedures are proposed for Power System Stabilizers (PSSs) [14–16]. The evolutionary algorithms such as GA are also employed [17,18]. The available methods for PSS tunings mostly use one of the heuristic approaches to find the PSSs' optimum parameters. This is done with either the operating point being fixed, or using the scenario based methods to observe the changing operating points. That is why in [18], a deterministic objective function is considered. Due to the increasing penetration of the wind farms in power systems, the generation level dynamic characteristics of the system are continuously varied, so the behavior of the system cannot readily be modeled with the traditional methods so that using the probabilistic methods is essential. In [22], the modeling of small signal stability considering the uncertain wind generation is implemented and the critical modes of the system are detected, but no tuning procedure is introduced to tune the PSSs parameters in uncertain condition.

The above mentioned approaches for PSSs tuning are, normally, based on a dominant operating point, yet with an acceptable performance for other operating conditions. Such tuning is only effective if the dominant operating point can be determined. In using the probabilistic approach for modeling the behaviors of the power system in presence of the wind farms, the determination of a dominant operating point is not possible, as the operating point is continuously changing. In such situation, the tuning procedures should be implemented based on an operation region. So, this paper presents a probabilistic SSS analysis with taking the wind farm generation uncertainty, into account. The Monte Carlo method and the modal analysis are used to achieve the PDF of the critical eigenvalues from the wind speed PDF. Then, a sampling method based on GA is used to coordinate tuning of PSSs. The stochastic behaviors of the critical eigenvalues are determined and PSS parameters are tuned for a region of operating points.

The major practical usefulness of the proposed method is the PSS tuning procedure. Otherwise, the PSSs as tuned for one dominant operating point may lead to instability for a continuous changing operating point. As the PSSs are tuned based on an operation region, acceptable performance may be achieved for the changing conditions.

This paper is organized as follows. Section 'The proposed algorithm' is devoted to the description of the proposed method. The mathematical formulation of the problem is given in Section 'Problem formulation'. The PSS tuning procedure is described in Section 'Tuning procedure'. Numerical results are provided in Section 'Numerical results' and some concluding remarks are finally given in Section 'Conclusion'.

The proposed algorithm

The proposed algorithm is depicted in Fig. 1. As shown, following modeling the system, as the first step the small signal stability of the power system should be studied, so random numbers are generated from the PDF of the wind speed. By using the mechanical model of the wind farm, the PDF of the wind farm mechanical output, then, is achieved. Thereafter and following the load flow and modal analysis, through checking a convergence criterion, which is the number of iterations, the PDFs of critical eigenvalues and their respective damping ratios are identified for various wind farm generation levels which are achieved based on the wind farm mechanical output PDF. Following that, according to the modal analysis results, the PDF of the damping ratios are calculated and the region with the high probability is determined and the PSS parameters are tuned. Initially, M samples are selected from the high probability region of the damping ratios PDF and a modified objective function which is described in Section 'Tuning procedure' is calculated and optimized with GA, to achieve the optimal tuning of the PSS parameters. The mathematical formulation and the details are given in Section 'Problem formulation'.

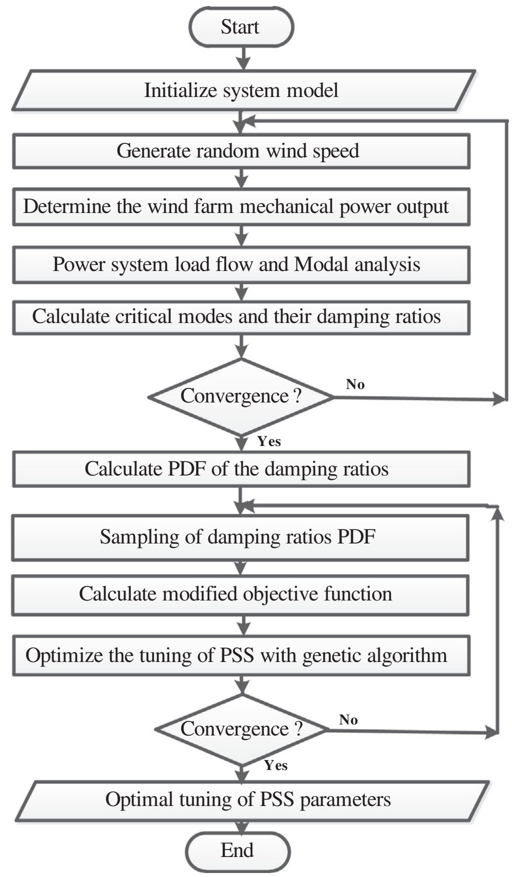

Fig. 1. The flowchart of the proposed method.

Problem formulation

Basic concepts

Uncertainty analysis of a system can be simply demonstrated as follows [19]:

$$\mathbf{v} = \mathbf{h}(\mathbf{z}) \tag{1}$$

Vector $\mathbf{h}$ represents the characteristics of the system, $\mathbf{z} = [z_1, z_2, \ldots]^T$ is the input variables vector and $\mathbf{v} = [v_1, v_2, \ldots]^T$ is the output variables vector. The purpose of the uncertainty analysis of a system is to define the uncertainty of $\mathbf{v}$ elements, arisen from the uncertainty. From the point of view of probability theory, uncertainty analysis involves determination of the PDF of output variables $\mathbf{v}$ that results from the function $\mathbf{h}$ and the PDFs which define the probability space of input variables $\mathbf{z}$. The Monte Carlo approach is a well-known method for modeling the uncertainties. The details are given in [19] and a brief description is provided here.