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An Analytical Approach to Probabilistic Dynamic Security Assessment of Power Systems Incorporating Wind Farms

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Abstract

An analytical approach to probabilistic dynamic security assessment of power systems incorporating wind farms is proposed. As the most important and complex step of the evaluation process, the probability of transient stability given a specific fault and uncertainties of output power of wind farm and load is calculated analytically based on the practical dynamic security region of power system with double fed induction generator and Cornish-Fisher expansion. The proposed method can provide meaningful and reliable evaluation results with high accuracy and much less computing time compared with Monte Carlo simulation.

Keywords: Probabilistic dynamic security assessment; Security region; Wind farm.

1. Introduction

An ever-increasing amount of renewable energy, in particular wind power, has been integrated into power systems. The intermittent nature of wind power makes the nodal injection power more uncertain than before, which brings severe risks to power system operation. Compared with 0-1 type indicators provided by deterministic security assessment, probabilistic approaches can consider uncertain factors and reflect the stochastic nature of operating conditions, which can further help operators understand system states [1,2].

Probabilistic dynamic security assessment (PDSA) calculates the probability of dynamic security (PDS) by considering the uncertainties of nodal injection power and faults. For PDSA of a power system incorporating wind farms, existing studies commonly use Monte Carlo simulation (MC) based approaches [1,2]. For a given set of faults, the MC based approach samples a large number of cases based on the probabilistic models for nodal injection power and faults, analyses the transient stability of every single case, and then calculates the PDS. While MC can achieve reliable results, it is time-consuming and impractical for online application [3].

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The security region (SR) approaches for power systems have developed rapidly in recent years, providing a powerful analytic tool for stability and security assessment [4,5]. Dynamic security region (DSR) guaranteeing transient stability is defined in nodal power injection space. In the scope of engineers' concern, the boundary of practical dynamic security region (PDSR) can be approximated by one or several hyper-planes. We found the same conclusion recently for PDSR of power system with double fed induction generator (DFIG) [6], which provides a feasible and analytical way to obtain PDS considering the uncertainties of fault and output power of wind farm and load.

In this letter, an analytical approach to PDSA of power systems incorporating wind farms is proposed. The general analytical expression of PDS, derived from the conditional probability theory, is solved analytically through PDSR of power system with DFIG and Cornish-Fisher expansion. Test results on the New England system show that the method can obtain reliable results with high accuracy and much less computing time than the MC based method. The effectiveness and practical application prospect in large-scale power system of the proposed approach is also given.

2. An Analytical Approach based on Practical Dynamic Security Region and Cornish-Fisher Expansion

2.1. Probability of Dynamic Security (PDS)

The conditional probability theory is used to derive the basic expression of PDS as Eq. (1).

$$\text{PDS}=\sum_{i}^{N}\Pr(F_i)\cdot\Pr(\text{TS}\,|\,F_i) \tag{1}$$

where N is the number of faults; $\Pr(F_i)$ is the probability of fault F_i; $\Pr(\text{TS}|F_i)$ is the probability of transient stability (PTS) given F_i.

$\Pr(F_i)$ can be extended to consider the uncertain factors related with a fault if needed. Considering the uncertainties of fault type, fault clearing time and fault location, which is usually modelled by discrete probability models [1], the detailed expression of PDS is given by Eq. (2).

$$\text{PDS}=\sum_{i}^{N}\Pr(F_i)\cdot\sum_{j=1}^{N_T}\Pr(A=j\,|\,F_i)\cdot\sum_{c=1}^{N_C}\xi_c[\sum_{l=1}^{N_L}\xi_l\Pr(\text{TS}\,|\,F_i\cap(A=j)\cap\tau_c\cap\gamma_l)] \tag{2}$$

where N is the number of faults; N_T is the number of fault types; N_C is the number of discrete intervals about fault clearing time; N_L is the number of discrete intervals about fault locations; $\Pr(A=j|F_i)$ is the probability of F_i with type j; $\Pr(\text{TS}|F_i\cap(A=j)\cap\tau_c\cap\gamma_l)$ is the PTS of fault i with type j, clearing time τ_c and location γ_l; γ_l is the ratio of the distance between the fault location and the head-end bus to the total length of the line; ξ_c and ξ_l are the corresponding probabilities of τ_c and γ_l respectively.

The probability of type j, clearing time τ_c and location γ_l is given directly in their discrete probability model, which is taken according to ref. [1] in this paper. It can be seen from Eq. (2) that the number of fault scenarios is $N\times N_T\times N_C\times N_L$ and the same amount of $\Pr(\text{TS}|F_i\cap(A=j)\cap\tau_c\cap\gamma_l)$ is required to be calculated. It is not hard to find that calculating PTS is the most fundamental and critical step, however, PTS is the extraordinary complicated n-degree integral in n-dimension power injection space given uncertainties of output power of wind farm and load and no simple mathematical description about the DSR [4,7] and Monte Carlo is usually used with huge computation burden. An efficient method for calculating PTS analytically is the key and achieved in this letter based on PDSR of power system with DFIG and Cornish-Fisher expansion.

2.2. PDSR of Power System with DFIG