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.

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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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2.1. Probability of Dynamic Security (PDS)

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

\[
PDS = \sum_{i}^{N} \Pr(F_i) \cdot \Pr(TS | F_i)
\]

where \(N\) is the number of faults; \(\Pr(F_i)\) is the probability of fault \(F_i\); \(\Pr(TS | F_i)\) 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).

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

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 \(j\); \(\Pr(TS | F_i \cap (A = j) \cap \tau_c \cap \gamma_l)\) is the PTS of fault \(i\) with type \(j\), clearing time \(\tau_c\) and location \(\gamma_l\); \(\gamma_l\) is the ratio of the distance between the fault location and the head-end bus to the total length of the line; \(\xi_c\) and \(\xi_l\) are the corresponding probabilities of \(\tau_c\) and \(\gamma_l\), respectively.

The probability of type \(j\), clearing time \(\tau_c\) and location \(\gamma_l\) 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 \(\Pr(TS | F_i \cap (A = j) \cap \tau_c \cap \gamma_l)\) 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
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