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Reliability based power systems planning and operation with wind power integration: A review to models, algorithms and applications

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ABSTRACT

Wind energy has been considered as an important substitution of fossil-based energy for future society. However large-scale integration of wind power will introduce great risks to both power system planning and operation due to its stochastic nature. By adopting power system reliability theory, the risks can be quantitatively estimated so that numerous publications have been published to study reliability impacts caused by wind power. This paper thoroughly investigates the features of existing reliability models of wind power, reliability assessment algorithms and its applications in wind power related decision making problems. The paper also reveals significant differences existed in reliability models and algorithms between planning and operational phase of power systems, which are neglected in existing review articles.

Contents

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1. Introduction

Wind energy has been widely recognized as an important energy alternative of fossil fuel. Many countries, e.g. US, China, Germany and Denmark [1], have set various ambitious targets so as to integrate large scale wind power into their power systems in very near future. However, stochastic power output has become one major difficulty while planning or operating a power system with high wind penetration. Existing deterministic methods, which do not fully consider with uncertain factors, are no longer capable enough of evaluating system risks due to wind integration. Therefore it motivates researchers to look for stochastic-based methods for risk assessments.

One technical solution is of the theory of power system reliability, which was first proposed by Billiton [2] for quantitatively estimating impacts caused by component uncertainties, e.g. unexpected generator outages. Since the theory is suitable for studying stochastic factors, a large number of studies have been carried out based on its framework in order to estimate reliability performances of one power system with high wind penetration level. Literatures concerning this topic shall be carefully organized and reviewed for a better understanding on the development as well as the applications of the reliability theory on technical issues raised by stochastic wind power integration.

Many review works have been presented by several previous studies. Ref. [3] surveyed literatures from four different technical aspects, i.e. modeling of wind farms, methods of wind speed parameters assessment, reliability assessment algorithms as well as relevant factors affecting the reliability of wind power system (e.g. wake effect). Ref. [4] aimed at categorizing the reliability models of various kinds of renewable energy e.g. wind, solar as well as hydro power proposed from the published literatures. Similar review and survey works are also published in [5–7]. Literature [8] is focused on emphasizing the importance of reliability theory in long-term power system planning with large-scale integration of wind energy. Ref. [9] listed a series of uncertainties that would affect the integration of wind energy, such as energy storage capacity, market pricing and transmission ability and so on. However the paper did not present a thorough review to the approaches of estimating the risks of these uncertainties. A category of long-term wind power reliability models, which are the auto aggressive moving average (ARMA) models, were reviewed in [10]. Although these studies have provided excellent works, they are still insufficient for summarizing the state-of-art of reliability theory completely, which can be demonstrated from the following two aspects:

(1) Regarding power system planning phase. Most of previous review works only listed the basic ideas of available literatures in a much simple manner. However the features of models or algorithms are not clearly explained or further compared. That might result in difficulties for readers to find a best or most suitable model and algorithm for a specific problem. Meanwhile, some state-of-art works, involving reliability models and assessment algorithms proposed recently, are also not included in the existing reviews.

(2) Regarding power system operational phase. Previous review works are mostly concentrated on the studies about power system planning. In contrast, literatures concerning reliability-based system operation with wind power were not paid enough attentions. However, since stochastic wind integration has introduced significant risks within system operation, the concept of reliability is becoming more-widely accepted and recognized by system operators. In addition to that, the models as well as algorithms applied in operational phase are quite different from those in planning phase. Therefore these works shall be distinguishingly picked up and then carefully reviewed.

Under that background, this work is motivated by the purpose of compensating previous studies. We aim at presenting a more systematic literature review from the aspect of power system reliability concerning wind power. First, reliability models of wind power in planning and operation phase will be carefully investigated hence their characteristics can be revealed. Second, the reliability assessment algorithms in planning and operation phase will be reviewed. We focus on the algorithms which are being or potentially capable of being adopted to deal with the uncertainties of wind. And third, we review various kinds of reliability-based power system decision making problems when wind power is integrated. By doing so, the importance of reliability in modern power system can be demonstrated.

This paper is organized as followings: In Section 2 a brief introduction to power system reliability theory is provided in order to explain the basic concepts and theory architecture. Reliability-based power system planning with wind power integration is discussed in Section 3, which includes various applications, planning-phase reliability models of wind power as well as corresponding reliability algorithms. Section 4 investigates the reliability applications as well as corresponding models and algorithms under operational phase. At last Section 5 concludes the paper.

2. An introduction of power system reliability theory

The most fundamental function of modern power systems is to fully satisfy the load demand under every possible circumstance.

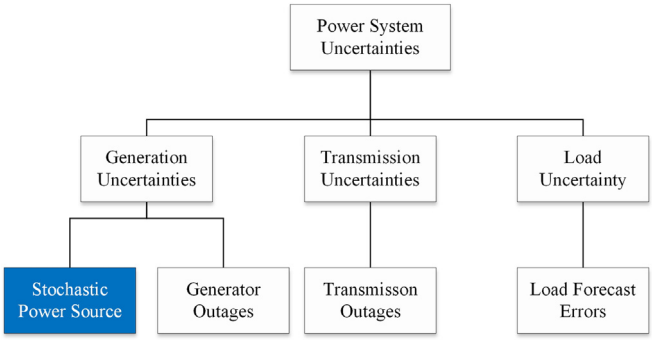

Fig. 2.1. Typical uncertainties in power system.