Renewable and Sustainable Energy Reviews 58 (2016) 537–547

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Reliability and economic evaluation of power system with renewables: A review

P. Zhou [a,*], R.Y. Jin [a], L.W. Fan [b]

[a] College of Economics and Management & Research Centre for Soft Energy Science, Nanjing University of Aeronautics and Astronautics, 29 Jiangjun Avenue, Nanjing 211106, China

[b] Business School, Hohai University, 8 Focheng West Road, Nanjing 211100, China

ARTICLE INFO

Article history:
Received 16 April 2015
Received in revised form
20 October 2015
Accepted 18 December 2015

Keywords:
Electric power system
Renewable energy
Reliability
Cost-benefit

ABSTRACT

The share of renewable energy generation has been increasing as a result of the world-wide concern on environmental deterioration and climate change associated with burning fossil fuel. Due to the stochastic and intermittent characteristics of renewable energy resources, assessing the reliability of power systems with renewables has become challengeable and been widely studied for the past several decades. This paper provides a review of the studies on the reliability and economic evaluation of power system with renewables. It starts from a summary of the key indicators and models for assessing the reliability and economics of power systems. Different studies are then compared in terms of type of renewables, evaluation method, application area, level of study and country involved, through which the main features of past studies are identified. We also discuss the relationship between economics and reliability that shows the necessity of evaluating reliability and economics of power system with renewables simultaneously. A case study is finally proposed to illustrate the differences between alternative system settings in reliability and economic evaluation. It is found that the types and scales of renewable energy generation have significant impacts on system reliability and economics, which needs to be taken into account in the development of renewable energy power systems.

Contents

* Corresponding author. Tel.: +86 25 84893751x813; Fax: +86 25 84892751
E-mail addresses: rocy_zhou@hotmail.com (P. Zhou), jin_rongying@163.com (R.Y. Jin).

http://dx.doi.org/10.1016/j.rser.2015.12.344
1364-0321/

1. Introduction

Renewables, also known as renewable energy, is energy that is derived from natural processes (e.g. solar and wind) that are replenished at a higher rate than they are consumed [1]. Promoting renewable energy consumption has widely been regarded as one viable way of reducing carbon dioxide emissions, improving energy supply security and developing green economy. Past decades have seen a rapid growth of the installed capacity of renewable energy power generation in the world. For example, in 1996 the installed capacity of wind turbine generator (WTG) was only 6.1 GW, but it reached 318.2 GW in 2013 with an annual growth rate lying between 20 and 40 percent [2]. For solar PV power generation, the global installed capacity increased from 0.96 GW in 1998 to 141.5 GW in 2013 [3]. It is no doubt that the renewable energy power generation will play more and more important role in the future energy mix [4].

There are two inevitable and fundamental characteristics for renewable energy power generation, i.e. reliability and economics. Reliability is composed of adequacy and security. Adequacy refers to the ability of a system to meet the aggregate power and energy requirement of all consumers at all times, and security is the ability of a power system to deal with sudden interruption [5]. Economics represents an ultimate cost-benefit evaluation of a power system on an acceptable level of reliability. Reliability is connected with economics that has impacts on investment decisions. When electricity generated from renewables parallels in the grid, several issues may arise in power grid operation and management. First, renewable energy is highly random and intermittent due to the uncertainty in wind speed and solar irradiance. Second, the volatility of distributed power is high but the electricity output is small. Third, the co-existence of in-grid and off-grid modes increases the complexity of power system. These issues will certainly affect the reliability of power system. In addition, the initial investment cost of renewable power generation, including both installment cost and equipment replacement cost, is substantially higher than the conventional fossil fuel -fired power generation. One main goal of modern power grid is to transmit electricity uninterruptedly at a relatively lower cost, and reliability and economics become two crucial characteristics of electric power system [6].

Many earlier studies inclusive of several review ones have contributed to examine the reliability and economics of renewable power system. For example, Lin et al. [7] reviewed the models and algorithms for evaluating the reliability of wind power system in the planning and operational phases. Jiang et al. [8] reviewed the reliability evaluation methods and models for wind power generation. Borges [9] summarized three types of reliability evaluation methods for electricity distribution with renewables. Chaiamarit and Nuchprayoon [4] reviewed the reliability models for power generation by renewable energy resources. Fathima and Palanisamy [10] provided a review of models for reliability assessment of renewable power generation with an applications to micro-grid optimization. It can be found that these earlier review studies summarize the models and algorithms in a relatively comprehensive way but provide insufficient discussions on the application features of past studies. In addition, they mainly deal with wind power. On the other hand, economics as an indispensable characteristic in renewable power system assessment was not discussed in the earlier review studies. In view of the connection between reliability and economics, it is worthwhile conducting a review of the studies on both reliability and economic evaluation of power system with renewables, which is the purpose of the study. It is expected that such a review study not only provides a useful guide to the beginners but also helps identify the potential future research directions in this area from both theoretical and application perspectives.

The remainder of this paper is organized as follows. In Section 2, several commonly used reliability indicators of power generation and distribution are introduced. The conventional reliability evaluation methods as well as their extensions to renewable power generation are categorized into the analytical, simulation and hybrid methods. Section 3 reviews the methods for economic evaluation of power system with renewables. In Section 4, we summarize the main features of past studies in terms of type of renewables, evaluation method, application area, level of study and country involved. Possible future research directions in this field have also been identified. Section 5 provides a case study to show the necessity of considering economics in reliability evaluation of power system. Section 6 concludes this study.

2. Reliability evaluation

Assessing the reliability of electric power system with renewables as an important research area in energy systems modeling has continuously been developed and advanced. The study by Billinton and Hossain [11] provided a foundation for quantifying the impacts of component uncertainty such as unexpected generator outages on power system reliability. Since then, many methods for evaluating the reliability of electric power system have been proposed. In the followings, we summarize the key indicators and models employed in the earlier studies.

2.1. Reliability indicators

An electric power system can be classified into power generation, transmission and distribution systems. Modeling the reliability of an electric power system may be conducted from three hierarchical levels [12]. The first level considers only the adequacy of electricity generated. The second level, covering both generation and transmission, evaluates the transmission continuity from supply point to load point. The third level encompasses the first and second levels but mainly evaluates the reliability of distribution system due to the complexity of the whole power system. In literature, most studies evaluate the reliability of power system from the perspective of the third level. Evaluating the reliability of power system often consists of three steps, i.e. state selection, state estimation and the calculation of indicator value. As such, the reliability evaluation of power system is heavily dependent on the definition of reliability indicators and their calculation process. A sketch of past studies shows that different indicators have been used to evaluate the system reliability for power generation and distribution systems. Furthermore, we classify the reliability indicators for power distribution system into two groups, i.e. load point reliability indicators and system reliability indicators. Table 1 provides several popular indicators used in the past studies.

For power generation system, three reliability indicators are often used, namely frequency (*F*), average duration (*D*) and unavailability (*U*). *F* denotes the frequency of a component from