Renewable and Sustainable Energy Reviews 42 (2015) 26–42

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Estimation methods review and analysis of offshore extreme wind speeds and wind energy resources

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ARTICLE INFO

Article history:
Received 29 April 2014
Received in revised form
31 July 2014
Accepted 26 September 2014

Keywords:
Comprehensive estimation
Offshore wind energy/power
Extreme wind speeds
Distributional function
Model optimization

ABSTRACT

Offshore wind resources are more abundant and stronger and they blow more consistently than land-based wind resources. While gale force winds are easier to hit on the sea, the strong wind vibration and wind loads may exert severe damage and shock to wind turbines and wind power grids, even resulting in power grid collapse. Thus, to develop offshore wind power, apart from accurate quantitative wind energy potential assessments, it is necessary to effectively estimate extreme wind speeds. Toward this purpose, this paper investigates the current status of extreme wind speeds and wind energy assessment from literature review. It turns out that much work on wind energy estimation has been performed, whereas relatively little research involves extreme wind speeds, the main challenge stemming from the limited availability of derived extreme winds. Then a GH method based on artificial intelligence optimization algorithms is developed to re-analyze future samples of extreme wind speeds. On the basis of the re-analyzed extreme samples, as well as the Generalized Extreme Value (GEV) and Gumbel models optimized by Cuckoo Search (CS) and Chaotic Particle Swarm Optimization (CPSO) algorithms, the potential risks of extreme wind speeds are conducted based on 23-year (1990–2012) historic wind speeds. Thus, in terms of wind speeds, a comprehensive estimation for offshore wind energy is initially implemented in Bohai Rim, China. The assessment shows that the study areas have high-strength wind power but are rarely subjected to extreme wind speeds, which implies that it is suitable for wind farm construction.

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http://dx.doi.org/10.1016/j.rser.2014.09.042
1364-0321/

1. Introduction

With the increased interest in global energy conservation and emission reduction, the pace of new energy development and utilization in each country is accelerating [1]. In recent years, the study of wind energy and wind development has been a topic of great interest for developers and researchers in developing countries [2]. Wind power, as a strategic emerging industry, has been growing rapidly due to the inexhaustible and clean nature of wind energy [3]. It will continue to be a core strength for new energy industry development, particularly for offshore wind power construction, which is rapidly becoming an area of worldwide focus.

Around the world, the potential of offshore wind energy is enormous; it could meet the United States' energy demand four times over or Europe's energy demand seven times over [4]. Currently, more than 90% of the world's offshore wind power is installed off of northern Europe, in the North, Baltic and Irish Seas and the English Channel. The UK and Denmark remain the two largest markets for offshore wind in Europe, followed by Belgium, the Netherlands, Germany, Sweden, Finland and Ireland. The Europe Wind Energy Association (EWEA) estimates that by 2020, 60,000 MW of offshore wind power can supply 148 TWh per year, which is enough to meet more than 4% of the total electricity demand in Europe and which can reduce 87 million metric tons of carbon dioxide emissions [5].

Additionally, there are great expectations for major deployment elsewhere. Governments and companies in Japan, Korea, the United States, Canada and even India have shown enthusiasm for developing offshore in their waters. According to the more ambitious projections, a total of 80 GW of offshore wind capacity could be installed by 2020 worldwide, with three-quarters of this in Europe [6].

In the Copenhagen Climate Change Conference in 2009, China made two strong commitments: by 2020, the non-fossil energy share of energy consumption will increase to 15%, and carbon emissions of per unit of GDP will decrease by 40–45% of the value in 2005 [7]. To accomplish this goal, a series of policies in China have been formulated. China's installed offshore capacity today accounts for 258.4 MW, ranking number three globally. Offshore wind still only provides a tiny share of the total wind capacity in China, accounting for less than 0.5% of the total wind energy installed in the country. China has an ambitious target for offshore development of 5 GW by 2015 and 30 GW by 2020. To reach this goal, China's offshore development follows a concession tender model in which both developers and tariffs are determined by a tender. The second round of offshore concession tendering of 2000 MW was supposed to take place in 2011 but has been postponed until 2012, primarily due to planning and siting difficulties faced by the projects tendered in the first round in 2010 [6], which indicates that offshore wind farm selection is a significant procedure for wind farm construction.

For the past few years, offshore wind has received much attention when onshore wind is now directly competitive with conventional energy sources in an increasing number of markets around the world. Offshore wind has a number of advantages [6]: (a) Higher wind speeds and less turbulence than on land and fewer environmental constraints; (b) Particular suitability for large-scale development near the major demand centers represented by the major port cities of the world, avoiding the need for long transmission lines to get power to demand centers, which is often the case onshore; and (c) Sensibility of building wind farms offshore in very densely populated coastal regions with high property values because high property values make onshore development expensive, sometimes leading to public opposition. Offshore is a relatively new technology, with significant opportunities for cost reduction, technical innovations and 'revolutionary' developments that may change the face of renewables in some parts of the world.

With the abundant wind energy resources on the eastern coast of China, wind energy development has become an important way to ease the power shortage situation in the coastal areas and greenhouse gas emissions. Meanwhile, another significant factor that should be taken into consideration for offshore wind farm selection is the risk or probability that offshore wind turbines suffer from severe extreme wind speeds. The fact is offshore areas are more likely to encounter a typhoon, which rarely occurs inland. A typhoon, with the characteristic of having a complicated structure and being highly devastating, can exert a destructive influence on wind turbines. When the typhoon hits, it often leads to wind direction mutation, strong turbulence, thunderstorms and storm surges, which pose a great threat to offshore wind turbines, such as generator parts or blade damage and even tower collapse. Specifically, in 2003, twenty wind turbines of Plum wind farm were destructed or partially damaged by tropical cyclone Erica in New Caledonia, six wind turbines were destroyed by the typhoon Maemi in Okinawa, and many wind turbines of Shanwei wind farm were damaged when typhoon Dujuan struck Guangdong province of China. In 2006, super typhoon Saomai struck Cangnan county of China, resulting in 70 million dollars losing due to 27 wind turbine failures, including five wind turbine towers collapsed [8]. Typhoons, which have extensively destructive power, are difficult to predict, the reason for which is the fact that the path of the typhoon is mainly affected by sea surface temperature that cannot be monitored effectively due to the complexity of ocean currents.

Based on the above analysis and considering the destructive influences of extreme wind speeds on wind turbines and wind power grid, as well as the high cost of offshore wind farm construction, there is a need to explore wind energy resources, wind turbine power efficiency, stability and security to guarantee the reliability of offshore wind farm generation. A measure of the potential risk is very helpful when a wind farm operator considers