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Technical characteristic analysis of wind energy conversion systems for sustainable development

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ABSTRACT

Wind energy as a clean, environmentally friendly and cost effective renewable energy resource, is taken into consideration by many developed and developing countries as a promising means to provide electrical energy. In feasibility study stage of the wind energy systems, the sustainability analysis is one of the main issues that can assure the investors and stockholders to invest in this renewable energy. Since a system can be truly sustainable by achieving the energetic, ecological and economic sustainability, the present study will focus on the technical characteristics and performance analysis of the wind energy systems. The relations between reliability, availability, energy and exergy efficiency, risk management and the environmental impact of the wind energy systems are investigated in the context of this study. It is concluded that the wind characteristics data and the wind speed are the main effective parameters on its reliability and availability. It is also revealed that considering the system loss, exergy efficiency results of the wind energy systems are more reliable than the energy efficiencies. Due to avoid future failure of the systems, the causes of the failure are investigated and it was concluded that the structural failures caused by storms and strong winds are known as the most prevalent failures.

1. Introduction

Renewable energy as the best substitution of fossil fuels is taking into account during the past decades to supply the worldwide energy demand. As the renewable energies are pollution-free, the produced electricity from them is called "green power" [1]. Among various renewable resources, wind energy as an abundant, free and environmentally friendly energy, experienced the fastest growing trend [2]. In order to evaluate the feasibility of wind power to provide energy, technical characteristics, energy and exergy analysis are studied. Generally, technical characteristics are studied in five aspects of reliability, maintenance requirements, availability, sustainability and environmental impacts. However, these aspects are interrelated, for instance, the maintenance and availability of the system have significant effects on its reliability. BoroumandJazi et al. [3] provide a comprehensive discussion on the technical characteristics of the renewable energy applications and their relation with system's performances. The classification of the technical characteristics and their relations are illustrated schematically in Fig. 1.

An alternative means to evaluate the performance of wind energy is exergy analysis. Applying this contemporary thermodynamic method to the system can give a more realistic view of its performance. Numbers of studies are conducted in performance evaluation of various systems using second law of thermodynamic, such as industrial boilers [4], gas turbines [5], and refrigeration cycles [6]. There are number of studies in literature, which computed the exergy efficiency of the renewable resources. A comprehensive review on application of the second law of thermodynamic in investigating the performance of the different solar systems is presented recently by Saidur et al. [7].

The performance analysis and technical characteristic investigation of a system play a crucial role in evaluating the renewable energy systems and lead to the development and the optimization methods of the systems. The present study reviews the existing surveys on the exergy analysis, sustainability, reliability and risk management of wind energy applications. In the context of this study, general characteristics of wind energy and wind turbine technologies are presented in Section 2. Moreover, the sustainability aspects of wind energy are investigated in Section 3. Furthermore, the reliability and availability of wind energy are studied in Section 4, which is followed by performance analysis, and risk management of the system in Sections 5 and 6, respectively. The environmental impacts of wind energy are studied in Section 7. Section 8 is a summary of analysis procedure of effective technical characteristic of wind energy system on its sustainability. The future direction in Section 9 will give some outlines to who are interested to continue their studies in this field. Finally, the conclusions of the study are presented in Section 9.

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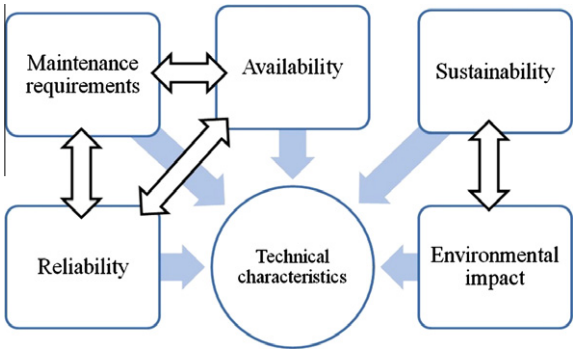

Fig. 1. The relation between technical characteristics aspects of a system.

2. General consideration of wind energy

2.1. Global wind energy production capacity

Due to the fact that wind is caused by the air pressure difference produced from heating effects of sun, the wind energy can be considered as a form of solar energy. The wind energy is mostly employed for electricity generation. There are various measurement methods to evaluate the performance of wind power such as capacity factor, availability, connect time, lifetime, reliability and specific output [8]. Wind turbines are utilized as the means of converting the wind energy into rotating mechanical energy [9,10]. To highlight the importance of wind energy, the global wind energy production capacities are presented in Table 1.

It can be clearly observed that the wind energy production capacity altered from 4800MW in 1995 to more than 237GW in 2011. Since the capacity and usage of wind energy is increasing significantly, it is reasonable to invest on utilizing sustainable technologies to convert the potential energy of wind.

2.2. Wind turbine

Wind turbines are generally classified based on their configuration into two main groups of horizontal and vertical axis. The advantages and disadvantages of both categories are compared in Table 2.

The exergy efficiency of the wind turbine is a measure for investigating the amount of stream exergy that turns into useful work. The exergy efficiency of the wind turbines is significantly affected by the meteorological parameters [15]. The detailed meteorological characteristics of wind power are presented in literature [16–19]. For instance, the season wise and location wise data of wind velocity was used to assess and investigate the wind energy resources Karnataka in India [20]. In another study temperature, pressure, relative humidity and wind speed were applied to propose a continuous bivariate model for wind power density and wind turbine output [21]. Besides the wind conditions, the mechanical performance and wind turbine design affect the wind power, significantly [22,23]. The wind conditions such as velocity, distribution, etc. determine the potential of applying it for power generation. Although wind is known as a clean source for energy, but because of its uncertainty and unreliability in some cases, it cannot be used as the load generation for the power dispatchers in large scales [1]. The advantages and disadvantages of wind energy as a summary of this section are tabulated in Table 3.

3. Sustainability aspects

A sustainable system is a system that can maintain a set of key characteristics within certain ranges indefinitely. Sustainability of a system can be investigated based on different aspects of human, social, economic and ecologic. The main steps to achieve a sustainable wind power plant (WPP) are shown in Fig. 2 [24].

It can be clearly seen that the Weibull probability density function and artificial neural networks are the prevalent methods for evaluating the site potential. The rotor model, gearbox model and generator model are investigated to assess the energetic and exergetic performance of the system. The environmental impact assessment and the economic analysis are conducted to ensure the ecological and economic sustainability of the system.

The sustainability aspects of wind energy conversion systems are investigated hereinafter in Section 4–7. In order to choose a suitable wind site with a good potential, the methods to evaluate the reliability and availability of wind energy are explained. To meet the energetic sustainability, the performance of the system based on the first and second law of thermodynamics is analyzed. Furthermore, the risk managements and failure analysis would be used as an effective tool to achieve an energetic sustainable system. Last but not least, critical assessment on the impact of wind energy conversion systems on the environment is a must complete task to cover the ecological sustainability aspect.

4. Reliability and availability of wind energy systems

As the renewable energy sources fluctuate in highly stochastic, non-linear and multidisciplinary environments, the reliability and performance assessment of the renewable energy conversion systems are considered as challenging issues [25]. Reliability assessment of wind farms plays a crucial role in generation system designing in order to meet the expected total demand. Determining the availability and reliability of wind sources should be taken into account in both stand-alone and hybrid systems.

Wind speed is considered as one of the parameters with significant effect on the reliability of the system. It is shown that the cut-in and rotated wind speeds affect the reliability whilst the cut-out speed has no effect [26]. Xie and Billinton [27] stated that the reliability and energy production of the system are related to the wind

Table 1
Global wind energy production capacity [11].

Year	Capacity (MW)	Annual growth (MW)	Annual growth (%)	Year	Capacity (MW)	Annual growth (MW)	Annual growth (%)
1995	4800	–	–	2004	49,461	8108	19.7
1996	6100	1300	27.1	2005	59,135	9674	19.6
1997	7482	1382	22.7	2006	74,176	15,042	25.5
1998	9670	2188	29.3	2007	93,959	19,783	26.7
1999	13,699	4029	64.3	2008	121,335	27,376	29.2
2000	18,040	4341	31.7	2009	158,012	36,678	30.3
2001	24,318	6279	34.9	2010	194,680	36,669	23.3
2002	31,184	6866	28.3	2011	237,502	42,822	22
2003	41,354	10,170	32.7				