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Statistical analysis of wind characteristics and wind energy potential in Hong Kong

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ABSTRACT

The harvesting of renewable energy sources has become increasingly important to take account of the gradual decline of fossil fuel reserves and the environment degradation associated with the use of fossil fuels. Wind energy, as one of the most well-known renewable energy sources, has been extensively harnessed across the world. Nevertheless, the wind energy exploitation in Hong Kong is still rare.

Based on 6-year wind data recorded at five meteorological stations with different terrain conditions, this study presents a statistical analysis of the wind characteristics and wind energy potential at typical sites in Hong Kong by the assistance of Weibull distribution model. The variations of mean wind speed, as well as Weibull parameters, were highlighted on various timescales. Among all the sites, the annual Weibull scale parameter varied from 2.85 m/s to 10.19 m/s, and the range of the annual shape parameter was 1.65–1.99. The highest Weibull scale parameter was observed at a hilltop, whilst the lowest was found at an urban site. The monthly variation of wind power density was presented and discussed for each site. Hilltops and offshore islands demonstrated prominently greater wind power density than urban areas. It was thus indicated that hilltops and offshore islands are the most promising locations for wind energy exploitation in Hong Kong.

1. Introduction

Over the past decades, the natural environments in many countries and regions have degraded noticeably in parallel with the rapid industrialization development. Undoubtedly, the excessive consumption of fossil fuels has displayed negative effect to the environments, which led to a variety of environmental problems [20]. Under such circumstances, the necessity to achieve sustainable development has been emphasized constantly on account of increasing awareness and expectation for the better natural environment. As one of the key elements of sustainable development, the exploration and harnessing of renewable energy has attracted broad attention. Currently, the most well-known renewable energy sources include solar, wind, ocean, hydropower and geothermal energy, among which wind energy is arguably one of the oldest sources of energy used by mankind [33].

Wind energy has demonstrated certain superiorities in comparison with traditional energy sources. Wind energy is energized by nature wind, therefore it can be considered as a clean and environmentally preferable source of energy [33]. Wind energy is literally inexhaustible and abundantly available worldwide, which can be used as a promising domestic source of energy in many countries. More importantly, with the continuous development of wind energy technologies, it has become one of the lowest-priced renewable energy sources [33]. Nowadays, the harvesting of wind power has been widely extended throughout the world. The world's total installed wind power capacity has grown surprisingly fast, from 47.620 GW to 318.105 GW during the period of 2004–2013 [12]. The global annual installed wind capacity has continuously surpassed 35 GW since 2009 [12]. Regionally, China was well-placed to lead the total installed wind capacity with a value of 91.142 GW by the end of 2013, followed by USA and Germany [12]. Nevertheless, in spite of the rapid-growing wind energy industry, it is worth noting that due to the stochastic and variable nature of wind, electricity power generated by wind turbines is generally characterized with high intermittency, which may affect both the power quality and the planning of power systems [28]. Therefore, energy storage systems (ESSs) are usually introduced to facilitate the integration of intermittent wind energy [4]. Efforts have been made to enhance our understanding of energy storage systems. Barton and Infield [3] proposed a probabilistic method to estimate the capability of energy storage. Paatero and Lund [28] focused on the effects of energy storage to reduce the

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Nomenclature

U	wind speed at height Z (m/s)
U_R	wind speed at reference height Z_R (m/s)
α	power law exponent
$f(V)$	Weibull probability density function
k	Weibull shape parameter
c	Weibull scale parameter (m/s)
$F(V)$	Weibull cumulative density function
V_m	mean wind speed (m/s)
σ^2	variance of wind speed (m^2/s^2)
$\Gamma(x)$	Gamma function
P_{op}	operating probability
V_{mp}	most probable wind speed (m/s)
$V_{\max E}$	wind speed carrying maximum energy (m/s)
P/A	wind power density (W/m^2)
k_z	Weibull shape parameter at height Z
c_z	Weibull scale parameter at height Z (m/s)
k_a	Weibull shape parameter at anemometer height
c_a	Weibull scale parameter at anemometer height (m/s)
ξ	relative error
E_{pf}	energy pattern factor
ρ	air density (kg/m^3)

Abbreviations

WGL	Waglan weather station
TMS	Tai Mo Shan weather station
HKO	Hong Kong Observatory station
CCH	Cheung Chau weather station
TC	Tate's Cairn weather station

fluctuations of wind power. Beaudin et al. [4] provided a detailed review of several electrical energy storage systems in relation to renewable energy applications, while Díaz-González et al. [14] highlighted the energy storage technologies associated with wind power integration. Sundararagavan and Baker [32] investigated the economic feasibility of energy storage technologies. More recently, Hu et al. [19] introduced a dual-objective optimal charging strategy for two types of Li-ion batteries with attention on the conflict between charging time and charging loss. Shortly after, they also carried out a comparative analysis to evaluate the viability of three electrochemical energy storage systems applied to a hybrid bus powertrain [21].

As a highly developed city and the leading commercial center in Asia, Hong Kong needs a mass of energy supply to support its economic development. With nearly no indigenous fossil resources, Hong Kong demonstrates heavy dependence on external sources [7]. However, due to the gradual reduction of fossil fuel reserves and the environment degradation resulting from fossil fuel uses, the exploration of the available renewable energy source becomes prominently important.

Fortunately, Hong Kong has been benefited from wind power generation from early 2006, with the ever first wind turbine installed in Lamma Island [7]. In fact, investigations on the viability of wind power utilization in Hong Kong have been carried out successively over the years. Lun and Lam [27] derived the two Weibull distribution parameters for three different locations on the basis of a database including 30 years wind speed measurements. The results offered useful information for the further assessment of wind energy potential in Hong Kong. Li [25] presented a feasibility study on the application of offshore wind energy. Based on the analysis of wind data measured at Waglan Island in 1998, the mean wind power density was calculated as 310 W/m^2. It showed that offshore wind energy has the potential to be a promising contributor for the city's electricity supply. Wong and Kwan [34] conducted a comprehensive investigation of the wind characteristics in Hong Kong in relation to wind power. By applying the Weibull distribution model to analyze the wind data available at 13 meteorological stations, they stated that hilltops and offshore islands are the most attractive locations for exploiting wind energy, among which Tai Mo Shan has the highest wind power density with a value of 485 W/m^2. Lu et al. [26] proposed a new simulation model to evaluate the potential of wind power generation at a given location. The case study indicates that Waglan Island is a satisfactory location for wind power generation, so are the islands surrounding Hong Kong. More recently, Gao et al. [15] identified the potential offshore wind farm locations in Hong Kong and highlighted four representative offshore wind farms with a total area of 421.48 km^2. It was suggested that the potential annual wind power generation in Hong Kong's offshore wind farms may reach to 112.81×10^8 kW h. Nevertheless, the implementation of wind power generation is still rare in Hong Kong.

This study attempts to explore the wind characteristics at different locations in Hong Kong, and estimate the wind energy potential by means of statistical analysis. The outcomes of the present paper tend to be advantageous for the strategic development of wind energy in later phases. The remainder of this paper is arranged as follows: Section 2 gives a brief introduction about the meteorological stations adopted in this study. Section 3 describes the wind data adjustment method. Section 4 highlights the estimation procedure of Weibull parameters, as well as other key parameters. Detailed interpretations and discussions of the results are addressed in Section 5 and the main findings of this study are presented in Section 6. A flowchart is given in Fig. 1 to illustrate the analysis procedure of this study.

2. Wind data measurement

For the assessment of wind energy potential, the wind characteristics at the desired locations should be fully understood. The Hong Kong Observatory has established 51 meteorological stations at various locations across the territory to monitor the wind climate. Anemometers are installed at different heights at the

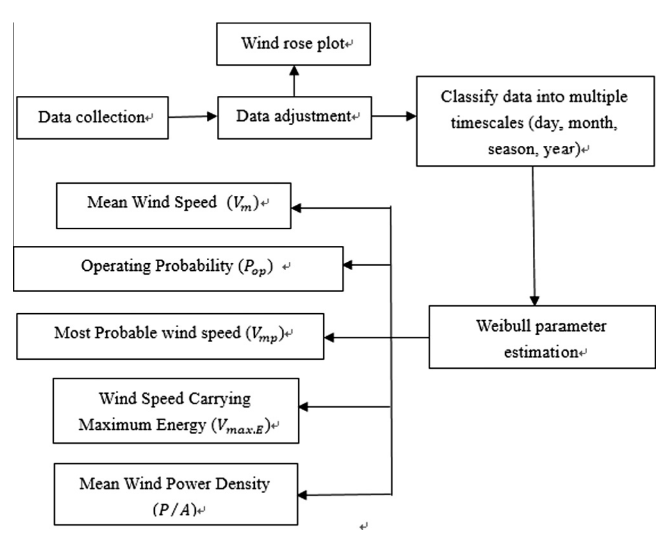

Fig. 1. Flowchart of analysis procedure of the present study.