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Study on offshore wind power potential and wind farm optimization in Hong Kong

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HIGHLIGHTS

- The potential offshore wind farm area (357.78 km^2) in HK has been selected.
- 10 years' wind data were used for the wind farm layout optimization.
- The annual wind power potential of optimized OWFs in HK has been investigated.
- The potential monthly power generation of different OWFs was calculated.
- A universal method for the wind power potential assessment was proposed.

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ABSTRACT

This paper investigates the potential and feasibility of the offshore wind energy in Hong Kong. The potential offshore wind farm locations are selected after considering the man-made activities in Hong Kong waters that may come into conflict with the development of the offshore wind farms. The hourly wind data of ten years (2002–2011) in the corresponding potential wind farms are analyzed. The assessment for offshore power potential is obtained with the potential wind farm being optimized using the Multi-Population Genetic Algorithm (MPGA) which aims at getting a minimum cost of energy (COE) with a maximum power generation. The optimal wind turbine layout configurations are proposed with an economic analysis and monthly power generation. Results show that the potential offshore wind farm area in and beyond (2 km away from its boundary) Hong Kong is 357.78 km^2 (21.68% of the HK water area) and southeastern water area is the most suitable location for offshore wind farm development. In additions, the potential annual offshore wind power generation is 112.81×10^8 kW h which accounts for 25.06% of the total annual power consumption in 2011 if the wind turbine layout is optimized. The potential monthly offshore wind power contribution to the electricity demand is the highest in October (46.46%) and lowest in August (7.93%).

1. Introduction

Hong Kong, as one of the international business center and China's leading economic trading post, has a high population density ranking number 3 in the world in 2011 [1]. With a high population density and a small land area of about 1100 square kilometers, there is no primary energy reservation such as fossil oil, gas and coal [2]. Hong Kong derives its energy supplies almost entirely from external resource [3]. Fig. 1 is the local electricity consumption as well as the imported electricity during the year 1993–2011. The electricity demand is growing year by year. Meanwhile, the electricity import is increasing which occupies about 27% of the total local electricity consumption in Hong Kong [4]. The excessive dependence on the imported energy will inevitably influence the regional security and economic development of Hong Kong. The ever-increasing energy demand has caused great attentions on the exploration of renewable energy.

Hong Kong is located in eastern Asia, on the southeast coast of the People's Republic of China, facing the South China Sea. The special geography location benefits Hong Kong with abundant wind resource. Taking Waglan Island as an example, the annual average wind speed in the past ten years is 6.14 m/s at 26.3 m above ground level, 83 m above sea level, as obtained from the weather data recorded by the Hong Kong Observatory [5]. The abundant wind resource provides obviously opportunities for wind power applications.

What's more, the 1650.64 km^2 water area in Hong Kong is about 59.91% of the Hong Kong territory area (2755.03 km^2) [6]. The depth in most Hong Kong water area is less than 30 m, which is suitable for

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Nomenclature

List of abbreviations

OWF	offshore wind farm
MPGA	Multi-Population Genetic Algorithm
COE	cost of energy
ENC	electronic nautical chart
WFPGCTs	wind farm power generation calculation tools
WT	wind turbine
FCR	fixed charge rate
O&M	operation and maintenance cost
N	wind turbine number
PG	power generation
PC	power consumption

List of symbols

A	power exponent year
δ	gradient height (m)
C_{Tur}	installation cost of turbine ($/MW)
C_{SS}	installation cost of support structure ($/MW)
C_{TS}	installation cost of transmission ($/MW)
C_T	turbine thrust coefficient
Z	hub height of WTs (m)
r_d	wind turbine rotor radius (m)
Z_0	roughness length of ground (m)
a	axial induction factor
u_0	free stream wind speed m
θ	wind direction
P_v	wind turbine power generation at wind speed v (kW)

List of subscript

i	i-th wind turbine
j	j-th wind turbine

wind turbine installation. 1180-km-long coastline with no obstacle as well as the vast water area increases the feasibility for offshore wind farm development. To estimate the offshore wind source potential, some research on wind power application all over the world has been developed. An investigation for future offshore wind energy in the United States has been done by Musial and Butterfield [7,8] using a 5 MW wind turbine for economic analysis. Results showed that the offshore wind energy can diversify the U.S. electric energy supply. Dvorak et al. [9] did a wind energy resource assessment for offshore California focuses on all current and future turbine foundation technologies for the water depth of 0–200 m. Youm et al. [10] did an investigation on the wind energy potential along the northern coast of Senegal based on Weibull probability distribution function. For the Korea offshore, Oh et al. [11] gave an assessment of wind potential at the demonstration offshore wind farm in a southwestern sea-area of the Korean Peninsula. The long-term wind potential, the annual energy production as well as the wind farm capacity factor of the candidate site were evaluated.

For Hong Kong, Fung [12] did a preliminary study on a wind farm annual power generation of 25 wind turbine on Lantau Island. The one year average wind speed was used for the calculation without the consideration on the wind turbines layout as well as the different wind directions. Li [13] did an investigation on the potential and feasibility of offshore wind energy in Hong Kong using the 1998 wind data collected from Waglan Island. However, the wind resource in Waglan Island cannot represent the wind resource overall the territory. The recommended spacing of the turbine layout is selected. Lu et al. [14,15] did a research on wind power potential at five typical onshore sites in Hong Kong. The annual power generation of a selected wind turbine was calculated based on the Weibull parameters of wind data without the consideration of wind farm capacity. Ni et al. [16] did a review on the recent development of hydrogen production as well as the other renewable energy resources in Hong Kong. Hong and Möller [17] did an investigation on the available offshore wind energy in China and showed that the shallow water along the Northern Guangdong coast is one of the most suitable water area for offshore wind farm development with a good economic benefit.

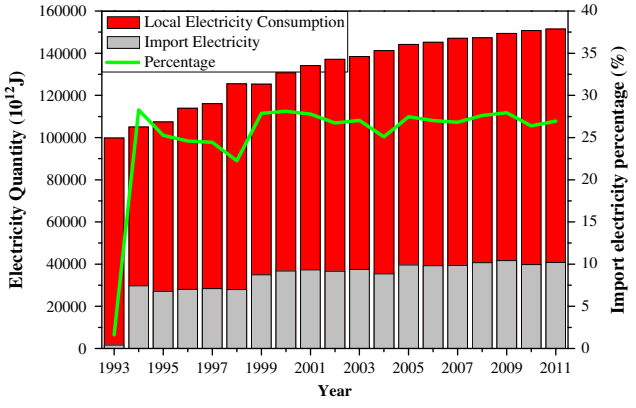

Fig. 1. Electricity imports and consumption in Hong Kong in 1993–2011.

In previous studies, the wind turbines were installed in a wind farm using recommended spacing which intended to avoid the wake interaction. However, proper WT spacing changes under different wind farm development conditions (different wind condition and terrain types). Thus, the power generation assessment would be more accurate after the wind farm being optimized. Besides, wind data obtained from different locations for a potential offshore wind farm make the assessment more comprehensive. This paper is to present a detailed study of potential offshore wind power generation in Hong Kong.

This study can be divided into three parts. First of all, the potential offshore wind farm area over Hong Kong is selected after considering the detailed water circumstance. In addition, the corresponding wind resource processing is conducted and the probability of wind speed in different directions is obtained for the wind turbine layout optimization using the Multi-Population Genetic Algorithm. Finally, a code named 'Wind Farm Power Generation Calculation Tools' (WFPGCTs) is developed for calculating the wind farm power generation after wind turbine layout is established. The wake effect of all the wind directions as well as the wind speed probability is considered. The annual power generation is calculated with the monthly power generations at different potential offshore wind farm locations for the assessment of potential offshore wind energy in Hong Kong.

2. Materials and methodologies

2.1. Constraints identification for potential offshore wind farm

Fig. 2 is a map of the Hong Kong territory. The wide water area in and beyond Hong Kong (2 km away from the boundary) seems quite suitable for offshore wind farm development. However, for selection of potential OWF sites, there are many restriction factors

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