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Study on offshore wind farm layout optimization based on decommissioning strategy

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Abstract

In recent years, along with the first generation of wind power reaching retirement age, the high decommissioning cost arises with more and more attention all around the word. To reduce this huge cost, an innovative offshore wind farm layout optimization method based on decommissioning strategy is presented in this paper. In the optimization method, the decommissioning strategy means that the foundations can be reused after the retirement of the first generation of wind turbines, and then smaller second-generation wind turbines will be installed on the original foundations. The optimization process is based on the Multi-Population Genetic Algorithm (MPGA). A conceptual two-dimensional (2D) wake model is adopted to calculate wind losses caused by wake effect. The Cost of Energy (COE) is regarded as the criteria to judge the effectiveness of this new method. The way to estimate costs will also be introduced in this study. Finally, a case study in Waglan sea area in Hong Kong is analyzed and discussed. From the case results, Hong Kong is an ideal region to develop the offshore wind industry, and the proposed optimization method can reduce the COE down to 1.02 HK$/kWh.

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Keywords: Offshore wind farm layout optimization; Decommissioning strategy; Multi-population genetic algorithm; Cost of energy.

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1. Introduction

With global population and economy increase annually, the demand of energy, one crucial input for socio-economic development, is also increasing dramatically [1]. Offshore wind power generation develops rapidly at moment and represents the most potential renewable energy supply to coastal cities in the future. In the year 2016, global new offshore wind capacity additions totaled 2.219 GW, which brought total offshore wind installed capacity to 14.384 GW [2].

On the other hand, as the first generation of offshore wind turbines approaches the end of their 20-year service, a new decommissioning market is emerging [3]. However, unlike onshore wind turbine decommissioning, where service providers have accumulated sufficient experience to enable them to carry out the works rapidly, decommissioning offshore wind turbines requires a much larger spatial and time scale. Thus, a new challenge may arise due to an unexpected increase in decommissioning costs.

Offshore wind turbines have a longer life expectancy than onshore turbines, which is around 25–30 years [4]. The offshore wind farm will be decommissioned in order to protect marine ecological environment after its life cycle's operation. However, the foundation is too often overdesigned [5]. To reduce the huge decommissioning cost, an original decommissioning strategy based offshore wind farm layout optimization method is presented in this paper. In the optimization method, the COE criteria is on account of two generations' energy output and total cost, the COE comparison of this innovative method and conventional method will be shown in this paper.

Nomenclature

2D	two-dimensional
COE	cost of energy
MHK$	million Hong Kong dollar
MPGA	Multi-Population Genetic Algorithm
O&M	operation and maintenance
WT	wind turbine

2. Decommissioning strategy

The decommissioning strategy presented means when the first generation offshore wind turbines are decommissioned, foundations can still be utilized after some strengthen strategies in the second generation. In this study, costs include: capital cost, operation and maintenance (O&M) cost and levelised cost. The difference between conventional strategy and decommissioning strategy lies in the capital cost, which consists of WT cost, foundation cost, installation cost and other costs (like grid connection cost and decommissioning cost). The capital costs of conventional strategy and decommissioning strategy are shown in (1) and (2) respectively.

$$Cost_{capital} = Cost_{WT} + Cost_{f} + Cost_{installation} + Cost_{decommissioning} \tag{1}$$

$$Cost_{capital} = Cost_{WT1} + Cost_{f1} + Cost_{installation} + Cost_{strengthening} + Cost_{WT2} + Cost_{installation} + Cost_{decommissioning2} \tag{2}$$

In the formulae, $Cost_{WT}$ is the WT cost, referenced from $Cost_{WT} = A_P + B_P \cdot P_{rated}$ [6]; $Cost_f$ is the foundation cost, assumed to be 6.075 MHK$ per foundation; $Cost_{installing}$ is the installation cost, assumed to be 80% of the wind turbine cost; $Cost_{decommissioning}$ is the decommissioning cost, assumed to be 60% of the installation cost; $Cost_{strengthening}$ is the strengthening cost, assumed to be 10% of the installation cost.

3. Optimization method

3.1. MPGA

A decommissioning strategy based offshore wind farm layout optimization method is developed to optimize the wind turbines' coordinates in this study. As the decommissioning strategy is adopted, the total service time is two generations' turbine life cycle (40 years). The optimizing process is based on the MPGA. The initial parameters setting for MPGA is listed in Table 1. In MPGA, the objective COE, contributed by total energy yield and total cost, is the average of two generations' COEs.

Table 1. The initial parameters setting for MPGA.

Parameters	Values
Population number	10
Probability of crossover	0.7-0.9
Probability of mutation	0.001-0.05
Number of individual	40
The least keeping generations	500
Binary digits of variable	20

3.2. Wake model

Wind turbines not only generate energy but also induce wakes behind their swept areas, which will diminish the power generation performance of downstream wind turbines [7]. The power losses caused by wind turbine wakes are of 10-20% of the total power output in large wind farms [8, 9]. In this study, a conceptual 2D wake model, as shown in Fig. 1, is presented to estimate the wind losses more accurately.

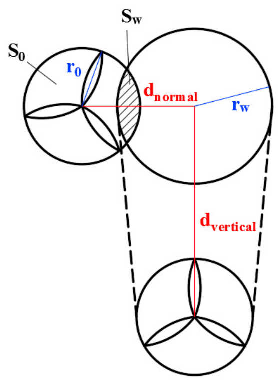

Fig. 1. 2D wake model.

In the formulae, r_0 is the radius of wind turbine blade; r_w is the radius of wake; s_0 is the swept area of a wind turbine; s_w is the area of downstream wind turbine under wake effect. Then the single wake formula and multiple wake formula are modified as (3) and (4).

$$\begin{cases} u = u_0, & r_w + r_0 < d_{normal} \\ u = u_0\left[1 - \dfrac{2ar_0^2}{(r_0 + \alpha \cdot d_{vertical})^2}\right] \cdot \dfrac{S_w}{S_0}, & r_w - r_0 \le d_{normal} \le r_0 + r_w \\ u = u_0\left[1 - \dfrac{2ar_0^2}{(r_0 + \alpha \cdot d_{vertical})^2}\right], & d_{normal} < r_w - r_0 \end{cases} \quad (3)$$

$$u_i = u_0\left[1 - \sqrt{\sum_{i=1}^{N}\left(1 - \frac{u}{u_0}\right)^2}\right] \quad (4)$$

4. A case study in Hong Kong

4.1. Offshore wind farm site selection

According to the previous study of Gao, et al. [10], there are four potential sea areas in Hong Kong that can be selected to build offshore wind farm. Waglan Island sea area is just chosen as a case study (Fig. 2). The size of the offshore wind farm is 3740m×5828m. The hourly wind speed data (from the year 2001 to 2011) comes from Royal Observatory, Hong Kong.

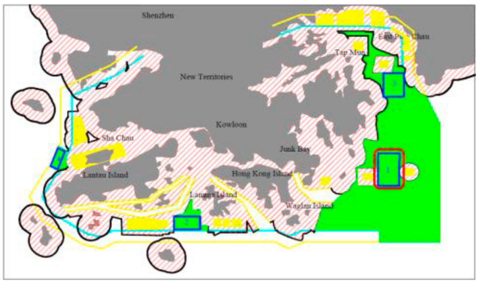

Fig. 2. Offshore wind farm site selection in Hong Kong [10].

4.2. Wind turbines

The 2.5MW and 1.65MW wind turbines are considered in the first generation and second generation, respectively. The parameters of wind turbines are listed in Table 2.

Table 2. The parameters of wind turbines.

Parameters	Turbine 1	Turbine 2
Rated power	2.5 MW	1.65 MW
Cut-in wind speed	3 m/s	3 m/s
Rated wind speed	11.1 m/s	10.5 m/s
Cut-out wind speed	25 m/s	23 m/s
Rotor diameter	108 m	88 m
Hub height	80m	70m

4.3. Results

According to the optimization method, both the locations and average power of wind turbines can be obtained as shown in Fig. 3. The main results of the optimized layouts are listed in Table 3.

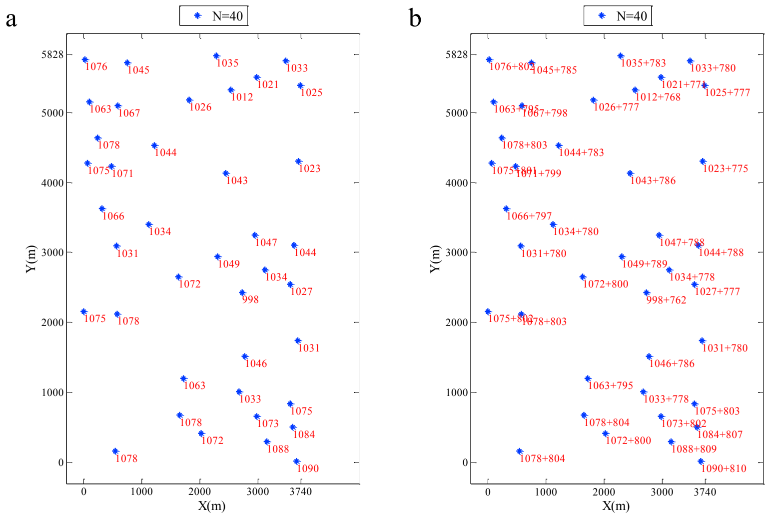

Fig. 3. Optimized layout and wind turbine power with (a) convention strategy and (b) with decommissioning strategy.

Table 3. Main results of optimized layouts.

	Convention strategy	Decommissioning strategy
Number of wind turbine	2.5 MW	1.65 MW
Service years	2×20	40
Energy yield (GWh)	$2\times7.55\times10^3$	13.18×10^3
Total cost (MHK$)	$2\times8.96\times10^3$	13.47×10^3
COE (HK$/kWh)	1.19	1.02

4.4. Discussions

From the energy yield aspect, for a conventional strategy, the energy yield within 20 years is 7.55×10^3 GWh. With the new decommissioning strategy, the energy yield is 13.18×10^3 GWh. From the cost aspect, the decommissioning strategy can reduce the cost apparently by 24.83% of the total cost with a conventional strategy. Finally, comparing the COE results, it is obvious that decommissioning strategy can reduce 13.94% of the COE, which is decreased to just 1.02 HK$/kWh.

5. Conclusions

The proposed offshore wind farm layout optimization method based on decommissioning strategy is a practical way to decrease the offshore wind energy cost. By reusing the foundations of offshore wind turbines, it is expected to reduce the COE by nearly 14%.

Hong Kong is an ideal region to utilize offshore wind energy. Taking the Waglan Island offshore area (3740m×5828m) as an example, the potential offshore wind farm can generate 13.18×10^3 GWh electricity in 40 years. The COE will be decreased to 1.02 HK$/kWh if the decommissioning strategy is adopted.

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