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Study on three wake models' effect on wind energy estimation in Hong Kong

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Abstract

Wake effect is one of the most vital factors in wind farm layout design and energy output estimation. Some wake models have been used to improve the power generation estimation precision. In this study, three typical wake models (Jensen wake model, two-dimensional (2D) Jensen wake model and Jensen-Gaussian wake model) are compared and adopted to estimate the offshore wind energy output in Hong Kong. Both the total electricity generation and power output from each wind turbine are compared when different wake models are used. The results show that the three different wake models have not produced significant different results on their total energy output estimations. The estimation error from the 2D Jensen wake model and Jensen-Gaussian wake model compared with the Jensen wake model are 1.55% and 0.38%, respectively. However, the wake's effect on each wind turbine's power estimation cannot be ignored, which is important to wind turbine's structural study. Based on the 2D Jensen wake model, an assumption of 3D Jensen-Gaussian wake model is discussed at the end of this paper, which is supposed to be studied in the near future. In conclusion, this study contributes to wake model selection, wind farm layout design and wake model's further development.

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Keywords: wind energy; wake models; wind energy output estimation;

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1. Introduction

When wind turbines capture energy from incoming wind, the downstream wind usually contains less energy content than the upstream wind [1]. This is because that wind has an impact on turbine's blades where it becomes slower and produces more turbulent, resulting on a wake behind the wind turbine. The wake will spread a long distance downstream a wind turbine and then return to surrounding wind characteristics gradually. That means in a wind farm where there are multiple wind turbines, it is most likely that one turbine may be under the influences of more than one upstream turbines. If not evaluate this wake effect properly, the overestimation of energy yields will cause the higher requirement of electrical equipment's voltage level and cables' capacity, also further influence the operating reserve and control strategy of a wind farm, which induces the investment waste on components' redundancy [2, 3]. Therefore, it is necessary to develop a useful method to assess the wake effect.

2. Wake Models

Some scholars have worked on the wake model issue. Several studies [4-6] have make quantitative comparisons between various wake models and concluded that all compared models' performance are not as certain as wished. In this study, three wake models are adopted to make comparison of the estimations on electricity production in Hong Kong sea area. The results are supposed to contribute to the wake model selection when design a wind farm.

2.1. Jensen wake model

Among all wake models, Jensen wake model (also named as Park model) is a preferential choice to estimate the wind farm energy losses problem due to its simplicity as well as the relatively high accuracy [7]. Jensen wake model assumes that along the downstream distance, the wake expands linearly and the wind velocity deficit has a top-hat shape in the wake regions (as shown in Fig. 1). A set of numerical experiments [8-10] have proved acceptable prediction of Jensen wake model in a wind farm.

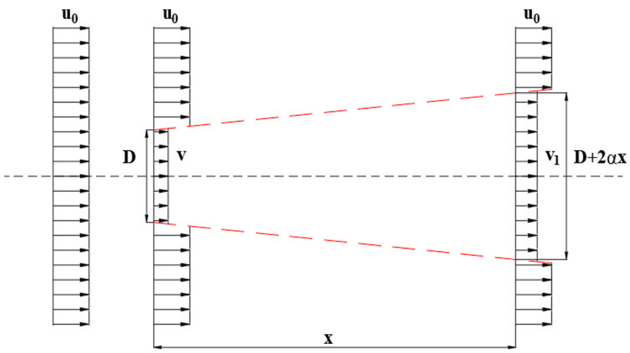

Fig. 1 Jensen wake model

In Jensen wake model, d_{normal} and r_w (see Fig. 2) are two important parameters to judge if the downstream wind turbine is under the wake effect. If d_{normal} is less than r_w, the downstream wind turbine's wind velocity will be calculated on the basis of Jensen wake model, otherwise it is seen as not under the upstream wind turbine's wake influence. The inaccuracy of this judgement method lies in that downstream wind turbine is either totally under the wake effect or totally not under the upstream wind turbine's wake influence, which is far from the reality. So based on this fact, a novel 2D Jensen wake model is presented in this study, which is introduced in the next section.

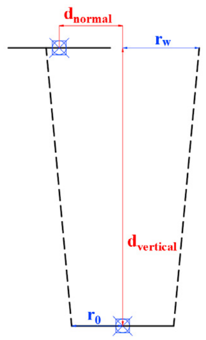

Fig. 2 The way to judge Jensen wake effect

2.2. Two-dimensional Jensen wake model

The presented 2D Jensen wake model is the development of Jensen wake model, but additionally take the partial wake influenced area into consideration. As shown in Fig. 3, the shadow area S_w is the wake effected area rather than the whole area. This wake model will definitely estimate wind power losses more accurately.

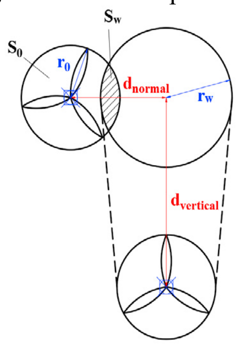

Fig. 3 2D Jensen wake model

2.3. Jensen-Gaussian wake model

Though Jensen wake model has been widely accepted, both the classical theories analysis about wake's shear flows in bluff bodies [11] and the wind tunnel investigations [12] demonstrate that the velocity profile in the turbine wake flow 'tube' section is more like an approximately Gaussian axisymmetric shape [13]. Based on this conclusion, Gao, et al. [14] presented a 2D analytical wind turbine wake model based on Gaussian function (see Fig. 4). The specific formula of the Jensen-Gaussian wake model can be found in [14].

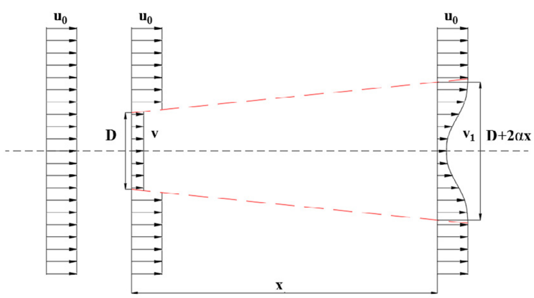

Fig. 4 Jensen-Gaussian wake model

3. Case study analysis

3.1. Wind farm site selection

The wind farm site selected in this study is the Waglan Island sea are in Hong Kong. The size of the offshore wind farm is 3,740m×5,828m. The hourly wind speed data (from the year 2001 to 2011) comes from Royal Observatory, Hong Kong.

3.2. Wind turbines

A 5MW wind turbine is considered in this study, the main parameters of which is listed in Table 1.

Table 1 The parameters of wind turbine

Items	Parameters
Rated power	5 MW
Cut-in wind speed	3 m/s
Rated wind speed	11.1 m/s
Cut-out wind speed	25 m/s
Rotor diameter	128 m
Hub height	90m

4. Results

The comparison results of three wake models are shown in Fig. 5. The assumption is that there are 40 wind turbines installed aligned in the wind farm. Each blue point represents a wind turbine and the number beside the point is the annual average power. And Table 2 lists the comparison of whole wind farm's total powers under three wake models.

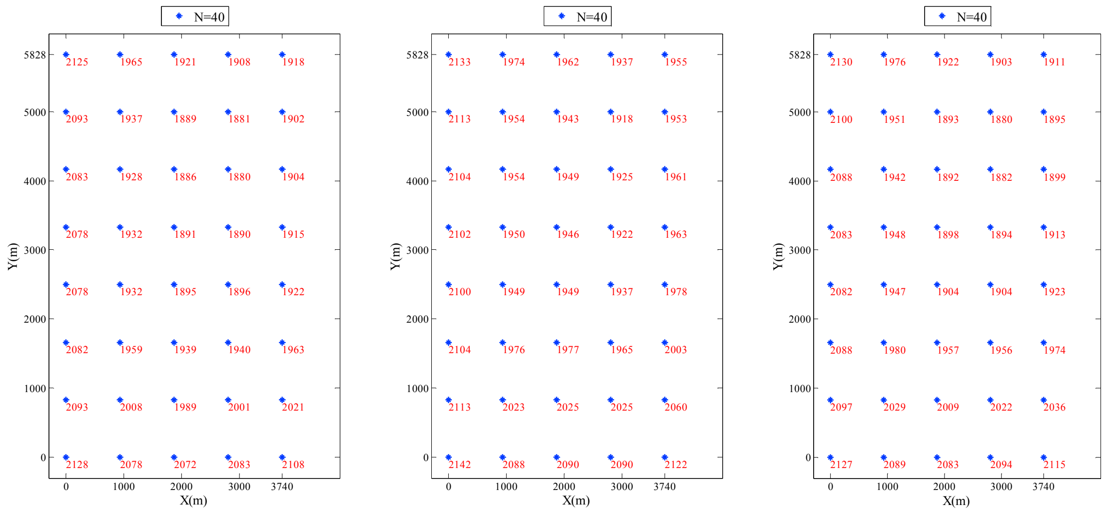

Fig. 5 (a) result of Jensen wake model; (b) result of 2D Jensen wake model; (c) result of Jensen-Gaussian wake model

Table 2 Comparison of total power under three wake models

	Jensen wake model	2D Jensen wake model	Jensen-Gaussian wake model
Total average power of whole wind farm	79,112MW	80,337MW	79,416MW
error	-	+1.55%	+0.38%

From the results, we can see that the Jensen wake model overestimates power losses generally. The power estimation of total power from the 2D Jensen wake model is more than that from Jensen wake model at around 1.55%. As for the Jensen-Gaussian wake model, which is verified to be more accurate than Jensen wake model [14], the power estimations depend on wind turbine's position, but most are less than that of 2D Jensen wake model. The power estimation of total power from the Jensen-Gaussian wake model is more than that from Jensen wake model at around 0.38%.

5. Conclusions

In this paper, a novel 2D Jensen wake model is presented and compared with the original Jensen wake model and Jensen-Gaussian wake model in aspect of the impact on wind turbine power estimation. The comparison result shows that the Jensen wake model overestimates the power losses, which means if the Jensen wake model is adopted, the power prediction is less than that of the estimation from the 2D Jensen wake model and Jensen-Gaussian wake model at 1.55% and 0.38%, respectively.

However, compared with this overestimation in energy losses of a whole wind farm, the wake model's impact on wind turbine structure deserves more attention. For a particular wind turbine, the difference of power estimations using different wake models means different external load, which directly influences wind turbine's structural performance. So the wake's influence on wind turbine structure may also indirectly affect wind farm's economical efficiency.

Based on the finding of this research, a further study on 3D Jensen-Gaussian wake model will be conducted in the near future. The new wake model will integrate both the 2D Jensen wake model and Jensen-Gaussian wake model, which is expected to describe wake characteristics more precisely. Apart from the energy output estimation, wake's impact on wind turbine's structure will also be further investigated.

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