Study on wake effect of series fans

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Abstract. Within the range of finite land resources, in order to improve the power generation efficiency of wind farms and reduce the impact of wake effects on the output power of fans, the rationality of wind farm fan layout is very important. The wake velocity and output power of two 2.5MW experimental fans in series 5D spacing are obtained by means of Doppler measured anemometer of windcube2. Based on CFX numerical simulation method, the simulation of the wake field is carried out by ANSYS software. The results showed that the fan spacing of 5D, the simulation and experimental results were basically the same. As the axial distance increased, the axial velocity first decreased and then increased, gradually recovered the incoming wind speed. The radial velocity and the tangential velocity amplitude and frequency fluctuation of different sections at the same angle were gradually reduced. The amplitude and frequency fluctuation of the tangential velocity were the largest at 3D, and were the minimum at 8D. The amplitude and frequency fluctuation of the radial velocity were the largest at 5D, and were the minimum at 3D. The velocity at the center of the bub gradually increased, and the velocity variation was the most obvious at 3D. The simulation speed first appeared an upward trend. Due to the superposition of the upstream fan wake, the output power of the downstream fan was greatly affected. Therefore, in the actual planning of the wind farm, the downstream fan should not be completely arranged in the wake field of the upstream fan.

1. Introduction

At present, the total installed capacity of fans in China is increasing, and it is estimated that the new hoisting capacity of fans will exceed 60GW in 2019[1,2,3]. The wind power industry has become the third largest power source for China’s power system, and the maximization of wind farm power generation efficiency is becoming more and more important[4,11,12]. The wake effect is one of the main reasons affecting the power generation efficiency of wind farms. The downstream fan is arranged in the wake field of the upstream fan, which will affect the whole power generation efficiency of wind farm[12,13,14,15]. The downstream fan is generally in the wake field of the upstream fan, and the power loss of the downstream fan reaches 23%~45%[16,17,18,19]. In order to improve the power generation efficiency of the wind farm, the arrangement of wind farm fans is particularly important[20,21]. Therefore, it is of great significance to study the wake of two series fans.

The study of wake effects mainly uses numerical. Gustavo S. Böhme et al.[5] studied the wind farm power output of wake-up and wake-free in Brazil’s onshore wind farms with complex terrain under the condition of MCP, and found that the wake-up output is 64%~85% of that of wind farms wake-free. Mike T.van Dijk et al.[6] simulated the wake field of the yaw state, indicating that the yaw not increased the generating capacity of the wind farm, and at the same time reduced the unit load caused by the superposition of some wakes. Alfredo Peña[7] studied the wake effect of the Anhalt wind farm in
Denmark. Through the analysis of scale simulation and data acquisition (SCADA), which showed that SCADA data acquisition and analysis can better estimate the power generation efficiency of wind farm than the simulation of mesoscale-wake model. Liu Qingqing et al. [8] established a wind farm model by using Wasp10.0 wind resource assessment software, and compared with the wind farm without the optimization method. It was concluded that with the continuous increase of elevation difference between the front and rear wheel hubs of the main wind directions, the annual power generation of wind farms increased continuously. Li pin et al. [9] obtained the distribution law of wind speed in wake area by using CFD simulation. Shi Shuai et al. [10] used MATLAB software to calculate and simulate the wake effect of wind fans with different wind speeds and directions, and obtained the wake field changes of wind farms under different wind speeds and directions.

In this paper, the Doppler radar wind meter is used to measure the wake field changes of two series fans. By establishing the 3D model of the whole machine and the 3Dmodel of the wake field, the change of the wind fan’s wake field was verified by simulation experiments, and the change of the wind fan’s wake field and power parameters was discussed to provide a theoretical reference for the reasonable layout of wind farm fans.

2. Wind Farm Experiment

The experiment layout is shown in Figure1. The experiment uses Gold wind GW106/2500 horizontal axis fan, rated wind speed 10.3m/s, average wind speed 13.5m/s and single fan power of 2.5MW. The experimental equipment used is shown in Table1.

| Equipment name | Type / measuring range | number | error |
|----------------|------------------------|--------|-------|
| fan            | GW106/2500             | 2      | ±0.5m/s |
| Doppler radar  | Windcube2/300m         | 2      |       |
| Computer       | Lenovo                 | 1      |       |
| Indicator light| 220V/100w              | 1      |       |
| Power source   | NP12-38Ah              | 2      |       |
| GPS locator    | LT500 H                | 1      |       |

In order to ensure the rationality and accuracy of the experiment, a large measurement range is selected. With the horizontal axis of the hub as the measuring center, the measuring radius is 800m and is divided into 10 segments on average. Fives angles, 0°, 30°, 45°, 60°, 90°, are selected for measurement. The measuring range and distribution of measuring points are shown in Figure2.

(a) Experimental site layout
(b) Schematic diagram of experiment layout

Figure 1. Field layout diagram and schematic diagram of the series fans.
3. Simulation Experiment

3.1 3D geometric modeling of wind fan
Taking the gold wind Technology 2.5MW large onshore unit as a prototype, which is established through SolidWorks and imported into Ansys software for model repair. The model includes blade, hub, engine room and tower. In order to approach the running state of wind farm fan, consider the cone angle and elevation angle of the wind rotor, and establish the whole machine model at a 1:1 ratio, as shown in Figure 3. Table 2 shows the main parameters of the unit.

Table 2. Main parameters of GW106/2500 fan

| Unit name                  | Parameter values |
|----------------------------|------------------|
| Wind wheel elevation cone angle | 3°               |
| diameter                   | 106 D/m          |
| Height of tower            | 90 H/m           |
| Wind wheel cutting-in      | 3 m/s            |
| cutting-out                | 25 m/s           |
| rated (m/s)                | 10.3 m/s         |

(a) 3D Geometric model
(b) 3D Geometric model repair model

Figure 3. Wind fan 3D geometry machine model
The total length of the calculation domain is 14D, in which the distance from the upstream fan to the flow field inlet is 1D, the distance between the upstream fan and the downstream fan is 5D, the distance from the downstream fan to the flow field outlet is 8D, the width of the calculation domain is 4D, and the height is 4D. The whole calculation domain is divided into a static domain and a rotating domain. The cylinder calculation domain of the wind wheel is the rotating domain and the rest is a static domain. The rotating domain has a diameter of 1.1D and a thickness of 0.1D.

The unstructured grid of the whole flow field is established for the wake field model. The rotating domain adopts the grid type “Quad/tri-pave” and the static domain grid type “Tet/Hybrid-TGrid”. The total number of grids is about 5.8 million, and the maximum grid quality is 0.89, which meets the calculation requirements. Fig. 4 shows the 3D model of wake field and the results of global meshing.

![3D Model of wake field of series fans.](image)
![Global grid of wake field of series fans.](image)

Figure 4. 3D Wake field model and global grid of series fans.

3.2 Boundary Condition Setting and Numerical Calculation

The initial wind speed is the shear index wind speed, and the calculation formula is shown as formula (1), where $\theta$ is the wind shear index; $z_1$ is the known height; $z_2$ is the height of the wind speed after the change; $v_1$ is the wind speed at height $z_1$, $v_2$ is the wind speed at height $z_2$. In this paper, the onshore wind shear index is 0.14. The wind speed $v_1$ at the center of the wind wheel is set at 10.6 m/s, and the uniform turbulence intensity at the inlet is 12%.

$$v_2 = v_1 \left( \frac{z_2}{z_1} \right)^{\theta}$$

Surface setting, the inlet of the outflow field is set as the velocity “INLET”, the outlet of the outflow field and internal flow field and other surfaces are set as the “OPENING”; The contact surface of the outflow field and internal flow field is set as the “INTERFACE”; The hub, main engine room and tower are set as the “WALL”. When the inner flow field is set, the inner flow field of the upstream fan is set as the “XUANZHUAN1”, the inner flow field of the downstream fan is set as the “XUANZHUAN2”, and the outer flow field is set as “JING”. The turbulence model is selected from the model, and the pressure-velocity coupling algorithm is “SIMPLE”. The inlet velocity of the outflow field is set as 10.6 m/s, and the internal flow field is set as Moving Wall without slip. Unsteady Reynolds time-averaged numerical simulation method is adopted.

Initialize the flow field, set the accuracy of each parameter to 10-3, and finally save the file and perform iterative calculation.

4. Result Analysis

4.1 Analysis of Experimental Results

Under the 5D spacing of the series fans, the measurement results of the downstream fan were analyzed to obtain the corresponding velocity field distribution and the output power of the two series fans. The
axial velocity at 30°, 45°, 90°, the velocity and tangential velocity at 30° were selected for analysis.

Fig. 5a showed when the incoming flow through the fan, part of the energy was converted into electrical energy, and the axial velocity was missing. As the axial distance increased, the fluid in the wake field exchanged energy continuously, and the axial velocity gradually recovered until the flow was restored. Due to the turbulence changes in the wake field, the fan rotation would produce strong turbulence phenomenon and wake vortex phenomenon.

Fig. 5b showed when the radial velocity increased with the axial distance, the fluctuation of velocity amplitude and frequency gradually decreased, with the maximum at 5D and the minimum at 3D. The maximum influence of the wake field between 3D and 6D, and then the radial velocity first increased and then decreased, and the upstream fan wake superposition effect gradually decreased until it disappeared.

Fig. 5c showed when the tangential velocity increased with the axial distance at 30°, the fluctuation of velocity amplitude and frequency was the largest at 3D and the smallest at 8D. As the axial distance increased, the influence of fan rotation on the wake field became weaker until it disappeared.

**4.2 Simulation Experiment Verification**

In order to facilitate the experimental data processing, the axial velocity simulation values and experimental values at different sections of 30°, 45°, 90° were selected for analysis. Fig. 6a, 6b, 6c, the overall variation trend of the downstream fan wake field experiment and simulation results was basically consistent. At the same angle, due to the superposition of the upstream fan’s wake, as the axial distance increased, the downstream fan was more affected by the upstream fan, the speed defect was more. The axial velocity at the 3D, 5D, 8D sections was compared and analyzed. The experimental value was larger than the simulated value on the whole, but the velocity of the simulated value first showed an upward trend, which was mainly caused by the actual environment of the wind farm. The value of velocity at the center of each section of the simulated value and the experimental value was basically the minimum, but with the increase of axial distance, the velocity at the center of the hub increased gradually, and the change of velocity at the 3D section was the most obvious. For the same section, the simulation values of axial velocity at different angles were basically the same, and the experimental values showed large velocity fluctuations. However, the velocity fluctuation became gentle.

Fig. 7 showed a comparison of the power curve of the upstream fan and the downstream fan. The power of the downstream fan was 59.09% ~ 78% of the upstream fan power, mainly because of the superposition of the upstream fan wake, which had a great influence on the output power of the downstream fan, therefore, in the actual operation of the wind field, the downstream fan should be
avoided to be completely arranged in the wake field of the upstream fan.

![Figure 6(a). Comparison between the simulated and experimental values of axial velocity at 3D.](image)

![Figure 6(b). Comparison between the simulated and experimental values of axial velocity at 5D.](image)

![Figure 6(c). Comparison between the simulated and experimental values of axial velocity at 8D.](image)

![Figure 7. Comparison of power curves between upstream and downstream fans.](image)

5. Conclusion

1. 5D series fans spacing, with the increase of axial distance, axial velocity first decreased and increased. because the incoming wind speed through the fan, part of the energy was absorbed and converted into electrical energy, and because of the turbulent wake field existed, the rotation of the fan would produce strong turbulence phenomenon and the phenomenon of wake vortex, the fluid in the wake field exchanged energy continuously, and the axial velocity gradually recovered until the incoming wind speed was restored.

2. 5D series fans spacing, with the increase of axial distance, the amplitude and frequency of the radial velocity and tangential velocity fluctuate gradually until it was stable; the amplitude and frequency fluctuation of the tangential velocity were the largest at 3D, and were the minimum at 8D. the amplitude and frequency fluctuation of the radial velocity were the largest at 5D, and were the minimum at 3D.

3. 5D series fans spacing, the simulation experiment was basically the same as the experimental results. The overall experimental value of axial velocity was larger than the simulation value, and the simulation speed first rose, which was caused the actual operating environment of the wind farm. The velocity values at the center of each section of the simulated value and the experimental value were basically the minimum. With the axial distance increased, the velocity at the center of the hub gradually
increased, and the velocity change was most obvious at the 3D section. The magnitude of the axial velocity with the same section and different angles was basically the same in the simulation experiment, and the axial velocity fluctuated greatly. With the increase of the axial distance, the velocity fluctuation gradually alleviated.

4. 5D series fans spacing, the power of the downstream fan was 59.09%~78% of the upstream fan power. because the superposition of the upstream fan wake, which had a large influence on the output power of the downstream wind fan. Therefore, in the actual planning of the wind farm, the downstream fans should not be completely arranged in the wake field of the upstream fans.

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