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Impact Assessment of Wind Energy Resources of Hangzhou Bay Offshore Wind Power Project

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Abstract. In the development and construction of offshore wind farms, it is essential to consider various factors such as wind energy resources, hydrogeology, grid-connected conditions, transportation, construction and installation, socio-economic environment, and ecological protection. Additionally, the meteorological conditions at sea should also be evaluated. This study aims to evaluate the situation of offshore wind energy and wind resources in Hangzhou Bay. The evaluation was conducted based on the relevant methods in the "Wind Farm Wind Energy Resource Evaluation Method" and the "National Wind Energy Resource Evaluation Technical Regulations". The analysis was carried out using meteorological observation data and ERA5 reanalysis data. Through the analysis of WS, average wind power density, representative annual wind energy resource analysis, and maximum WS during the reproduction period of meteorological stations indicate that the sea area is rich in wind energy resources. The main wind direction is consistent with the main wind direction, which is conducive to fan arrangement.

Keywords. Wind power, meteorology, ERA5, wind energy resources, offshore resource assessment

1. Introduction

Energy is extremely important for national development and is an important material foundation and guarantee for the rapid economic development of various countries and the improvement of people's living standards. Among them, coal used for power generation is the most widely used energy source. However, coal, natural gas, etc. cannot be reused as disposable energy sources [1]. In addition, the use of coal, etc., will emit a large number of pollutants, causing nearly half of our country's urban pollutants to exceed the standard, seriously affecting the environment. At the same time, the large use of coal leads to low energy efficiency. As one of the most technologically mature, large-scale development conditions and commercial development prospects in the field of new energy, wind energy resources are one of the power generation methods [2]. Moreover, our country is rich in offshore wind energy resources, the economy of coastal areas is relatively developed, and the demand for electricity is large. The development and utilization of offshore wind energy resources play an important role

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in meeting electricity demand, improving the energy structure, reducing environmental pollution, responding to global climate change, and promoting sustainable and healthy economic development [3].

Time, cost and quality are the focus of the construction project. In order to balance time cost and time quality, Liu used genetic algorithm strategies to search for the best engineering parameters of offshore wind farm projects, and accurately predict the construction time, cost and quality of the project in the pre-construction stage. He established a series of practical mathematical models and studied a real offshore wind farm project to determine and verify the applicability and feasibility of mathematical models [4]. A feasible and sustainable source of power is an urgent problem to be solved today. Offshore wind farms can solve the problem of power generation, but they are relatively expensive. Tusar M proposed some strategies that can solve the problem well. The best maintenance strategy depends on many factors, such as energy costs, the required level of reliability, and weather conditions [5]. In addition, Xiao proposed an automatic tool for optimizing the layout of cable systems between offshore arrays. The tool performs advanced identification of suitable locations for multiple offshore substations of large wind farms [6]. The above studies have all utilized the resources of the upstream wind energy project to achieve the expected results. However, the operating efficiency of the process needs to be improved.

Therefore, the assessment of the impact of wind energy resources and the tropical cyclones on the Hangzhou Bay offshore wind farm is of great significance to the construction of the Hangzhou Bay offshore wind farm, the selection of fan models, and the operation and maintenance of fans.

2. Overview of Information and Basis

2.1. Information

It mainly collects data from meteorological stations around the site, data from offshore wind towers, ERA5 reanalysis data and tropical cyclone data. The geographical location of the weather station and wind tower is shown in Figure 1.

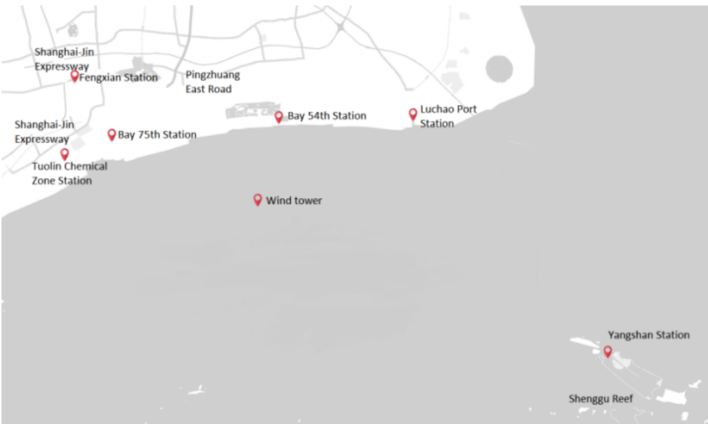

Figure 1. Schematic diagram of the location of meteorological stations and surrounding observation stations.

(1) Weather stations around the site all belong to the ground comprehensive meteorological observation station.

(2) Wind tower data. The live data comes from the offshore wind tower, which is located in the northern part of Hangzhou Bay (121°41’8” E, 30°46’35” N), about 8 km from the coast of Fengxian. The effective data rate collected by the NRG#40 type of wind tower reached 98.3%, which is higher than the effective data rate of the NOMAD2 type.

In order to ensure the reliability and rationality of wind resource analysis, the measured data of the Fengxian offshore wind tower was verified in accordance with the requirements of the “Wind Energy Resource Evaluation Method for Wind Farms” (GB/T18710-2002) [7].

According to the specification, when analyzing wind resources, it is necessary to collect continuous and complete wind measurement data from the site for at least one year. Complete wind measurement data from January 2007 to December 2007 were obtained [8]. Based on this set of data sets, this report makes a statistical analysis of the characteristics of the waters of Hangzhou Bay.

(3) The reanalysis data includes high-altitude circulation data such as high-altitude temperature, pressure, humidity and wind, as well as ground temperature, precipitation, wind and other elements.

The authors use offshore wind towers to evaluate the applicability of ERA5 reanalysis data in the assessment of wind energy resources in offshore wind farms. From October 2006 to June 2008, the correlation coefficient of the average daily WS of the 10-meter-high offshore wind tower and the reanalysis data was 0.91. In 2007, the average monthly WS changes of the offshore wind tower and the reanalysis data were consistent, and the windy month and the small windy month were the same [9]. Therefore, it is feasible to use ERA5 reanalysis data to evaluate the climate average state of wind energy data in wind farms at sea.

2.2. Climate Overview

Shanghai is located in the subtropical region on the east coast of the mainland, adjacent to the ocean to the east, and is not blocked by tall and continuous mountains. The cold, warm, dry and humid currents and weather systems on all sides may affect or control the region. Table 1 shows the average monthly hourly maximum WSs of Fengxian, Xiaoyangshan, Bay 54, Bay 75, Tuolin Chemical Zone and Luchao Port at a height of 10 m from 2012 to 2021.

3. Analysis of Wind Energy Resources

3.1. Air Density

Air density directly affects the size of wind energy. Under the same WS conditions, the higher the air density, the greater the wind energy. The calculation equation is as follows:

$$\rho = \frac{1.276}{1+0.00366t}\frac{p-0.378e}{1000} \tag{1}$$

Among them, ρ is the air density (kg/m^3), p is the air pressure (hPa), t is the air temperature (°C), and e is the water vapor pressure (hPa).

Table 1. 2012-2021 10 m altitude monthly hourly maximum WSs average (unit: m/s).

	1	2	3	4	5	6	7	8	9	10	11	12	Average
Fengxian	4.56	4.84	5.13	5.31	5.27	4.83	5.51	5.79	4.88	4.78	4.52	4.48	5.00
Xiaoyangshan	8.94	8.72	8.49	8.30	7.82	7.28	8.18	8.58	8.45	9.03	8.75	9.19	8.47
Gulf May 4th	4.58	4.99	5.13	5.36	5.35	4.97	5.63	6.18	5.01	4.67	4.52	4.43	5.08
Gulf July 1st	6.68	7.08	7.38	7.54	7.55	7.18	7.89	8.40	7.18	6.83	6.62	6.49	7.24
Tuolin chemical zone	4.86	5.21	5.41	5.60	5.56	5.33	5.79	6.19	5.22	4.84	4.67	4.64	5.29
Luchao Port	4.37	4.82	4.87	5.11	5.20	4.94	5.41	6.06	5.21	4.97	4.68	4.57	5.02

Based on the data of the wind measuring tower installed at a height of 100 m on Hengsha Island, Chongming, the average annual air density at altitudes of 30, 50, 70, and 100 m are 1.213 kg/m^3, 1.211 kg/m^3, 1.209 kg/m^3, and 1.206 kg//m^3 respectively. Based on the above data, the air density at a height of 130 m is 1.205 kg/m^3.

3.2. Vertical Shear of WS

For the ocean, the newly revised "Building Structure Design Specifications" in China also recommends the use of the power-exponential equation, the expression of which is

$$V_2 = V_1\left(\frac{Z_2}{Z_1}\right)^{\alpha} \tag{2}$$

where V_2 is the WS (m/s) at height Z_2; V_1 is the WS (m/s) at height Z_1, and Z_1 generally takes a height of 10 m; α is the wind shear index, and the size of its value indicates the intensity of the vertical shear of the WS.

The wind profile of the wind measuring tower at a height of 10m-70m in 2007 is shown in Figure 2. The wind shear indexes of the offshore wind measuring tower between 10 m-70 m, 25 m-70 m, 40 m-70 m, 50 m-70 m, and 60 m-70 m are 0.09, 0.09, 0.10, 0.09, 0.13 respectively. Therefore, the wind shear index of 100m-130m is reported to be 0.09.

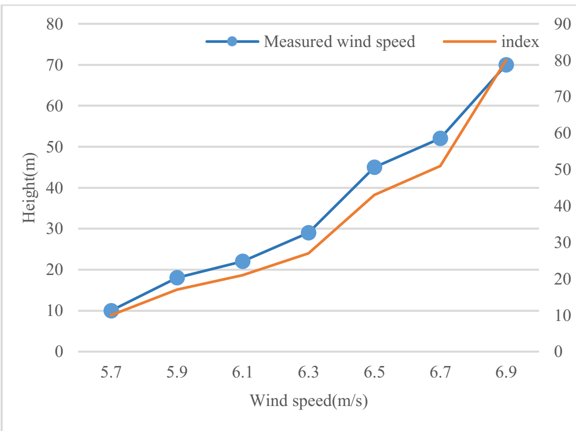

Figure 2. Wind profile diagram of offshore wind tower at 10m~70m height in 2007.

3.3. Turbulence Intensity

The turbulence intensity indicates the degree to which the instantaneous WS deviates from the average WS, and it is an indicator to evaluate the stability of the airflow. Turbulence is related to factors such as geographical location, topography, surface roughness, and weather system type. The calculation equation is:

$$I = \frac{\sigma_v}{V} \tag{3}$$

where V is 10-minute average WS (m/s); σ_V is The standard deviation of the instantaneous WS relative to the average WS within 10 minutes.

Table 2 shows the atmospheric turbulence intensity of the full WS range of the offshore wind measuring tower in 2007. As can be seen from the table, the average annual turbulence intensity of the wind measuring tower at each height does not exceed 0.12, and the turbulence intensity above 25 m in the 15 m/s WS range does not exceed 0.11. According to the IEC61400-1 standard, it is determined that the turbulence intensity of wind turbines in offshore wind farms is category C. Offshore electric field wind turbines are considered according to the turbulence intensity of Category C.

Table 2. The full WS range of the wind tower and the turbulence intensity of 15 m/s.

Wind measurement height (m)	Annual average	15 m/s
70	0.10	0.06
60	0.10	0.07
50	0.10	0.08
40	0.11	0.09
25	0.11	0.10
10	0.12	0.11

4. Wind Energy Resource Analysis

4.1. WS

In 2007, the average WS of the six height layers of the wind measuring tower from 10 m to 70 m was between 5.7 m/s-6.9 m/s as shown in Table 3; in 2007, the average WS of the 10 m height of the wind measuring tower at ERA5 was 5.9 m/s, and the average WS at the height of 100 m was 7.2 m/s; in 2007, the typhoon affected the WS in August was large; the average WS in July was the smallest, mainly because the atmospheric circulation has been stable this month, mainly in the zonal direction, the pressure difference between high and low pressure is small, and the WS is too small. The wind tower is consistent with the average monthly WS change of ERA5 at a height of 10 m. The daily change in the average WS of the offshore wind tower is generally smaller than that of the inland.

4.2. Average Wind Power Density

The average wind power density is calculated by the following equation:

$$\overline{D_{WP}} = \frac{1}{2n}\sum_{i=1}^{n} \rho \cdot v_i^3 \tag{4}$$

$\overline{D_{WP}}$: the average wind power density (W/m^2) during the set period; n: the number of records during the set period; v_i^3: the ith recorded wind speed value (m/s); ρ: air density.

Table 3. Wind tower and ERA5 monthly average WS (unit: m/s).

Month	Wind tower						ERA5	
	70 m	60 m	50 m	40 m	25 m	10 m	100 m	10 m
1	6.4	6.3	6.3	6.2	5.8	5.7	7	6.0
2	6.8	6.6	6.4	6.2	5.6	4.9	7.2	5.2
3	8.0	7.8	7.5	7.3	6.7	5.9	7.5	5.6
4	6.4	6.3	6.3	6.0	5.9	5.3	7.7	6.1
5	7.9	7.7	7.4	7.1	6.8	6.0	7.3	5.5
6	6.6	6.5	6.4	6.2	6.0	5.4	6.9	5.7
7	5.9	5.8	5.7	5.5	5.4	4.8	7.8	6.5
8	8.0	8.0	7.9	7.8	7.8	7.3	7.6	6.8
9	6.3	6.3	6.2	6.1	6.0	5.7	6.9	6.1
10	6.8	6.7	6.7	6.6	6.5	6.2	6.7	6.0
11	6.4	6.2	6.2	6.0	5.9	5.5	6.8	5.9
12	6.7	6.5	6.5	6.3	6.1	5.8	6.9	5.9
Average	6.9	6.7	6.6	6.4	6.2	5.7	7.1	5.8

The average wind power density of each height layer of the wind tower and ERA5 in 2007 is shown in Table 4. The average monthly wind power density is completely synchronized with the monthly average WS change, the monthly change is greater. The monthly average wind power density in March of each height year was the largest; July was the smallest; the monthly average wind power density in the smallest month was less than half of the largest month.

Table 4. Wind tower and ERA5 monthly wind power density (unit: W/m$^{2)}$.

Month	Wind tower						ERA5	
	70 m	60 m	50 m	40 m	25 m	10 m	100 m	10 m
1	234.9	224	221.6	210	171.6	164.3	333.1	180.3
2	289.4	260.2	233.9	204.5	153.9	105.9	376.9	148.4
3	489.5	442.3	394.3	349.4	267	196.6	363.8	148.1
4	267	254.9	241.5	221	194.8	149.1	487.5	215.3
5	443.3	406.5	365.4	326.5	280.6	203.7	376.6	151.6
6	232.7	218.8	204.6	185.6	169.3	126.1	349.8	166.5
7	188.9	176.3	163.3	145.8	128.7	94.7	430.5	189.0
8	448.2	436.5	421.1	405.4	408.6	327	348.9	177.5
9	246.1	237.2	231.2	215.3	199.5	170.9	293.3	158.0
10	321.4	307.5	301.9	290	265	219.4	296.1	163.5
11	206.8	194.9	193.1	183.8	167.5	148.7	256.6	159.0
12	262.3	246.8	241.6	223.4	200	180.1	305.4	166.9
Average	303.4	284.6	268.6	247.6	218.1	174.7	353.2	169.9

4.3. Analysis of Wind Energy Resources in the Representative Year

We used the offshore wind tower to evaluate the applicability of ERA5 reanalysis data in the assessment of wind energy resources in offshore wind farms, and believe that it is feasible to use ERA5 reanalysis data at sea to evaluate the average climate state of wind energy data in wind farms.

To this end, we use the ERA5 reanalysis data of the center point of the offshore wind farm (121.75, 30.75) to analyze offshore wind energy resources.

(1) From 1959 to 2021, the average annual WS of offshore wind farms was 5.73 m/s at a height of 10 m and 7.19 m/s at a height of 100 m. The average annual WS of offshore wind farms has changed steadily, which is inconsistent with the trend of the average annual WS on land becoming smaller, mainly due to the small environmental impact on the sea.

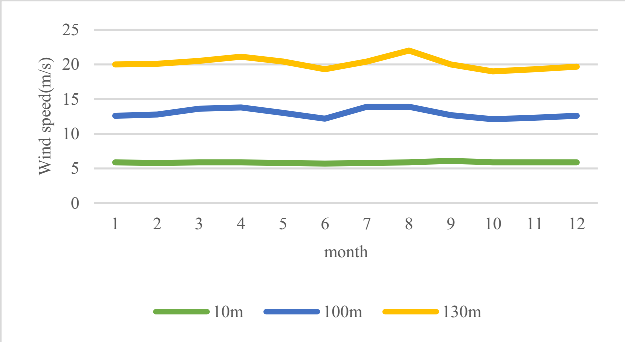

Figure 3. Monthly changes in WS at altitudes of 10 m, 100 m and 130 m in offshore wind farms.

From 1959 to 2021, the average monthly WS changed significantly (Figure 3), showing a trend of high summer and low autumn. It is mainly manifested in June as a small wind month, with an average monthly WS of 5.4 m/s at a height of 10 m, 6.9 m/s at a height of 100 m, and 7.1 m/s at a height of 130 m. July is a windy month, with an average monthly WS of 6 m/s at a height of 10 m, 7.8 m/s at a height of 100 m, and 8 m/s at a height of 130 m.

(2) We use the 100 m altitude ERA5 and then analyze the data to calculate the 130 m altitude 1959-2021. The average WS of the month and the average WS of the cumulative year are close to the year as the representative month and then use each representative month to construct the representative year. See Table 5 for the monthly average wind speed for years and representative months, and the years of representative months.

Table 5. Monthly average wind speed for years and representative months, and the years of representative months.

	1	2	3	4	5	6	7	8	9	10	11	12	Year
Monthly average wind speed for years (m/s)	7.2	7.4	7.70	7.90	7.50	7.10	8.0	7.80	7.10	6.80	7.00	7.00	7.37
Monthly average wind speed for representative months (m/s)	7.21	7.35	7.67	7.86	7.31	7.49	7.1	8.01	7.75	7.05	6.83	7.00	7.36
Years of representative months	1999	1980	1987	1985	2004	1971	1991	1990	1976	1983	1966	2000	---

5. Conclusion

(1) This sea area is rich in wind energy resources. It means that the average annual WS at an altitude of 130 m is 7.4 m/s, and the average annual wind power density is 375.8 W/m^2. According to GB/T18710-2002, the wind power density level of the wind farm

is level 3 indicating that it belongs to a wind resource-rich area.

(2) The average WS and average wind power in this area are lower during the day and higher at night, with relatively small daily changes compared to inland areas. The daily change in the average WS at a height of 130 m representing the year shows the same trend as the daily change of the average wind power. During the day the average WS and the average wind power are small, and the WS and the average wind power are large at night. The maximum WS and wind power gradually decrease from 1 o'clock in each period, reaching the lowest value around noon, and then the WS gradually increases, and the wind power density also increases.

(3) This sea area is more stable with a more concentrated distribution of wind energy. It means that the main annual wind direction is in the direction of SE-SSE-S (27.7%) and NNE-NE-ENE (26.1%). It means that the SE-SSE-S direction has the highest wind energy accounting for 40.7% of the total wind energy, followed by the NNE-NE-ENE direction, which accounts for 25.0% of the total wind energy. The main wind direction is consistent with the main wind direction, which is conducive to fan arrangement and can reduce power loss caused by the wake effect between fans.

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