

Analysis of the Principles of Marine Green Energy Building Design

Haidong Cheng^{1,†}, Boxuan Huang^{2,*†}, Qijian Lei^{3,†}, Yu Yuan^{4,*†}

¹ School of civil engineering, Central South university of Forestry and Technology, Changsha, China

² Department of Architecture and Engineering, Tianjin Ren'ai College, Tianjin, China

³ Agriculture and Engineering, School of Urban and rural construction Zhongkai University, Guangzhou, China

⁴ Department of Mechanical and Electrical Engineering, Changchun University of Technology, Changchun, China

* Corresponding Author Email: 20201313@stu.ccut.edu.cn

† These authors contributed equally.

Abstract. The depletion of mineral resources on land, the increasingly bad environmental problems, and the beginning of the marine blue encirclement movement in the early 21st century mean that ocean energy has gradually become the focus of human resources development. To better develop and utilize marine green energy, we study the sea level according to specific sea conditions. A semi-submersible offshore platform is designed to collect and use offshore wind and solar power. In this paper, the semi-submersible platform is introduced from the design concept, initial stability calculation, load calculation and cost calculation. Through the measure of wind load, wave load and stability, the offshore platform can normally work under specific sea conditions. In this paper, it is calculated that the unballast center of gravity of the whole structure is 41.31 meters, the floating center of the system is 9.23 meters, and the center of gravity is under the steady center. The result of the wind load calculation is 21990110.4 N, the total cost of the whole semi-submersible platform is 170340458.14 RMB, and the unit cost is 14195.0381784 RMB/kW. This paper looks forward to designing a semi-submersible platform with solid stability and high efficiency in the collection of wind energy and light energy, and hopes to alleviate the environmental problems and make people pay more attention to the use of marine green energy.

Keywords: Ocean green energy, structural design, semi-submersible platforms, wave load, wind load.

1. Introduction

The ocean is a vital treasure house for expanding space and resources for China's economic and social development. Because of the accelerated growth of industrial civilization, the combustion of coal, oil and other fossil fuels has increased the content of carbon dioxide in the air, resulting in global warming, affecting the balance of the ecological environment system. Ocean energy usually includes tidal energy wave energy ocean temperature difference energy ocean salt difference energy and current energy and so on [1]. Among these many sources of energy, the utilization of wind energy is the first, because of its high efficiency and enforceability, and the use of offshore solar energy also has great advantages. Wind power accounts for 16 percent of the world's renewable resources. In 2017, the installed capacity of offshore wind power in the world totaled about 18.8 GW, with an annual increase of 3 GW. At the present, the world attaches great importance to the implementation of a low-carbon economy, advocating the reduction of carbon emissions. The use of offshore wind power and solar energy is in line with these objective conditions and policies, both economic applicability and conducive to the improvement of the world environment, we can predict that offshore wind power generation will usher in its era.

The development of offshore wind in China is relatively late, and it is also facing many problems, such as the problem of wind power absorption in China, which is easy to produce the phenomenon of abandoning wind and increasing the cost of electricity consumption. Although the capacity of offshore wind turbines is also improving in recent years, it is still far from the land wind turbines; far sea power generation also needs to be further developed. Far sea power generation accounts for 80% of offshore wind power resources, but at present, it is still facing some technical problems.

The semi-submersible platform is optimized in structure. According to the specific sea conditions, the wind power generation and light energy generation are combined, and the photovoltaic plate of power 2.107 MW and a power 10 MW wind motor are laid on the platform. Later, the corresponding process of analysis and calculation of initial stability, wind load, wave load and cost budget will be given.

2. Method

2.1. Structural design

Since the maximum water depth of this working water is 50 m, Semi-submersible platforms are more suitable for water depths of 50 meters than SPAR platforms. This ensures optimal stability under wave and wind loads. Therefore, the floating platform chose a semi-submersible platform structure with solid versatility. This design is based on the semi-shallow platform for optimization. The structure as a whole consists of a square floating platform, four column pontoons, a square floating box, a fan, and a photovoltaic power generation device.

2.2. Initial stability calculation

According to the formula Calculation of stability, need to know the center of gravity, floating center, and ballast of the structure. The calculation of center of gravity should calculate the height and mass of each part. The semi-submersible platform of this thesis requires a center of gravity below the stable center. After calculation of the overall center of gravity height of the platform, the platform center of gravity is high. Therefore, additional ballast is required. According to Archimedes' principle, the buoyancy of an object in water is equal to the weight of the discharged water. That is, the weight of water with the same volume as the ship's hull immersed in water, this is the displacement of the boat [2]. The floating center is the shape center of the submerged part of the platform, here it is assumed that the density of seawater is uniform, so finding the shape center is also equivalent to finding the center of gravity of the volume of water discharged by the part of the platform in the water [3]. Therefore, the initial stability formula is used to calculate the stability center height. The difference is obtained by subtracting the size of the center of gravity from the size of the stable center. Determine if the structure is in a steady state.

The stable performance of the structure depends entirely on the relationship between the relative positions of the floating center B and the center of gravity G. (Fig. 1). (i) The center of gravity G is under the floating center B, and the direction of MR is opposite to the law of cross-tilt, thus allowing the floating body to return to the original equilibrium, which is called stable equilibrium. (ii) The center of gravity G is above the floating center B, and the direction of MR is the same as the cross-tilt direction, thus making the floating body tilt and no longer return to the original equilibrium state. To the initial equilibrium, so it is called unstable equilibrium. (iii) The center of gravity G and floating center B coincide, MR was 0, and the floating body can be balanced in any position, called neutral equilibrium.

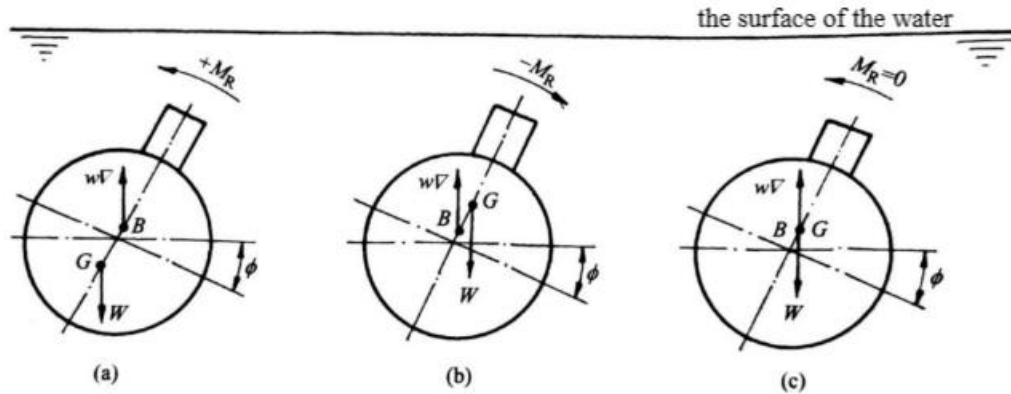


Figure 1. Stable and unstable equilibrium of a submarine

The formula for calculating the center of gravity of an object in the physical mechanics tutorial on rigid body mechanics is equation (1) [4].

$$x_g = \frac{\sum_{i=1}^n \Delta m_i x_i}{\sum_{i=1}^n \Delta m_i}, \quad y_g = \frac{\sum_{i=1}^n \Delta m_i y_i}{\sum_{i=1}^n \Delta m_i}, \quad z_g = \frac{\sum_{i=1}^n \Delta m_i z_i}{\sum_{i=1}^n \Delta m_i} \quad (1)$$

Under the minor inclination condition (Fig. 2), the steady moment M_s can be expressed as $M_s=GM$, $GZ=GM$, the stability height GM can be expressed as equation (2) [5]. For the Fig. 2, KB is the height of floating center from baseline (m) abbreviated floating center height; BM is the radius of transverse stability center; KM is the height of cross-stable center from baseline; KG is the height of the ship's center of gravity from the baseline (m) is referred to as the center of gravity height. The radius of the transverse stability center BM is the vertical distance between the floating center and the stability center, which can be found by the equation (3).

$$GM=KB+BM-KG=KM-KG \quad (2)$$

$$BM = \frac{I_x}{V} \quad (3)$$

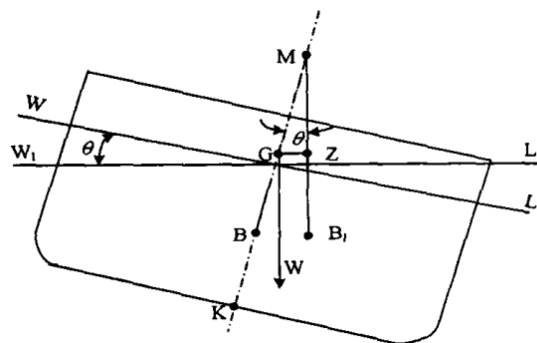


Figure 2. Ship Initial Stability

2.3. Load

2.3.1 Wave load

The Morrison equation was used (equation4) to calculate Wave load (equation (4)) [6].

$$f = f_I + f_D = C_M A_I a + C_D A_D u |u| \quad (4)$$

Where, the value of C_M is generally 2 in uniformly accelerated fluid. The value of C_M and C_D are depended on KC number (equation (5)), Reynolds number (equation (6)) and surface roughness coefficient (equation (7)).

$$KC = \frac{\pi H}{D} \quad (5)$$

$$Re = \frac{umaxD}{\nu} \tag{6}$$

$$\Delta = \frac{K}{D} \tag{7}$$

According to the result of the Reynolds number, the value of CD, CA, CM can be obtained. Numeration of Morrison needs area formula of Inertia force (equation (8)) and area formula of Drag force (equation (9)). Because the velocity varies with depth, the velocity formula and acceleration formula are obtained, as shown in equation (10) and equation (11).

$$A_I = \rho \frac{\pi D^2}{4} \tag{8}$$

$$A_D = \frac{1}{2} \rho D \tag{9}$$

$$u = \frac{\pi H \cosh(ks \frac{d}{d+\eta}) \cos \alpha}{T \sinh kd} \tag{10}$$

$$a = \frac{2\pi^2 H \cosh ks}{T^2 \sinh kd} \sin(\alpha) \tag{11}$$

2.3.2 Wind load

The force on the structure under constant wind speed, is equivalent to static force, and the greater the wind speed, the larger pressure on the structure is, the corresponding relationship exists between wind speed and wind pressure. That unit surface can be derived from the Bernoulli equation [7]. Accumulated formula about wind pressure (equation (12)). Equation (13) is wind load calculation formula.

$$\rho_0 = \frac{1}{2} \rho V^2 = \frac{1}{2} \gamma V^2 \tag{12}$$

$$F = \frac{\rho}{2} u^2 C_S A \tag{13}$$

Where, the ρ is air density which is 1.29 kg/m³, u is wind speed, a is Stressed area. The shape coefficient (Cs) of the structure can be obtained from Table.1.

Table 1. Form factor table

shape	beam	Side of building	Circular section	Total projection plane of platform
Cs	1.5	1.5	0.5	1.0

2.4. Cost estimate

The construction project cost is the total cost according to the design of the construction content, scale, standard, and the use of functions and requirements, etc. All the contents of the construction project will be completed after the completion of acceptance until the delivery process [8]. The economic estimation including engineering design fee, material purchase, and processing fee, engineering construction and installation fee, inspection and operation and maintenance fee, and construction machinery use fee. The structure's pontoons, floats, and towers are constructed using Q345D steel. The cost is determined by calculating the quality of the steel. The platform comprises 0.2 m thick reinforced concrete 4.8 m thick C25 concrete. The platform area is 100×100, a total of 10,000 m². The volume of reinforced concrete was determined to be 2000 m³, and the importance of C25 concrete was 48000 m³. Through the inspection and research of the market, determined the cost per cubic meter of reinforced concrete and C25 concrete. After calculations, it was found that the effect of seawater on ballast is not very good. Therefore, C25 concrete was used as ballast instead. The wind turbine is a Mitsubishi Heavy Industries-Vestas MHIVestas V164-10.0 MW wind turbine. The cost is known by checking the official website and analyzing the actual construction examples.

Photovoltaic panels using Hikid Solar 600M12-6/20, Contact the manufacturer to customize the photovoltaic panels with an area of 9948 m².

3. Results and discussion

3.1. Semi-shallow platform design

3.1.1 The structural design and selection of the platform

The semi-shallow platform designed this time is compares to other offshore platforms, Semi-shallow platform design, Semi-shallow platform design, Advantages such as lower cost, Suitable for the current wind power development environment.

The platform design is similar to a box. Above the platform, you can also live, work, and so on. The working life is 60 years. The overall structure of the platform consists of two cuboids above and below the four columns. Other economic operations such as farming operations can also be carried out between "gaps" in the platform structure. The following are the semi-shallow platform parameters (Table 2).

Table 2. Semi-submersible platform parameters

parameter	numerical value
Total platform height	50 m
Platform draft	30 m
Platform width	100 m
Platform height	100 m
Platform total mass	140750.73 t
Ballast-free construction quality	126424.29 t
Displacement	142750.73 t
Drainage volume	139269 m ³

The whole float is composed of three parts: the float box, the pontoon, and the platform. The floating box and pontoon are mainly use to stabilize the entire platform, The platform can still maintain its stability under the action of wind loads and wave loads. The whole platform consists of four pontoons and a pontoon. So it can also be classified as a column stability platform. Relative to another kind of bottom-type column stability platform, the semi-shallow platform designed this time allows for better mobility. It is also possible to operate in different waters. In marine engineering, the semi-shallow type of this design can not only be used for drilling. Others such as production platforms, Pipe laying boats, Supply boats, Offshore crane ships, etc. can be used. Such as the storage of oil and gas, Offshore plants farther offshore, Offshore power plants, etc., will be the development areas of semi-submersible platforms.

The platform design is similar to a box. Above the platform, you can also live, work, and so on. The active life is 60 years. The overall structure of the platform consists of two cuboids above and below the four columns. Farming operations can also be carried out between "gaps" in the platform structure. Q345D steel is used in the selection of columns and floating boxes. It was found after later calculations, when using seawater as ballast. The results are not ideal, the platform is therefore made of 0.2 m thick reinforced concrete and +4.8 m thick C25 concrete, Reinforced concrete total of 2000 m³ C25 concrete total of 53969.35 m³ Column, floating box, and platform parameters such as (Table 3-5)

Table 3. Column parameters

parameter	numerical value
Column diameter	25 m
Column height	30 m
Column thickness	20 mm
Column total mass	1478.47 t

Table 4. Floating box parameters

parameter	numerical value
Float length	100 m
Float width	100 m
Float height	10 m
Float thickness	25 mm
Total mass of floating box	4321.82 t

Table 5. Platform Parameters

parameter	numerical value
Platform length	100 m
Platform width	100 m
Platform height	5 m
Platform total mass	120000 t

3.1.2 Wind power plants

A wind turbine is a device that uses the mechanical energy of the wind be used as electrical energy. Wind turbines are generally composed of generators, blades, towers, and other devices. Some wind turbines are also composed of limited speed devices, direction adjusters, and energy storage devices. The requirement of wind power generation of not less than 10 mw, the design of the wind turbine adopts a single fan; compared to the creation of multi-blowers, the maximum use of the mechanical energy of the wind. Make power generation more efficient, and it is also more economical to build offshore wind power. The design used is for the V164-10.0MW wind turbine of Mitsubishi Heavy Industries-Vestas. The fan parameters are shown in Table 6 [9].

Table 6. Fan parameters

parameter	numerical value
Rated power	10 MW
Rotor diameter	164 m
The single leaf is long	80 m
Sweeping area	21124 m ²
Bottom diameter	10 m
Top diameter	5 m
Hub height	105 m
Leaf tip height	187 m
The total mass of the tower	390 t
Total mass	495 t

3.1.3 Photovoltaic power generation

This design considers the maximization of power generation efficiency. It uses a 600 w monocrystalline solar panel [10]. The plan was initially designed with an inclination angle of 37 degrees on the plane. At the same time, the plan is also equipped with a lifting device that changes the inclination angle to self-adjust at different latitudes. Maximize the efficiency of solar energy utilization. Suitable for solar power generation in various sea areas. The following are the parameters of photovoltaic power generation panels (Table 7).

Table 7. Photovoltaic panel parameters

parameter	numerical value
Single-chip photovoltaic panel area	2 m ²
Monolithic photovoltaic panel power	600 w
Photovoltaic panel area	9948 m ²
Total capacity of photovoltaic panels	2.1 MW

3.1.4 Model of a semi-shallow platform

The following is the model of the offshore power generation platform: Model diagram (Fig. 3), Side view (Fig. 4)

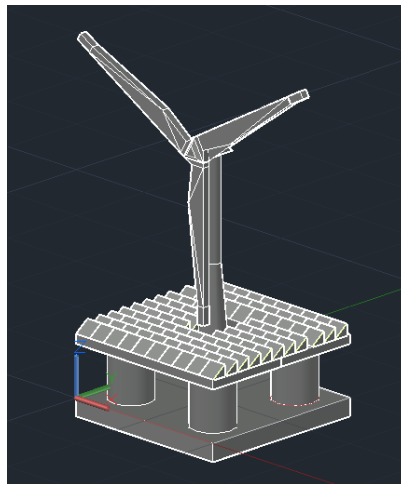


Figure 3. Model diagram

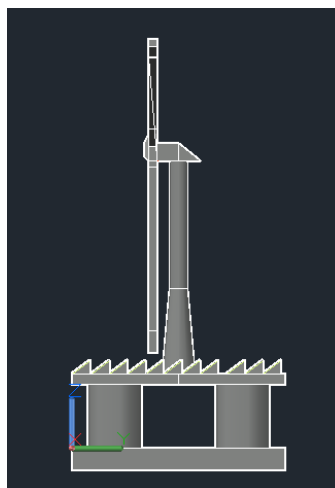


Figure 4. Side view

3.2. Initial stability test

The height of the center of gravity of the floating tank is 5 m, and the mass of the floating box is 4321.82 tons. The height of the center of gravity of the float is 25 m, the mass of the float is 1478.47 tons. Platform center of gravity height is 42.5 m, platform + PV panel mass is 120100 tons. The height of the center of gravity of the wind turbine 95 m, wind turbine + tower mass is 1278.43 tons. Therefore, the height of the center of gravity without ballast is 41.31 m.

Drainage volume $139269 \text{ m}^3 \times \text{Seawater density } 1.025 \text{ tons/m}^3$, which is displacement 142,750.73 tons. The no ballast structural mass is 126,424.29 tons. In summary the ballast is 14,326.44 tons. Ballasted center of gravity height of 37.62 m. Floating box floating center height is 5 m, of floating tank is 100000 m^3 , the floating center of the float is 20 m, and the volume of the float submerged in water is 39269.92 m^3 . Therefore, the floating center height of the structure is 9.23 m.

Because the equation $|BB_1| = 2|g_1 o| \frac{v_1}{\varphi}$, $|BM| = \frac{|BB_1|}{\varphi}$, the BM is calculated as 29.92, $|GB|$ is calculated as 27.79, GM is calculated as 2.13. The stable center M is located above the center of gravity G and is in stable equilibrium.

4. Load calculation

4.1. Wave load

According to equation 4, before calculate the wave load, we need to obtain the values of the following elements.

KC number is 1.0053, Reynolds number is 44.8035×10^7 and surface roughness coefficient is 8×10^{-4} (equation (7)). According to the data comparison and analysis in Fig 7, the value of CD is approximately equal to 1 and CA is 1 too. CA plus 1 equals CM, so CM is 2. The speed is calculated according equation (14) and acceleration is calculated according equation (15). According to equations (8) and (9), the values of and are 500691.3kg/m and 12750kg/m² respectively.

$$u = 2.5132 \cosh\left(ks \frac{d}{d + \eta}\right) \cos \alpha \quad (14)$$

$$a = 1.9739 \cos\left(ks \frac{d}{d + \eta}\right) \sin \alpha \quad (15)$$

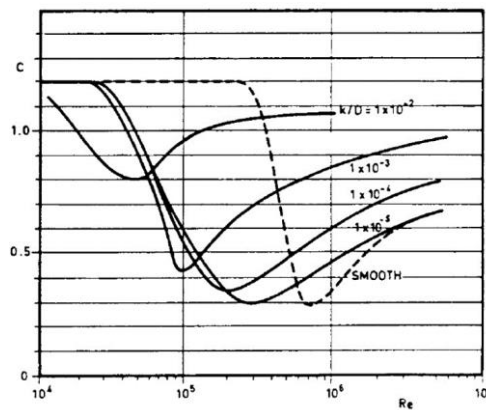


Figure 5. The drag force coefficient

The draft depth is 30m and the seawater depth is 50m, and the Morrison force is obtained by integrating over the force interval. When $\alpha \in [0, \frac{\pi}{2}] \cup [\frac{3\pi}{2}, 2\pi]$, the result is shown in equation (16).

The amplitude of the wave is shown in equation (17). When $\alpha \in (\frac{\pi}{2}, \frac{3\pi}{2})$, F is shown in equation (18), the force of wave load is shown in equation (19).

$$f = 1.976628 \times 10^6 \times \cosh\left(\frac{2S}{50 + \eta}\right) \sin \alpha + 8.0531 \times 10^4 \times [\cosh\left(\frac{2S}{50 + \eta}\right) \cos \alpha]^2 \quad (16)$$

$$\eta = \frac{H}{2} \cos \alpha = 4 \cos \alpha \quad (17)$$

$$F = \int_{20}^{50 + \eta} 1.976628 \times 10^6 \cosh\left(\frac{2S}{50 + 4 \cos \alpha}\right) \sin \alpha + 8.0531 \times 10^4 \times [\cosh\left(\frac{2S}{50 + 4 \cos \alpha}\right) \cos \alpha]^2 ds \quad (18)$$

$$f = 1.976628 \times 10^6 \times \cosh\left(\frac{2S}{50 + 4 \cos \alpha}\right) \sin \alpha - 8.0531 \times 10^4 \times [\cosh\left(\frac{2S}{50 + 4 \cos \alpha}\right) \cos \alpha]^2 ds \quad (19)$$

4.2. Wind Load

The value of air density, wind speed, Cs and A are calculated according to equation (12). The average density of air is 1.29 kg/m³, wind speed is 36 km/h, Cs is 1.0, stressed area is 2620 m². According to the equation (12), the wind load is calculated as 2,190,110.4 N.

5. Costing budget

The mass of the floating tank, the float of the structure, was calculated to be 5800.2865 tons, using Q345D steel, price is 5400 RMB/ton. The construction cost is 31321547.1 RMB. The tower barrel is made of Q345D steel, with a mass of 783.43 tons. The construction cost is 4,230,522 RMB. Platform reinforced concrete total 2000 m³, the unit cost is 1700 RMB/m³. The construction cost is 3400000 RMB. Ballast C25 concrete total 5969.35 m³, together with the C25 concrete used for the platform, a total of 53,969.35 m³, the unit cost is 1200 RMB/m³. The construction cost is 64,763,220 RMB. Mitsubishi Heavy Industries-Vestas MHIVestas'V164-10.0MW wind turbine, unit cost: 6000 RMB/kw. The cost of the wind turbine is 60 million RMB. The photovoltaic panels are made of Hikade Solar 600M12-6/20, with an area of 9,948 m². Unit cost is 665.98 RMB/m², and the cost of the photovoltaic panels is 6,625,169.04 RMB. Therefore, the total cost of the whole structure is 170,340,458.14 RMB, and the unit cost is 14,195.0381784 RMB/kw.

6. Conclusion

Offshore wind power and photovoltaics constitute a significant prospect for future green energy. After entering the 21st century, Marine engineering has a prominent position and development in the development of the country and even the world. The most promising in future energy development and the marine economy. This paper calculates that the ballast-free center of gravity of the entire structure is 41.31 meters. The system has a floating center of 9.23 meters, and the center of gravity is located below the steady center. The wind load was calculated as 2190110.4 N and the total cost of the entire semi-submersible platform is 170,340,458.14 RMB, the unit cost is 14195.0381784 RMB/kw. This paper makes some suggestions for developing offshore platforms, and some improvements have been made to offshore platforms in specific waters.

References

- [1] Fu Hu, Ask for energy from the oceans, *The Mystery of Vientiane*, 2013, 62.
- [2] Yang Qiguang, Revisiting the physical meaning of "immersion" in Archimedes' law physics teacher 1993, 3:26.
- [3] Wu Haibin Research on the floating and sinking motion of offshore platform based on semi-physical simulation, Doctoral thesis of Zhejiang University, 19.
- [4] Chang Shengli, C, Finding the coordinates of the center of gravity of a polygon, *Advanced mathematical research*, 2005.
- [5] Xu Jianhong, X, Research on Floating Steadiness Calculation System of Ships Based on Digital Value Table, Master's thesis of Dalian Maritime University, 2007, 28.
- [6] Mo Kaiyan, Calculation of wave loads for offshore wind turbines, 2017, 7.
- [7] Yan Jun, Study on wind load calculation method of large equipment group in offshore deep-water port, 2011, 22.
- [8] Yang Fan, Research on residential project cost estimation model based on improved BP neural network, 2016, 16.
- [9] Vestas Wind System A/S, www.vestas.com.
- [10] Xuzhou Xikaide Energy Co, Ltd. <https://xzxkd147.d17.cc/introduce.html>.