Design and analysis of semi-submersible offshore floating wind and photovoltaic platforms

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Abstract. The ocean holds excellent potential for green energy, and the sea can provide green energy to humans. For offshore structures and green energy development, the current floating offshore system has a single function and cannot fully utilize green energy. Therefore, this paper combines the development of wind and solar power to design a floating offshore structure. The report determined the configuration design of the platform and decided to choose a semi-submersible platform, select the type and size of wind turbine and photovoltaic panel models, calculate the wind load and wave load that the platform is subjected to, and finally calculate the cost of the forum. The wind load on a single wind turbine is estimated to be 26590.14N, and the wind load on all PV panels is 216180N, costing about 18487 RMB/kW. In this paper, the close combination of photovoltaic and wind power generation can guarantee the effective implementation of renewable energy and then improve the wind power generation and photovoltaic power generation application system based on the effective combination of the two.

Keywords: Semi-submersible platform, wind load, wave load, initial stability, cost budget.

1. Introduction

The ocean is a vast treasure trove of energy, and the sea can provide green energy to humanity. The ocean contains green energy with great potential. Common ocean green energy sources include wave energy, tidal energy, temperature difference energy, salt difference energy and ocean current energy, which the United Nations Environment Organization considers as one of the most desirable and promising alternative energy sources at present due to their abundance, cleanliness, renewable nature, and harmony with the ecological environment [1]. The development of wind energy as a green energy source is developing rapidly, such as installing wind turbine generators offshore for power generation. Because offshore winds have low turbulence intensity, low wind shear and high wind speeds, none of these properties is conducive to developing and utilizing wind energy. At the same time, no structures on the sea surface block the wind, and wind conditions are better, so more power generation can be obtained, making it more energy efficient. Moreover, transportation costs are low, there are no road restrictions for offshore wind farm construction, and there are vast set-up areas where you can freely choose a suitable site.

In addition to offshore wind energy, there is abundant solar energy on the sea surface, and solar power generation has significant advantages. The solar photovoltaic power generation process is simple, no mechanical rotating parts, no fuel consumption, no emissions including greenhouse gases, no noise, and no pollution. Solar energy resources are widely distributed and inexhaustible. The current offshore structures used for offshore green energy development mainly target one energy source. To develop and utilize offshore green energy more efficiently, the advantages of wind power generation and photovoltaic power generation can be fully used to complement the stability of photovoltaic power generation with the efficiency of wind power generation.

This paper proposes a new type of offshore floating structure based on this design concept that can exploit wind and solar energy. The system utilizes a semi-submersible platform that includes two wind turbines and thousands of photovoltaic panels on the forum, allowing it to operate with a total power of 12MW. The design concept is given later for this structure, and a b55rief analysis of its structural reliability and economy is presented.

2. Method

2.1. Conformation design

The maximum water depth of the working water is 50 m, and the semi-submersible platform is selected. A semi-submersible platform is a floating-type mobile platform whose stability mainly depends on the stability column; it is also a column stability platform. A semi-submersible platform is a platform that uses several columns with buoyancy to attach the upper shell to the lower body or column shoe and is supported by its buoyancy. In deep water semi-submersible operation, the lower casing or column shoe is submerged in the water, and the column is partially submerged in the water in a semi-submersible state. When shallow water sitting bottom operation, the lower shell or column shoe sits on the base for sitting bottom shape. The components of the selected platform broadly include floating tanks, floats and fans and photovoltaic power panels. The floats are all cylindrical structures, with a total of eight floats. Ballast can be added to the platform pontoon, and seawater is used as ballast to save cost.

2.2. Calculation of initial stability

Its stable center needs to be determined to design the platform to ensure structural stability. It is necessary to calculate the structure's floating center and center of gravity; when the center of gravity is lower than the floating center, the system is stable and balanced. Since the platform is a semi-submersible structure, the initial stability height GM is calculated by the formula, and the forum is unconditionally stable when GM is greater than 0 (equation (1)).

$$|GM| = |BM| - |BG| \tag{1}$$

2.3. Loads

2.3.1 Wind load calculation

In this paper, the wind load on the structure is mainly the wind pressure to which the system is subjected, and the essential wind pressure value is calculated using the formula (equation (2)). The wind load calculation formula provided in the API specification (2000) is used to calculate the wind load (equation (3)). Wind loads are calculated for the solar PV panels, the tower of the wind turbine and the part of the platform exposed to the water.

$$p_0 = 0.613V^2 \left(N / m^2 \right) \tag{2}$$

$$F = \frac{\rho}{2} u^2 C_S A \tag{3}$$

where, u for the sea surface reference height of 10m at 1h average wind speed, take the speed of 10 m/s for constant wind speed; Cs for the shape coefficient, in accordance with the following table 1 to take the value.

Table 1. Cs shape factor values

Shape	beam	Side of the building	Round section	Total projected surface of the platform
Cs	1.5	1.5	0.5	1.0

2.3.2 Wave load calculation

The platform is a small-scale structure, and the wave loads are calculated by approximating the floats and using the Morrison equation to calculate the wave forces (equation (4)).

$$f = f_I + f_D = C_M A_I a + C_D A_D u|u| \tag{4}$$

2.4. Cost calculation

The calculation of the platform cost needs to consider the cost of the wind turbine, the cost of the solar power panels, the construction cost of the platform, labor, and other fees.

3. Structural design and initial stability calculations

3.1. Conformation design

As the maximum water depth of this working water is 50 m, the SPAR-type platform is more suitable for water with greater depth. The TLP platform is more challenging to design and requires more steps to install, which is more expensive and not ideal for the current wind power development environment, so the floating platform decided to choose the semi-submersible platform structure with more versatility [2]. The semi-submersible platform was created later than the pontoon-type platform and was designed to overcome the disadvantage of poor wind and wave resistance of the pontoon-type drilling platform. Semi-submersible can operate in deep waters and harsh environmental conditions, with good movement characteristics and wind and wave resistance.

The platform mainly consists of floats and pontoons. The pontoons are made of steel, and the platform includes eight pontoons, enough of which can provide sufficient drainage for the structure. The material of the floating tank is also steel, the wall thickness of the floating tank is 0.02 m, and the height is 2 m, filled with seawater as ballast. The specific parameters are shown in Table 2.

Table 2. Platform parameters

Parameters	Unit	
Diameter of the float	m	16
Height of the float	m	34
Float wall thickness	m	0.02
Design Draught	m	28
Floating tank height	m	2

This platform is mainly used for wind power generation and photovoltaic power generation, which requires the selection of wind power generation devices and photovoltaic power generation devices. A wind turbine combines mechanical, electrical and control equipment that converts wind energy into electrical energy. Wind turbines generally have turbines, generators (including appliances), regulators (tail fins), towers, speed limiting safety mechanisms, energy storage devices, and other components. Medium and large wind turbines also include devices such as gearboxes and nacelles. The 5 MW offshore wind turbine developed by the Renewable Energy Laboratory in the U.S. is used in this case; Table 3 indicates the tower parameters, and Table 4 shows the wind turbine parameters [3].

Table 3. Tower parameters

Parameters	Unit	
Bottom diameter	m	6
Top diameter	m	3.87
Bottom wall thickness	m	0.027
Top wall thickness	m	0.019
Total mass	t	347.46
Density	kg/m3	8500

Table 4. Fan parameters

Parameters	Unit	
Rotor radius	m	63
Rotor mass	t	110
Motor quality	t	240
Power Rating	MW	5
Wheel height	m	90

Photovoltaic power generation is a technology that uses the photovoltaic effect at the semiconductor interface to convert light energy directly into electricity. The photovoltaic power generation panel uses 300 w monocrystalline silicon home solar panels with the specific parameters shown in Table 4. During the installation, the photovoltaic panels are arranged in an oblique plane, with an angle of thirty degrees to the horizontal plane. The reserved bases, holes, and pre-buried parts on the platform are constructed according to the relevant installation regulations. Pay attention not to damage the waterproof layer of the platform to prevent water erosion during installation. Anti-corrosion treatment is required when installing the bracket.

Table 5. Photovoltaic panel parameters

Parameters	value
Individual PV panel area	1.95 m^2
Individual PV panel power	300 w
Individual PV panel quality	24 kg
Total mass	172,800 kg
Photovoltaic panel area	14400 m^2
Complete control of photovoltaic panels	2160000 w

The platform is roughly rectangular, and most of China's offshore wind farms have been built in recent years, and foreign offshore wind farms have not reached their service life, and the design life of the platform is 30 years [4]. The float of the platform is cylindrical, and the float tank is a circular, rectangular body; both the float and the float tank are of a single-layer shell structure. A walking corridor is set up between the floats to connect the individual floats and facilitate the flow of people while strengthening the platform. Figure 1 shows the conceptual diagram of the forum, and Figure 2 shows some of the platform's parameters. The ring pontoon increases the drag resistance but makes the float's environmental load more consistent and strengthens the forum [5].

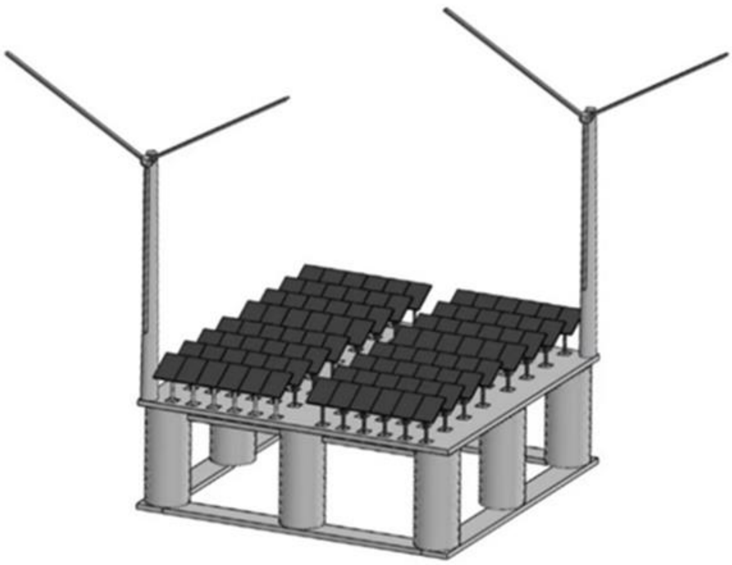

Fig. 1 Conceptual diagram of semi-submersible platform

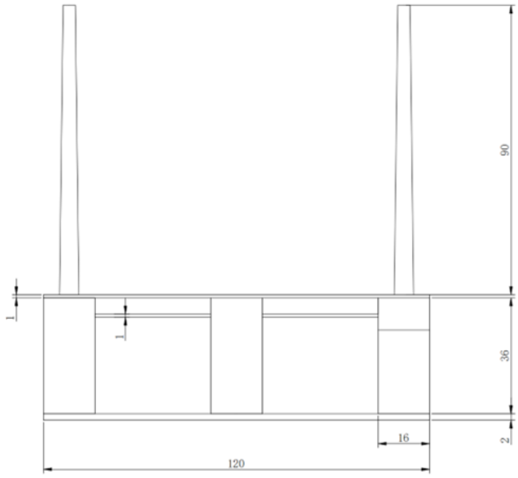

Fig. 2 Parameter diagram of the platform

3.2. Initial stability test

Verification of the initial stability of the platform requires the calculation of the platform buoyancy and center of gravity. The material of the platform is steel with a density of 7850 kg/m^3, and the ballast is seawater with a thickness of 1025 kg/m^3. No ballast is added to the float, but the float tank is filled with seawater. Ballast in the float tank can adjust the draught of the float, generally, tow the float to the designated sea area, and then ballast seawater to facilitate transportation and reduce transportation costs to stabilize the platform. The platform's floating center needs to be lower than the center of gravity, which gives the forum a high stability. The model is simplified, and the calculation of initial strength is carried out. The calculated height of the floating center is 12.6 m, and the size of the center of gravity is 12 m.

The platform is approximated, and its stable center is calculated by tilting the platform by five degrees. The volume of the intercepted part of the middle float is 29.86 cubic meters, and the importance of the intercepted part of the two side floats is 914.71 cubic meters obtained by the software. The value of GM is calculated using equation (1), and it is found that GM>0, and the platform stability center is greater than the center of gravity.

4. Load calculation

4.1. Wind load

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The wind is a significant scale movement of air at a certain speed in a horizontal or vertical direction and is an important natural phenomenon in the marine environment [6]. Wind load, also known as dynamic wind pressure, is the pressure generated by the airflow on the engineering structure. The wind load is related to the primary wind pressure, the roughness of the structure surface, the contact area with the wind, the building body types and other factors. Assuming that the structure is subjected to the type-average wind, the equation (5) for the wind pressure per unit area can be deduced from Bernoulli's equation.

$$p_0 = \frac{1}{2}\frac{\gamma}{g}V^2 \tag{5}$$

where, V is the wind speed (m/s); γ is the air gravity, generally is 12.01 N/m^2; g is 9.8 m/s^2.

The wind load on a single wind turbine is calculated to be 26,590.14 N, and the wind load on all solar PV panels is 216,180 N.

4.2. Wave load

When working, offshore floating structures are susceptible to wind, waves, and currents, and the wave load effects caused by the environment are significant. They can have wave-induced damage or even destructive effect on wind turbine infrastructure structures [7]. Wave loads on structures, often also referred to as wave forces, need to be calculated and are the effects of waves on structures in the ocean. Wave loads are caused by the relative motion between the water quality point of the lock and the design. Wave action on marine structures causes loads to be generated. Wave loads include hydrodynamic pressure acting directly on marine systems; inertial forces due to acceleration caused by the movement of marine engineering structures in wind and wave currents. According to the different load sources, the load is generally classified as drag, inertia, and bypass. Drag and inertia forces dominate in small-scale structures and rounding, and inertia forces dominate in large-scale networks. Therefore, different wave load calculation theories should be selected for calculation according to the size of the system. Wave loads are usually calculated using the semi-empirical and semi-theoretical Morrison equation, and the platform is a small-scale structure; the calculations in this paper are roughly done to approximate the Morrison force calculation for the float, and the Morrison equation ignores the effect brought by the wave motion [8]. The problem requires that the wave height H is 8m, the period is 10s, the diameter of the float is 16m, and the water depth d of the given sea is 50m.

According to Morrison's equation, the wave force f on the cylinder at any height can be divided into two parts: one is the horizontal drag force f_D, the force generated by the velocity of the wave water quality point in the horizontal direction; the second is the horizontal inertia force f_I, the force generated by the acceleration of the wave water quality point in the horizontal direction.

The wave force is calculated using equation (4). The v was calculated as 1.306×10-6 m2/s, the Reynolds number was calculated as 3.07×107 according to equation (6). KC was calculated as 1.571, according to equation (7) [9]. CM was 2.0 due to C_A=1.0 and $C_M = 1+C_A$. u_{max} was calculated as 2.512 m/s, according to equation (8). Then using equation (9), equation (10) and equation (4), f was calculated as $8.8 \times 10^5 \times (e^{0.04s} + e^{-0.04s}) \times sina + 9 \times 10^2 \times (e^{0.04s} + e^{-0.04s})^2 \times cosa|cosa|$. Then, when $\alpha \in \left[0, \frac{\pi}{2}\right], \left[\frac{3\pi}{2}, 2\pi\right]$, the total wave load on the float was shown in equation (11). When $\alpha \in \left[\frac{\pi}{2}, \frac{3\pi}{2}\right]$, the total wave load on the float was shown in equation (12)).

$$Re = \frac{u_{max}}{v^7} \tag{6}$$

$$KC = \frac{\pi H}{D} \tag{7}$$

$$u_{max} = \frac{\pi H}{T} = 2.512(m/s) \tag{8}$$

$$u = \frac{\pi H_{max}}{T_{max}} \frac{coshks}{sinhkd} cosa = \begin{cases} \frac{\pi H_{max}}{T_{max}} \frac{coshks}{sinhkd} cosa & s \le 50m \\ \frac{\pi H_{max}}{T_{max}} \frac{coshkd}{sinhkd} cosa & s > 50m \end{cases} \tag{9}$$

$$a = \dot{u} = \frac{2\pi^2 H_{max}}{T_{max}{}^2} \frac{coshks}{sinhkd} sina = \begin{cases} \frac{2\pi^2 H_{max}}{T_{max}{}^2} \frac{coshks}{sinhkd} sina & s < 50m \\ \frac{2\pi^2 H_{max}}{T_{max}{}^2} \frac{coshkd}{sinhkd} sina & s > 50m \end{cases} \tag{10}$$

$$F = 2.2 \times 10^7 \times \left(e^{0.04(50+4\cos\alpha)} - e^{-0.04(50+4\cos\alpha)} - 1.1\right) \times \sin\alpha + 1.125 \times 10^3 \times \left(e^{0.08(50+4\cos\alpha)} - e^{-0.08(50+4\cos\alpha)} + 100\cos\alpha + 897\right) \times \cos^2\alpha \tag{11}$$

$$F = 2.2 \times 10^7 \times \left(e^{0.04(50+4\cos\alpha)} - e^{-0.04(50+4\cos\alpha)} - 1.1\right) \times \sin\alpha - 1.125 \times 10^3 \times \left(e^{0.08(50+4\cos\alpha)} - e^{-0.08(50+4\cos\alpha)} + 100\cos\alpha + 897\right) \times \cos^2\alpha \quad (12)$$

5. Cosing budget

The economic cost includes floating tank and float, the mass of floating tank is 273.271 t, the mass of float is 2147.760 t, both use the medium thick plate, you can check the price of the medium thick plate on the internet is 4360 RMB/ton, you can calculate the need steel price is roughly 3526930.44 RMB. For a 5MW wind turbine, in addition to the generator, blade, and tower base, to build a complete wind power station, but also need a lot of tedious and complex steps to deal with, such as unit transformer installation, distribution equipment engineering, external transmission line construction, grounding engineering, etc., which all add up to an estimated cost of about 3.5 million. Then a complete wind power plant costs 19 million to build. 450(blade) + 850(generator) + 250(tower base) + 350(other) = 19 million units: million. Two such turbines are needed for this project, so the cost of the turbines is 38 million RMB. In the completed project, the single unit capacity is 4-6.5 MW and the unit price per kW is equivalent to RMB 5890/kW.

In this project, 300w photovoltaic panels are used, the size of the photovoltaic panels is 1995×996 mm after the network query 300w monocrystalline solar panels 787 RMB/piece, this structure requires 7200 details, you can calculate the unit price of photovoltaic panels is 5666400 RMB.

The cost of construction and installation works should also be considered, mainly the cost of power generation buildings, the cost of boosting and substation works, the cost of installation works of the power plant, the cost of other related electrical installation works platform construction and additional charges. Tables 6 and 7 show that the total can be approximately 4,800 RMB/kW for platform construction and roughly 5200 RMB/KW for labor and other expenses. The final total cost is 18487 RMB/KW.

Table 6. Major material costs

Materials	Unit cost	Total cost
Photovoltaic power panels	400 RMB/m^2	5666400
Wind Turbines	5890 RMB/kw	
Steel	4360 RMB/t	10555695

Table 7. Estimated construction cost analysis of offshore wind power projects [10]

Fee Components		Unit construction cost (RMB/kW)	Percentage of construction cost components (%)
Equipment purchase cost	Wind turbine and tower	7500~8000	42.5
	In-field submarine cable and outgoing submarine cable	1000~1500	7.0
	Other related electrical equipment	500	3.0
Building construction costs	Power plant construction	4000~4800	24.0
	Boosting substation project	350~400	2.0
	Other construction works	300	1.5
	Construction auxiliary engineering costs	150~200	1.0
Installation project fee	Power plant installation project	800~1000	5.0
	Submarine cable installation project	350~400	2.0
	Other related electrical installation works	150~200	7.0
	Other Fees	1100~1400	4.0

6. Conclusion

Based on several classical floating offshore structures, a multi-floating semi-submersible platform has been designed. The platform closely combines photovoltaic power generation and wind power generation, which can guarantee the effective conduct of renewable energy, and then improve the wind power generation and photovoltaic power generation application system based on the effective combination of the two. In this paper, the initial stability and economy are analyzed, and the floating center of the structure is calculated to be 12.9 m, and the total center of gravity is 12 m, and the center of gravity is lower than the floating center. The BM>0 of the structure was verified, and the center of gravity was lower than the stable center, which was more stable. After rough calculations an average of $18,487 per kilowatt of electricity generated is required, which is in line with the normal market price. There are still shortcomings in this paper. Due to the large scale of the structure, the long construction time and the large weight of the structural design, modular manufacturing and assembly can be realized through subsequent research to reduce the manufacturing difficulty, shorten the construction time, and reduce the weight compared with the existing box-type floating platform to achieve a lightweight structural design. In general, only the initial stability of the structure is calculated in this paper, and other properties of the platform will continue to be studied in the future. In general, only the initial stability of the structure is calculated in this paper, and other properties of the platform will continue to be studied in the future.

References

[1] Wang Tao, Li Ping, Ni Ya, Chao Bin. Importance of the Anti-corrosion on the Marine Green Energy Utilization. Total Corrosion Control, 2013,27(06):7-8+39.DOI:10.13726/j.cnki.11-2706/tq.2013.06.001.

[2] Hu Chao. The Conceptual Design and Research of Semi-submersible Offshore Floating Wind Turbine Platform. Harbin Engineering University, 2018.

[3] Hu Binfen. Fatigue analysis of mooring systems and compartment optimization of pontoon for floating offshore wind turbine platform. Hunan University, 2018.

[4] Ji Chunyan, Zhang Yun, RMB Zhiming. Stochastic prediction method of ultimate strength of semi-submersible platforms in total life cycle. Journal of Jiangsu University of Science and Technology(Natural Science Edition), 2012,26(01):8-12.

[5] Du Qinggui, Fen Wei, Shi Zhongmin, et al. Preliminary Study on Development and Application of SEMI. Oil Field Equipment, 2015,44(10):72-78.

[6] Li Jingwei. Dynamic response and overall strength analysis of semi-submersible floating foundation. Jiangsu University of Science And Technology, 2021.DOI:10.27171/d.cnki.ghdcc.2021.000485.

[7] Wang Shuo, Ke Shitang, Zhang Wei, et al. Research on the characteristics of wav we load distribution of offshore wind turbine foundations under the combined action of wind, wave and current. Journal of Ship Mechanics, 2022,26(05):653-666.

[8] Luo Min. The mechanism and numerical computation of net under wave loads. Shanghai Jiao Tong University, 2020.DOI:10.27307/d.cnki.gsjtu.2020.001642.

[9] Liu Guijie, Wang Qingyang, Tian Xiaojie, Xie Yingchun. Recent Research and Progress on Hydrodynamic Coefficients of Marine Structures with Small Scale Pile. Periodical of Ocean University of China, 2020,50(01):136-144.DOI:10.16441/j.cnki.hdxb.20170255.

[10] Jin Changyin. Cost composition of whole life cycle and sensitivity analysis of offshore wind power project. Solar Energy,2022(03):10-16.DOI:10.19911/j.1003-0417.tyn20201230.01.