The Design and Application of a Wind Turbine System for the Floating Wind Farm with Stationary and Anti-Typhoon

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Abstract. In the paper a new kind of wind turbine system has solved the important technical problems of the offshore triangle-platform being affected by the waves and tides, i.e. the small amplitude of sloshing, and the vibration amplification of 6-degrees-of-freedom. The sea water in the cylinder, which is fixed with the triangle platform, is basically stable, so the hollow inverted cone is stable and the fan is stable. When the triangular platform is swayed by wind and wave, the movement of the balance steel bar under the inverted cone is blocked in the balance box, and the wind turbine vibration is reduced. In order to reduce the construction cost of offshore platform, the results show that the design idea of the offshore wind turbine can realize anti-typhoon in the respects of the structure of fan rod and barrel and wind blade.

1. Introduction

The influence of occasional typhoon and cold high front wind in winter is common along the coast of China. When the wind reaches Grade 8 or above, the wind will have a negative impact on offshore facilities and even destroy the offshore facilities.

Offshore platform is a kind of trussed structure with horizontal Mesa above sea level, which can be used for production or other activities. Fans can be installed on the offshore platform to generate electricity. However, under the influence of typhoon and other strong winds, the large swell and wind waves on the sea surface, in addition, different degrees of freedom sloshing of the offshore platform being affected by the waves and tides, can make the generating fan on the platform sway by vibration amplification of 6-degrees-of-freedom.

In order to ensure the stable operation of the fan and prevent the damage of strong wind such as typhoon, it is necessary to take relevant measures in the design of the fan, in order to effectively restrain the adverse effects brought by external factors, and to suppress or reduce the shaking of various degrees of freedom, so as to resist the impact of typhoons on installations and equipment at sea.

2. Design content

A. Design purpose

The purpose of this design is to provide a wind turbine system for the floating wind farm with stationary and anti-typhoon, which has the advantages of smooth operation of fan, strong ability of resisting typhoon, low construction cost, easy installation and maintenance. [1-6]

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B. Technical solutions of the design

A wind turbine system for the floating wind farm with stationary and anti-typhoon comprises an offshore platform and a plurality of fan units arranged on the offshore platform. The fan unit comprises a wind turbine generating set, a supporting tower, a hollow inverted cone and a cylinder tank with seawater inside. The wind turbine generating set is installed at the top of the support tower, and the bottom of the support tower is fixed on the bottom of the hollow inverted cone, and the hollow inverted cone is arranged in the cylinder tank which can be floating on the inside of the sea water. The height of the cylinder tank is greater than the thickness of the offshore platform, and along its axis through the sea platform, the side wall of which is fixed to the offshore platform, and meanwhile the opening and closing inlet and outlet are provided.

In the wind turbine system for the floating wind farm with stationary and anti-typhoon, the cylinder tank fixed on the offshore platform and the hollow inverted cone floating in the cylinder tank are arranged. So the wind turbine generating set and the supporting tower can be increased or decreased with the change of the water level in the cylinder tank, which is helpful to reduce the position height of the wind turbine generating set and the supporting tower in time during the typhoon and other strong winds, and to protect the equipment by using the cylinder tank. It can avoid the destruction of the equipment, resist typhoon and other strong winds, and the seawater in the cylinder can be basically stable, which can reduce the rocking amplitude of the equipment and improve the smooth operation of the equipment. Moreover, the size of the cylinder is much smaller than that of the offshore platform, and it is more stable than the previous technical means of increasing the width and thickness of the offshore platform, so it is designed to greatly reduce the amount of steel used and the corresponding cost of construction, and meanwhile the same effect of resistance to typhoon can be achieved. In addition, the characteristics of wind turbine can be easy to install and daily maintenance.

C. Description of the components

1) The fan unit includes a balance device, which comprises a balance steel bar, four balance blocks and four transmission rods. The balance steel bar is arranged under the hollow inverted cone and is arranged along its axis, one end of which is fixed at the vertex of the hollow inverted cone. The four balancing blocks are arranged in the cylinder tank, the one end of the four transmission rods is respectively fixed with the four balanced blocks, and the other end is connected with a synchronous mechanism through the side wall of the cylinder respectively. When four transmission rods drive four balance blocks to form a limit hole, the balance steel bar is inserted into the limit hole.

2) The limit hole formed by the four balance blocks can block the movement of the balanced steel bar inserted in it, thus avoiding the hollow inverted cone above the balanced steel bar, the support tower and the whole wind turbine wobbling by a large margin, and effectively improving the stability.

3) The wind turbine generating set includes the generators and the wind rotor installed on the generator. The limit hole is a rectangular hole, the length direction of which is the upwind direction of the wind rotor, and the width direction of which is perpendicular to the wind direction of the wind rotor.

4) The amplitude of shaking in upwind direction of wind turbine generating set is usually larger than that in vertical direction of upwind direction, so the direction of length and width of limit hole should be set reasonably. It can reduce the unnecessary collision between the balance bar and the balance box during normal operation, and prolong the service life of the balancing device.

5) The length of the limit hole is 3 times of the diameter of the balance steel bar, and the width is 2 times of the diameter of the balance steel bar. By reasonable design of the length and width of the limit hole, it can reduce the unnecessary collision between the balance steel bar and the balance block in the normal operation, and prolong the service life of the balance device, and at the same time improve the stability of the operation of the equipment.

6) The thickness of the offshore platform is 5 meters, and the height of the cylinder is 75 meters, and the height of the part above the offshore platform is 35 meters, and the height of the supporting tower is 60 meters. Wind turbines and support towers can safely drop 30~40 meters when a typhoon strikes. The cylinder tank is 30 meters high below the offshore platform, which is immersed in seawater and is filled with seawater inside, which can reduce the overall shaking of the system.

7) The fan system consists of 9 fan units. The offshore platform is an equilateral triangular structure with one fan unit for each angle and two fan units for each side. The offshore platform has an equilateral triangular structure and a symmetrical distribution of nine fan units, which can improve the stability of the fan system as a whole.

8) A T-type skeleton is in the middle of the offshore platform, the three ends of which are fixed to the middle of the three sides of the offshore platform.

9) The length and width of each side of the offshore platform is 1353 meters and 50 meters, which can dock 36 ships for seamless power supply.

10) The inlet and outlet of the cylinder tank are connected to a pump unit.

11) There are three types about the power of the wind turbine generating set, which is 2 megawatts or 4 megawatts or 6 megawatts. Because the position height of wind turbine generating set has a wide range of variations, different power can be selected to match the corresponding air volume and power generation.

For better understanding and implementation, the detailed description of the design content with the accompanying drawings is as the follow.

3. Best Mode For Carrying Out The Invention

1) Figure 1 is a schematic diagram of the wind turbine system for the floating wind farm with stationary and anti-typhoon.

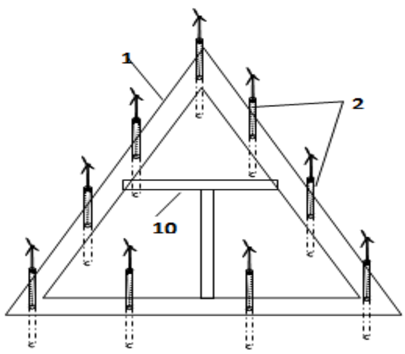

Fig. 1.Structural diagram of the wind turbine system for the floating wind farm with stationary and anti-typhoon

The wind turbine system for the floating wind farm with stationary and anti-typhoon includes the offshore platform NO.1 and the multiple fan units NO.2 set up on the offshore platform. The fan system consists of 9 fan units.

The offshore platform NO.1 is an equilateral triangular structure floating on the sea with a T-shaped skeleton NO.10 in the middle. The three ends of the T-shaped skeleton are respectively fixed to the middle of the three sides of the offshore platform. A fan unit is arranged on each corner of the offshore platform and 2 fan units are arranged at intervals within each edge. The offshore platform is 5 meters thick, 1353 meters long and 50 meters wide, and it can dock 36 ships for seamless power supply, in addition, it can also be designed in and around the offshore platform for entertainment, playing, such as diving and swimming, fishing, breeding and other multi-functional places. In the offshore platform, the anchor chain is intersected and fixed, which is beneficial to the stability of the whole structure.

2) Figure 2 is the state diagram of fan unit without typhoon.

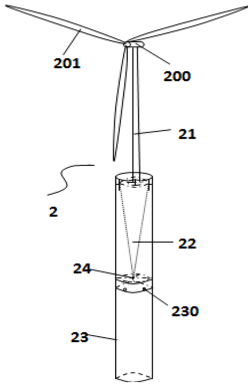

Fig. 2.Operational status diagram of fan unit without typhoon

Fan unit NO.2 includes a wind turbine generator set, a support tower NO.21, a hollow inverted cone NO.22, a cylindrical tank NO.23 with seawater inside and a balancing device NO.24. The wind turbine generator set is installed at the top of the supporting tower. The bottom of the supporting tower is fixed on the bottom of the hollow inverted cone. The hollow inverted cone is arranged in the cylinder tank and floating on the inner sea water. And the balance device is arranged in the cylinder tank.

The wind turbine includes a generator NO.200 and a wind rotor NO.201 mounted on the generator with impellers and three blades. The blade length of the wind turbine is 58 meters (2 megawatts as an example). The power of wind turbine can be selected from the three types, i.e. 2 megawatts or 4 megawatts or 6 megawatts.

The height of the support tower is 60 meters, which is made of high strength and high quality steel for better protection against typhoons.

The hollow inverted cone is an inner hollow and inverted cone structure, the height is 30 meters, the diameter of the bottom surface is 6 meters, and the distance between the bottom edge of the bottom surface and the side wall of the cylindrical tank is 0.5 meters.

The bottom of the cylinder tank is closed and its height is greater than the thickness of the offshore platform. The cylindrical tank runs through the offshore platform along its axial direction, its side wall is fixed to the offshore platform NO.1, and the middle part is provided with an open and closed inlet and outlet NO.230. The inlet and outlet are connected to a pump unit used to pump seawater into the cylinder tank or to drain the water from the cylinder tank. Specifically, the cylinder is 7 meters in diameter and 75 meters in height, and the height of the part above the offshore platform is 35 meters, which is lower than that of the part of the offshore platform.

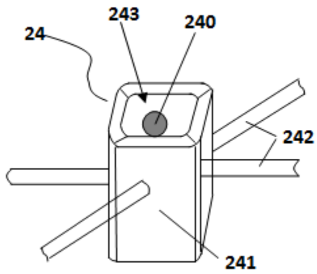

Fig. 3 .Structural diagram of balancing device

3) Figure 3 shows the structure of the balancing device, which includes the balance steel bar NO.240, the four balance blocks NO.241, and the four transmission rods NO.242.

The balanced steel bar is arranged under the hollow inverted cone and is arranged along its axis, one end of which is fixed at the vertex of the hollow inverted cone. Four balance squares are arranged in the cylinder tank. One end of the four transmission rods is fixed to the four balance blocks, the other end can move through the side wall of the cylinder, and is connected with a synchronous mechanism, which is used to drive the motion of the four transmission bars, in order to drive the four balance blocks in the cylinder tank motion.

4) Figure 4 is the top view of figure 3

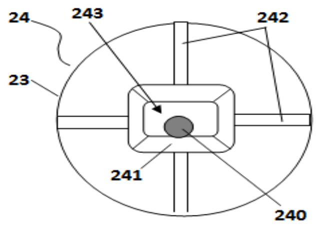

Fig. 4. The top view of the balancing device structure

When four transmission rods are extended into the cylinder tank to drive four balanced blocks to form a limit hole, the balance steel bar is inserted into the limit hole, thus blocking the movement, and preventing swaying by a large margin of the hollow inverted cone above the balance steel bar, and the support tower and the wind turbine together. The four transmission rods move near the side wall of the cylinder and drive the four balance block apart, which provides the descending space for the hollow inverted cone. The limit hole is rectangular hole 243, its length direction is upwind direction of wind turbine, and width direction is perpendicular to upwind direction of wind turbine. The length of the limit hole is 3 times as long as the diameter of the balanced steel bar, and the width is 2 times of the diameter of the balanced steel bar.

The wind turbine system for the floating wind farm with stationary and anti-typhoon has the following three states as follows.

1) As is shown in figure 2, when there is no typhoon or strong wind, the wind turbine system is in normal use, and the wind turbine unit reaches to the highest position, where the height of the support tower projecting out of the cylinder tank is 55 meters, and the bottom surface of the hollow inverted cone is level with the water surface in the cylinder tank, And the distance from the top of the cylinder is 5 meters. The four balance blocks close together to form a limit hole, and the balanced steel bar is inserted into the limit hole to prevent the hollow inverted cone above the cylinder, the support tower and the whole wind turbine wobbling by a large margin, in order to maintain the smooth operation of the wind turbine.

2) Operational status diagram of the fan unit in the event of a typhoon is shown in figure 5. When a typhoon or strong wind strikes, the four balance squares are sunk to the bottom of the cylinder tank and the seawater in the cylinder tank is released through the inlet and outlet, When the

wind turbine is 30 meters down, the height of the support tower can be shortened to 25 meters, and the blade can be lowered by the intelligent control of the blade position, which can effectively prevent the blade from blowing off by typhoon or strong wind.

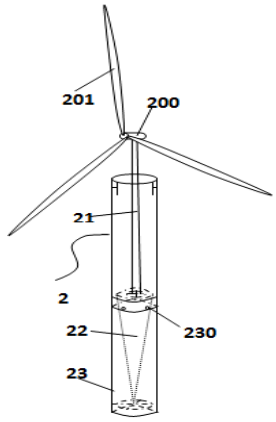

Fig. 5. Operational status diagram of fan unit when typhoon comes

3) When the strong typhoon comes, the seawater in the cylinder can be pumped out through the inlet and outlet, and the wind turbine will continue to be lowered by 10 meters, then the height of the support tower will reach only 15 meters, which can effectively prevent the strong typhoon from blowing off the supporting tower and blade.

4. Design buoyancy of calculation

1) Using the 2MW fan as an example. The weight of the generator is 49.6 tons, the weight of the blade is 11.2 tons, the weight of the engine room is 22.1 tons, the weight of the impeller is 23.7 tons, the weight of the supporting tower is 125 tons, and the total weight of the wind turbine and the support tower is 231.6 tons.

2) If the thickness of steel plate of hollow inverted cone is 1 cm and the density of steel plate is $7.85 g/cm^3$, the weight of cylinder can be estimated by 20% of the total weight of wind turbine and supporting tower.

3) The buoyancy volume of the hollow inverted cone is $\frac{1}{3}\pi r^2 h$, the buoyancy of the hollow inverted cone is $\frac{1}{3}\pi r^2 h \cdot \rho = 1.2 \times 231.6$ tons (only relying on the buoyancy of the hollow inverted cone to support the total weight of the wind turbine and the supporting tower), in which the density of seawater is $1.025\ g/cm^3$, the height of the hollow inverted cone is 30 meters. Then the radius is 2.94 meters, the diameter is 5.88 m, and the diameter is 3.0m by calculation.

4) The weight of hollow inverted cone is 24.52 tons calculated as $\pi r(L + r) \cdot d \cdot \rho$. Then its buoyancy is 289.8 tons calculated as $\frac{1}{3}\pi r^2 h \cdot \rho$, which is greater than the sum of between the total weight of wind turbine and support tower that is 231.6 tons, and the hollow cone weighs that is 24.5 tons, so it is shown that the buoyancy of hollow inverted cone is enough to support.

5) The diameter of the cylinder is 7.0 meters, which is lower than the 35 meters part of the offshore platform. The buoyancy volume of this part:

$V = \pi r^2 \cdot h = 3.14 \times 3.5^2 \times 35 = 1347\ m^3$

And the buoyancy is 1347×1.025=1381 tons.

The thickness of the cylinder (Manufactured sheet thickness d=1cm):

$T = (\pi r^2 + 2\pi r \cdot h) = 16.88 \times 7.85 = 132.5$tons

If seawater is injected into the cylinder to bring the bottom surface of the hollow inverted cone to five meters below the top of the cylinder, the weight of seawater in the cylinder located above the offshore platform:

$T=2/3\pi r^2 h\cdot\rho$ =789tons.

That is to say, when the fan system is in normal working condition, the shear force at the junction of the cylinder tank and the offshore platform is=132.5+789 +231.6+24.5=1177.6 tons. When a typhoon strikes, the seawater of the cylinder tank is discharged and the fan sinks. The shear force=1381- (132.5+231.6+24.5) tons=992.4 tons at the junction of cylindrical tank and offshore platform is 992.4 tons, so the corresponding strengthening structure should be set up at the junction of cylinder tank and offshore platform.

5. Force calculation of wind turbine system of offshore platform

A. Wind load

1) Selection of wind speed: according to clause SY/T 10030-2004 2.3.2.

2) The formula for calculating wind force is as follow:

$$F=\frac{1}{2}\rho C_s A V^2 \qquad (1)$$

Where, F denotes wind force (N), ρ denotes density of air (kg/m^3), A denotes the upwind area of the body (m^2), and V denotes wind speed (m/s), C_s denotes shape coefficient.

3) Shape coefficient and masking effect: according to clause SSY/T 10030-2004 2.3.2e and clause2.3.2f. For example, when the wind is of grade 8 (V=20 m/s), taking 2MW fan as an example, the projected area of the wind blade is about 330 m^2 (measured by the manufacturer), the density of air is 1.225 and the coefficient of shape is 1.0, then the wind blade of the fan is subjected to wind force F_1=1.225×330×20^2×1/2=80850 (N). The projection area of the cylinder tank and the supporting tower is about 350 m^2 (data from the manufacturer), the shape coefficient is 0.5, and the wind force is F_2=42875 (N). Therefore, the wind force $F=F_1+F_2$=123725 (N) =123.7kN. Considering the influence of wind force on the balancing device, the balancing device should meet the relevant requirements.

4) The average pressure of the fan acting on the wind turbine under normal operation is calculated by the following formula:

$$p_{\mathrm{H}}=\frac{1}{2}\rho C_{\mathrm{FB}} V_r^2 \qquad (2)$$

Where, C_{FB}=8/9, calculated according to the Bates formula, ρ is air density and V_r is rated wind speed (m/s). Then substituting values of the coefficients into the equation (1) and using the dimensionality conversion to get a result:

$$p_{\mathrm{H}}=\frac{V_r^2}{1800}(\mathrm{KN}/\mathrm{m}^2) \qquad (3)$$

B. Wave load

In the calculation of wave loads, appropriate wave theory should be adopted according to the depth of water, environmental conditions and structural form. And the wave forces on slender structures, such as cylinders immersed in water, should be adopted. It can be predicted by the Morison equation.

$$dF=dF_M+dF_D=C_M\rho\pi\frac{D^2}{4}\ddot{x}dz+C_D\rho\frac{D}{2}|\dot{x}|\dot{x}dz \qquad (4)$$

Where, the first term is the inertial force and the second term is the drag force, C_D is drag force and C_M is inertia force coefficient, D is cylinder diameter, ρ is the density of water, x is the horizontal velocity of water quality point. Therefore, at the bottom of the sea, the depth of water is d.

C.Current load

Calculation of the single flow force of the current load:

$$F = \frac{1}{2}\rho C_d DV|V| \qquad (5)$$

At the same time as the wave, the velocity of current should be superposed with the point velocity vector of the water quality of the wave, and then calculated.

6. Balance force analysis

1) As shown in figure 6, the buoyancy force direction i.e. F of the hollow inverted cone is opposite to the total gravity direction i.e. G of the hollow inverted cone and its upper equipment.

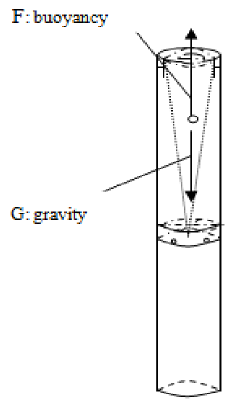

Fig. 6. Force analysis of the hollow inverted cone

When the hollow inverted cone shakes in the cylinder tank, since the lower balance bar moves only within the range of one time to 3 times the diameter of the steel bar, the drainage volume center of the hollow inverted cone has almost no change. Therefore the buoyancy force direction i.e. F is always in line with gravity direction i.e. G to maintain balance.

2) As shown in figure 7, the wind turbine and its supporting tower, on the liquid surface of the cylinder, can move along the three axes and rotate around the three axes under the influence of external environmental factors.

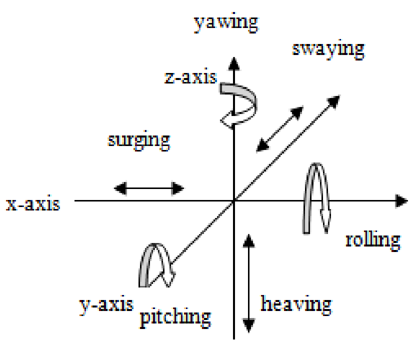

Fig. 7. Space movement

Because the cylinder tank and the offshore platform are fixed as a whole, the external factors such as wind, current, wave and other factors affect the offshore platform. At the same time, it also produces the corresponding effect on the cylinder tank, thus causing the motion of hollow inverted cone. The hollow inverted cone is less affected by z-axis in the cylinder tank. In the upwind direction, the wind turbine will move on the x-axis, so that the balance steel bar under the hollow inverted cone moves in the range of three times the diameter of the steel bar on the x axis, and the balance square inhibits the movement of the balanced steel bar, thus stabilizing the hollow inverted cone. The wind turbine moves on the y-axis so that the balance bar below the hollow inverted cone moves within the range of one time the diameter of the steel bar on the y axis, and the balance box inhibits the movement of the balanced steel bar, thus stabilizing the hollow inverted cone. Therefore, the wind turbine and the supporting tower are stabilized in the horizontal and longitudinal direction to achieve the stable operation of the fan system.

The anti-collision surface is strengthened between the top of the cylinder and the hollow inverted cones, which can prevent the vertical and transverse movement of the hollow inverted cone caused by the gust in it, and protect the equipment on the hollow inverted cone from running normally.

7. Conclusions

Through reasonable design and the prior technology, wind turbine system for the floating wind farm with stationary and anti-typhoon can not only generate electricity normally in the stable wind field in the sea area, but also resist the unfavorable influence of unsteady typhoon or unconventional wind. It also reduces the cost of construction. The fan platform system can be built in the open coastal waters, 30-50 km offshore, and 30-50 m water depth. The offshore wind field is stable, no matter northeast monsoon or southwest monsoon, so there is a relatively stable wind speed for fan stable power generation area. It is also possible to develop related multifunctional facilities in and around the platform system, combining offshore platform fan power generation and tourism, and aquaculture integration.

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