# Research on Design and Application Technology of Anchorage System for Floating Photovoltaic Power Plant

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**Abstract:** At present, photovoltaic power plant technology has become increasingly mature. Due to changes in the installation geography environment, various forms of photovoltaic power plants have emerged, such as rooftop photovoltaic power plants, mountain photovoltaic power plants, agricultural photovoltaic power plants, fish photovoltaic power plants, and floating photovoltaic power plants. Compared with traditional ground and roof photovoltaic power plants, the biggest technical difference of floating photovoltaic power plants is the design and application of anchorage systems. In this paper, by analyzing the wind load and wave force and current force which affect the anchoring force, the theoretical calculation and simulation analysis of the anchoring force are introduced, and the principle of setting the anchoring points around the photovoltaic floating array is proposed. By comparing the implementation and performance of different anchoring methods, the anchoring method suitable for geological unsteady zone is proposed, and the anchoring system formed by various anchoring modes is provided with high reliability and economy.

**Keywords:** Anchorage system. Wind load. Wave force. Current force.

## Abstract

**I. FOREWORD**

The floating photovoltaic power plant is a new type of photovoltaic power generation system, showing a large market potential. The construction technology of floating power plant is quite different from that of traditional ground and roof power plants. The most obvious one is the design of the power plant foundation. Floating photovoltaic power plants use floating bodies to float on the water surface, and it is difficult to apply the conventional ground structure infrastructure for design. It is necessary to consider the force of the floating power plant under multiphase current.

**II. THEORETICAL CALCULATION OF ANCHORING FORCE**

When calculating the drag force of the anchorage system of the photovoltaic array floating body, wave force and current force on the floating body should be considered in addition to the conventional wind pressure.

The wind load calculation can refer to the Chinese National Standard GB50797-2012 *Code for Design of photovoltaic power station*. The wind load calculation of this code is formulated with reference to the Chinese National Standard GB50009-2012 *Load code for the design of building*. Wave force calculation can refer to the Chinese industry standard SL274-2001 *Design* *Code for rolled earth-rock fill dams*. Current force calculation can refer to American Petroleum Institute standard API-RP-2SK-2005 *Design and Analysis of Stationkeeping Systems for Floating Structures* and the Chinese industry standard JTS165-7-2014 *Code of design of marinas*, the latter is based on the American Society of Civil Engineers Design Guide *Planning and Design Guidelines for Small Craft Harbors, Manual of Practice No. 50*.

**A. Wind load calculation**

Refer to the Chinese National Standard GB50797-2012 to calculate the wind load of the PV array.

The wind load standard value acting on the structure of the floating system could be calculated as follows:

$$W\_{k}=Kμ\_{s}μ\_{z}W\_{0}$$

Where:

$W\_{k}$$W\_{k}$——Wind load standard value（kN/m2）

$μ\_{s}$$μ\_{s}$——Wind load shape coefficient

$μ\_{z}$$μ\_{z}$——Wind pressure height variation coefficient

$W\_{0}$$W\_{0}$——Basic wind pressure（kN/m2）

The wind load design value acting on the structure of the floating system could be calculated as follows:

$$W=KW\_{k}A$$

Where:

W——Wind load design value（kN/m2）

A——Calculated area（m2），The projected area of the module in the vertical direction on the north side.

K——Floating photovoltaic array correction factor. According to the current field simulation results, generally take 0.2~0.5.

**B. Wave force calculation**

Refer to Appendix A of the Chinese industry standard SL274-2001 to calculate wave elements such as wave height, wavelength, and wave period.

Wind and wave elements can be calculated and determined according to the following formula:

$$\frac{g\overbar{H}}{V^{2}}=0.13th\left[0.7\left(\frac{gd}{V^{2}}\right)^{0.7}\right]th\left\{\frac{0.0018\left(\frac{gF}{V^{2}}\right)^{0.45}}{0.13th\left[0.7\left(\frac{gd}{V^{2}}\right)^{0.7}\right]}\right\}$$

$$\frac{g\overbar{T}}{V}=13.9\left(\frac{g\overbar{H}}{V^{2}}\right)^{0.5}$$

$$\frac{gt\_{min}}{V}=168\left(\frac{g\overbar{T}}{V}\right)^{3.45}$$

Where:

$\overbar{H}$$\overbar{H}$——Average wave height（m）

$\overbar{T}$$\overbar{T}$——Average wave period（s）

$V$$V$——Calculating wind speed（m/s）

$F$$F$——Wind zone length（m）

$d$$d$——Average water depth（m）

$g$$g$——Gravity acceleration（m/s2）；

$t\_{min}$$t\_{min}$——The minimum wind time when the wind and waves reach a fixed length（s）

The period of the irregular wave can be expressed by the average wave period $\overbar{T}$, and the wavelength L calculated by the average wave period can be determined by the following formula.

$$L=\frac{g\overbar{T}^{2}}{2π}th\frac{2πd}{L}$$

Wave height, wavelength, wave period, etc. are used as input values to simulate the wave force acting on the floating array:

$$F\_{w}=F\_{0}A$$

Where:

$F$$F$w——Wave force acting on the photovoltaic array of the floating photovoltaic power system（kN）

$F$$F$0——Standard value of wave load acting on the photovoltaic array（kN/m2）.

$A$$A$——The projected area of the underwater portion of the first row of floating bodies of the floating photovoltaic array perpendicular to the direction of current（m2）

**C. Current force calculation**

C.1. In American Petroleum Institute standard API-RP-2SK-2005, Current force on semisubmersible hulls:

$$F\_{CS}=C\_{SS}×（C\_{d}A\_{c}+C\_{d}A\_{f}）V\_{C}^{2}$$

Where:

FCS——current force，lb（N）

CSS——current force coefficient for semisubmersible hulls,2.85lb/（ft2.kt2）（515.62Nsec2/m4）

Cd ——drag coefficient (dimensionless)

Ac——summation of total projected areas of all cylindrical member below the waterline, ft2 (mt2）

Af——summation of projected areas of all members having flat surface below the waterline, ft2 (mt2）

VC——design current speed, kts（m/sec）

C.2. In the Chinese industry standard JTS 165-7-2014, current force on the craft:

Calculate the current force of the photovoltaic array of the floating photovoltaic power system according to the relevant requirements of Appendix B of JTS 165-7-2014:

$$F=KC\_{d}V^{2}A$$

Where:

$F$$F$——Current force acting on floating body（kN）

$C\_{d}$$C\_{d}$——The coefficient of current resistance force, take 0.8, the coefficient content conversion.

$V$$V$—— Current speed（m/s）, the current speed V should be the maximum average current speed that may occur within the range of the structure.

$A$$A$——The projected area of the underwater portion of the first row of floating bodies of the floating photovoltaic array perpendicular to the direction of current（m2）

K——Floating photovoltaic array correction factor. According to the current field simulation results, generally take 5-10.

The calculation method in the above is only for reference. It is also necessary to combine the simulation analysis to simulate the current field and calculate the force.

**III. SIMULATION ANALYSIS OF ANCHORING FORCE**

The drag force calculation of the anchorage system involves multiple calculations such as fluid-structure coupling, three-dimensional and one-dimensional coupling. The main calculation ideas are divided into the following three steps:

**A. Calculation of wind load of 3D full-size photovoltaic panel array**

Due to the amount of calculation and the complexity of the model, the current calculation of the wind load of the photovoltaic panel array is usually obtained by two-dimensional simplification or empirical formula calculation. However, the two-dimensional calculation results are significantly different from the actual load conditions. The computer-modeled rapid meshing scheme can complete the wind load calculation of 3D full-size photovoltaic panel arrays, and obtain high-precision calculation results:

A.1. Accurate wind load for structural strength design to reduce overload design;

A.2. Ultimate wind load prediction, the ultimate wind load is analyzed according to the requirements of the specification to verify the strength design;

A.3. Assist in reducing wind tunnel testing, reducing costs and testing cycles.

**B. Force of floating photovoltaic power plant under multiphase flow**

At present, the calculation of multiphase flow considering wind load, wave force and current force is still rarely carried out. Because of its computational difficulty and computational computing resources, it is difficult to meet the engineering design cycle requirements. Through fluid-structure coupling calculations, we can get:

A.1. Under the action of multi-phase flow, the floating photovoltaic power plant is subjected to various forces;

A.2. Numerically obtained, the overall force of the wind load and water waves on the power station. Optimize the structural or fluid design of each part.

**C. Drag force of the anchorage system**

The drag force calculation of the anchorage system involves multiple calculations such as fluid-structure coupling, three-dimensional and one-dimensional coupling. Two solutions are proposed for this purpose:

(1) Calculate the single array anchorage system and extrapolate the force of the entire floating photovoltaic power plant.

(2) The calculation results of the floating photovoltaic power plant under the action of multi-phase flow are used for the boundary conditions, and the structural calculation of the anchoring system.

Through calculation, we can get:

(1) Ultimate strength of anchorage system;

(2) Deformation of anchorage system under different loads;

(3) Combined with structural design, optimize the configuration and distribution of anchorage system

In order to simulate the actual situation, the wind flow field simulation analysis of the photovoltaic array, the steady-state simulation analysis results are as follows:





Fig.1 Simulation analysis of photovoltaic array wind flow field

It can be seen from the simulation results:

(1) When the actual wind load acts, the front row modules will form a certain occlusion for the rear row modules, so that the wind load received by the rear row modules is reduced, and the force is less than that of the single row modules.

(2) Under the wind load of the east and west sides of the array, the wind surface is limited, and the horizontal force formed by the other side is small, which can reduce the anchor density reasonably.

(3) The north and south sides of the array are under the action of south wind or north wind. As the windward and leeward faces of the module, the wind is large and bears a large wind load, so the wind in the positive south and north is the important factor affecting the array displacement. Therefore, key control should be carried out when designing the anchorage system.

(4) Comparing the south wind and the north wind, it can be found that the wind pressure reduction of the multi-row array is slower than the south wind direction when the north wind blows, so the influence of the north direction on the stability of the array is greater than that of the south wind. In the anchorage system design, the north side of the array is the weakest point, and the anchor point needs to be encrypted.

**IV. APPLICATION OF ANCHORAGE SYSTEM**

A variety of anchoring methods can be combined to create a more stable anchorage system wherever possible. The form of the anchorage system is diverse, including: shore piling, underwater piling, underwater anchoring (special iron anchor or concrete anchor), struts, adaptive anchors, etc.

Tab. 1 Comparative analysis of various anchoring methods

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| --- | --- | --- | --- |
| Serial number | Anchor form | Implementation | Performance analysis |
| 1 | Piling on the shore | Piling on the shore, connected to the floating body by steel ropes, anchor chains and adapters. | This form is better when the geological conditions on the shore are stable. |
| 2 | Piling under water | Screw piles or prestressed pipe piles are driven under water and connected to the floating body by steel ropes, anchor chains and adapters. | The pipe pile only provides the anchoring force by the frictional force and self-weight of the pile side wall and the underwater soil layer, and the reliability is relatively poor.The working principle of the screw pile is equivalent to the self-tapping screw. By its own thread, the soil is tapping, drilling, squeezing and pressing the corresponding threads to make them closely match each other, and the reliability is better. |
| 3 | Anchor in water(iron anchor) | Throw the iron anchor in the water and drag it to the top of the anchor to bury the soil layer, and keep the anchoring angle 10 ° ~ 15 °, connected to the floating body through steel wire, anchor chain and adapter. | The anchoring force is provided by the drag force of the anchor claw, and is only applicable to the thick bottom of the sludge layer. |
| 4 | Anchor in water (concrete anchor) | Throw the concrete anchor block in the water, keep the anchorage angle 30 ° ~ 45 °, and connect it to the floating body through steel wire, anchor chain and adapter. | The anchoring force is provided only by the friction of the bottom layer of the concrete block and self-weight of the concrete block, and the reliability is relatively poor. |
| 5 | Adaptive anchor | A plurality of fixed pulleys are arranged on the transfer floating platform, and the steel rope is arranged. One end of the steel rope is cast iron anchored in the water, and one end is connected to the floating body through a steel rope, an anchor chain and an adapter. | Applicable to waters with large changes in water level (generally more than 10m), reliability needs further study. |
| 6 | Pole | The hinged device is arranged at both ends of the steel pipe, one end is connected with the fixed point of the bank, and one end is connected with the floating body adapter. | As an auxiliary device of the anchoring system, it prevents collision between the floating body and the shore or the floating body. The length of the strut should not be too long, generally less than 10m. |

**V. CONCCLUSION**

(1) Wind load acts on large-scale photovoltaic arrays, and the actual force of the array will be reduced. When the anchoring force is calculated in the array, the reduction should be considered to prevent overload design. The wind load combined with the wave force and current force has a complicated influence on the photovoltaic array, and the parameters need to be obtained through simulation.

(2) The selection of the anchoring form must fully consider the influencing factors such as structural stress, geological conditions and economy.

(3) At present, most of the floating photovoltaic power plants are built in a shallow water environment with little change in water level. The anchoring technology of the floating photovoltaic power plant in deep waters needs further study.

**Reference**

e.g. [1] Guo Jiabao et. al., 2012, Code for Design of photovoltaic power station, Chinese national standard , GB50797-2012, pp. 20-23.

e.g. [2] Jin xinyang et. al., 2012, Load code for the design of building, Chinese national standard , GB50009-2012, pp. 30-63.

e.g. [3] Gan Xianzhang et. al., 2001, Design Code for rolled, SL274-2001, pp. 521-526.

e.g. [4] American Petroleum Institute, 2005, Design and Analysis of Stationkeeping Systems for Floating Structures, API-RP-2SK-2005, p. 79.

e.g. [5] American Society of Civil Engineers , 1994, Planning and Design Guidelines for Small Craft Harbors, Manual of Practice No. 50., p. 102.