

Discussion of Several Key Technologies about Offshore Wind Power

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Abstract. The development, structure type of foundation, trial pile experiment of the offshore wind power station is investigated and the application of foundation type is analysed for different seabed. The future development of the offshore wind power is forecasted. The documents about the trial pile experiment is collected for the guidance of the design, construction and monitoring.

1. Introduction

In order to satisfy the development of economy and environment protection, the construction of conservation culture has been promoted to the same importance level with the construction of economy, politics, culture and society, which also shows that as one of the most important recycle energies the wind energy is more and more highly regarded and the intestinal fortitude and develop tendency of clean energy is promoted at the nation interest. The wind energy can be classified into land wind power and offshore wind power. Compared with the land wind power, the offshore wind power possesses the advantages including stable wind resources, low onflow strength, strong wind intensity, high output and long service life. From thirty years ago, Denmark, Holland, U.K. and Sweden have firstly carried out the exploitation of the offshore wind power. Until now, the total installed gross capacity has already been over 4.2MW[1]. From 2005, the offshore wind farm has been prepared to build successively at Jiangsu, Zhejiang province. The representative offshore wind farm includes Bohai sea gulf farm, Donghai Bridge farm, Rudong tidal range farm etc.

Meanwhile the high-speed development of offshore wind power also faces many challenges. One of the main reasons that resulted in the lag of development lies in the high cost of construction and maintenance[2]. The difficulty and risk of design and construction of offshore wind power is greatly enlarged by the complexity and diversity of the hydrology and wave under the marine condition. In order to utilize the offshore wind energy sufficiently and to promote the spread of the offshore wind resource, this paper investigates and summarizes the technology related with the offshore wind development in recent years, which can provides some reference for the future development.

2. Development summary

There are very long coastline and spacious exclusive economic zone in China. The amount of the feasible wind power is around 7~12MW. According to the distance from the coastal line, the offshore



wind farm can be divided into tidal range, mudflat area, offshore area and open-sea area. According to the construction type, it can be classified into experimental offshore wind farm and practical offshore wind farm. The experimental offshore wind farm is usually used to evaluate the feasibility and economical efficiency of certain sea area and to accumulate reference and experiment for the follow-up large-scale development. The beginning of the development of the offshore wind farm is the Bohai sea farm in Liaoning province. Now the total installed gross capacity of China locates at the top level in the world. The representative offshore wind farms built, building and to be built are listed in Table 1. Until 2016, the total installed, installing and to be installed gross capacity of offshore wind power is 1000MW, 2300MW and 1240MW respectively.

Table 1 General list of offshore wind power in China

NO.	Project name	Gross capacity(MW)	Foundation	Year
1	Bohai sea farm	1.5	single pile/offshore jacket	2007
2	Xiangshui offshore experimental farm	2	single pile/offshore jacket	2011
3	Weifang offshore experimental farm	6	single pile/offshore jacket	2012
4	Dagang offshore wind farm	33	single pile/offshore jacket	2013
5	Donghai bridge offshore wind farm	102	elevated pile cap	2010
6	Rudong offshore wind farm	50	single pile/offshore jacket	2012
7	Rudong offshore wind farm I	20	multiple pile caps	2014
8	Donghai bridge offshore wind farm I	102	elevated pile cap	2014
9	Xiangshui offshore wind farm	202	elevated pile cap	buliding
10	Dafeng offshore wind farm	200	single pile/offshore jacket	buliding
11	Nanri Island offshore wind farm	400	elevated pile with low cap	buliding
12	Tangshan offshore wind farm I	300	-	to be built
13	Zhoushan offshore wind farm II	250	-	to be built

3. Foundation form and its applicability

Compared to the offshore oil platform, the foundation of offshore wind power mainly bears the horizontal load and overturn moment and the vertical load is relatively small, which makes the structure of the offshore wind energy quite different from the offshore oil platform. Usually the investment of the foundation occupies around 15~25% in the total investment [4]. Because the feasibility of the offshore wind farm is determined by its construction cost, it is necessary to consider the economic to control the construction cost. Now the common foundation form of the offshore wind energy includes gravity foundation, single pile foundation, multiple-pile cap foundation, tripod foundation, jacket foundation, negative-pressure cylinder foundation and floating foundation.

The working mechanism of the gravity foundation is that the stability and stiffness of the foundation depends on its gravity. The weight of the foundation is generally over 1000t. After it is prefabricated overland, the large floating derrick is utilized to install the foundation into the seabed. Considering its large weight, the soft ground should be improved to satisfy the requirement of bearing capacity, before which the broken stone hardcore cushion should be installed and the protection

against erosion should also be prepared. It is studied that the construction cost increases twice against the depth of the sea. Therefore, the gravity foundation is usually used for the sea area with depth less than 10m and its stability and reliability has been verified in the offshore wind power site in Europe[5]. Particularly, in the Seabreeze engineering a new type of gravity foundation is used and it is suitable for the deep sea with depth over 50m[6].

The single pile foundation is composed by welded steel pipe piles and the diameters of the single pile depend on the water depth and installed capacity, which is usually around 4~7m. It is the most common offshore wind power foundation. The horizontal load is sustained by the soil pressure around the pile and the vertical load is sustained by the frictional force between the pile and the ground, which is suitable for the sea area with depth less than 30m. The merits of the single pile are of simple structure, convenient installation, short construction period. However, the disadvantages also exist, such as poor stability, low stiffness in the deep sea area and it is restricted by the wash out, vibration and verticality. The multiple-pile cap foundation is mainly composed by the pile foundation and the cushion cap. The pile foundation is usually PHC, driven cast-in-place pile and steel pile. According to the geological condition and the complexity of construction, the surrounding piles can be spur pile to support the horizontal load. The connection between the cap and the top of the pile is rigid to exert the interaction between the soil and the pile. There is nearly no difference compared with the single pile foundation essentially and its application arrange is similar to the single pile foundation. The merits are relative large stiffness, high stability, regular structure. The disadvantages are great amount of engineer, long construction period and many construction procedures.

The tripod foundation is composed of central cylinder and three steel pipe piles inserted into the seabed, which is the monolithic supporting system. The horizontal load, wave load and vertical load is transferred to the three steel pipe piles from the central cylinder, until the seabed foundation. Compared to the single pile foundation the tripod foundation can enhance the stability and reliability of the foundation efficiently by increasing the stiffness and strength. It is usually used in the sea area with depth over than 30m. The jacket foundation uses the foundation of the offshore platform as a source of reference. The truss is assembled overland and then hauled to the installation site. The characteristics of the jacket foundation are simple making, convenient installation, low cost and low requirement of the geological conditions, which is suitable for the sea area with depth over 40m.

The negative-pressure cylinder foundation is a cylinder caisson structure without bottom surface. It is prefabricated overland and then hauled to the installation site. The air inside the cylinder is drawn out during the installation and the cylinder gradually sinks towards the designated elevation under the combined action of hydraulic pressure difference, air pressure difference and self-weight. As a new type of offshore wind power foundation, the negative-pressure cylinder foundation is more and more popular. However, there are still some problems such as the controversial working mechanism, the difficulty of installation and the wash out around the foundation. The floating foundation is a boxlike platform that is floating on the sea and it is fixed to the seabed utilizing the mooring facilities. According to the environment and the installing requirement, it can be divided into single-column type, tension-leg type, semi-submersible type, draw of barge type etc. It can be used in the sea area with depth over 50m and it is one of the developing tendency for the future deep-sea wind power foundation. Now the floating foundation engineering is mainly located abroad and it still lies at the research and exploration stage. Blue Technologies company developed the first floating wind power station using offshore oilwell technology in 2008. Two single-column floating foundation and semi-submersible floating foundation are constructed in 2013 in Japan. The Pilot Part floating foundation with single-column type is built in 2017 in Norway.

For the coastal countries in Western Europe the seabed is mainly sandy soils with relatively large bearing capacity and well engineering mechanics properties, therefore the offshore wind power foundations are usually gravity foundation and single-pile foundation. By contrast, for the adjacent sea area such as Bohai Sea, East China Sea, South China Sea the seabed is mainly soft soils such as sludge, mucky soil, silty clay and silt. Such kind of soft soils is of large void ratio, high water content, small bearing capacity and poor engineering mechanics properties, which is not suitable for supporting layer.

At the bottom layer, the soils are mainly fine sand, medium coarse sand and decomposed rock with large bearing capacity, which can be used as supporting layer[7]. In this situation, the offshore wind power foundation can be single-pile foundation and tripod foundation. When the water is relatively deep, the jacket foundation can be used. When determining the type of the offshore wind power foundation, the sediment accumulation, wash out and ice slush action should be considered sufficiently and the influence factors such as economical efficiency, feasibility, reliability and durability should also be considered generally by referring the built engineering.

Before the construction of engineering pile, the trial pile experiments should be carried out to evaluate the bearing capacity and deformation of the pile. Now the test methods of the bearing capacity are mainly conventional static loading method, self-balanced method, dynamic testing method and static-dynamic testing method. Nowadays, the diameter of the steel pipe pile foundation increases gradually as the installed capacity of wind turbine increases. Because the offshore trial pile test costs long time and easy to be influenced by outer environment, the documents about the detailed datum are not very plenty. Moreover, the experiment of the large-diameter steel pipe pile may be unable to obtain accurate results due to the experiment methods or the experiment facilities, and it should be optimized for the in-site trial pile plan. There have been many researches aiming at the bearing capacity of the large-diameter steel pipe pile using in-site experiment and numerical methods respectively[8-9].

4. Conclusions

The paper researches and analyses the general development, the foundation structure, the trial pile method of the offshore wind power foundation, which can provide certain guidance for the design, construction and monitor of the offshore wind power foundation. The conclusions are as follows:

(1) Now the offshore wind power industry is widely developing, but the construction site is still concentrating at the tidal range with shallow water and the foundation types are mainly single-pile foundation, gravity foundation and tripod foundation. In the future, the target of the offshore wind power station should be the deep sea area with depth of 10~40m and the foundation will be mainly the multi-pile foundation and jacket foundation.

(2) It is very important to accumulate the documents of offshore wind power trial pile. The influence of geological condition, pile diameters, trial-pile method on the results should be analysed qualitatively, based on which the detailed trial pile plan can be obtained. The application of the finite element method in the bearing capacity of large-diameter steel pipe pile should be further explored. It is better to compare the calculated results with the in-site measured results to analyse the sensitivity of parameters to improve the accuracy of the numerical calculation.

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