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Investigation on Installation of Offshore Wind Turbines

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Abstract: Wind power has made rapid progress and should gain significance as an energy resource, given growing interest in renewable energy and clean energy. Offshore wind energy resources have attracted significant attention, as, compared with land-based wind energy resources, offshore wind energy resources are more promising candidates for development. Sea winds are generally stronger and more reliable and with improvements in technology, the sea has become a hot spot for new designs and installation methods for wind turbines. In the present paper, based on experience building offshore wind farms, recommended foundation styles have been examined. Furthermore, wave effects have been investigated. The split installation and overall installation have been illustrated. Methods appropriate when installing a small number of turbines as well as those useful when installing large numbers of turbines were analyzed. This investigation of installation methods for wind turbines should provide practical technical guidance for their installation.

Keywords: wind turbine; foundation style; split installation; overall installation
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1 Introduction

The market structure for international resources has seen vast changes in the last decade. As a competitive candidate among renewable resources, wind resources evolved from demonstrations of the concept to practical usage applied on a large scale after several decades of investigation (Li and Yu, 2004). With the rapid expansion of land-based wind farms, some limitations have been noticed such as large floor space and noise pollution (Liu and Xu, 2007). Due to the abundance and technical practicability of offshore wind resources, the ocean will become a promising wind power market (Zhan *et al.,* 2005). However, owing to the complexity of the hydrological, climatic and seabed geological conditions for the establishment of an offshore wind farm, it is difficult to choose a wind turbine design and construction method for the foundations, which becomes a hard problem to resolve and thus influences the feasability of a particular offshore wind farm (Lin et al., 2007). No matter where the wind turbine might be built, on land or offshore, the design should be conducted under certain conditions (Manwell et al., 2007).

Because of the formidable nature of the marine environment, the hoisting of wind turbine, as a key part of offshore wind farm construction, should receive special attention (Hasager *et al.*, 2003; Choisnard *et al.*, 2003). While there can be no doubt that Northern European offshore wind resources are 'truly enormous' (Garrad *et al*., 1994; Bishop and Miller, 2007), there is considerably less consensus with respect to how many of that resources are feasible to be exploited. Current concerns within the wind industry focus on the technical and economic barriers to offshore wind farm development. Work has been done to deal exclusively with "bottom-mounted" technologies, which are generally regarded as more realistic for medium term development than floating concepts (Cockerill *et al*., 2001). Several studies have been carried out on the offshore wind energy resources for European countries (Antonio *et al*. 2005**)**. By selecting areas which were deemed suitable for wind development, including predictions of public acceptability such as minimum allowed distance to shore, the results indicated a very large resource (Hassan and Lloyd, 1995). The ongoing R and D efforts in the offshore wind sector were described by Halliday (2001). Most of them aimed to improve the short term prediction of energy production, while other studies investigated possible cost reduction related to the redesign of offshore wind turbines (Kuhn *et al*., 1998).

In the present paper, the wind turbine foundation is appropriately selected through the investigation on the characteristics of several commonly used wind turbine forms. The split installation and overall installation of offshore wind turbine are discussed on the basis of the construction experience, both at home and abroad, in which split installation has borrowed ideas of Scroby Sands, of Britain and Nysted of Denmark and the overall installation on Beatrice, Britain.

2 Foundation forms of offshore wind turbines

The offshore wind turbine foundation has several forms, i.e.

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monopole, tripod, jacket, gravity-based, suction bucket and floating platform foundations, as shown in the following Figs 1~3 (Zaaijer, 2006).

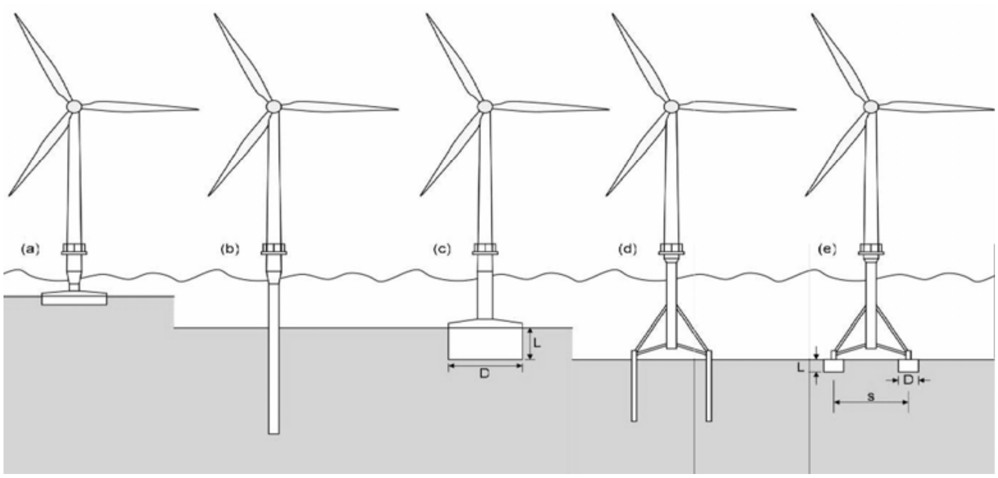

Fig. 1 The offshore turbine foundations

(a) gravity-based foundation; (b) monopole foundation; (c) suction bucket foundation; (d) tripod foundation;(e) tripod suction bucket foundation;

Fig. 2 Jacket foundation

Fig. 3 Floating platform foundation

The influencing factors on the selection of offshore wind turbine foundation forms include water depth, soil and sea-bed conditions, environmental load, construction methods and cost. Generally, the selections follow the rules seen in the following table.

Table 1 The selection of offshore wind turbine foundation

Water depth / m	Types of foundation
0~10	Gravity foundation
0~30	Pile foundation
>20	Tripod / Jacket
>50	Floating platform

3 Installation of offshore wind turbines

The construction plan of the offshore wind farm should be thoroughly considered in terms of safety and economy because of the severe environment, construction difficulty and high construction cost. This paper emphasizes on the installation of the offshore wind turbine.

The wave's effect on installation ship is complicated. The wave movement is simplified as installation ship's movement. The movement of installation ship's drop hanger is shown as follows:

$$X_1(t) = B\sin(\omega t + \theta) - V_{at} + n \tag{1}$$

where B is the movement amplitude, n, ω are the constants, θ is the initial phase.

The corresponding equation is

$$m\dot{X}_2 = K\left(X_1 - X_2\right) + C\left(\dot{X}_1 - \dot{X}_2\right) \tag{2}$$

where K is elastic coefficient of steel cable, C is the damp coefficient of steel cable.

The transfer function is

$$G(S)=\frac{X_2(S)}{X_1(S)}=\frac{CS+K}{mS^2+CS+K} \tag{3}$$

The damping ratio is

$$\xi=\frac{C}{2m} \tag{4}$$

From these equations, the wave effect can be calculated. In the following, from two sides, the installation methods are illustrated.

3.1 Offshore split installation

The offshore split installation is similar to that of land. Firstly, assemble the cabin, wheel hub and two blades together, make the two blades into a “rabbit ears” type, which will be installed in the cabin of the wheel hub, and make them into a lifting body (Jiang et al., 2007). Then, hoist them from land onto the installation ship. Other components, such as the tower tube and the other blades, will be hoisted in turn on board. The installation order is: the lower part of tower, the upper tower tube, lifting body (cabin with two blades) and the last blade. The split installation is most commonly used up to now and in order to ensure the safety and reliability of installation, the platform should stay stable. Installation ships equipped with the jack-leg system are generally adopted abroad.

The internationally renowned offshore wind turbine installation company, A2SEA, owns the world leading installation vessels: Mayflower Reaolution, M/V Sea Energy and Jumping Jack. The specialized vessels, equipped with hydraulic jack-leg system on the left and right sides, have been transformed by the container ships. When the installation location is reached, the anchor is cast to stabilize the ship. Then, through the hydraulic system, the landing legs, which bear the entire hull and equipments contained are laid down to the seabed surface so that the hull would not sway in the waves and the installation stability can be guaranteed.

The installation experience of British Scroby Sands and the Danish Nysted offshore will be illustrated in the following.

3.1.1 The installation experience of British Scroby Sands offshore wind farm

The Scroby Sands offshore wind farm is the first British offshore wind farm built in 2004, owned by the British E. ON UK Renewable Offshore Wind Ltd. (EROWL). The basic installation process is as follows:

(1) Base construction.

Monopole foundation is adopted by Scroby Sands. J-platform is used and the conditions of waves and currents in the location have been considered. Two access ladders are set to accommodate the entry of vessels in different directions. Near the top of the pile there is a working platform. The pile is 4.2 meters in diameter; it connects the pile with the tower by the welding of the flange. The installation of the pile is done by pure piling method. The ferry and platform are connected directly after piling, which is highly efficient; it was firstly introduced by Scroby Sands. The self-elevating barge can transport 200 tons of piles and steel structure to the construction site, which will reduce the maritime operations process. The construction time is about 24 hours for the entire base.

(2) Erosion protection.

Scroby Sands wind farm is located in the sandy area where the large-scale tide exists with a 3m tidal range and up to 1.5m/s tidal speed. In the recent 30 years, the sea-bed depth has changed 8 m (data acquired by the UK Department of the Navy in the past 50 years). It is of great significance to erosion protection, especially to the protection of the cables, because of the huge sea-bed sediment and scour hole with the depth of up to 6~8m. The scouring protection materials are composed of the rock composition. With the use of side-dumping barge, the rocks are dumped to form an erosion protective layer. In order to achieve uniform distribution of the stone around the pile, the barge dumps the rock 2 meters away from the pile in six different directions and leaves the pile while dumping.

(3) Piling process.

The foundation installation construction has been accomplished by the self-elevating barge, JUMPING JACK, owned by Mammoet Van Oord company. The construction work includes 30 monopole foundation installations. The pile with a diameter of 4m can be installed by pure piling method. IHC S1200 hydraulic piling hammer is placed directly on top of the pile welding flange.

(4) Installation of towers, turbines and wind wheel blades.

A2SEA and Seacore companies have applied MV OCEAN ADY and Excalibur self-elevating barges to install 30 units. A 450-ton crane that can operate smoothly at sea is loaded on MV OCEAN ADY and a unique design which can realize rapid transportation is adopted. Excalibur, built and designed by Seacore company, can carry two complete wind generator with the hub height of 60m. A2SEA A/S company has installed 24 turbines in deep water zone (From March 26, 2004 to May 14, 2004) and 6 turbines in shallow water zone (a period of 12 days, the last one was completed on July 1, 2004).

(5) Installation of the cables.

Meteorological data are often insufficient to determine the starting time. During the laying process of 3 submarine cables, the construction was always interrupted by the laying process of a single cable. In some cases, the current data are not sufficient, either, and as a result, the divers’ activities are impeded by the strong tidal flow.

3.1.2 Danish Nysted offshore wind farm installation experience

(1) The sea-bed preparation.

A hydraulic excavator equipped with a small dredger has been used to do a major dredging work. The average depth of dredging is approximately two meters below the seabed. Dredging error has been set at ± 0.30m. The dredged mud has been dumped in the vicinity of sea area. The steel structure has been set down and laid smooth as the guidance of stone bed.

(2) Concrete foundation.

The foundation is designed in a form of hexagonal bottom structure with six holes, single pole and the ice cone at the tope. The bottom diameter is 15 meters, the maximum height is 16.25 meters and the single foundation in the air weights less than 1 300 tons, which are suitable for maritime operations. The crane ship, EIDE V, carries the foundation from the ferry. Then, by adding weights and single-pole inside the hole, a weight of 500 tons has been gained, which can maintain the stability of the base to prevent sliding and overturning. The scouring protection can be done in two layers: stone outer layer and filter layer. The material can be placed by the hydraulic excavator on the barge.

(3) The hoisting work to place the foundation.

(a) EIDE V remained near the foundation beside the transport ship. The two ships were bound.

(b) The bandage on the foundation was removed and the hoisting frame could be placed in the ice cone direction.

(c) The foundation was lifted from the transport ship and in the mean while, the transport vessel adjusted the ballast to keep balance.

(d) EIDE V was sealed to the place where the foundation needed to be installed. After the arrival, it was connected with the pre-set anchor. With the aid of anchor and pile feet, the ship was fixed on the precise location.

(e) The foundation was lain down slowly on the stone bed. At the same time, continuous position monitoring was conducted. If necessary, the anchor would be used to fix the location of the foundation.

(f) When the foundation reached the Stone bed and transferred the weight to the Stone bed, it required to control the position and weight of location of foundation. After the lifting frame was loosened by Hydraulic method, EIDE V was sealed to the location for the next-step operation.

(g) The cable tube's extending from the foundation to the sea bed was completed and the cable installation was ready.

(4) The installation of wind turbines, piles and blades.

The transportation and installation of 72 units of Bonus 2.3MW turbines were conducted by A2SEA with a transport path of 85 miles and 80 days. The impellors of the 4 units were stacked on the board of the ship. To ensure a safe working environment, prior to installation, the company manufactured and tested an integral model of impeller bracket. 4 cranes, which were used at the top and bottom of the tower, the cabin and impeller, were used in lifting the turbine. After the 4 units had been placed, the staff immediately fastened the hoop belt. Then, the installation ship went towards the next foundation. The installation time for each turbine should not be more than one day. Under the best circumstances, the installation ship travels back and forth for 72 hours, that is, a turbine installation should be completed within 18 hours. This project was finally accomplished one month ahead of schedule. In addition, A2SEA is particularly concerned about the condition of seabed where the shipping starts and a sonar system is installed to detect the debris and other obstacles on the sea bed, which was to avoid the bottom metal sheet damage occurred in other projects.

3.2 Offshore overall installation

The overall installation is to choose an open space on the docks as the assembly site, fix the temporary support on the ground, put the tower tube into the support and use bolt to connect them, lift the upper tower tube, cabin, wheel hub and blades and complete the assembling and debugging of wind turbine on land; then, a large crane is used to lift the turbine and the temporary support on the lower part of the turbine to ship. The tugboat will tow the crane ship to the installation point and the crane ship lifts the integral turbine onto the turbine platform. After connecting the tower tube with the bolt, the temporary support can be removed. The offshore overall installation has been conducted in the construction of British Beatrice wind farm.

Two 5MW offshore wind turbines have been installed in Beatrice offshore wind power exemplary project by the overall installation method. A jacket foundation is applied with the total height of 70 meters and 43.5 meters below the water surface. The total height of the turbine is 145 meters above the water with the blade length of 63 meters. The crane ship, Rambizin, with the maximum lifting capacity of 4000tons, has been used in the overall installation. The mast with a length of 68m weights 4000 tons and the mast with a length of 82m weights 3256 tons.

The jacket foundation was built in Scottish shipyard and transported to Beatrice wind farm, horizontally placed on a barge. Upon arrival, Rambiz lifted the jacket and basic installation was conducted. In the mean time, the barge returned to Scottish shipyard for the transportation of the second jacket.

Four foundation piles were cast into the seabed through the jacket legs and a "swaging" connection method was used between the foundation pile and the jacket, instead of cement connection. Foundation pile deformed under high pressure and was attached to the casing, so that jacket was embedded in the seabed. When the first foundation was fixed, the lifting operation of the second one began. The turbines of Beatrice wind farm were constructed completely on land and lifted by Rambiz on board. The turbines have been lifted when the bottom leaves the deck. During transportation, in order to prevent vertical movement of the turbine, welding reinforcement was done on the deck mutation area. In addition, before official shipping start, a series of swing tests were conducted for the crane ship to ensure safety transportation. When the turbine was transported to the place where the jacket was placed, the crane ship had been anchored at four points and then unit lifting started. The soft-landing system was applied in the lifting of Beatrice farm. The possible impact load is collected by hydraulic cylinder and the load on the upper pulley will be passed gradually down to the jacket foundation.

Fig.4 The overall hoisting process of Beatrice wind turbines

4 Conclusions

The present paper mainly introduces the foundation form and general selection criteria of offshore wind turbines. In the meanwhile, the major methods and practical experiences are discussed on the offshore split and overall installations, respectively.

Through the analysis on the split and overall installation, some conclusions can be drawn as follows:
(1)When a few of turbines need to be installed, the following order can be carried out.

(a) In such cases, the improvement of the piling vessel is recommended and the split installation is needed.

(b) The crane ship needs to be rented for overall installation.

(2)When a large number of wind turbines need to be installed, some suggestions are made: a platform, with simple structure and lifting and piling equipments, could be built by the owner or the construction party. The piling equipment is recommended to realize 4m diameter piling function, which can fulfill the requirements of installation of the monopole foundation.

With further development of renewable resources, offshore wind power technology will achieve greater success in the future.

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