Systematic Appraisal of Offshore Wind turbine support structures

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Abstract: In present scenario, there is dearth of energy and energy resources. Wind energy has long been recognized as a potential source of renewable energy. Wind acts as a source of en-ergy from which energy can be generated with the help of wind turbines, which converts wind energy to electric energy. To meet the growing demand of renewable energy, an in-creasing number of wind turbines are being planned to be installed offshore. Because the power output of offshore wind turbines (OWT) is comparatively higher than onshore tur-bines due to the better wind speed because open sea presents a lower category of rough-ness to the free stream wind. Therefore, we install wind turbines, at the considerable dis-tance from the shore of the sea where the wind turbine is more effective. But, the installa-tion of these OWT structures requires larger support structure which poses great challenge to the offshore engineers because of high hydro-dynamic force, wave pressure, wind load and buoyant force which leads to the overturning of the structure. This paper presents the systematic appraisal of the selection of the most preferable, among the different configura-tions support structures like mono pile, tripod and jacket for offshore wind turbines. And from this encyclopaedic study of load assessment and economic assessment it is observed that suction bucket is the best available option. Although, mono pile is the most economi-cal option and less harmful to the environment, the tripod suffers less from wave-resonance than mono pile.

Keywords: Wind Turbine Supporting Structure, Offshore Structure, Monoplie, Tripod, Jacket, Suction Bucket.

Introduction

The support structure is the main component of the off-shore wind turbine that supports the wind turbine and in combination with suitable foundation transfers all the load to the sea bed and has a crucial involvement to lucrative in-stallations especially in large water depths. Offshore fixed wind turbines which mainly includes mono piles, gravity and tripod foundations are used for shallow water depth of 20-30m and for large water depth like 40-100m research work is in progress where jacket structures are commonly used in the oil and gas sector[1]. The first on shore wind turbine was installed in 1980. For establishment of the wind energy as a safe & clean source of energy on the UK's map , the first wind farm was built in 1991 at Delabole which had a total capacity of 4MW [2]. In 2006, the Beatrice wind De-monstrator farm was installed adjacent to Beatrice oil field, 25 km off the east coast of the Scotland which has two 5MW wind turbines at a total cost of 41 mil-lion[1]. Interest in wind energy throughout Europe has moved offshore be-cause of the ad-vantages provided due to unrestricted space, lower social impact and higher wind resource condi-tions, aided by further developments in research. It is esti-mated that due to low category of roughness that an addi-tional 50% of the electricity can be generated by the same turbine in offshore condition than onshore condition. Over the last few years the de-mand of the renewable energy has been increased significantly. To decrease the CO2 emissions by a minimum of 26% by 2020 and 60% by 2050, UK aims to obtain 15%of its final energy consumption from renewable sources by 2020. This fashion led to the increase in the size and power of the wind turbines. As we know that onshore wind farms are reached to their potential limits and this led to move to offshore as we go to the higher depth the wind velocity increases which in turn increases the efficiency of the offshore wind turbines [3]. It is also a vital requirement to make offshore wind turbine more eco-nomically efficient through the optimization of components such as offshore wind turbine support structures [2].As compared to on-shore wind turbines their construction cost is higher and al-so the installation of offshore wind turbines is difficult due to presence of hydrodynamic , wind and buoyancy force so a rigorous viability revision must be con-ducted in advance of construction. This paper aims to classify the available off-shore wind turbine support structures along various criteria and thus select the best amongst them.

Wind Turbine Supporting Structures

The prerequisite factors/design inputs which affect the choice of wind turbine support structures are water depth, turbine loads which are dependent on size and weight, site loads due to waves, current and tide, design, construction and installation costs, cost per unit of power generated from the completed wind farm and installation time for the same, and meteorological ocean and soil conditions. The water depth, soil properties, environmental loads such as wind, hydrodynamic loads (due to waves and currents), earth-quake loads, tidal effects, marine growth, snow and ice loads and ship impact loads are site specific[4]. The perma-nent loads include the mass of structure, mass permanent ballast and equipment, external and internal hydrostatic pressure of a permanent nature and the collective reaction to the above, i.e., articulated tower base reaction [4] and these are common to all support structures. To date, most wind turbines have been installed with monopile or gravity foun-dations in shallow water, and these solutions may be stretched to deeper water and larger wind turbines[5]. The classification of offshore wind turbine supporting structures is shown in figure 1.

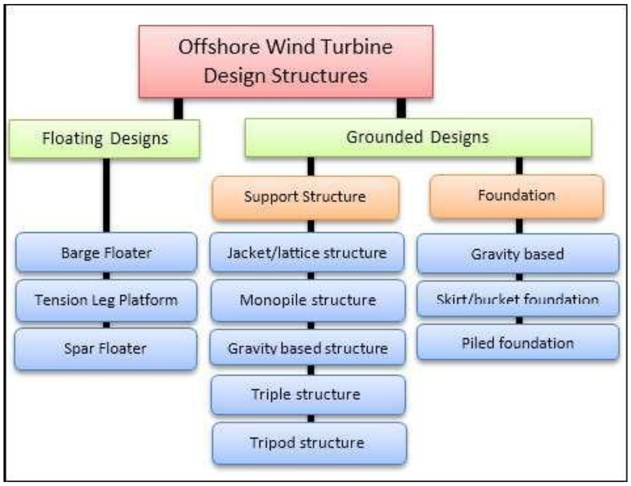

Figure.1 Classification of Offshore Wind turbine supporting structures[6]

Monopile is a simple design, the foundation of which consists of a tubular structure that extends into the seabed; it is used for installations at water depths of up to 25 m. The de-tails of a monopile structure are shown in figure 2

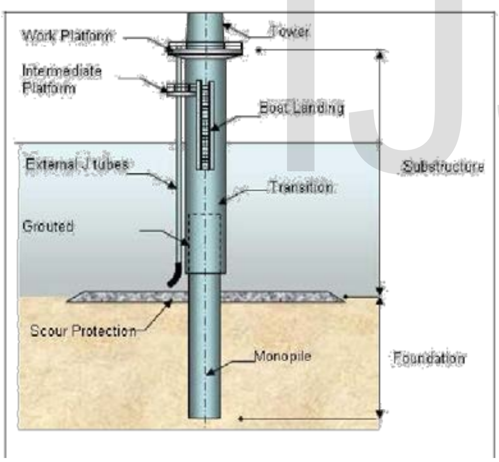

Figure 2. Details of monopile[6]

The advantages of the monopile are easy fabrication, easy installation, low construction risks up to 5m and proven support. The vertical loads are transferred to the seabed by shaft friction and tip resistance. The main parameters of the monopile are the diameter and the thickness of the wall and the ratio between them. Increase of this ratio results in a lighter construction, but buckling risk imposes a limit [5]. If the buckling check is satisfied, the wall thickness may be optimized until the final wall thickness is found. If not, the wall thickness is increased and the buckling check repeated. The vertical bearing ca-pacity is therefore largely determined by the diameter of the mono pile, which influences the horizontal loads due to wind, waves and current. These horizontal loads will be trans-ferred to the soil by bending moments. The passive soil resistance should therefore be large enough, which can be reached by a large pile diameter, influencing the horizontal and vertical forces again. In general, the horizontal forces on wind turbines will be much larger compared to topsides of oil- and gas platforms[4]. If a monopile support structure is placed in deeper water, hydrodynamic loads and bending moments at the seabed increase, and the dynamic behaviour of the structure changes. The designs will sub- sequently be subjected to buckling checks for a single location at the mud line. The design procedure is depicted in the flow chart given below Based on the environmental data and the rotor diameter the design levels are determined. Using the turbine properties and a wave spectrum that is representative for fatigue, the allowable natural frequency band can be determined. Based on this allowable frequency band a target natural frequency is set. Subsequently, the diameter and the wall thickness of the support structure are chosen such that the target frequency is attained. This is an iterative process in which a set ratio between the diameter and the wall thickness is maintained. The diameter, having the largest effect on the natural frequency, is varied until the desired natural frequency is obtained. With the geometry known, the extreme loads can be determined. The extreme loads are due to wind, wave and current loads. Usually a combination of an extreme wind speed and a reduced maximum wave height or a reduced wind speed and an extreme wave height is applied. Conservatively, the maximum wind speed, current and wave height can be combined. Using the thus determined loads, the penetration depth can be determined[7]. The flow chart for the design discussed above is given in figure 3.

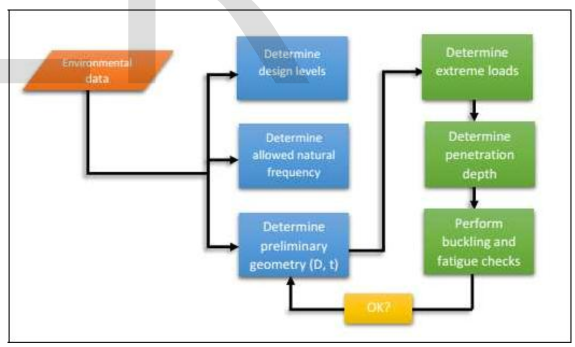

Figure 3. Flow chart for design process of monopole

Tripod

Tripod is a three-leg support structure made of cylindrical steel tubes and is used for instal-lations at water depths between 25 and 50 m. The details of tripod are given in figure 4. The main advantages of the tripod support structures compared to the mono pile are a lar-ger base, shallower foundation pile requirement and requirement of less scour. The disad-vantages of using the tripod foundation compared to the mono pile are the design of the complex joint which is required to connect the three legs to the upper mono pile, the direc-tionality of wind and waves which needs to be taken into account in the design stage, the joint between the three legs is highly susceptible to fatigue and the transportation is more difficult because the tripod requires more space on deck [4].

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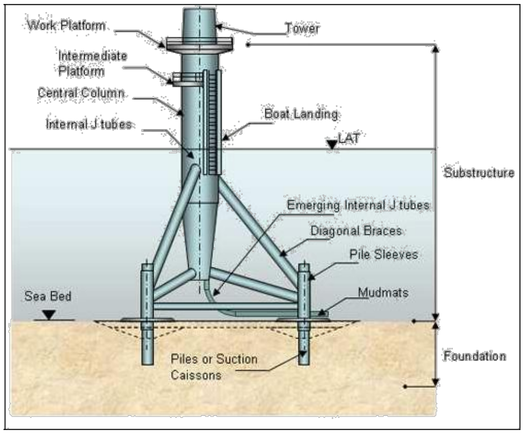

Figure 4. Details of Tripod[6]

Jacket

Jacket is a (usually) four-legged structure made of cylindrical steel tubes and, as with the tripod, is used for installations at water depths between 25 and 50 m.

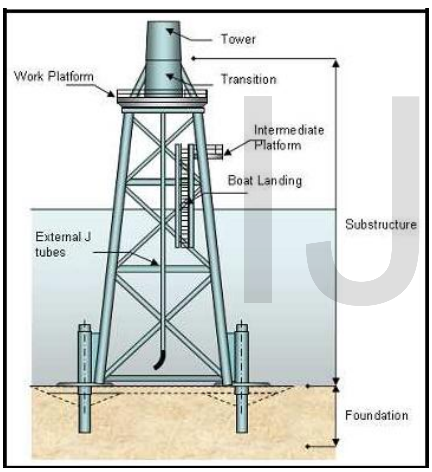

Figure 5. Details of Jacket Truss[6]

It consists of a welded tubular space frame with three or more legs. The forces are trans-ferred to the seabed by axial forces in the members. The advantages of adopting a jacket support are a larger base, light and efficient frame and hence, construction, and extra stiffness with respect to the monopile. The disadvantages are the extra effort along with the costs involved in the node design of every truss and the cumbersome tendency of transpor-tation for trusses. There are mostly two variations of the jacket structure used, the three leg type and the four leg type. The four legged jacket structure is preferred over the three legged one, however there is a less requirement of material in the design and construction of the three legged variation. On the other hand, a three legged jacket needs some extra detailing work because the angle between the legs becomes smaller and the joints gets more difficult in the context of design, construction and maintenance. The connection can therefore be made above water, which makes it easier and better accessible for mainte-nance. The piles need to be very long, even when a relatively small jacket is considered. For instance for a water depth of 45 meters, the jacket will be up to 60 or 70 meters long, requiring piles of even 100 meter. The pile sections have to be welded offshore, resulting in less welding quality, making this an uneconomical choice.[4]

Bucket

This is a recent development in the arena of offshore wind support structures and is today used for a Vestas V90-3.0 MW offshore wind turbines as a prototype. This offshore wind turbine was erected in November 2002, next to the harbour of Frederikshavn, Denmark. It is a new development and an innovative foundation solution with great potential and advantageous in the context of being economically /environmentally sound construction for offshore wind turbines considering a life cycle analysis, i.e., the structure has no adverse environment effects nor is economically damaging on a cost basis throughout its life. Comparing the bucket foundation to the suction caisson, the only thing they have in common is that they are installed in the same fashion. Both of them use suction as the driving force during installation. The lowering of the pressure in the cavity between the bucket and the soil surface causes a water flow to be generated, which again reduces the effective stresses around the tip of the skirt and consequently, the penetration resistance is re-duced[8]. The flow chart regarding the design of a bucket support structure is given in fig-ure 6.

Suction Bucket

There are two basic requirements for the suction buckets: installation has to be possible with the achievable hydrostatic force and resistance to operational loads has to be suffi-cient. The main dimensions that can be varied are the bucket diameter and penetration depth.[5]. The advantages are the reduction of magnitude of loads during wave loading and requirement of less application of driving forces. The disadvantage is the uncertainty of stability due to its dependency on external geotechnical factors[8].

Comparision among the different wind turbine supporting structures

Based on the above study we can draw inferences in context of various factors. For exam-ple with respect to depth, constructions in shallow waters favour monopile while jacket structures are the best option for deep waters. Of course, bucket and suction bucket types are applicable across all ranges (Table 1).

Type of support structure	Typical depths of installation (m)
Monopile	~35
Tripod	25 to 50
Jacket	25 to 70
Bucket	No set limit
Suction bucket	No set limit

Table 1. Typical installation depths of different support structure [4],[9]

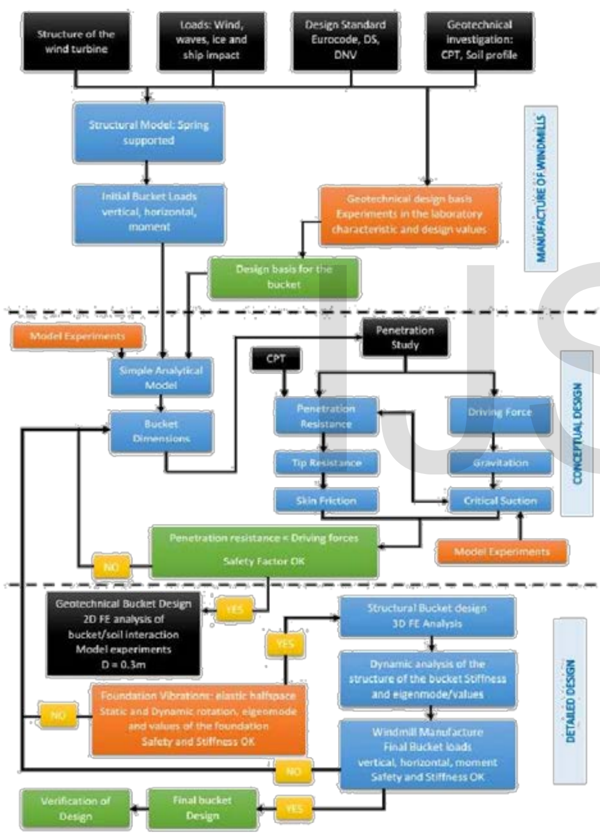

Figure 6. Flow chart on design process of bucket structure[8]

If we analyse the available options on a cost basis, monopile is the most economical with the tripod coming a close second, while jackets and suction buckets are the less economi-cally viable options. From the stability point of view, the monopile is the weakest, suscep-tible to buckling while jacket trusses and tripod are the most rigid and less vulnerable to extreme load conditions. The bucket and suction designs are susceptible to external geo-technical factors such as the negative pore pressure required during the driving process. Design wise, the monopile is the easiest to design with the tripod being the next one. How-ever the design of jackets, bucket and suction buckets is an iterative process, taking into account many and varied factors, thereby becoming time consuming and labour intensive. With respect to the transportation and installation constraints, the monopile and the suction bucket are easier to install while the tripod and jacket pose problems and risks installation and transportation.

Conclusion

In this study we attempted to and successfully verified all the characteristics of the differ-ent kinds of offshore wind turbine support structures while learning about their develop-ment and the examples of usage throughout the preceding years. We also identified their respective advantages and disadvantages thus giving us an overview and comparison between these options and thus making it easier and simpler to choose based on different site scenarios. Hence we find out that monopiles are best at shallow depths and the most economical while being easy to install and maintain. Jackets and tripods are the most stable choices and have a long life cycle. However above all of these, the suction bucket adheres to all depths is the easiest to customize and even easier to install.

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