IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

CHALLENGES IN THE DESIGN OF OFFSHORE WIND TURBINE FOUNDATIONS

Mr.Vishnu A.J
B tech Student
Musaliar College of Engineering

INTRODUCTION:

High quality wind resources, less negative impact on aesthetics of the landscape and ease of transportation and installation are some of the advantages of offshore wind farms over wind farm projects on land. Furthermore, wind turbines are designed to take advantage of the steady wind speed prevalent over the ocean thus enabling higher utilization rate for offshore wind energy generation capacity. More than 66 percentage of offshore wind in the United States (U.S.) is in high wind power density. The National Renewable Energy Laboratory (NREL) estimates that the U.S. has 4,200 Giga Watts of developable offshore wind potential. Despite these attributes, there are no offshore wind farms in the U.S. Offshore wind projects have grown steadily in Europe and Asia, with Europe accounting for 90 percentages of the roughly 8.8 Giga Watts (GW) global offshore wind turbine capacities. The challenges of offshore wind energy projects include, significantly high support structure cost, high Operating and Maintenance (O&M) costs, high electrical infrastructure costs, high turbine costs, stricter environmental standards, and less developed construction techniques.

NEED OF THE STUDY:

With the growing energy needs of the world and the sustainable nature of wind energy this sector is a highly innovative growth industry. The past years have seen the industry develop and test not only more efficient, but also much larger wind turbines than those that are in current use. The next generation of wind turbines that are on the drawing boards are gigantic in size. These huge dimensions of the proposed wind turbines will put large demands on the foundations. As an increasing number of wind farms are being planned offshore in water depths of over 40 m, the combination of water depth and the increased windmilltower.

Heights and rotor blade diameters create loads that make foundation design very complex. Moreover, offshore foundations are exposed to additional loads such as ocean currents, storm wave loading, ice loads and potential ship impact loads. All of these factors pose significant challenges in the design and construction of wind turbine foundations.

LITERATURE REVIEW:

Hongwang Ma,Jun Yang and Longzhu Chen(2019) : Scour has a minor effect on the natural frequency of the tripod supported wind turbine but can significantly increase the maximum cross sectional von mises stress of piles under the ULS and increase the deflection of piles nearly 20m below the original seabed under the SLS. As for the fatigue life of the tripod structure, it can also be reduced by the effect of scour.

Jiale Li, yong Zhang, Xuefei Wang and Zizheng Sun(2021) : In offshore applications, the larger lateral resistances than the open ended pile foundation. The rotation axis is located at 80%of the embedded depth, and distribution of earth pressure is determined.

Zhiyu Jiang(2021) : Technical aspects of offshore wind turbine and various installation methods and concepts for bottom fixed and floating wind turbines are critically discussed.

Xiamoi Wu, Yu Hu, Jian Yang and Lei Duan(2020) : The present state of knowledge concerning geo technical and structural issues affecting foundation.

IMPORTANCEOF FOUNDATION DESIGN:

Foundation selection plays an important role in the overall concept design for offshore wind farms as there are large financial implications attachedto the choices made Typically, foundations costs25 to 34% of the overall costs. For the NorthHoyle project the cost of foundation was 34%,Carter (2007) and it has been reported that development of Atlantic Array wind farm did not go ahead and one of the main reason is the expensive foundation. Foundations for wind turbines can be classified into two main types: fixed (or grounded to the seabed) and floating. Different types of foundations are shown in figure 1.

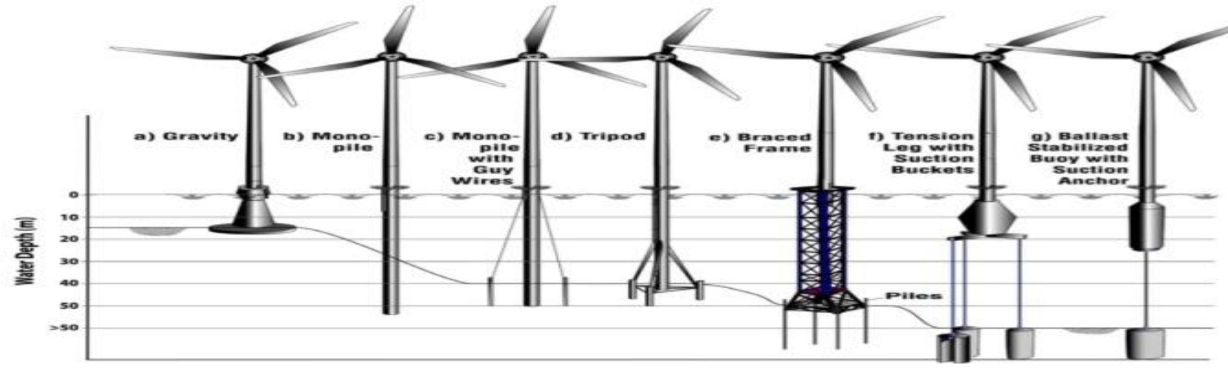

Figure 1:different type foundations

TYPES AND NATURE OF THE LOADS ACTING ON THE FOUNDATIONS:

Offshore wind turbines, due to their shape and form (i.e., along slender column with a heavy mass as well as a rotating mass at the top) are dynamically sensitive because the natural frequency of these slender structures are very close to the excitation frequencies imposed by the environmental and mechanical loads. Figure 4 shows a simple mechanical model of the whole system showing the different components and the design variables. In the model of whole system showing the different components and the design variables. In the model, the foundation is replaced by 4 springs: KL(lateral spring), KR(Rocking spring), KV(Vertical spring) and KLR(Cross-coupling spring). It is therefore clear that the stability and deformation of the system is very much dependent on these 4 springs.

Few things may be noted regarding the spring:

a) The properties and shape of the springs (load-deformation characteristics) should be such that the whole structure should not collapse under the action of extreme loads and the deformation is acceptable under the working loads;

b) The values of the spring (stiffness of the foundation) are necessary to compute the natural period of the whole structure as this is linear Eigen value analysis.

c) The values of the springs will also dictate the overall dynamic stability of the system due to its non-linear nature.

CHALLENGES IN ANALYSIS OF DYNAMIC SOIL STRUCTURE INTERACTION:

Offshore wind turbines are new types of offshore structures and are unique in their features. The most important difference with respect to oil and gas installation structures is that they are dynamically sensitive and moment-resisting. Figure 6 shows a typical Monopile supported wind turbine and a pile supported fixed offshore jacket structure. There are, however, obvious differences between those two types of foundations. Piles for offshore structures are typically 60-110 m long and 1.8-2.7 m diameter and monopiles for offshore wind turbines commonly 30-40 m long and 3.5-6 m diameter. Degradation in the upper soil layers resulting from cyclic loading is less severe for offshore piles which are significantly restrained from pile head rotation, whereas monopiles are free-headed. The commonly used design method using a beam on non-linear Winkler springs may be used to obtain pile head deflection under cyclic loading, but its use is limited for wind turbines because:

(a) The widely used API model is calibrated against response to a small number of cycles (maximum 200 cycles) for offshore fixed platform applications. In contrast, for a real offshore wind turbine 107-108 cycles of loading are expected over a lifetime of 20-25 years.

(b) Under cyclic loading, the API or DNV model always predicts degradation of foundation stiffness in sandy soil.

(c) The ratio of horizontal load (P) to vertical load(V) is very high in offshore wind turbines when compared with fixed jacket structures.

While, offshore wind turbine structures are designed for an intended life of 25 to 30 years, but little is known about their long term dynamic behaviour under millions of cycles of loading. While monitoring of existing offshore wind turbine installation is a possibility and can be achieved at a reasonable cost, full scale testing is very expensive.

An alternative method is to carry out a carefully planned scaled dynamic testing to understand the scaling/similitude relationships which can be later used for interpretation of the experimental data and also for scaling up the results to real prototypes. There are mainly two approaches to scale up the model test results to prototype consequences: first is to use standard tables for scaling and multiply the model observations by the scale factor to predict the prototype response and the alternative is to study the underlying mechanics/physics of the problem based on the model tests recognising that not all the interaction can be scaled accurately in a particular test. Once the mechanics/physics of the problem are understood, the prototype response can be predicted through analytical and/or numerical modelling in which the physics/mechanics discovered will be implemented in a suitable way. The second approach is particularly useful to study the dynamics of

offshore wind turbines as it involves complex dynamic wind-wave-foundation-structure interaction and none of the physical modelling techniques can simultaneously satisfy all the interactions to the appropriate scale. Ideally, a wind tunnel combined with a wave tank on a geotechnical centrifuge would serve the purpose but this is unfortunately not feasible. It is recognised that not all physical mechanisms can be modelled adequately and therefore those need special consideration while interpreting the test results. As dynamic soil structure interaction of wind turbines are being studied, stiffness of the system is a top priority.

(a) The change in natural frequencies of the wind turbine system may be affected by the choice of foundation system i.e. Deep foundation or multiple pods on shallow foundations. Deep foundations such as monopiles will exhibit sway-bending mode i.e. the first two vibration modes are widely spaced - typical ratio is 4 to 5. However multiple pod foundations supported on shallow foundations (such as tetrapod or tripod on suction caisson) will exhibit rocking modes in two principle planes (which are of course orthogonal).

(b) The natural frequencies of wind turbine systems change with repeated cyclic/dynamic loading. In the case of strain-hardening site (such as loose to medium dense sandy site) the natural frequency is expected to increase and for strain-softening site (such as normally consolidated clay) the natural frequency will decrease.

FOUNDATION DESIGN:

While design guidelines are available for offshore oil and gas installation foundations, its direct extrapolation/ interpolation to offshore wind turbine foundation design is not always possible, the reasons of which is explored in the earlier section. There are two reasons: (a) The foundations of these structures are moment resisting i.e. large overturning moments at the foundation which are disproportionately higher that the vertical load; (b) The structure is dynamically sensitive and therefore fatigue is a design driver. This section therefore explores a simplified foundation design methodology which may be used during option engineering or preliminary design.

- Compute the maximum mud line bending moment considering the different load combinations. The overturning moments due to 1P (misalignment) and 3P (blade shadowing) may be neglected in this step.
- Based on the allowable tilt criteria for the particular project- determine the foundation stiffness required . This is the minimum stiffness that is required to satisfy the SLS.
- It is then required to check the ULS criteria i.e. the foundation capacity. If the foundation is not adequate, the size must be increased.
- The soil surrounding the foundations will be subjected to tens of millions of cycles of cyclic and dynamic loading of varying strain as well as varying frequency. It must be ensured that the soil remains in the linear elastic range so as not to alter the dynamic stiffness of the foundation.
- Beam on Non-linear Winkler Model or Finite Element Analysis can be carried out and it must be ensured that the p-y curves in soil are within the linear elastic section at all depths. However, 3D Finite Element Analyses are recommended to understand the strains around the foundation.
- It is now required to obtain stiffness of the foundation to calculate natural frequency of the whole system to check where the overall system is placed: soft-soft, soft-stiff or stiff-stiff. If the natural frequency is not acceptable, the design parameters such as foundation stiffness, tower stiffness and mass may be altered so that the desired frequency is obtained. This is an iterative process.
- The foundation stiffness may change over the life time of the wind turbine due to soil structure interaction which will have an impact on the natural frequency of the system and tilt. If the ground is sandy site the natural frequency to expected to increase and if it is a clay site the natural frequency may decrease. If the site is layered, the change in natural frequency cannot be ascertained a priory and depends on various factors including the geometry of layering.

CONSTRUCTION CHALLENGES:

Transition piece assembly: Transition piece have to be precoated using a heavy duty protective epoxy coating which increases costTransportation: Larger diameter monopiles can't be transported to the site on barges, they have to be floated to the site. Piles, and turbine and foundation should be transported in horizontal / vertical orientation. A small tilt often causes the complete failure of the system.Erection: Jack up rig serves fairly stable platform for tower system installation. But its inherent stability brings with it a lack of manoeuvrability during installation. Ship shaped vessels and flat bottom barges are most commonly available but provide least constructional stability.

CHALLENGES AFTERCONSTRUCTON:

1. Fatigue of joints
2. Corrosion
3. Scour potential
4. Protection for marine growth
5. Mud mat formation

OTHER CHALLENGES:

Environmental issues such as permitting process, siting and impact on marine wildlife are more stringent and expensive for offshore wind farm developments.

Abundant natural gas presents challenges for wind energy. The U.S. is presently experiencing low natural gas prices due to high production of gas from shale deposits. Availability of energy incentive such as the Production Tax Credit (PTC) may affect costs. High risk of offshore investment - Risk areas that may affect investing in offshore wind projects include the complexities of constructing in the deep sea, uncertainty surrounding wind resource availability, and high capital costs, contractor's track record.

HOW TO OVER COME THE CHALLENGES:

RESEARCH AND DEVELOPMENT:

Foundations- By introducing new technologies and through optimization of the existing technologies and design methods, costs of foundations can be reduced. The foundations currently employed commercially for offshore wind farms are shown in Figure 7. As shown, the Monopile is the most common foundation concept due to its robust design, mass fabrication and ease of installation. However, its application is mostly suited for shallow waters. Since many new offshore farms will be in deep waters, application of Monopile foundation will be quite expensive. The current design can only support 6 megawatts (MW) wind turbine for water depth of 35m. Research and development efforts have shown that jacket type structures supported on piles are better suited for deep water applications and may be more economically viable. In addition, since the Monopile has a high degree of standardization and productivity in the supply chain, the current design can be optimized and made cheaper and technically efficient by varying its geometric parameters such as length, diameter and thickness hence its weight. The diameter is governed by the fundamental frequency of the turbine and thickness is governed by fatigue loads and shell buckling. Research work should also consider optimization under fatigue load especially in welded attachments of the shell.

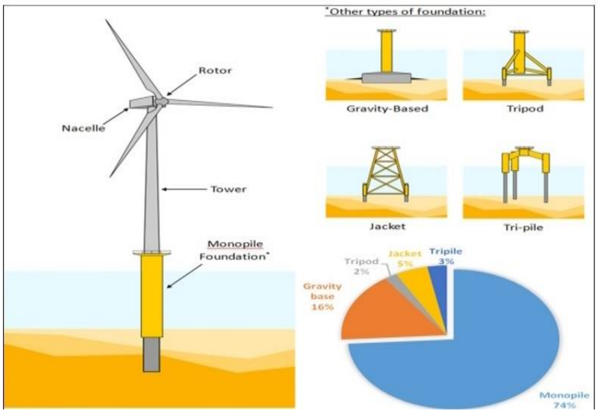

Fig 2 : offshore wind turbine foundation types

INSTALLATION AND CONSTRUCTION TECHNIQUES:

Traditional approach for installation of offshore projects is pile driving. A new approach that can reduce installation time and cost is the Mono Bucket foundation concept . It can be installed in a variety of site conditions such as sand, silt, clay and mixed strata for water depths of up to 55m and does not require seabed preparation. It consists of a large Monopile welded to the top of a single giant suction bucket. It is installed by using a jet suction system as a driving force. This lowers the pressure in the cavity between the foundation and the seabed generating water flow and lowering the resistance around the edge of the foundation skirt for ease of penetration as shown in Figure 8. A jetting system controls the vertical alignment ensuring the foundation is installed with tolerances. State of the art equipment for offshore foundation construction is the Suction jacket by Geotherm. It has three legs welded together forming a jacket structure attached to three giant suction buckets that is anchored to the foundation. It reduces foundation time and installation thus lowering costs.

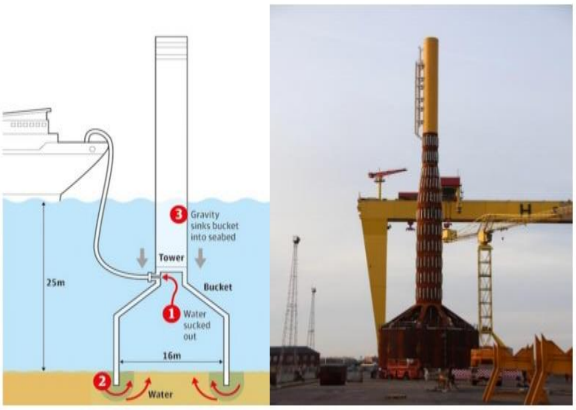

Fig.4 : Schematic diagram of mono bucket

a) Turbine installation procedure – the rotor and the tower would be pre-assembled in port before shipment for offshore installation so that only one single offshore lift will be necessary installation.

b) Use of improved crew transfer system – This will reduce waiting time caused by weather conditions.

c) Mother vessel accommodation – A mother vessel is located close to the wind plant from which workboats can be launched with average traveltime of 30 minutes for repair work and transfer of personnel for the turbine.

d) This system provides the benefit of reduced travel time to the wind plant for minor repairs and inspection.

RESEARCH AND EDUCATIONAL APPROACH:

Environmental Issues- Permitting for offshore wind farm takes between 6 to 8 years. It is difficult for investors to get financing for a project that takes such a long time. However, comprehensive research study conducted by [8] will provide valuable educational tool to regulators, researchers, developers, resource managers and developers to adjust requirements for offshore wind siting and permitting processes and provide a better understanding of natural resource management and conservation efforts. Studies conducted on the Outer Continental Shelf waters of the Mid Atlantic coast involved using various technologies and methods to monitor and analyse wildlife distribution patterns. Boat-based surveys are used to monitor behavioural data of dolphins and seabirds. State-of-the-art video aerial surveys flown at high altitudes are used to monitor and collect data on marine animals. Tracking techniques which involve attaching satellite transmitters to various birds also provided valuable information in this study. Offshore wildlife migration timing and pathways are monitored and recorded using weather surveillance radar. This study provides a comprehensive data on wildlife distribution across the Mid-Atlantic coast. Thus, through engineering education and increased public awareness, barriers to offshore wind power deployment can be removed and permitting and siting procedures minimized.Environmental management decisions can be easily made by stakeholders such as government agencies, developers and environmental consultants. High risks of offshore wind investments - Risk areas that may affect investing in offshore wind projects include the complexities of constructing in the deep sea, uncertainty surrounding wind resource availability, and high capital costs, contractor's track record. To mitigate these risks, adequate considerations should be given to various foundation technologies currently available such as tripods, jackets and extra-large monopiles.

CONCLUSION:

Offshore Wind Turbines are new types of offshore structure characterised by low stiffness (as a result flexible and having low natural frequency) and therefore sensitive to the dynamic loading imposed upon them. It has been shown that design guidelines available for offshore oil and gas installation foundations cannot be direct extrapolated/ interpolated to offshore wind turbine foundation design. Challenges and risks to offshore wind projects can be mitigated through research on improved wind turbine concepts, design and fabrication of substructures and new offshore to grid connection techniques. In order for engineers graduating from higher institutions to have a good understanding of sustainable engineering, a curriculum transformation through engineering education is imperative. This will help the society to focus on sustainable development and policy makers can draw investors' awareness to the benefits of wind energy investments.

REFERENCES

[1] Ben He, Shaoli Yang and Hendrik Sturm (2020): Case studies on suction caisson foundations in offshore wind farms in China, International Journal Of Geotechnical Engineering.

[2] Hongwang Ma , Jun Yang , Longzhu Chen (2018): Effect of scour on the structural response of an offshore wind turbine supported on tripod foundation

[3] Jiale Li , Yong Zhang , Xuefei Wang , Zizheng Sun(2021): Assessment of offshore wind turbine with an innovative monopile foundation under lateral loading.

[4] Lei Duan Jian Yang , Yu Hu and Xiamoi Wu (2019): Foundation of offshore wind turbines.

[5] Subhamoy Bhattacharya (2020): "Challenges in design of foundation for offshore wind turbine," *Indaian Institute of Engineering and Technology*.

[6] Zhiyu Jiang (2021): Installation of offshore wind turbines.

[7]https://images.app.goo.gl/UWvHSALAmRAN7ZPg9.

[8]https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.power.jpg

[9]https://www.google.com/imgres?imgurl=https%3A%2F%2Fars.els-cm%2Fcgs2.0-S0141029613004537-gr1.jpg