Offshore wind turbine design using site data

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Wind turbines are always designed to withstand fatigue and ultimate loading. The design standards for the offshore wind conditions are the same as the onshore wind conditions. However, advances in this field of research have shown that it is not entirely true [1]. Especially, the thermal effects may have an influence on the wind conditions due to low mechanical turbulence offshore as compared to the conditions onshore. Moreover the land sea interaction can also alter the normal wind conditions. These alterations may affect the loading on the turbines, which are otherwise not taken into consideration in the normal design standards. Under the scope of this PhD research, different offshore wind conditions would be investigated and its impact on the design of wind turbines would be investigated. This research would enable us to better understand the need of having a specific design for the offshore wind turbines, contrary to what is mentioned in the current standards for the rotor nacelle assembly. It will give us more confidence in the design process. Moreover as the size of the turbines goes on increasing the atmospheric dynamics would be different from what the current wind turbines experience. Thus it will also give a good understanding of the problems that the future offshore wind turbines may encounter. Thus the product of this research would be to provide guidelines for the design of offshore wind turbines at specific offshore sites. The reference wind farm for this research would be Egmond aan zee, which is the first Dutch offshore wind farm in The Netherlands. Simulations would be carried out in design software 'Bladed', developed by Garrad Hassan Ltd. The simulation results would be compared to the load measurements at Egmond aan zee wind farm. The wind farm consists of Vestas V 90 3MW wind turbines. The results would provide an insight into the validity of the models used for different offshore wind conditions. Some of the research areas for this PhD research are elaborated further.

Influence of atmospheric stability on the design on wind turbines

There are basically two mechanisms for the generation of turbulence. One is due to the friction at the surface of the earth and the other is due to the thermal influences. Thermally generated turbulence is due to the buoyancy effects in the atmosphere and is classified in terms of stability parameters. There are basically 3 classes of stability, viz. stable, neutral and unstable. When the air below is colder than the air above it, it results in the suppression of turbulence due to the density differences between the two layers of air and the condition in the atmosphere is called as stable condition. When the entire layer of atmosphere has the same temperature then the condition is called as neutral stability. Unstable condition results in the enhancement of the turbulence because the air below is warmer than the air above it. Hence, the colder air will displace the air below it resulting in the generation of turbulence. At onshore sites the friction at the surface of the earth is quite predominant due to the topology of the earth surface and the constructions by human as compared to the thermal effects. On the contrary at offshore sites there is less mechanical turbulence as compared to the onshore sites and hence during certain periods the thermal effects have an influence over the mechanically generated turbulence. The thermal effects have an influence on the wind shear, which is one of the design drivers for wind turbines. The models that are used for wind shear are either logarithmic or exponential law. The exponential law is derived empirically whereas the logarithmic law is derived from the laws of physics. Both laws do not take into account the stability effects in the atmosphere as neutral conditions is assumed all the time. However the logarithmic law provides an opportunity to incorporate the stability effects using the Bussinger–Dyer formulation for different stability classes. The impact of stability on the wind shear is such that for stable conditions, there is a greater velocity difference at different heights than predicted by the logarithmic or the exponential law. On the other hand for unstable conditions the difference is smaller than predicted by the already existing models. This can have a significant impact on the fatigue damage of the wind turbines. Also, as the size of the wind turbines is increasing there is a possibility that the turbines operate beyond the surface layer. However the logarithmic law is only applicable to the surface layer. Recently, research has been carried out to develop a new equation for the wind shear which takes into account the height of the atmospheric boundary layer [4]. This equation applies to areas having a flat surface. Since the sea conditions represent very closely to the flat conditions onshore this equation can be used for offshore conditions too. Thus the following equations would be used to analyze the influence of different wind profiles on the fatigue damage of wind turbines:

1. Exponential law
2. Logarithmic law without stability effects
3. Logarithmic law with the stability effects
4. Logarithmic law with stability effects and height of the boundary layer
5. Logarithmic law using varying sea surface roughness

Preliminary simulations were run on an example turbine taking into account the stability effects and using the logarithmic law. Typical values were used to estimate the Obukhov length [1], [2] and [3]. Fatigue damage was estimated and the differences in the fatigue damage at two different sites were compared. The preliminary results show that stability effects are important for the fatigue damage on wind turbines. Hence, it would be interesting to investigate the stability effects on the fatigue damage using the real values from the site.

Influence of land sea transition on the design of wind turbines

Due to the large differences in heat capacity and conduction between land and water, the air over land will often be warmer than the sea surface temperature. Warm air is advected over the colder sea especially at daytime, when the land is heated by the sun, and in early spring, when the water temperature is still low from winter. Large temperature differences between the advected air and the sea surface can occur. When warm air is blown over the cold sea, a stable stratification develops immediately as the air adjacent to the sea surface will be cooled. Simultaneously, an internal boundary layer develops at the shoreline due to the roughness and heat flux changes. In the case when warm air advects over a cold sea, a stable internal boundary layer (SIBL) emerges, characterized by low turbulence and therefore small fluxes and slow growth. The warm air is cooled from below while the sea surface temperature almost remains constant due to the large heat capacity of water. Eventually, the air close to the sea surface will have the same temperature as the water and the atmospheric stability will be close to neutral at low heights. Above the internal boundary layer the air still has the temperature of the air over land, and near the top of the SIBL an inversion lid has developed with strongly stable stratification separating these two regions. Thus, while the stability in the mixed layer is close to neutral, the elevated stable layer influences the wind speed profile and leads to a larger wind speed gradient than expected for an ordinary near neutral condition. The quantification of this coastal effect is done in terms of the inversion height, which is developed by Csanady [5]. Using the inversion height a simple correction factor is introduced in the equation for wind profile, which takes into account the coastal effect. This wind profile would be used to carry out the load calculations on the turbine and compared with load calculations obtained from the standard models.

Influence of wind farms on atmospheric boundary layer

As the size of the offshore wind farms increase, the turbulence generated in the wake of turbines also increase. The wakes travel a certain distance and it may alter the local meteorology, which in turn may affect the surface layer of the atmospheric boundary layer. Studies have been carried out to assess the impact of large wind farms on local meteorology [6]. The studies show that the heat flux and the moisture flux is reduced due to the turbulence in wakes. On the other hand the mean wind velocity may also get reduced due to the effect of the wakes. This may affect the design strategy of the turbines in the near vicinity of a large wind farm. The most important assessment for such a study is to check for how long the wakes from the wind farm persist and how much is the reduction in the mean velocity. Similarly the thermal stratifications in the wakes of wind turbines could affect the loading on the wind turbines operating in wakes. The turbulence wakes are usually modeled using the Reynolds averaged navier stokes equation with some closure model. Research has already shown that an improved k-ε model improves the accuracy of predicting the power output for thermally stratified flow in the wakes of the wind turbines [7]. The wake velocity defect is important for the stable conditions as compared to the unstable conditions as they induce a significant variation in the characteristics of the flow downstream of a wind turbine. This could in turn affect the loading of the wind turbines and may influence the design strategy of the turbines operating in wakes.

Site specific design of wind turbines

A site specific design of wind turbines is only useful if the wind conditions at different sites differ considerably from one another [8]. Wind turbines are designed using the generalized external conditions for the rotor nacelle assembly. Therefore the research is being carried out to identify the specific external conditions for offshore wind turbines. However, even then the generalization of offshore wind conditions would have to be tested for its accuracy and it may not be applicable for all offshore sites. An entire set of data would be used to check for different load cases. For e.g. the wind shear would be derived from the measurements of the 10 min average wind speed at different heights. At Egmond aan Zee it is being measured at 3 heights. An interpolation scheme would be used to get the wind speeds at the remaining heights. Similarly, the turbulence characteristics would be derived from the measurements. Standard turbulence spectrum would be compared with that obtained from the measurements. The spectrum from the measurements would be used for the turbulence input. It is not possible to derive the extreme wind parameters from the measurements for a short period of time. Hence, models will be used to derive the extreme wind parameters. A full scale load calculation would be carried using the data of the normal wind conditions from the site. The validation would be made using the load measurements on the turbines at the site. Besides this, it would also be worthwhile to check if the differences in the wind conditions at different sites affect the loading of the wind turbines and hence change its cost. Data would be obtained for various sites from different databases and a loading calculation would be carried out for the same turbine operating in different conditions. A comparison would be made to identify if the specific conditions lead to a substantial difference in the loading of wind turbines. The purpose of this research is to understand if the data that is usually gathered at the site can be of any use in the design process.

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