WIND TURBINE DESIGN

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ABSTRACT

This paper deals with main design of wind turbine concerning with structure of wind turbines, option between vertical and horizontal axis wind turbines to optimising count of rotor blades

1. INTRODUCTION

Design of wind turbine structures requires a broad spectrum of external load situations to be addressed including both *ultimate*- and *fatigue* type of loading. With the trend of turbines growing in size, the importance of ultimate loading seems relatively to increase.

The fatigue load analysis requires wind load components of both *periodic deterministic* and *stochastic* character to be considered. The wind contribution to the periodic deterministic load component basically arises from (horizontal/vertical) mean wind field shear (and yaw errors).

Contrary to onshore sites, the surface roughness, and thus the wind shear, associated with offshore sites depends on the mean wind speed through the wave characteristics. The stochastic wind loading, caused by turbulence, is traditionally being modeled by means of synthetic stochastic wind fields with prescribed turbulence characteristics. Gaussian statistics is conventionally assumed for simple terrain categories, whereas non-Gaussian statistics may be required for more complex types of terrain. In addition to traditional turbulence loading, caused by the "undisturbed" turbulence in the atmospheric boundary layer, the stochastic loading in wind farms, caused by meandering wakes, possesses a particular challenge.

The extreme loading to be considered in an ultimate limit state analyses of a wind turbine structure may result from a variety of extreme load events, among which are the *extreme wind events*. Extreme wind events include peak (mean) wind speeds (typically imposed on a wind turbine during stand-still) as well as peak (short term) changes in wind speed, wind direction and wind shear (typically to be imposed on a wind turbine during normal operation). In analogy with the fatigue load case, the extreme loading of stand-alone turbines usually differ from the extreme loading imposed on turbines situated in wind farms.

2. EXTREME LOADS (Forces)

Fig.1 Comodoro Rivadavia, Argentina (NEG Micon 750 kW turbines) [1]

Wind turbines are built to catch the wind's kinetic (motion) energy. You may therefore wonder why modern wind turbines are not built with a lot of rotor blades, like the old "Dutch" windmills. Turbines with **many** blades or very **wide** blades, i.e. turbines with a very **solid** rotor, however, will be subject to very large forces, when the wind blows at a hurricane speed. Wind turbine manufacturers have to certify that their turbines are built, so that they can withstand **extreme winds** which occur, say, during 10 minutes once every 50 years. To limit the influence of the extreme winds turbine manufacturers therefore generally prefer to build turbines with a few, long, narrow blades. In order to make up for the narrowness of the blades facing the wind, turbine manufacturers prefer to let the turbines rotate relatively quickly. [1]

3. FATIGUE LOADS (Forces)

Wind turbines are subject to fluctuating winds, and hence fluctuating forces. This is particularly the case if they are located in a very turbulent wind climate. Components, which are subject to repeated bending, such as rotor blades, may eventually develop cracks, which ultimately may make the component’s break. Metal **fatigue** is a well-known problem in many industries. Metal is therefore generally not favoured as a material for rotor blades. When designing a wind turbine it is extremely important to calculate in advance how the different components will vibrate, both individually, and jointly. It is also important to calculate the forces involved in each bending or stretching of a component. This is the subject of **structural dynamics**, where physicists have developed mathematical computer models that analyse the behaviour of an entire wind turbine. Wind turbine manufacturers to design their machines safely use these models. [1]

4. STRUCTURAL DYNAMICS

A 50 m tall wind turbine tower will have a tendency to swing back and forth, say, every three seconds. The frequency with which the tower oscillates back and forth is also known as the **eigenfrequency** of the tower. The eigenfrequency depends on both the height of the tower, the thickness of its walls, the type of steel, and the weight of the nacelle and rotor. Now, each time a rotor blade passes the wind shade of the tower, the rotor will push slightly less against the tower. If the rotor turns with a rotational speed such that a rotor blade passes the tower each time the tower is in one of its extreme positions, then the rotor blade may either **dampen** or **amplify** (reinforce) the oscillations of the tower. The rotor blades themselves are also flexible, and may have a tendency to vibrate, say, once per second. Hence, it is very important to know the eigenfreqencies of each component in order to design a safe turbine that does not oscillate out of control.

5. HORIZONTAL OR VERTICAL AXIS MACHINES?

5.1 Horizontal Axis Wind Turbines

Most of the technology is related to horizontal axis wind turbines (HAWTs, as some people like to call them). The reason is simple: All grid-connected commercial wind turbines today are built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). The purpose of the rotor, of course, is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. The same basic principle is used in a modern water turbine, where the flow of water is parallel to the rotational axis of the turbine blades. [2]

5.2 Vertical Axis Wind Turbines

As you will probably recall, classical water wheels let the water arrive at a right angle (perpendicular) to the rotational axis (shaft) of the water wheel. Vertical axis wind turbines (VAWTs as some people call them) are a bit like water wheels in that sense. (Some vertical axis turbine types could actually work with a horizontal axis as well, but they would hardly be able to beat the efficiency of a propeller-type turbine). The only vertical axis turbine, which has ever been manufactured commercially at any volume, is the **Darrieus machine**, named after the French engineer Georges Darrieus who patented the design in 1931. The Darrieus machine is characterised by its C-shaped rotor blades, which make it look a bit like an eggbeater. It is normally built with two or three blades.

Fig. 2 Eole C, a 4200 kW Vertical axis Darrieus wind turbine with 100 m rotor diameter at Cap Chat, Québec, Canada.

The basic theoretical advantages of a vertical axis machine are: [2]

1) You may place the generator, gearbox etc. on the ground, and you may not need a tower for the machine.
2) You do not need a turning mechanism to turn the rotor against the wind.

The basic disadvantages are: [3]

1) Wind speeds are very low close to ground level, so although you may save a tower, your wind speeds will be very low on the lower part of your rotor.
2) The overall efficiency of the vertical axis machines is not impressive.
3) The machine is not self-starting (e.g. a Darrieus machine will need a "push" before it starts. This is only a minor inconvenience for a grid-connected turbine, however, since you may use the generator as a motor drawing current from the grid to starting the machine).
4) The machine may need guy wires to hold it up, but guy wires are impractical in heavily farmed areas.
5) Replacing the main bearing for the rotor necessitates removing the rotor on both a horizontal and a vertical axis machine. In the case of the latter, it means tearing the whole machine down.

6. UPWIND OR DOWNWIND MACHINES?

6.1 Upwind Machines

Upwind wind turbine is a type of wind turbine in which the rotor faces the wind. The basic advantage of upwind designs is that one avoids the wind shade behind the tower. By far the vast majority of wind turbines have this design. On the other hand, there is also some wind shade in **front** of the tower, i.e. the wind starts bending away from the tower before it reaches the tower itself, even if the tower is round and smooth. Therefore, each time the rotor passes the tower, the power from the wind turbine drops slightly. The basic drawback of upwind designs is that the rotor needs to be made rather **inflexible**, and placed at some distance from the tower (as some manufacturers have found out to their cost). In addition an upwind machine needs a **yaw mechanism** to keep the rotor facing the wind. [4]

6.2 Downwind Machines

Downwind machines have the rotor placed on the lee side of the tower. They have the theoretical advantage that they may be built without a **yaw mechanism**, if the rotor and nacelle have a suitable design that makes the nacelle follow the wind passively. For large wind turbines this is a somewhat doubtful advantage, however, since you do need cables to lead the current away from the generator. How do you untwist the cables, when the machine has been yawing passively in the same direction for a long period of time, if you do not have a yaw mechanism? (Slip rings or mechanical collectors are not a very good idea if you are working with 1000-ampere currents). A more important advantage is that the rotor may be made more **flexible**. This is an advantage both in regard to weight, and the structural dynamics of the machine, i.e. the blades will bend at high wind speeds, thus taking part of the load off the tower. The basic advantage of the downwind machine is thus, that it may be built somewhat lighter than an upwind machine. The basic drawback is the fluctuation in the wind power due to the rotor passing through the wind shade of the tower. This may give more **fatigue loads** on the turbine than with an upwind design. [4]

7. HOW MANY BLADES?

7.1 Why Not an Even Number of Blades?

Modern wind turbine engineers avoid building large machines with an even number of rotor blades. The most important reason is the **stability** of the turbine. A rotor with an odd number of rotor blades (and at least three blades) can be considered to be similar to a disc when calculating the dynamic properties of the machine. A rotor with an even number of blades will give stability problems for a machine with a stiff structure. The reason is that at the very moment when the uppermost blade bends backwards, because it gets the maximum power from the wind, the lowermost blade passes into the wind shade in front of the tower. [5]

7.2 The Danish Three-Bladed Concept

Most modern wind turbines are three-bladed designs with the rotor position maintained **upwind** (on the windy side of the tower) using electrical motors in their yaw mechanism. This design is usually called the classical *Danish concept*, and tends to be a standard against which other concepts are evaluated. The vast majority of the turbines sold in world markets have this design. The basic design was first introduced with the renowned Gedser wind turbine. Another characteristic is the use of an asynchronous generator. You may read more about the Danish concept in the articles section of this web site.

7.3 Two-Bladed (Teetering) Concept

Two-bladed wind turbine designs have the advantage of saving the cost of one rotor blade and its weight, of course. However, they tend to have difficulty in penetrating the market, partly because they require higher rotational speed to yield the same energy output. This is a disadvantage both in regard to noise and visual intrusion. Lately, several traditional manufacturers of two bladed machines have switched to three-bladed designs. Two- and one-bladed machines require a more complex design with a hinged (teetering hub) rotor as shown in the picture, i.e. the rotor has to be able to tilt in order to avoid too heavy shocks to the turbine when a rotor blades passes the tower. The rotor is therefore fitted onto a shaft which is perpendicular to the main shaft, and which rotates along with the main shaft.

7.4 One-Bladed Concept

Yes, one-bladed wind turbines do exist, and indeed, they save the cost of another rotor blade! If anything can be built, engineers will do it. One-bladed wind turbines are not very widespread commercially, however, because the same problems that are mentioned under the two-bladed design apply to an even larger extent to one-bladed machines. In addition to higher rotational speed, and the noise and visual intrusion problems, they require a counterweight to be placed on the other side of the hub from the rotor blade in order to balance the rotor. This obviously negates the savings on weight compared to a two-bladed design.

8. CONCLUSIONS

Wind turbine design is dictated by a combination of technology, prevailing wind regime, and economics. Wind turbine manufacturers optimize machines to deliver electricity at the lowest possible cost per kilowatthour (kWh) of energy. Design efforts benefit from knowledge of the wind speed distribution and wind energy content corresponding to the different speeds and the comparative costs of different systems to arrive at the optimal rotor/generator combination. Optimizing for the lowest overall cost considers design factors such as relative sizes of rotor, generator, and tower height. For example, small generators (i.e., a generator with low rated power output in kW) require less force to turn than larger ones. Therefore, fitting a large wind turbine rotor with a small generator will produce electricity during many hours of the year (harvesting energy at lower wind speeds), but will capture only a small portion of high-speed wind energy. Conversely, a large generator will be efficient at high wind speeds, but unable to turn at low wind speeds.

9. REFERENCES

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