"Discover Engineering" Wind Turbine Workshop

SEA Background Notes

Information about the Workshop

The power output of a turbine will increase with the swept area (i.e. proportional to the square of the length of the blade). For this workshop, however, the fact that the wind source is a fan means that beyond a certain blade length, there will be no increase – in fact it will decrease due to the extra weight and increased drag force. Blade shapes which are more aerodynamic will increase the power output. Blade angle is an optimum at around 20^o in this case, with lower and higher angles giving less power output. The wind output from the fan is not very similar to real wind conditions, due to the rotating blades that increase the kinetic energy in the air (the windspeeds are similar though – on the highest setting, the wind speed from the fan is around $4.8ms^{-1}$, and in the square kilometer in which the engineering department is situated, the average windspeed 10m above ground level is $4.7ms^{-1}$, 25m above ground level it is $5.5ms^{-1}$, and 45m above ground level it is $6ms^{-1}$). This means that there will not be a steady power output from the turbine. The small turbines in this workshop work similarly well with both 3 and 6 blades.

The blades for the small turbines used can be made from either 3mm-thick corriflute, which slots onto the 3mm wooden dowel used, or from cardboard. The cardboard is attached to the dowels using spine bars. They should then be capped with axle bushes, to help hold the cardboard blades on (since there is a risk of them flying off), and taped into the angle that the team wishes to test. Real turbine blades are usually made from GFRP, Glass Fibre-Reinforced Plastics. When attaching blades to the rotor hub, the best results are produced when the blade is attached at one edge, rather than in the centre. If 3 blades are used, it is possible to fit larger blades on the turbine. The maximum length to produce a good output was found (in testing) to be about 18cm; the maximum useful width, about 7cm. These maximums may not be the same in the workshop, but it is an indication.

Wind Turbines

How do they work?

Wind turbines usually consist of a set of blades attached to a rotor hub, which together form the rotor; this rotor deflects the airflow, which produces a force on the blades, which in turn produces a torque on the shaft such that the rotor rotates about a horizontal axis (N.B. this does not apply to all wind turbines, some rotate about a vertical axis), which is connected to a gearbox and generator. These are housed in the nacelle (at the top of the tower) with other electrical components. The generator produces electricity, which is transmitted down the cables through the tower and out to a transformer, to convert it from the output voltage (typically around 700V) to the right voltage for either the national grid (33000V) or for whatever personal use it is being put to (so 240V).

These Horizontal Axis Wind Turbines must always be pointed in the correct direction (into or away from the wind, depending on the design) if they are to be used efficiently. Those which face away from the wind – downwind turbines ("downwind" referring to the position of the turbine relative to the tower) – are blown into the correct orientation. In older and smaller upwind wind turbines, correct orientation is achieved through use of a simple wind vane; larger turbines contain a yaw meter and yaw motor. The yaw meter detects the direction of the wind, and the yaw motor rotates the turbine so that it is always facing into the wind. Because it is possible for the turbine to thus yaw in the same direction for many turns, twisting the cables, turbines have a cable twist counter which causes the system to yaw back around so that the cables untwist, once they have reached a certain number of turns in one direction.

The shape of the blades is very important in controlling the turbine. The shape must be optimised to give lift so that the rotor will turn. To this end, for the most part they have an aerofoil shape (as an aeroplane's wing), but for large wind turbines the blades are always twisted. From the point of view of the blade, the wind will be coming from a much steeper angle as you move towards the root of the blade. Since the blade will stop giving lift (it will stall) if the blade is hit at an angle of attack which is too steep, the rotor blade must be twisted to achieve an optimum angle of attack throughout the length of the blade.

Lift and Stall

The reason that an aeroplane can fly is that the air sliding along the upper surface of the wing will move faster than the air on the lower surface, such that the pressure will be lower on the upper surface. This creates the lift, i.e. the force pulling upwards that enables the plane to fly. Lift is perpendicular to the direction of the wind.

If an aeroplane tilts backwards in an attempt to climb higher into the sky, the lift of the wing will increase at first as the wing is tilted backwards, but with increasing angle the air flow on the upper surface will separate and become turbulent. This means that the lift from the low pressure on the upper surface of the wing disappears – this is stall. A wing will stall if the shape of the wing tapers too quickly; in this case it is not due to the wing changing shape but the angle of the wing relative to the general direction of the airflow (angle of attack) is increased.

Stall can be provoked if the surface is not completely even and smooth. A dent can be enough to start turbulence on the back side of a rotor blade.

Power Output

The power output of the turbine is found using the following equation:

Power Delivered = C_p x (swept area) x ½ x d x u^3

where C_p is the power efficiency of the rotor, swept area = πr^2 where r is the blade length, d is the density of the air, and u is the wind speed.

The theoretical maximum for C_p is 0.59; this is the Betz limit. Ideally, a turbine which operates as close to this limit as possible over a wide range of wind speeds would be best. This would make the power output approximately proportional to u^3. The power must be limited at high u to protect mechanical and electrical components of the turbine from overloading – this is done by reducing C_p as the wind speed increases (as described above).

Typically, turbines are designed to achieve their maximum efficiency at wind speeds of around 8m/s. This is higher than the average wind speed in the UK (6m/s), because it is in the higher wind speeds that most of the energy is to be found.

Commercial turbines range in power capacity from a few hundred kilowatts to over 2 megawatts, and the current average size of new machines being installed is 1.3-1.85MW. These larger machines can produce electricity at a lower price.

The power at which a turbine is rated will not be achieved most of the time. Wind in the UK is estimated to blow at a high enough speed to achieve the rated power 30-40% of the time, so the installed capacity of a turbine or farm will be multiplied by this percentage to find a "declared net capacity", the expected amount of power from the site. Power output of a turbine in general will depend on many things, including: the size of the turbine; the shape and smoothness of the blades; the angle (pitch) and number of the blades; the wind speed; the height of the tower; the terrain of the location; the arrangement of turbines in a wind farm situation (to shelter each other as little as possible from the prevailing wind).

Number of blades

The number of blades will affect the power output from the turbine. The optimum number of blades for a wind turbine depends on the purpose of the turbine. Turbines for generating electricity need to operate at high speeds, but do not need much torque – these turbines generally have two or three blades, since this gives enough torque without adding the extra weight that can slow the turbine down. Wind pumps need a lot of torque but not much speed, and so have many blades.

Rotors with odd numbers of blades (and at least three) are more stable. Two-bladed rotors require a hinged (teetering hub) rotor, since it needs to be able to tilt or bend in order to avoid excessive shocks to the turbine under relatively strong winds.

The three-bladed rotor is the most popular model with a much smoother power output, more efficient and higher energy yield, a balanced gyroscopic force and a much better mechanical system compared to the rotors with two blades.

Controlling Wind Turbines

Wind turbines must not be run during wind speeds which are too high, since this may cause vibration that can shake the turbine into pieces; because of this they have brakes, and also a way to decrease the lift given to the blades. This can be done using a pitch-controller on the blades or a stall-controller (which can be active or passive). The passive stall controller makes use of the shape of the blade, designing it so that at high wind speeds it will stall gradually from the root of the blade. This occurs because as the actual wind speed in the area increases, the angle of attack of the rotor blade will increase until it starts to stall.

The pitch controller and the active stall controller use similar principles, rotating the blade to change the lift so that in low wind speeds they have a large torque. However, at high wind speeds the pitch controller will pitch the blades out of the wind (and turn them back whenever the wind drops), whereas the stall controller will pitch its blades in the opposite direction, increasing the angle of attack in order to make the blades go into a deeper stall, thus wasting the excess energy in the wind. This allows the active stall-controlled turbine to be run at almost exactly rated power for all high wind speeds, whereas the passive stall-controlled turbine will usually have a drop in the electrical power output for higher wind speeds as the blades go into deeper stall. With stationary blades, the passive stall system requires solving a complex aerodynamic design problem; but with pitchable blades, the engineering required to ensure that the rotor blades pitch exactly the right amount is also complex.

Wind Energy

Advantages

Making use of wind energy has many advantages. Wind energy is a clean fuel source and doesn't pollute the air like power plants that rely on combustion of fossil fuels. Wind turbines don't produce emissions that are greenhouse gases or cause acid rain. Wind energy is renewable – wind is actually a form of solar energy, since winds are caused by the heating of the atmosphere by the sun, and the convection currents that come about by the different heat in different areas (due to different distances from the sun). Wind energy is one of the cheapest renewable energy technologies available.

Wind energy technology is one of the safest energy technologies. No member of the public has ever been injured by wind energy or wind turbines anywhere in the world, despite the fact that there are over 68000 operational wind turbines.

Disadvantages

Although the cost of wind power is far less than it used to be, the technology requires a higher initial investment than fossil-fuelled generators and so depending on the energy available at the site, the wind farm may not be cost-competitive. Wind is intermittent, and so electricity may not always be being produced when it is needed. This means that it cannot be relied upon for all energy needs, unless it is energetic enough that it can be used to charge batteries which can be used when the wind is not blowing.

Wind Energy in Britain

Britain has an abundance of wind energy – the best wind resources in Europe. Wind speeds in Britain range between almost 0 and 40m/s (88mph), and average values are 3-8m/s. In Cambridge, the wind speed at 45m above ground is about 6m/s.

Currently 2.5GW of power in Britain comes from wind farms, enough to power 1,423,300 homes, and there are another 19GW worth in development. The capacity from wind farms has been growing at 86% per year, and the UK is about to overtake Denmark as the world's largest generator of onshore wind power. In one survey, it was found that 80% of people favour the use of wind power and 64%

would be happy to live within 5km (3 miles) of a wind farm.

Useful Links

Websites on Wind Turbines and Wind Energy

BWEA – The British Wind Energy Association: http://www.bwea.com/energy/how.html

Map of all wind farms (from Google Maps on BWEA): http://www.bwea.com/ukwed/google.asp

The Danish Wind Industry Association – guided tour about wind energy, turbines and how they work:

http://www.windpower.org/en/tour/wres/index.htm

The Wind and Hydropower Technologies Program from the US Department of Energy: http://www1.eere.energy.gov/windandhydro/wind_technologies.html

Windmill World: http://www.windmillworld.com/

Youtube video:

Vestas brake failure: http://youtube.com/watch?v=CqEccgR0q-o&feature=related