AS LEVEL

Environmental Technology

Energy from the Wind (2)

For first teaching from September 2013

For first award in Summer 2014

FACT FILE

environmental technology

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Specification Content

Students should be able to:

- define what is meant by the 'Betz Limit' and explain how it is related to real world wind turbine power efficiencies;
- explain the terms 'rotor collected energy' and 'rated energy output' and detail the reasons for the energy shortfall between them;
- explain the relationship between power output and swept area;
- explain the relationship between wind speed and power production and interpret power curves/profiles for different wind speeds;
- demonstrate the effect of blade diameter on the power output of a wind generator;
- describe how the power output from a wind turbine is affected by air density, temperature and altitude;
- assess the factors that affect maximum energy production in wind turbines within the context of cost benefit analysis;
- understand the terms hub height and rotor diameter and explain the critical factors used to determine hub height;
- explain that wind resource assessment, terrain, turbine size and visual impact are critical factors used to determine hub height;
- demonstrate that the mass of a turbine is approximately proportional to the cube of its blade length; and
- describe how turbine performance is influenced by the blade length, strength of materials and siting requirements.

Course Content

The power which can be extracted from the wind is given by the formula;

Power = ½ ρ x A x v3

** see Energy from the Wind Fact File 1*

Where ρ = density of the air being used in kg/m3

A = area swept out by the rotor blades in m2

v = velocity of the wind in m/s

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It can be seen from this equation that the main factors which affect the power available from a wind turbine are;

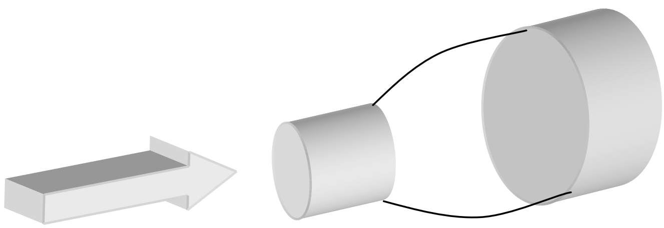
- The density of the air – air density is lower at higher elevations in mountainous regions but the average density in cold climates may be as much as 10% higher than in a tropical region;
- The area swept out by the rotor blades of the turbine; and
- The wind velocity.

In summary the power available is proportional to;

- the air density;
- the area swept out by the rotor, which in turn depends on the blade diameter as area =π x (diameter/ 2)2 – if diameter is doubled the area swept out increases by a factor of 4; and
- the cube of the wind velocity.

In reality the power obtained from a wind turbine does not match exactly the figure which might be suggested by using the equation above. This can be due to a number of factors, for example not all of the wind which appears to be available to the wind turbine is actually used by it. Some is "pushed aside" by the rotors and is not used in the energy conversion process. In addition there will be energy losses in the actual turbine itself. Not all of the "captured" energy will actually be converted into energy output. The effect of air being pushed aside and not used in the energy conversion process is summarised in what is known as the **Betz Limit**.

Albert Betz showed in 1928 that the maximum fraction of the power in the wind that can theoretically be extracted for use is **16/27 or 59.3%**. This is also due to the fact that some kinetic energy must be left in the air after it leaves the rotor blade area. All of the energy cannot be removed from the air otherwise it would slow down and get in the way.

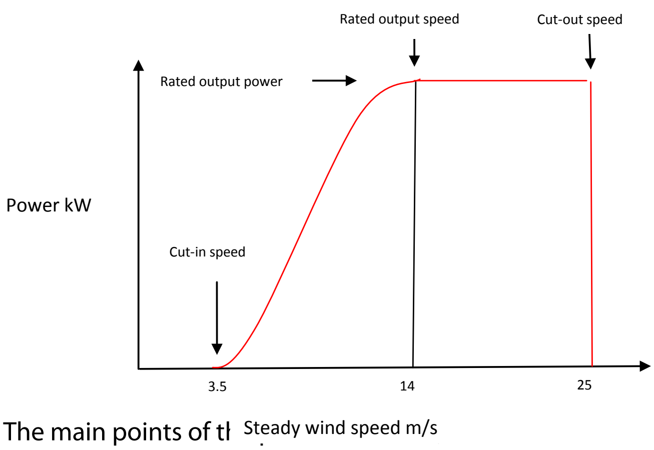


Flow of air past a wind turbine. The air slows down and is splayed out around the area created by the rotor blades

The Betz Limit suggests that the maximum efficiency of a wind generator is 59% but in reality this could be any figure less that this depending on the design of the system itself. This goes some way towards explaining the difference between" rotor collected energy" and "rated energy output" i.e. the difference between the available collected energy and the actual energy output of the system. **The efficiency of a wind turbine system could be as low as 20% depending on its design.**

Power curves

The diagram below shows the typical relationship between power output from a wind turbine and wind speed



The main points of tl

Cut-in speed

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. So there is no power output. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the **cut-in speed** and is typically between 3 and 4 metres per second.

Rated output power and rate output wind speed

As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly as shown. However, typically somewhere between 12 and 17 metres per second, the power output reaches the limit that the electrical generator is capable of. This limit to the generator output is called the **rated power output** and the wind speed at which it is reached is called the **rated output wind speed**. At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power. This is achieved in different ways depending on the design of the wind generator. Typically with large turbines, it is done by adjusting the angle between the blades of the rotor and the wind itself so as to keep the power at the constant level.

Cut-out speed

As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the cut-out speed and is usually around 25 metres per second.

Factors which affect maximum energy production in wind turbines

The ultimate influence on the amount of energy which a wind turbine system can produce is the speed at which the wind is blowing. As stated above there are other influential factors such as;

Air density – it must be stressed that air density is not

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always constant as it will decrease as both temperature and altitude increase.

Hub height is a term used to describe the overall height of the wind turbine system and can impact on the amount of energy generated as the wind speed tends to be higher as height increases from ground level. However, there are physical limits to the potential height of the hub and increasingly there are environmental factors to be considered. The critical factors used to determine hub height are open for discussion but the following should be used to inform any design decisions;

- Wind resource assessment of the proposed site, which could be considered to be the most critical factor. Every location will be different with issues to be considered such as average wind speed, distribution of wind, any potential obstructions to the flow of wind, and local environmental considerations.
- The topography or terrain of the site which would be analysed during a preliminary site assessment.
- The size of the turbine itself, the bigger the turbine the higher the hub height requirement, larger swept out area, etc.
- The visual impact of the turbine system to take into consideration the distance from which the turbine is visible. Obviously, the bigger the turbine and hence tower, the further it can be seen. Again this is dependent on the particular site whether on top of a mountain or a flat topography.

In practice, hub heights and blade lengths are selected for each wind installation depending on the wind profile, topography, vegetation and land use, and to comply with planning requirements and environmental restrictions. The design of wind turbine systems is also dependent on cost benefit analysis. This is where decisions have to

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be made about the relationship between the cost of an installation and the economic benefit which can be derived from it.

A consideration linked to this is that the price of a turbine increases disproportionately with its power output as its size increases. As the size of the blade increases, so also does the price of the turbine. Economic considerations and the overall cost of producing electricity would then need to be considered. This is a classic case of engineering 'trade-offs', where design, performance, efficiency, reliability are assessed.

The mass of a turbine is approximately proportional to

Activity

the cube of its blade length. Each particular blade design, within which there can be considerable variety, needs its own mathematical model. With increasing length and weight a new difficulty arises, because the pressure on the blades creates stresses that require increased dimensioning of the other components of the wind turbine. The variable in this equation is material type (i.e., carbon fibre vs. glass fibre), the choice of which can reduce blade weight and ultimately lifecycle performance.

Labour and maintenance costs only increase gradually with increasing turbine size so in practice, most turbine sizes are limited by the strength of the materials used and the siting of the turbine itself. Larger turbines need faster winds to operate.

The performance of a turbine will depend on the materials used for the rotor blades themselves, for example too weak and they will break; too strong and hence heavy will require larger wind speeds to make energy generation possible. Material technology is constantly changing but graphite composite materials have proved successful in use as blade material, being used for some of sixty metres in radius. Smaller household blades have been made from lightweight fibreglass, aluminium and sometimes laminated wood.

Q1. Provide a summary of the main issues which need to be considered when planning a wind turbine installation.

Q2. Make a presentation on the development of wind power from the earliest windmills to modern wind farms. Highlighting the changes in the technology being used; the different types of wind turbine systems; the relevant technical and environmental issues and the benefits and disadvantages of deriving energy from the wind.