Quiz AS104
Wind Energy and Wind Turbines

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PROBLEMS

Problem 1

Associate each mode of wind turbine output regulation with its corresponding definition.

1. Passive stall
2. Active stall
3. Variable pitch

I.( ) Fixed rotational speed and adjustable pitch blades
II.( ) Variable rotational speed and adjustable pitch blades
III.( ) Fixed rotational speed and fixed pitch blades

Problem 2

True or false?

1. ( ) Any variation in the swept area of a wind turbine will influence the power available from wind. Turbines with large rotors intercept more wind than those with smaller rotors and consequently capture more power from the wind. Doubling the area swept by a wind turbine rotor will multiply the power available from the wind by four.

2. ( ) The power available from wind is substantially dependent on the speed of wind inflow onto a turbine. In fact, increasing the wind speed by 25% will cause the power available to increase by over 80%.

3. ( ) Although most older turbines and other devices that convert wind energy to electricity have not attained aerodynamic efficiencies greater than 50%, modern designs produced since the early 2000s have reached as much as 65% efficiency.

4. ( ) Studies by wind turbine designers indicate that wind speed decreases near the summit of a long ridge across the wind path. The winds decelerate as they pass over the ridge. Consequently, these regions are generally not appropriate for the installation of wind turbines.

5. ( ) The blade element method is the paramount choice in the design of a wind turbine blade. Like any numerical method, however, this approach possesses inherent limitations. One of these shortcomings can be solved by the so-called *Prandtl tip loss factor*, which compensates for the fact that the axial induction factor might have a value greater than about 0.2, causing one-dimensional theory to break down and leading to thrust coefficients C_T exceedingly different from measured values.

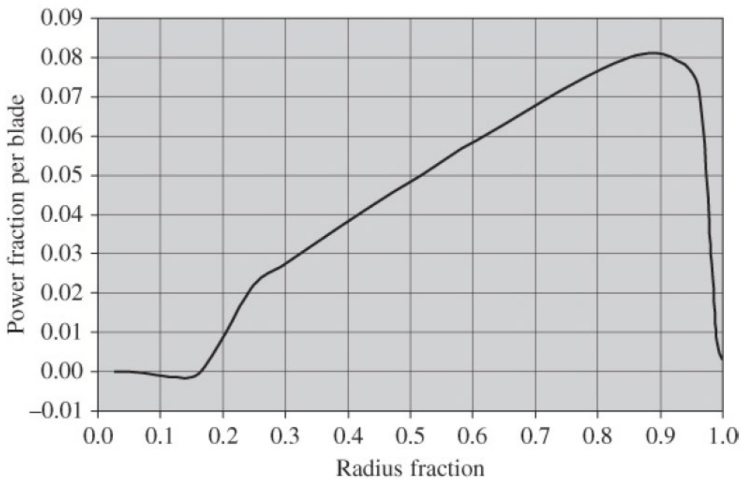
6. ( ) A larger generator does not necessarily mean more energy production because the efficiency at low wind speeds will change with generator size. One way to improve efficiency in large turbines is to use two generators and have the smaller one function at low wind speeds, thereby improving performance under these circumstances.

7. ( ) Control of rotor rotations per minute using adjustable pitch and dynamic blade positioning may be carried out in at least three ways: full-span control, use of variable pitch tips, and use of ailerons. The most common method for large wind turbines practice is the use of ailerons, since the theory underpinning the application of these devices, being borrowed from aircraft aerodynamics, is more theoretically well-established than other alternatives.

8. ( ) Although collisions of bird and bat species with the blades of large turbines have been reported, the rate of incidents has been far too low to cause, say, the endangerment of an animal population.

Problem 3

The following is a graph of fraction of power produced versus fraction of radial distance from the hub of a blade of a 3 MW wind turbine operating at rated speed. Which of the following is true?



A) The power fraction at mid-span is greater than 6 percent.

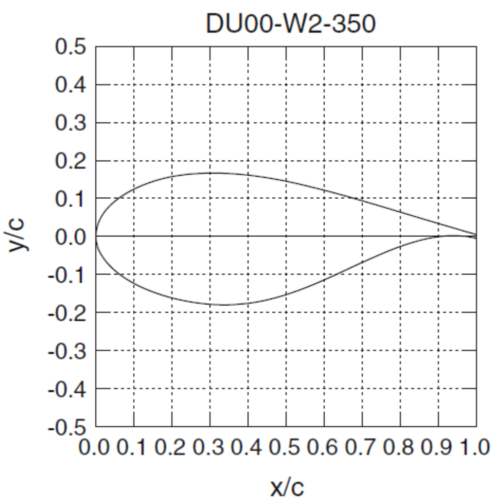
B) The contribution to the overall power produced by the blade is greatest at the tip.

C) The region of the blade closest to the hub contributes over 3 percent of the power fraction produced by the blade.

D) After the blade root, the power produced increases approximately linearly with radius up to a point where the tip effect attenuates it.

Problem 4

The following figure shows the shape of a 35% DU00-W2-350 blade profile. It can be surmised that this blade profile is most suitable for



A) the outer segment of a wind turbine blade.
B) the mid-span segment of a wind turbine blade.
C) the inner segment of a wind turbine blade.
D) The section in question is not suitable for a wind turbine blade.

Problem 5

The following photograph shows the inner portion of the blade of a GE wind turbine. As shown, the blade is equipped with a device conceived to delay flow separation, thereby preventing stall and improving aerodynamic performance. The device in question is

A) an aileron.
B) a series of vortex generators.
C) a set of pressure taps.
D) a smoke generator for flow visualization.

Problem 6

Which of the following variables is most preferably maintained constant when upscaling a smaller wind turbine design to a larger one?

A) Tip speed.
B) Blade mass.
C) Bending section modulus.
D) Aerodynamic moments.

Problem 7

The distribution of wind that passes over a wind turbine blade is altered by the presence of the tower. For upwind rotors, the wind directly in front of the tower is redirected and thereby reduces the torque at each blade when in front of the tower. The torque pulsations due to this effect are most significant when a turbine has blades downwind of the tower and wind is blocked as opposed to redirected. This affects the rotation regime of the blades and may lead to pronounced oscillations in the system's power generation performance.

The phenomenon discussed above is known as

A) Himmelskamp effect.
B) Wind shear.
C) 3p oscillation.
D) Tower shadow.

Problem 8

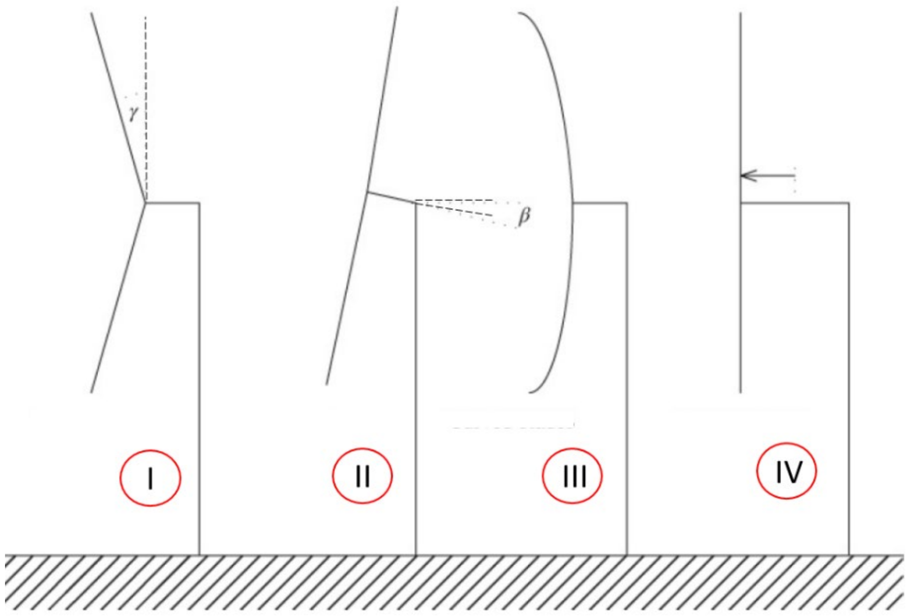
Below, we have the definitions of a few methods of rotor configuration used to improve the clearance of wind turbine systems. Associate each method with the correct illustration.

1. Coning the blades away from the tower, i.e., setting the connection of blade to hub at a small angle out of the rotor plane.

2. Introducing out-of-plane curvature into the manufactured blade shape, tilting the rotor axis.

3. Increasing the overhung distance between the rotor plane and the tower centerline.

4. Tilting the shaft axis.



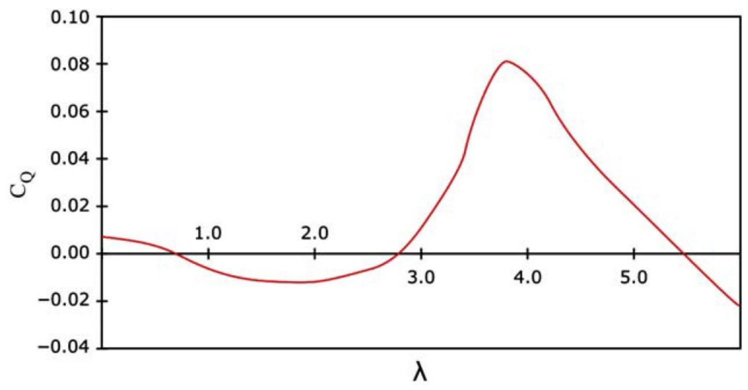
Problem 9

Which of the following is *not* a disadvantage of vertical axis wind turbines (VAWTs)?

A) Tendency to stall under gusty conditions.
B) Low starting torque.
C) Elimination of yawing mechanisms.
D) Low installation height, limiting operation to lower wind speed environments.

Problem 10

The following figure plots the torque coefficient produced by the blades of a typical lift-based vertical axis wind turbine in one revolution. The horizontal axis is the tip-speed ratio. Which of the following is true?



A) The torque coefficient is greatest when the tip-speed ratio ranges from 1.0 to 3.0.
B) The existence of a region of negative torque coefficient at a certain range of tip-speed ratios implies that this lift-based VAWT is not a viable power production device.
C) The existence of a region of negative torque coefficient at a certain range of tip-speed ratios implies that this lift-based VAWT is not able to self-start.
D) There are two values of tip-speed ratio for which the torque coefficient is zero.

Solutions

P.1 ■ Solution

The correct associations are **1-III, 2-I, and 3-II**. Doesn't get any easier than this, does it? Method 3 is the most efficient in aerodynamic terms, but the method of control chosen is always a trade-off between energy production and cost.

P.2 ■ Solution

1. False. The power available from the wind is given by

$$E = \frac{1}{2}\dot{m}V^2 = \frac{1}{2}\times\rho AV\times V^2 = \frac{1}{2}\rho AV^3$$

where ρ is the density of air, A is the swept area of the rotor, and V is the flow velocity. From this equation, it is clear that multiplying the area swept by the rotor by 2 will cause the available energy to increase two-fold as well. What would multiply the available energy by four is doubling the *rotor diameter D*, since $A = \pi D^2/4$ and, consequently,

$$E = \frac{1}{2}\rho\times\left(\pi D^2/4\right)\times V^3 = \frac{\pi}{8}\rho V^3 D^2$$

That is, the energy is proportional to the square of the diameter.

2. True. This statement can be verified by a straightforward application of the wind energy formula. If the energy E_1 associated with a velocity V_1 is

$$E_1 = \frac{1}{2}\rho AV_1^3$$

The energy E_2 associated with a velocity $V_2 = (5/4)V$ is, in turn,

$$E_2 = \frac{1}{2}\rho AV_2 \rightarrow E_2 = \frac{1}{2}\rho A\times\left(\frac{5}{4}V_1\right)^3 = 1.953\times\underbrace{\frac{1}{2}\rho AV_1^3}_{=E_1}$$

$$\therefore E_2 = 1.953E_1$$

That is, the energy associated with the increased velocity is about 95.3% greater than the energy associated with the initial velocity. The dependence of the available energy on the speed of the wind inflow is quite pronounced.

3. False. From elementary momentum theory, it can be shown that the power efficiency of a rotor cannot surpass 59.3%, i.e., the Betz limit. The highest experimental efficiencies for even the most advanced wind energy systems are around 50%. The reduction in power coefficient is due to losses from the viscous drag on the rotor blades, swirl imparted to the air flow by the rotor structure, losses at the gearbox, and electrical power losses in the transmission line, electrical generator, and step-up transformer at the tower base.

4. False. The opposite is true, that is, it has been found that wind speed increases substantially as it passes over a ridge. Increases in wind speed close to 200% have been observed at the peak of a ridge. Mountain passes can accelerate winds up to 50 m/s (180 km/h) during storms associated with cold fronts. It should be noted that, although a regime of intense winds is desirable at first, such environments may also be characterized by powerful turbulence, which is deleterious both for power generation and maintenance of the structural integrity of the turbine tower. Turbulent environments may wreak havoc on wind turbines. Assessing whether a strong-wind site is capable of ensuring good wind turbine performance without damaging its structure is a difficult task.

5. False. The Prandtl tip loss factor is used to compensate for the fact that the rotor modeled in the elementary blade element method has an infinite number of blades, whereas a real rotor has a finite number of blades. Needless to say, the vortex system in the wake is different in these two cases. Prandtl derived a correction F to the aerodynamic loads so that, when the corrected loads are evenly distributed azimuthally, they give results for the induction at the blades very similar to those found for a rotor with a finite number of blades. The adaptation described in the statement is the other major adjustment to elementary blade theory, the so-called *Glauert correction*, an empirical correlation proposed to fit the value of the thrust coefficient C_T to measured results outside of the scope of the Froude-Rankine momentum theory. One way to express this correlation is

$$C_T = \begin{cases} 4a(1-a)F \ ; \ a \le 1/3 \\ 4a\left[1 - \frac{1}{4}(5-3a)a\right]F \ ; \ a > 1/3 \end{cases}$$

where a is the axial induction factor.

6. True. To increase generator efficiency, some units have two generators, one operating at low wind speeds and the other at high wind speeds. For instance, the Vestas V27 utilized a 50/225 kW asynchronous generator with synchronous speeds of 750/1000 rpm. Another possibility for increasing generator efficiency is to change the number of poles of the generator between low and high wind speeds.

7. False. The most common method of pitch control in large wind turbines is full-span control. Ailerons, when used in HAWTs, are moved to the low-pressure side of a blade to reduce lift, in contrast to flaps on airplanes, which are displaced in the opposite direction to increase lift. Unlike use of full-span control, which is simple in functioning and has been tested for many years, turbine blades endowed with ailerons have produced mixed results in experiments across the world. For instance, Zond built and installed 12,500-kW units with aileron control near Fort Davis, Texas, but the units were dismantled after four years of operation because, among other reasons, the difficulty in maintenance of the ailerons.

8. True. Although there have been reports of incidents involving wildlife and turbine blades, the number is quite low – in northwest Europe, for instance, the annual average collision rates ranged from 0.01 to 1.2 birds per turbine. One reason to dispel worries is that migratory birds fly well above the heights of wind turbines. Nevertheless, in order to prevent environmental conflicts, construction of wind farms in refuges of endangered species should be avoided altogether.

P.3 ■ Solution

After the blade root, which contributes minimally to the overall power fraction, we have a nearly linear increase in power fraction as we proceed in the radial direction. At around 0.9 blade fraction, the power fraction reaches a maximum and then drops precipitously, most likely because of tip losses.

➡ The correct answer is **D**.

P.4 ■ Solution

Relatively thick airfoils are particularly suitable for the root segment of a wind turbine blade so as to ensure structural integrity in the presence of high bending moments. The thickness of airfoils used in the innermost part of a blade are quite high, ranging from 35%, as in the present case, to as much as 50%. According to the values summarized by one author, the thickness-to-chord ratio in the mid-span part, in turn, ranges from 21 to 27%, and, in the outermost part, usually goes from 15 to 21%.

➡ The correct answer is **C**.

P.5 ■ Solution

The device shown is a set of vortex generators. This type of blade appendage induces faster moving laminar flow, thus delaying flow separation from the blade and the occurrence of stall. Vortex generators were shown to produce an appreciable, if modest, increase in wind turbine blade performance, usually ranging from 4 to 6%. The added power comes at the cost of a certain increase in drag, and the compromise between benefits and disadvantages must be assessed by the wind engineer.

➡ The correct answer is **B**.

P.6 ■ Solution

In upscaling a wind turbine system, a consistent basis for comparison requires that a representative tip speed be constant. Scaling with similarity boils down to scaling at constant design tip speed. This preserves the flow geometry in terms of the relationship between rotor speed and wind speed at any given operating point. In order for the tip speed to remain constant at any given wind speed, we must have, in upscaling, a rotor angular velocity ω that varies inversely with diameter D and decreases with increasing turbine size.

➡ The correct answer is **A**.

P.7 ■ Solution

The excerpt describes the so-called tower shadow effect. This phenomenon occurs when the wind inflow gets disturbed (or perhaps even blocked) due to the presence of the tower before reaching the blades. The effect is most severe for downwind turbines. Combined with the variation of wind speed with height, or wind shear, this phenomenon may lead to a disturbed inflow in the rotor, causing torque pulsations and, ultimately, power pulsations. Such power fluctuations occur at what is known as 3p frequency.

➡ The correct answer is **D**.

P.8 ■ Solution

The correct associations are **1-I, 2-III, 3-IV, 4-II**. These options may be combined with one another to further improve clearance. There are inherent downsides to some methods; for instance, tilting the shaft axis much beyond 4° or 5° may introduce undesirable cyclic loads. Coning introduces a moment at the blade root from centrifugal forces on the blade elements, which could (in a critical overspeed design case) become designing for the blade root if the cone angles are 4° or 5°. Out-of-plane curvature in the blade is a better solution in respect of blade loads and structure. All these options, in principle, reduce power slightly or require marginally longer blades to maintain power.

P.9 ■ Solution

The fact that vertical wind turbines do away with the need for yawing mechanisms is in fact a significant advantage, as it allows for a broader range of useful wind directions, decreases the cost associated with expensive tilting mechanisms, and adds to ease of operation. The remaining alternatives are all downsides of VATWs. For instance, control of the response of the turbine to incoming air flow is quite clumsy, as the development of stall under wind gusts is almost certain and, unlike stall-controlled HATWs, it does not aid in overall performance at all. Another disadvantage of VATWs is their inherently low installation height, which restricts the turbine to low intensity winds, even though the installation of power generation parts close to the ground can be interpreted as an additional convenience. Finally, VATWs present greater stability problems and vulnerability to off-design conditions than do their horizontal counterparts.

➡ The correct answer is **C**.

P.10 ■ Solution

HAWTs and drag-based VAWTs are able to self-start. By contrast, lift-based VAWTs such as the one studied herein have difficulty starting by themselves. Consider the graph in question. When the torque is positive, the turbine continues to spin and power is produced. However, if the torque coefficient is negative, as is the case for λ ranging from about 1.0 to 3.0, the turbine stops spinning on its own. That is, the results show that there is a “dead-band” region through which the VAWT must be driven to get to the most efficient power production range. Accelerating through this dead-band region requires power – the turbine must be driven by a motor at least to start. More recently, the VAWT industry has turned to self-starting designs, such as some types of rotors equipped with cambered airfoils, but even those seem to feature dead-band regions that delay or impede self-starting.

➡ The correct answer is **C**.

Answer Summary

Problem 1	Associative pb.
Problem 2	T/F
Problem 3	**D**
Problem 4	**C**
Problem 5	**B**
Problem 6	**A**
Problem 7	**D**
Problem 8	Associative pb.
Problem 9	**C**
Problem 10	**C**

References

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