CORNWALL COLLEGE

Exam– Academic Year 2014-2015

BSc Renewable Energy and Carbon Management

CORC2089

Wind Energy

Time Allowed: Two Hours

Permitted Materials: Non-programmable Calculators; Formula Sheet

Formulae and constants

Star :$V_{\mathrm{L}} = \sqrt{3}V_{\mathrm{P}}$

Star :$I_{\mathrm{L}} = I_{\mathrm{P}}$

Delta :$V_{\mathrm{L}} = V_{\mathrm{P}}$

Delta :$I_{\mathrm{L}} = \sqrt{3}I_{\mathrm{P}}$

$P = 3V_{\mathrm{P}}I_{\mathrm{P}} = \sqrt{3}V_{\mathrm{L}}I_{\mathrm{L}}$

$\mathrm{rpm} = \dfrac{60f}{n_{\mathrm{P}}}$

Tip speed $u = \dfrac{\mathrm{rpm}}{60} \cdot \pi D$

TSR $\lambda = \dfrac{u}{v}$

$P = \omega\tau$

$P = \dfrac{1}{2}\rho A v^3$

*Answer **all** questions. Note the different weightings of each question. Answers are expected to contain clear mathematical workings where appropriate.*

Question 1: (37 marks) A wind turbine has a three phase 50 kW, 4-pole, 400 V 50 Hz synchronous generator that is connected in star and directly coupled to the grid.

a) [2 marks] Sketch the connectivity of the three coils (phases) in the generator.

b) [2 marks] If 400 V is the line voltage, what is the phase voltage?

c) [1 mark] What is the power in each phase if the total power is 50 kW?

d) [2 marks] If the power factor is 1, what is the line current when the total power is 50 kW?

e) [2 marks] At what frequency does the magnetic field in the stator rotate?

f) [2 marks] At what frequency does the rotor coil rotate?

g) [2 marks] Name two advantages of using a 3-phase generator instead of a single phase alternator.

The turbine is a horizontal axis, downwind device of low solidity with 3 rotor blades of diameter 19 m which rotate at a fixed speed of 43 rpm

h) [2 marks] Explain the meaning of the phrase "horizontal axis, downwind device".

i) [3 marks] Explain why the turbine has been made to have low solidity.

The power and power coefficient as a function of wind speed and the annual energy production as a function of mean wind speed at hub height are shown in Figure (top and middle)

j) [3 marks] Show that the power coefficient is maximised when the tip speed ratio is about 6.

k) [2 marks] The turbine is stall controlled. How is this evident from the power curve?

l) [2 marks] If the turbine were indirectly coupled to the grid and able to operate at varying rotor speeds, what advantage(s) would that bring?

The turbine is at a site where wind speeds have been monitored and where the wind speed duration curve at the hub height of the turbine is as shown in Figure (bottom). The mean wind speed at this height is 6.1 $\mathrm{m\,s^{-1}}$

m) [2 marks] Wind speed atlases exist for the UK, so why would the wind speeds at the site have been monitored?

n) [2 marks] What is the median wind speed at this site?

o) [2 marks] For what proportion of the time is the wind turbine not generating?

p) [2 marks] For what proportion of the time is the wind turbine generating 50 kW or more?

q) [4 marks] If the rated power of this turbine is 50 kW, what is its capacity factor at this site?

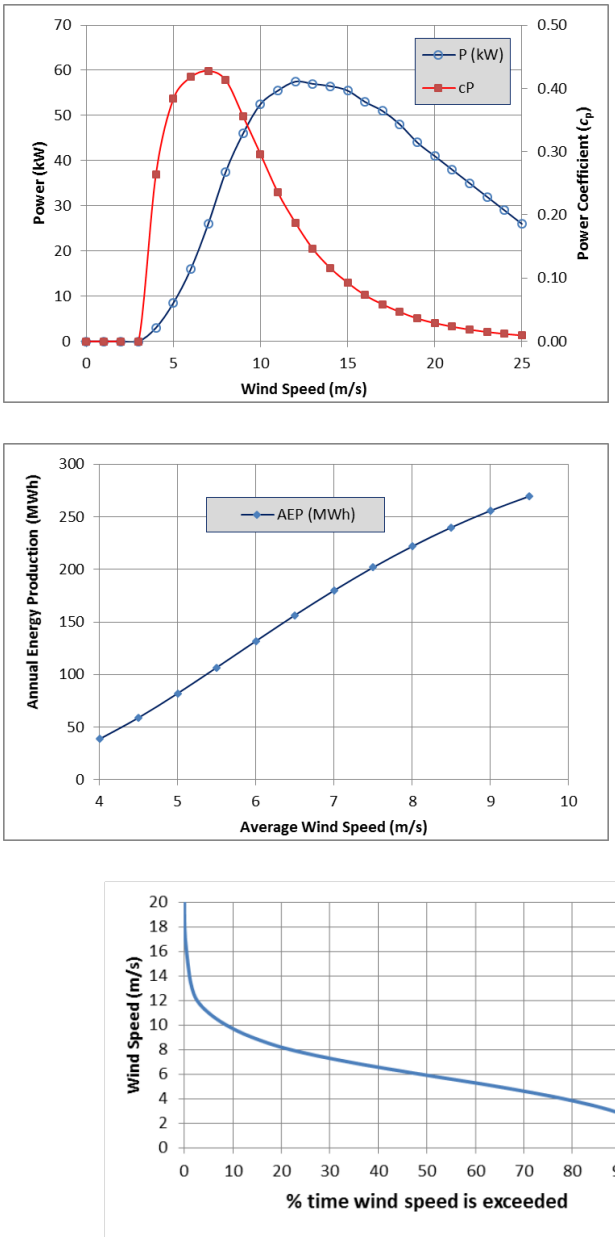

Figure 1: (top) Power and power coefficient of the wind turbine as a function of wind speed, (middle) Annual energy production of the turbine as a function of mean wind speed at hub height. (bottom) Wind speed duration curve at turbine site.

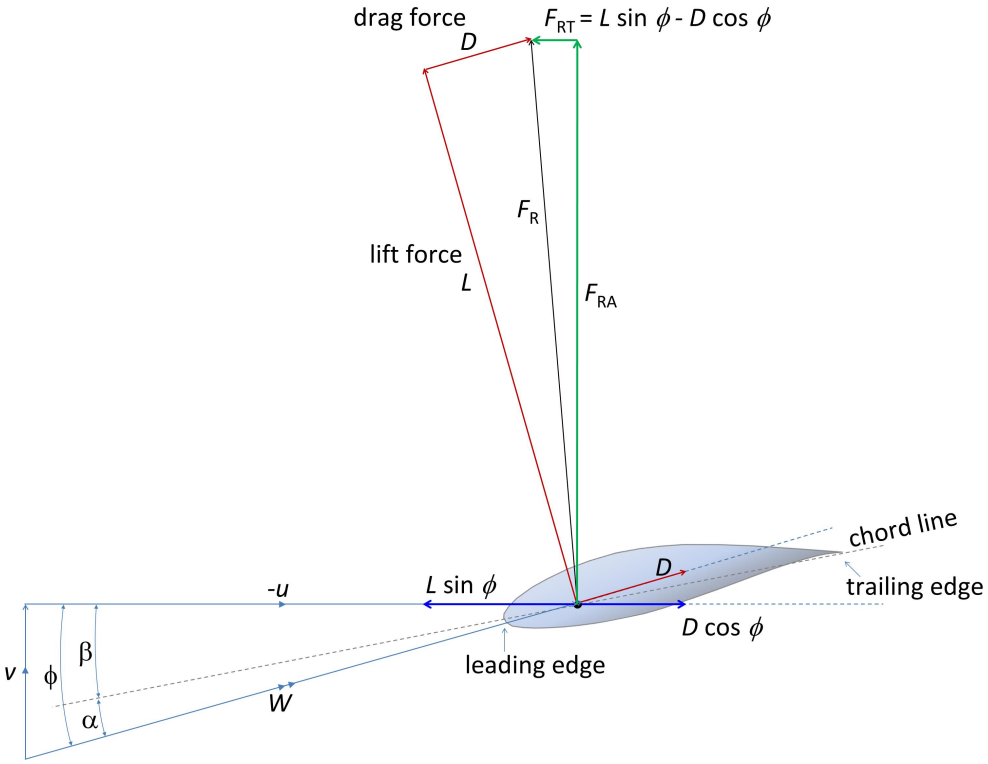

Figure 2: Section through foil of turbine

Question 2: (11 marks) Figure 2 shows a section through a rotor blade of the wind turbine of Question 1, at a point where the forward velocity of the leading edge is u, and at a time when the wind speed is v.

a) [3 marks] Identify from this diagram the quantities that represent the

   i) pitch angle

   ii) angle of attack

   iii) apparent velocity

b) [3 marks] Draw a sketch to show that if the wind speed were to increase, then the angle of attack would also increase.

c) [2 marks] If that happened, what could be done to reduce the angle of attack back to its original value?

d) [3 marks] Explain why the rotor blade stalls if the angle of attack becomes too large.

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Question 3: (11 marks) A 6 kW wind turbine on a small holding generates 10 000 kWh per year. The household uses 4000 kWh per year and 8000 kilowatthour per year is exported. The Feed-in tariff (FiT) for this turbine when commissioned was 23 p kWh^{-1}, the export tariff was 4.7 p kWh^{-1} and the import tariff is 15 p kWh^{-1}. The cost of the turbine was 25000 pounds sterling.

a) [2 marks]What is the annual income from the FiT?

b) [2 marks]By how much is the annual electricity bill of the small holding reduced because of the turbine?

c) [3 marks]Estimate the simple pay-back time of this turbine.

d) [2 marks]If discounting is taken into account, what impact would that have on the pay-back time as calculated in the previous part?

e) [2 marks]What could the owners do to reduce this payback time?

Question 4: (10 marks) Wind power is widely regarded as a low-carbon source of electricity. Briefly outline the circumstances (if any) under which this is true. A good answer will demonstrate knowledge of the actual carbon intensity of wind-produced electricity, how this compares to the carbon intensity of electricity from other sources and of the factors that most contribute to it.

——— *End of Exam* ———