IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2015

EEE PART IV: MEng and ACGI

SUSTAINABLE ELECTRICAL SYSTEMS

Corrected Copy

Thursday, 7 May 10:00 am

Time allowed: 3:00 hours

There are FIVE questions on this paper.

Answer FOUR questions.

All questions carry equal marks.

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : A. Junyent-Ferre, G. Strbac
Second Marker(s) : G. Strbac, A. Junyent-Ferre

There are five questions; answer four.

1. Wind power

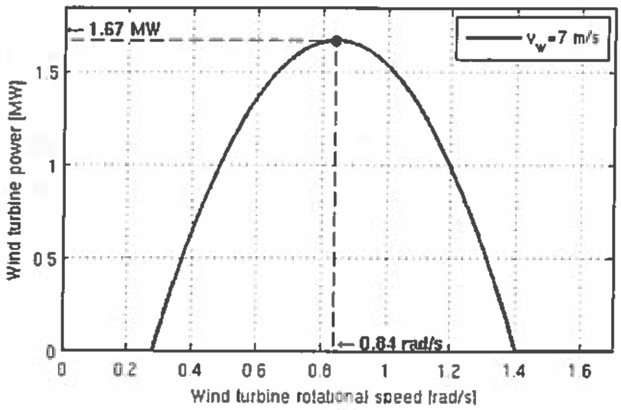
a)

i) Sketch and describe the characteristic curve of a wind turbine (power yield against wind speed). [3]

ii) Explain what mechanisms wind turbines use to control (or to limit) the power they extract from the wind. [4]

iii) Wind turbines have a power-limitation operating region. Explain the reasons in favour of having a power-limitation region. [2]

b) The following graph shows the power extracted by a wind turbine against its rotational speed for a wind speed of 7 m s^{-1}. To answer the following questions, take 75 m as the radius of the blades and assume the density of the air is 1.225 kg m^{-3}.



i) Calculate the power coefficient, the tip speed ratio (TSR) and the turbine torque at the maximum power point (MPP) for a wind speed of 7 m s^{-1}. [3]

ii) Sketch the power coefficient against the TSR. Mark on the graph the MPP. Confirm that the maximum power coefficient is consistent with maximum value predicted by the Betz limit. [3]

iii) Sketch the wind turbine torque against the rotational speed for a wind speed of 7 m s^{-1}. Mark on the graph the operating point that corresponds to the MPP. [2]

c)

i) Describe the differences and potential pros and cons of a wind turbine with direct-drive permanent magnet synchronous generator (PMSG) against a wind turbine with doubly-fed induction generator (DFIG). [3]

2. PV, hydro and marine

a)

i) Sketch and describe the characteristic curve (current against voltage) of a PV panel and explain how temperature and irradiation affect its shape. [5]

ii) What is the problem of connecting PV cells in series? How would you prevent this problem? [2]

iii) What is the meaning of the watt-peak rating of a PV panel? [2]

iv) What is the meaning of the Air Mass (AM) number? [2]

v) Explain why is it beneficial to adjust the position of a PV panel to track the position of the sun. [2]

b)

i) Two hydroelectric power plants are planned to be built in two different locations: one with 30 m of head and another with 600 m of head. Which location would be adequate for a Kaplan-type turbine and which would be adequate for a Pelton-type turbine? List the basic characteristics of these turbines. [3]

ii) Describe two different types of wave energy generators. [2]

iii) Compare the advantages and disadvantages of tidal barrage generation versus tidal stream generation. [2]

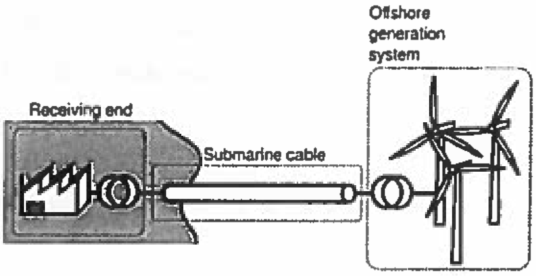
3. Offshore power transmission

a)

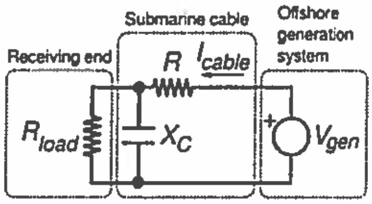
i) Explain why the space required to build an LCC-HVDC substation is greater than the space required for a VSC-HVDC substation. [2]

ii) List the advantages and disadvantages of XLPE cables compared to MI. [1]

b) An offshore transmission system feeds an onshore load from an offshore generator through a submarine HVAC cable (see diagram below). The generator can be modelled as a voltage source with V_{gen}= 220 kV and the load can be modelled as a resistor R_{load}= 440 Ω. According to the manufacturer, the submarine cable has a maximum rated current of 600 A and its equivalent circuit can be modelled using a resistor, R, and a capacitor X_c. The impedances of the resistor and the capacitor are: R=0.034·L Ω and X_c=23,000·$(1/L)$ Ω, where L is the length of the cable in kilometres (see equivalent circuit below).



Equivalent circuit:



i) Calculate the current flowing through the cable, I_{cable}, for a cable length of L=1 km and L=50 km. Which case causes the cable current rating to be exceeded? [2]

ii) Explain why the cable current rating is exceeded in one case only even though load and generation are the same. [3]

iii) Explain how would you modify the design of the transmission system to avoid this problem in a real application. [2]

c) It is expected that variable and difficult to predict wind generation will make a significant contribution to reducing carbon emissions in future UK electricity systems. List and briefly describe the key challenges associated with integration of wind generation in the future UK system, considering both short term operation and long term planning time horizons. [5]

d) Briefly describe how and why the level of redundancy in electricity network design changes with the level of connected load. Explain why it is important to consider the contribution that distributed generation can make to distribution network security. [5]

4. Heat

a)

i) In order to achieve the UK's 2050 CO_2 80% reduction target, heat will need to be decarbonised. Heat can be categorised as high grade heat and low grade heat. Briefly outline the difference between each category. [1]

b) In March 2013 the UK Government published "The future of heating: Meeting the challenge". Amongst a number of proposals it announced the establishment of a Heat Networks Delivery Unit to support the longer term development of heat networks.

i) Briefly outline the features of a district heating system and list the main components and their function. [3]

ii) List the heat sources that can be connected to a district heating system. [2]

iii) What are the benefits and drawbacks of a district heating system? [3]

iv) List the key challenges for the large scale deployment of district heating systems in GB. [3]

c) Heat pumps are generally seen as key technology for decarbonising heat.

i) Briefly explain how a heat pump works. [1]

ii) Briefly explain how a heat pump produces renewable heat and what factor influences the proportion of heat deemed to be renewable. [1]

d)

i) A householder is considering installing a heat pump to replace her gas boiler. The heat pump is subsidised by the Government so that the cost is the same as the gas boiler. Her annual heat demand averages 10 MWh and the electricity tariff 13p/kWh whereas the gas tariff is 5p/kWh. Stating any assumptions, calculate her expected annual cost or saving from installing a heat pump. [3]

ii) The householder has been advised that the heat pump will result in lower CO_2 emissions. Her gas boiler is 90% efficient whereas she expects her new heat pump to have an average efficiency of 270%. What information is required to determine whether or not the installation of electric heat pumps will lead to a reduction in CO_2 emissions? Assuming the CO_2 emissions from gas combustion is 190g/kWh and from grid electricity is 500 g/kWh, calculate the annual CO_2 savings she can expect from her heat pump. [3]

5. Active network management

a) A wind farm is connected to the electrical system via 11kV overhead line as shown in Figure 5.1. The 33kV/11kV transformer is equipped with automatic voltage regulator and keeps the voltage at busbars 1 at 11 kV. Overhead line length, unit resistance and reactance are shown in Figure 5.1.

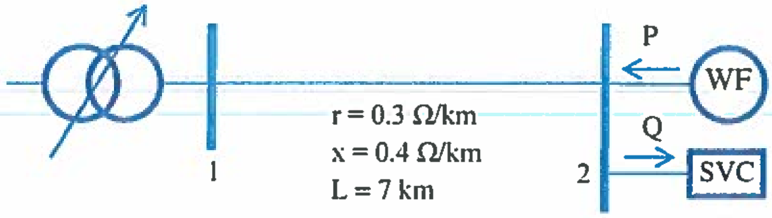


Figure 5.1: Wind farm connection.

i) Determine the maximum rating of the wind farm that can be connected without curtailment and without any active network management measure being applied, if maximum allowed voltage rise at the connection point is limited to 3%. Wind farm operates at the unity power factor. [5]

b) Energy production of the wind farm is variable and changes in time. The relative annual wind farm production duration curve is given in Figure 5.2.

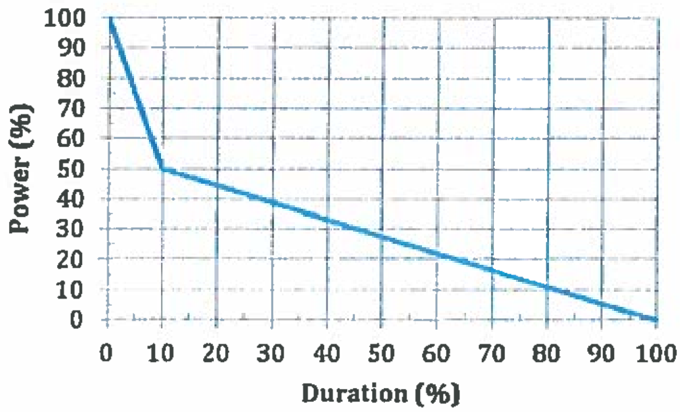


Figure 5.2: Wind farm production duration curve duration (100% = 8760h).

If the wind farm rating is 5 MW (power 100% in Figure 5.2) estimate the annual curtailment of wind energy for different active management techniques:

i) When only active power management is used for voltage control. [5]

ii) If a reactive compensation is applied in the busbar 2 and reactive power can be absorbed to compensate for voltage rise effect, so that the wind farm can operate at power factor of 0.95. [5]

iii) If a coordinated voltage control can be used, which would reduce the voltage at the busbar 1 for 2% (and hence allow additional voltage rise at the wind farm connection point of approximately 2%) combined with the active and reactive power management. [5]