IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2014

EEE PART IV: MEng and ACGI

Corrected Copy

SUSTAINABLE ELECTRICAL SYSTEMS

Thursday, 8 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) : T.C. Green, R. Silversides, G. Strbac
Second Marker(s) : G. Strbac, T.C. Green, T.C. Green

1.

a)

i) Explain why a wind turbine cannot capture all of the kinetic energy in an air flow. Describe the Betz limit and explain its importance. [4]

ii) Explain why is it important for a wind turbine to be able to operate at different rotational speeds. [3]

iii) Describe what is meant by the fault ride-through capability of a wind turbine. [2]

b) A particular variable speed wind turbine has a blade radius of 45 m, a cut-in wind speed of 3.5 m s^{-1}, a rated wind speed of 12 m s^{-1}, a cut-out wind speed of 26 m s^{-1}, a rated turbine power of 3.23 MW and a rated turbine speed of 18 min^{-1}. → RPM

i) Calculate the maximum power coefficient the wind turbine achieves and the optimal tip speed ratio assuming perfect maximum power point tracking below the rated wind speed and an air density of 1.225 kg m^{-3}. [2]

ii) Sketch the turbine power, the power coefficient, the turbine speed and the operating tip-speed ratio for a range of wind speeds from 0 to 30 m/s using the supplied graph paper. Assume the power reduction above the rated wind speed is achieved through blade pitch angle control only. Make sure you include a short description of the curves and any calculation required to plot them. [5]

c)

i) Compare the pitch-to-stall versus the pitch-to-feather power reduction methods for wind turbines equipped with variable pitch. [2]

ii) Discuss the benefits and drawbacks of a wind turbine designed to operate at a high tip-speed ratio versus one designed for a low tip-speed ratio. [2]

2.

a)

i) Describe the problems associated with integrating tidal electricity generation into an electricity network compared with hydroelectric electricity generation. [3]

ii) Describe the way in which both of these generation technologies can be used to provide on demand electricity. [4]

b)

i) Discuss why technology of both hydroelectric generation schemes and tidal generation schemes could lead to objections from the public. [4]

ii) Explain the way in which both generation technologies have produced a similar solution to overcome many of these objections. [3]

c)

i) Compare the variability in energy available from wave energy converters with the variability of energy available from wind turbines. [2]

ii) Explain the way in which wave energy converters, tidal generation schemes and offshore wind turbines are connected to the grid. What advantages are there to tidal generation schemes and wave energy converters. [4]

3.

a) Explain why it is important to quantify the ability of distributed generation to substitute for distribution network assets and incorporate this contribution in distribution network design standards? [3]

b) What are the key weaknesses of the method used in the UK for assessing contribution of DG to network security? [3]

c) Consider the network in which two embedded CHP generators of capacities of 2 MW and 3 MW are connected to a 33/11kV substation as shown on Figure 3. For the winter demand profile of the load connected to this network shown below, quantify the contribution to network security that would be effectively provided by the two generators, if the availability of individual generation unit is 85% (3 MW unit) and 90% (2 MW unit). [10]

d) If the peak demand is 15.8 MW, assess if this network is compliant with the UK network security standards. [4]

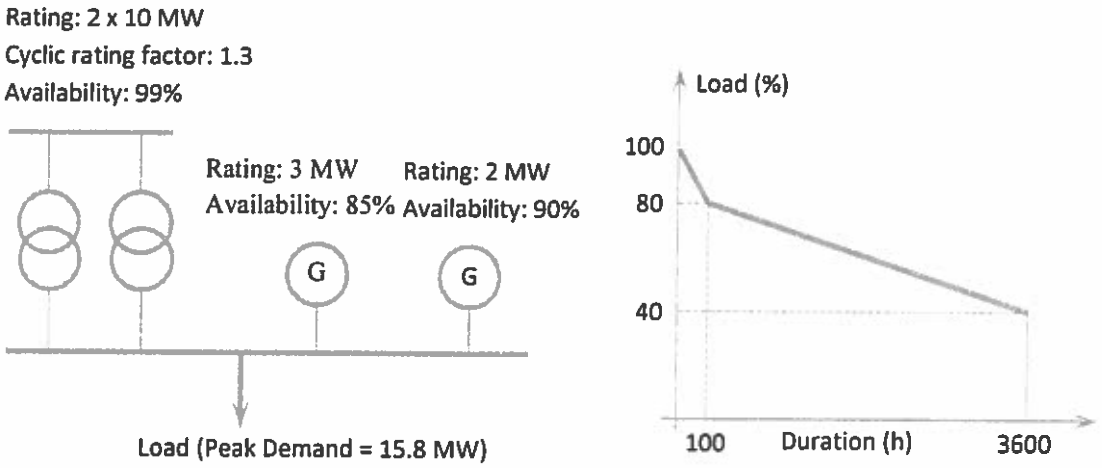

Figure 3

4.

a) In order to achieve the UK's 2050 CO_2 80% reduction target, heat will need to be decarbonised. 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. [4]

ii) What are the benefits and drawbacks of a district heating system? [4]

iii) 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 12p/kWh whereas the gas tariff is 5.5p/kWh. Stating any assumptions, calculate her expected annual cost or saving from installing a heat pump. [3]

iv) Assuming the CO_2 emissions from gas combustion is 190g/kWh and from grid electricity is 500 g/kWh, estimate the annual CO_2 savings from replacing the gas boiler with the heat pump. [3]

b) There has been growing interest in the application of energy efficiency and demand side management / response in supporting cost effective operation of future electricity systems.

i) List 3 measures introduced by the government to facilitate uptake of energy efficiency measures and demand side management / response. [3]

ii) Describe the effects of load reduction and load recovery when demand side management / response is used to provide peak demand reduction. [3]

5.

a) In the future UK electricity system, it is expected that inflexible nuclear generation and variable and difficult to predict wind generation, will make the key contribution to reducing carbon emissions in electricity production.

i) What are the advantages and disadvantages of providing reserves for managing uncertainty in wind generation production by part-loaded Combined Cycle Gas Turbines (spinning reserve) and by Open Cycle Gas Turbines (standing reserve)? [4]

ii) What are the advantages and disadvantages of using pumped-storage hydro generation to provide flexibility in systems with significant penetration of wind generation? [3]

iii) What are the advantages and disadvantages of enhancing the flexibility of nuclear generation to provide reserve in systems with intermittent renewables? [3]

b)

i) Which HVDC technology is preferred for offshore wind power transmission, VSC-HVDC or LCC-HVDC? Justify your answer. [3]

ii) Explain what transmission technology, HVAC or HVDC, would be most cost effective in the following cases: [2]

(1) An offshore wind farm located 150 km far from the shore.

(2) A wind farm located in a remote inland location connected to the main grid through a 200 km overhead line.

c)

i) Discuss the advantages and disadvantages of building multi-terminal HVDC grids compared to individual point-to-point HVDC links. [3]

ii) Sketch approximate graphs of maximum power transmission capacity against transmission distance for AC cables and DC cables. Explain why they are different. [2]