EGT3
ENGINEERING TRIPOS PART IIB

Thursday 28 April 2016 2 to 3.30

Module 4B19

RENEWABLE ELECTRICAL POWER

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) Explain the advantages and disadvantages of the following means of renewable electrical power generation in the context of the UK's generation mix: large-scale wind power; bio-mass incineration; tidal barrage schemes; hydro-electric schemes. [30%]

(b) Explain why there is much current interest in the generation of electricity from wave power, and give three challenges facing the exploitation of this resource. Also explain the principle of operation of buoy-type generators. [20%]

(c) The mean power per unit width of wavefront, P, is given by:

$$P = \frac{\rho g^2 T H^2}{32\pi}$$

where ρ is the density of sea water, 1030 kgm^{-3}, and H and T are the height and period of the waves respectively. A wave-power scheme is proposed which would populate a 2 km length of coastline with buoy-type devices coupled to vernier hybrid generators. The devices are 60% efficient and are spaced 5 m apart. Simplified data for the wave height, H, period, T and number of days of the year for which these values apply is given in Table 1.

Wave height, H (m)	Wave period, T (s)	No of days
1	4	100
2	6	200
4	9	65

Table 1

(i) Sketch a graph of the output voltage vs time for a vernier hybrid machine, and use the graph to explain why a fully-rated converter is required to connect the output of the machine to the grid. [15%]

(ii) Find the minimum and maximum available total electrical power. [10%]

(iii) Determine the required rating of the vernier hybrid generators assuming that they are capable of extracting the maximum available power. [5%]

(iv) Determine the annual electrical energy produced by the system and its capacity factor and comment on your answer. [20%]

2 (a) It has been quoted that the UK could generate around 20% of its electrical energy by large-scale wind power, but beyond that limit upgrades to the grid infrastructure would be needed. Explain the reasons for this limit, and give three measures that could be taken to increase this limit. [25%]

(b) The average complex power, $\bar{S}$, that can be transferred by a lossless transmission line of reactance X Ohms/phase is given by the equation below, in which V_1 and V_2 are the phase voltages at the load and source respectively, and δ is the angle between them. With reference to this equation, explain how real power and reactive power flows are controlled in electrical power systems.

$$\bar{S} = \frac{3V_1V_2\sin\delta}{X} + j\frac{3\left(V_2^2 - V_1^2\right)}{2X}$$

Also explain how Flexible AC Transmission Systems can be used to increase the capacity of a power system. [35%]

(c) A new 80 MVA wind farm with a rated real power output of 40 MW and rated voltage of 6.6 kV is proposed. The wind farm can be modelled as a synchronous generator of negligible pu synchronous reactance. The magnitude and angle of the generator excitation voltage are limited to 1.1 pu and 30° respectively. Fig. 1 shows the existing grid feeder and transformers proposed to be used to connect the wind farm to the 33 kV load bus. The voltage at the 33 kV load bus is always 1 pu and the load power factor can vary between unity and 0.8 lagging. Find the maximum real and reactive power that can be transmitted from the wind farm to the 33 kV distribution bus, and hence show that the existing grid infrastructure is inadequate. Assuming a 50 Hz grid, determine the value of the star-connected capacitors to be connected in parallel with the load to enable the existing grid infrastructure to operate as required. [40%]

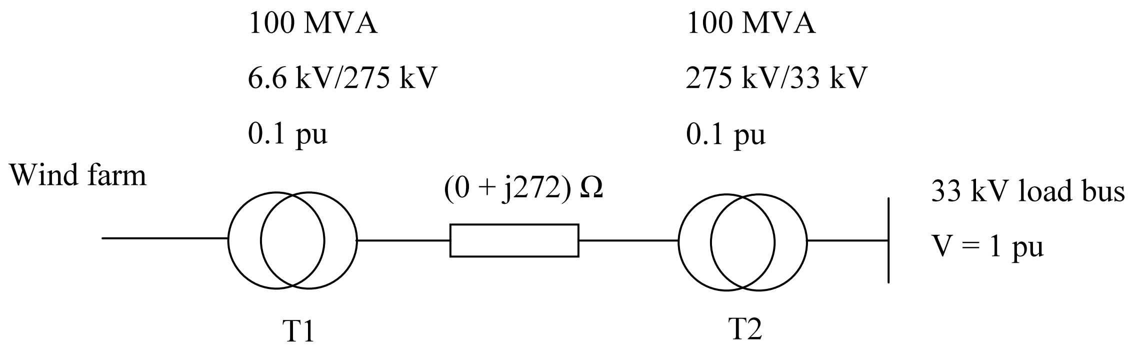

Fig. 1

3 (a) Explain the advantages and disadvantages of synchronous generators and induction generators for large scale wind generation. Explain, using the ideas of tip-speed ratio and power coefficient, why it is advantageous for wind turbines to operate at variable speed. Describe how power electronic converters can be used with these generators to enable variable speed operation. [30%]

(b) A large wind turbine is to be proposed for a site with the wind speed data shown in Table 2.

Wind speed [ms^{-1}]	2	6	10	14	18	22
Number of days	30	130	90	60	30	25

Table 2

The wind turbine has a rated wind speed of 12 ms^{-1} and a rated output power of 3.2 MW. The cut-in and stall speeds are 4 ms^{-1} and 20 ms^{-1}, respectively. The optimum tip-speed ratio is 8, at which the power coefficient is 0.4. Assume variable speed operation, such that the optimum tip-speed ratio is maintained between the cut-in and rated speeds, and 400 kW of power is generated at the most probable wind speed. Determine the output electrical power for each of the given wind speeds, and calculate the total annual energy supplied by the turbine, ignoring generator losses. What is the capacity factor of this wind turbine? [30%]

(c) An induction generator is to be used with the turbine of part (b) with variable speed operation. Consider an 8 pole, 11 kV, 50 Hz, star-connected three-phase induction generator with the following equivalent circuit parameters: $R_1 = 0.6\,\Omega, R_2' = 0.4\ \Omega$, $X_1 = 1.4\,\Omega, X_2' = 1.1\ \Omega$, and X_m and R_0 are large enough to be ignored. Assume an optimal tip-speed ratio of 8 and a turbine blade diameter of 98 m. Determine the following, at the rated wind speed:

(i) the turbine angular speed and torque; [5%]

(ii) the gearbox ratio required to operate at this optimum tip-speed ratio; [5%]

(iii) the slip and the generator speed; [10%]

(iv) the output real and reactive power; [10%]

(v) the generator power losses, the input mechanical power, and the generator efficiency. [10%]

4 (a) The output power of a hydroelectric power scheme is given by

$$P = \eta g H \rho Q$$

Define the terms in this expression and describe, using a diagram, how hydroelectric schemes are categorised. Give an expression for the specific speed of a turbine and explain how this is used to assess the optimum performance of a turbine for a particular site. Explain why hydroelectric power schemes use salient pole synchronous generators. [30%]

(b) A potential site for a hydroelectric scheme has an available head of 80 m and a flow rate of 15 m^3s^{-1}. The overall system efficiency has been estimated at 80%. A turbine with an ideal specific speed of 243.4 is coupled to a salient pole synchronous generator. The generator is connected directly to the 50 Hz grid and operates at a power factor of 0.8 lagging. Assume $g = 9.81$ ms^{-2} and $\rho = 1000$ kgm^{-3}.

Determine:

(i) an appropriate turbine type for this particular scheme; [5%]

(ii) the turbine rotational speed, assuming the turbine operates at its ideal specific speed; [10%]

(iii) the turbine torque at this speed; [5%]

(iv) the VA rating of the generator and its number of pole-pairs. [10%]

(c) An 11 kV, 50 Hz, star-connected, salient pole synchronous generator of the same rating and number of pole-pairs as determined in (b) part (iv) has equivalent circuit parameters $X_d = 1.5\ \Omega$ and $X_q = 0.9\ \Omega$. Using a phasor diagram, determine its load angle and line-line excitation voltage when delivering rated power to the 11 kV, 50 Hz bus at its operating power factor of 0.8 lagging. [40%]

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