Version RAM/3

EGT3

ENGINEERING TRIPOS PART IIB

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Friday 25 April 2014   2 to 3.30

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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

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

1 (a) Choosing a suitable site for a wind farm is a complex process and requires a number of careful considerations. Describe five factors involved in site selection for wind turbines. List two advantages and two disadvantages of offshore wind turbines in comparison to those onshore. [20%]

(b) Sketch a typical wind turbine-generator power versus wind speed characteristic, assuming a 2 MW rated generator output power and a rated wind speed of 10 ms^{-1}. Define the terms 'cut-in', 'rated' and 'stall' with respect to wind speed and label these on the sketch. Describe two ways in which the wind turbine power can be controlled so that the rated power is not exceeded between rated and stall wind speeds. [20%]

(c) A large wind turbine is to be proposed for a site with the following wind speed data:

Wind speed [ms^{-1}]	2	6	10	14	18	22
Number of days	40	150	80	50	30	15

The wind turbine has a rated output power of 2 MW and a rated wind speed of 12 ms^{-1}. The cut-in and stall speeds are 3 ms^{-1} and 20 ms^{-1}, respectively. The turbine is to be operated at its optimum tip-speed ratio between the cut-in and rated speeds.
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 installation? [30%]

(d) An induction generator is to be used with the turbine of part (c). Sketch a typical torque-speed curve for an induction machine and label the regions corresponding to motoring and generating, including the values of slip in each region.

Consider an 8 pole, 6.6 kV, 50 Hz, star-connected three-phase induction generator with the following equivalent circuit parameters:

$$R_1 = 0.3 \ \Omega, R_2' = 0.4 \ \Omega, X_1 = 1.2 \ \Omega, X_2' = 0.8 \ \Omega$$

(cont.

X_m and R_0 are large enough to be ignored. Assuming an optimal tip-speed ratio of 8 and a turbine blade diameter of 70 m, calculate the turbine angular speed and torque at rated speed. Determine the gearbox ratio required to operate at this optimum tip-speed ratio at rated wind speed. Estimate the slip at rated wind speed and the generator speed.   [30%]

2 (a) Give three advantages and three disadvantages of large scale hydroelectric power schemes as a source of power. [15%]

(b) Show that the power generated by a hydroelectric scheme in which the head of water is maintained constant is given by

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

and define all the terms in this expression. Describe how hydroelectric schemes are categorised by the head of water available and outline the turbine technologies associated with each turbine. [25%]

(c) Making appropriate assumptions for ρ and g, calculate the peak power output for each site and suggest the most applicable turbine for each of the following sites, including your reasons.

Site	Maximum head	Maximum flow	Efficiency
A	120 m	25 m^3s^{-1}	80%
B	9 m	20 m^3s^{-1}	89%

The specific speed N_S for a turbine for a hydroelectric scheme is given by

$$N_S = n \times P^{1/2} H^{5/4}$$

where P is expressed in kW and H in m. Given the following ranges of N_S, calculate the range of rotational speeds the turbines at sites A and B could operate at, and hence the range of pole numbers for the generators, assuming connection to a 50 Hz grid. Explain briefly why a salient pole synchronous machine would be preferred here rather than the cylindrical type used in conventional fossil fuel/nuclear power stations.

Turbine	N_S	
Propeller	350 – 1000 rpm	
Francis	70 – 500 rpm	
Impulse	10 – 80 rpm	[30%]

(d) Describe two ways in which potential investors can evaluate a renewable energy project.

A hydroelectric scheme has a peak capacity of 0.5 GW and the capacity factor is anticipated to be 20%. The civil engineering works are budgeted at £672 million, the generators and ancillary controls at £87 million. Operation and maintenance is estimated at £10 million over the anticipated 100 year lifetime of the project. The lifetime of the generators and ancillary controls is assumed to be 50 years. The electricity generated by this scheme will be sold at 10p per kWh to supply peak demand power only.

Ignoring the effects of interest and inflation, and assuming the construction time of the scheme is negligible, determine the payback time for the initial investment and the average cost per kWh of the electricity produced over the 100 year lifetime.

With respect to a large scale hydroelectric scheme, how valid are the assumptions made in the previous calculation? Describe how discounted flow analysis (DCF) can be used to more accurately assess a renewable energy project. [30%]

3   (a)   (i)   Why is generating at 900 V instead of the usual 690 V seen as attractive in the context of power conversion in a wind turbine.   [10%]

(ii)   The output of a generator is connected to a combined AC to DC and DC to AC converter for feeding into the grid. Suggest a value for the DC link voltage, with reasons, if the generator's maximum output voltage is 900 V.

Note

$$V_{AC} = m\frac{\sqrt{3}}{2\sqrt{2}}V_{DC}$$

where the symbols have their usual meanings.   [15%]

(b)   An 8-pole slip ring induction generator is to be used for a variable speed wind turbine. The operating speed range is to be 500 to 1000 rpm, with full power of 1.6 MW being delivered at 1000 rpm. The grid frequency is 50 Hz.

(i)   Calculate the power delivered from the stator and the power exported via the slip rings at 1000 rpm.   [15%]

(ii)   What range of frequencies must be supplied to the slip rings?   [10%]

(iii)   What machine side converter rating is required assuming that the power factor is 0.9 lagging?   [10%]

(c)   The blades of the wind turbine are increased in size so that maximum power is achieved at a generator speed of 750 rpm.

(i)   What advantages does this bring to the wind farm operator?   [10%]

(ii)   Find the powers exported from the stator and via the slip rings at 750 and 1000 rpm.   [15%]

(iii)   How should the ratings of the generator and converter be changed in this new arrangement? Comment on the implications.   [15%]

4   (a)   The three-bladed horizontal axis turbine configuration can be used for both wind (onshore and offshore) and tidal current applications. Compare these applications in terms of

    (i)   turbine dimensions   [10%]

    (ii)   expected capacity factor   [10%]

    (iii)   maturity of the technology   [10%]

    (iv)   grid connection issues   [10%]

(b)   Sites for the generation of power from sea waves are often classified as shoreline, near shore and deep water. Describe devices for power generation at any two of these locations, with particular regard to

    (i)   extent of resource   [5%]

    (ii)   principle of operation   [15%]

    (iii)   power take-off   [15%]

    (iv)   environmental impact.   [5%]

(c)   What impacts might the increasing use of renewable generation have on the management of the National Grid? How might these be mitigated?   [20%]

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4B19 Numerical answers

1 (c)   0.25 MW, 1.16 MW, 2 MW, 2 M", 6.96 GWhr, 39.7%

1 (d)   2.74 rads/S, 730 kNm, 29, 0.018, 79.9 rads/S

2 (c)   Francis turbine: 179 – 1282 rpm, 4-32 pole,

                         Propellor turbine: 136 – 390 rpm, 16 – 44 pole

2 (d)   8.67 years, 1p

3 (a)   At least 1470 V

3 (b) (i)   1.2 MW, 0.4 MW,

      (ii) $\pm 16^2/_3$ Hz

      (iii)   0.44 MVA

3 (c) (ii)   1.6 MW, 0 MW, 1.2 MW, 0.4 MW