ENGINEERING TRIPOS PART IIB

Wednesday 27 April 2011 9 to 10.30

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.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

TJF04

1 (a) The generation of power from wind and waves are two means of renewable generation. In the context of the British Isles, compare these two sources in terms of

(i) extent of the resource;

(ii) possible environmental impact. [10%]

(b) Describe the key components of the contemporary horizontal axis wind turbine as found in wind farms.

Explain the differences between

(i) systems using direct drive and those using a gearbox;

(ii) those using the doubly-fed scheme and those using a fully rated converter. [35%]

(c) Define the capacity factor of a wind turbine.

What considerations should a wind farm developer take into account to achieve a high capacity factor? [15%]

(d) Give two examples of methods of generating power from sea waves. Describe the essential features of the methods in terms of

(i) intended location;

(ii) classification of device;

(iii) power take-off principles.

Give two reasons why the development of renewable generation from sea waves has been relatively slow. [40%]

2 (a) Show that the electrical power which may be extracted by a wind turbine is given by

$$P=0.5\, C_p \rho A v^3$$

and define all the terms in this expression. [15%]

(b) A variable-speed wind turbine is to be designed to produce a total annual energy output of 8 GWhr. The system has a cut-in wind speed of 4 ms^{-1}, a rated wind speed of 13 ms^{-1} and a stall wind speed of 21 ms^{-1}. It is to operate at its optimal tip-speed ratio between cut-in and rated wind speeds. At wind speeds between rated and stall it is controlled so that it produces its rated output power. Its optimal tip-speed ratio is 9, at which its power coefficient is 0.36. A table with simplified wind speed data is below. The density of air should be taken to be 1.23 kgm^{-3}.

Wind speed (ms^{-1})	2	6	10	14	18	22
Number of days	25	160	120	40	16	4

Determine:

(i) the required power rating of the system and the turbine diameter;

(ii) the turbine rotational speed at wind speeds of 6 ms^{-1} and 10 ms^{-1}. [35%]

(c) An 11 kV, star-connected, 12 pole doubly-fed induction generator (DFIG) is to be used in the scheme of part (b). The generator equivalent circuit parameters are: $R_1 = 0.7\ \Omega$, $R_2' = 0.6\ \Omega$, $X_1 = X_2' = 0.5\ \Omega$, R_0 and X_m are large enough to be ignored. The DFIG is coupled to the turbine via a gearbox so that the injected rotor voltage is zero when the wind speed is 6 ms^{-1}. Determine:

(i) the required gearbox ratio;

(ii) the referred rotor injected voltage at the wind speed of 10 ms^{-1};

(iii) the converter power at the wind speed of 10 ms^{-1};

(iv) the generator power losses, net generator output power and the system efficiency at the wind speed of 10 ms^{-1}. [50%]

3 (a) Give two reasons why marine current turbines might be preferred to a fixed barrage for generating power from estuarial tidal flows. [10%]

(b) In a particular estuary, it is planned to use 1 MW turbines, with this power being reached at a flow of 5.1 ms^{-1}.

(i) What blade diameter will be needed? Note that the power P available from a tidal current is

$$P = 0.5\, C_p \rho A v^3$$

where the symbols have their usual meaning and the power coefficient can be taken to be 0.5.

(ii) The turbine is to generate down to 10% of full output. What flow rate will this correspond to?

(iii) The optimum tip-speed ratio is 12 for this turbine. If the maximum generator speed is 1250 rpm, what gearbox ratio will be required?

(iv) What will be the minimum generator speed? [40%]

(c) A converter arrangement as shown in Fig. 1 is used to change the generator's output to a three-phase output at 690 V for feeding to the 50 Hz grid.

(i) Show that the DC link voltage is related to the AC output by

$$V_{ac} = \frac{\sqrt{3}}{2\sqrt{2}} . V_{dc} . m$$

where m is the modulation index.

(ii) What will the minimum DC link voltage be if the grid voltage can fluctuate by +/- 10% and m is not allowed to exceed 0.95?

(iii) For what voltage should the induction generator be wound at 50 Hz for it to meet specifications over the expected speed range? [50%]

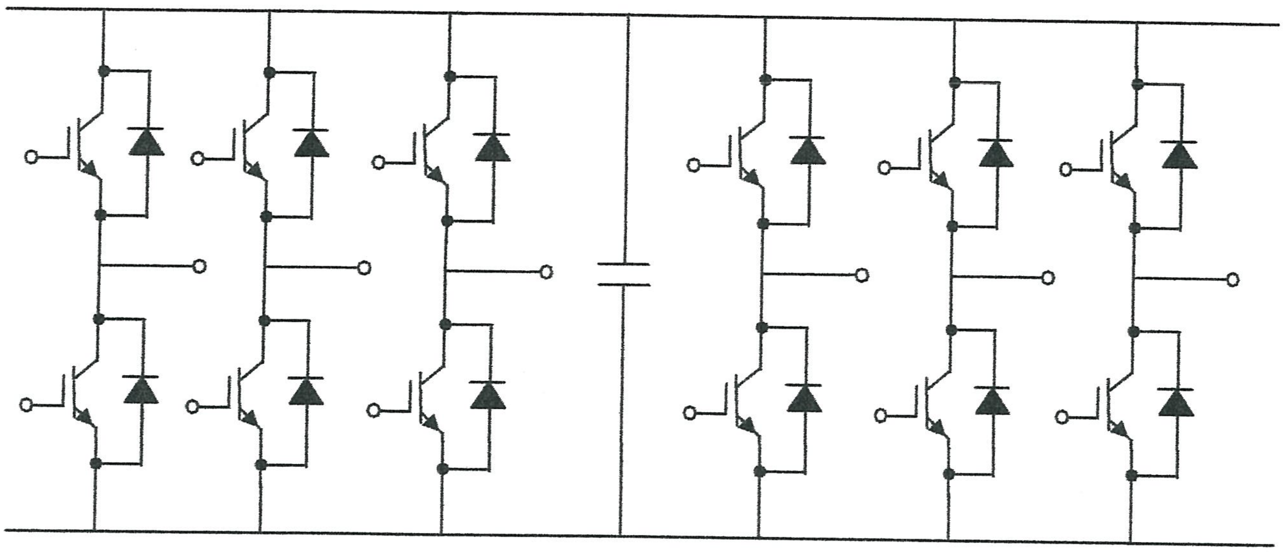

Fig. 1

(TURN OVER

4 (a) Explain the principles of ebb-flow tidal barrage schemes, and show that the theoretical upper limit to the average output power is given by

$$P = 0.5\rho g R^2 A/T$$

defining all the terms in this expression. [15%]

(b) Outline the main technologies used for the turbines and the generators in tidal barrage schemes. Explain what is meant by the specific speed, N_S, of a turbine, and define all the terms in the expression for specific speed below, giving their units.

$$N_S = nP^{1/2}H^{-5/4}$$ [15%]

(c) A proposed ebb-flow tidal barrage scheme has a tidal range of 16 m, a tidal period of 12 hours and a basin area of 160 km^2. It is able to extract an average output power of 40% of the theoretical upper limit of the average output power. Assuming that when the scheme is generating power, the flow rate through the barrage is constant and that power is generated over a period of 6 hours, estimate:

(i) the total flow rate through the barrage when generating power;

(ii) the average electrical output power and total annual electrical energy supplied by the scheme;

(iii) the peak electrical output power and the capacity factor of the scheme. [35%]

(d) In order to convert the tidal energy into electrical power for the scheme of part (c), it is proposed to use 200 propeller turbines all driving identical salient-pole synchronous generators which are connected directly to the 11 kV, 50 Hz grid. The specific speed of the propeller turbines should lie in the range 350 to 1000. The generators must be able to supply the rated power over a range of power factors, from 0.6 leading, to 0.8 lagging. Estimate, stating any assumptions made:

(i) the possible range of speeds and pole numbers of the generators;

(ii) the VA rating of the generators. [35%]

END OF PAPER