ENGINEERING TRIPOS PART IIB

Wednesday 23 April 2008 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.*

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

1 (a) Give two reasons for the current interest in the generation of electrical power from renewable sources. [10%]

(b) The generation of electrical power from the wind, sea waves and the combustion of biomass are three means of renewable generation. Write brief notes on these means of generation in terms of (i) availability of the resource and (ii) the state of development of the technology. [45%]

(c) In the context of the generation of power from sea waves, distinguish between *point absorbers, terminators* and *attenuators*. [15%]

(d) For a buoy-type marine generation system, compare power take-off systems using (i) an intermediate hydraulic system driving a rotating generator and (ii) a linear generator. The answer should include a brief description of any power conversion steps and how the power could be fed to a grid connection on shore. [30%]

2 (a) Define and explain the terms 'power coefficient' and 'tip-speed ratio' as applied to wind turbines, and sketch a typical graph of power coefficient vs tip-speed ratio. Use your graph to explain why it is advantageous for wind turbines to operate at variable speed. [30%]

(b) Show that the maximum power which may be extracted from the wind is given by

$$P = \frac{1}{2} \mathrm{C}_{\mathrm{p,max}} \rho A v^3$$

and define all the terms in this expression. [20%]

(c) A wind turbine has an optimum tip-speed ratio of 9, at which the power coefficient is 0.37. It has a rated wind speed of 12 ms^{-1} at which its rated power is 1.5 MW. Find:

(i) The turbine blade diameter.

(ii) The turbine angular speed and torque at rated wind speed.

Take the density of air to be 1.23 kgm^{-3}. [25%]

(d) A 6.6 kV, star-connected, 50 Hz, 6 pole induction generator has equivalent circuit parameters: $R_1 = 0.4\ \Omega$, $R_2' = 0.35\ \Omega$, $X_1 = 0.6\ \Omega$, $X_2' = 0.5\ \Omega$, X_m and R_0 are both large enough to be ignored. The generator is to be used with the turbine of part (c). Find the gearbox ratio required for the generator so that the system operates at optimum tip-speed ratio at rated wind speed. Also estimate the slip at rated wind speed and the output real and reactive powers. [25%]

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3 (a) Why are doubly fed systems popular for variable speed generation? [10%]

(b) A variable speed generation system using a brushless doubly fed machine (BDFM) is proposed for a marine current application. The BDFM has a 2 pole/6 pole configuration, giving a natural speed of 750 rpm. The operating speed range is to be 600 to 1000 rpm and the machine is to give a maximum output of 100 kW. A bi-directional converter for supplying the control winding of the BDFM is shown in Fig. 1.

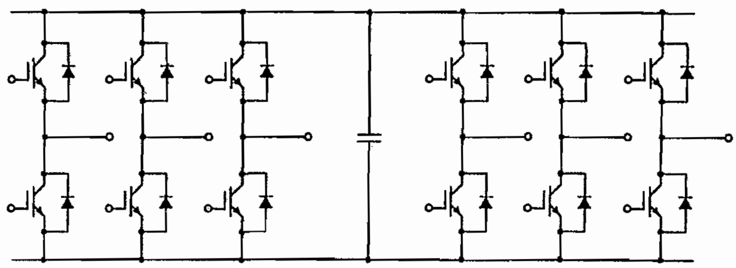

Fig. 1

(i) Calculate the ratings of the power and control windings, assuming that power is delivered at unity power factor from the power winding and at a power factor of 0.8 lagging from the control winding.

(ii) What is the minimum rating of the machine side of the converter and what range of frequencies must it deliver?

(iii) Find the minimum rating of the line-side converter.

(iv) Show that the line-to-line RMS voltage, V_{ac}, available from a 3-phase full-bridge convertor is related to the DC link voltage V_{dc}, by

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

where m is the modulation index.

(v) Calculate the minimum possible DC link voltage for successful power transfer to the grid if the voltage in the grid side of the converter is 690 V.

(cont.

(vi) If the control winding of the BDFM is star connected, and has a volts/Hertz ratio per-phase of 20, find the values of the modulation index required for operation at 600 and 1000 rpm. [80%]

(c) Why are insulated gate bipolar transistors (IGBTs) the switch of choice in power converters in this type of application? [10%]

Note: The rotational speed N of a BDFM is given by $N = 60.\frac{f_p + f_c}{p_p + p_c}$

where f_c and f_p are the frequencies of the power and control windings respectively and p_p and p_c are the respective pole pair numbers.

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4 (a) Explain how diversity of supply, and electrical energy storage technologies both help to overcome some of the problems of integrating renewable electricity sources into the existing electrical network. Give three examples of electrical energy storage technologies. [20%]

(b) Show that the average complex power transmitted between the two ends of a three-phase lossless transmission line of inductive reactance X ohms is

$$\overline{S} = P + jQ = \frac{3V_1 V_2 \sin\delta}{X} + j\frac{3(V_2^2 - V_1^2)}{2X}$$

where V_1 and V_2 are the magnitudes of the phase voltages at the two ends of the line and δ is the phase angle between these voltages. [25%]

(c) A wind farm is connected directly to the nearest load centre via a 3-phase, 50 Hz, 11 kV transmission line of phase impedance (0.4 + j2) Ω. The voltage at the load centre bus-bar is maintained at 11 kV. The wind farm supplies 10 MW of real power and no reactive power to the load. Find:

(i) the line current;

(ii) the voltage (magnitude and angle) at the wind farm bus-bar using the expression derived in part (b) or otherwise;

(iii) the power loss in the transmission line. [25%]

(d) The link between the wind farm and load is upgraded to a 33 kV link using step-up and step-down transformers at the wind farm and the load, respectively. Explain why this greatly reduces the transmission power losses, and estimate the new losses assuming that the wind farm still supplies 10 MW of real power and no reactive power to the load. [15%]

(e) Explain how discounted cash flow analysis would be used to assess the economic viability of the upgrade. [15%]

END OF PAPER