ENGINEERING TRIPOS PART IIB

Tuesday 23 April 2013 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.*

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) Give two reasons why the three-phase permanent magnet generator (PMG) is the preferred generator technology for small wind turbines. Draw the PMG equivalent circuit and the corresponding phasor diagram. Show that the PMG torque is proportional to the magnitude of its phase current when controlled at fixed torque angle, and that for optimum torque per unit current, the PMG should be operated at a torque angle of 90^0. [25%]

(b) A small wind turbine utilises a three-phase, 8 pole, star-connected PMG coupled directly to a turbine that is designed to produce its rated output power of 10 kW at its rated wind speed of 12 ms^{-1}. The system is controlled so that the turbine operates at its optimum tip-speed ratio of 9, at which the power coefficient is 0.35, between the cut-in wind speed of 4 ms^{-1} and rated wind speed. The PMG has an emf constant of 3.2 $Vsrad^{-1}$ and phase inductance of 5 mH. Assuming that the PMG is controlled so that it always operates at a torque angle of 90^0, determine:

(i) the turbine diameter; [15%]

(ii) the PMG output power, angular speed, input torque, phase current and line-line output voltage at a wind speed of 8 ms^{-1}. [20%]

(c) The generator output is connected to a full-wave three-phase rectifier. Draw the circuit diagram for this, and estimate the dc link voltage and current at the wind speed of (b) part (ii) above. You may neglect the voltage drop due to the PMG phase inductance, but assume a diode forward voltage drop of 1.2 V.

You may quote without proof that the mean output voltage, V_{dc}, of a full-wave three-phase rectifier is related to the input rms line-line voltage, V_l, by

$$V_{dc} = \frac{3\sqrt{2}}{\pi} V_l$$

[20%]

(d) For (c) above, sketch the generator phase current vs time for one of the phases. Hence explain why it is necessary to de-rate the generator when its output is connected to a three-phase full-wave rectifier. [20%]

2 (a) Explain why increasing the *diversity of supply* enables more renewable energy sources to be integrated into the power supply network. Give three examples of how this principle might be applied in practice. [15%]

(b) A lossless three-phase transmission line of inductive reactance X Ohms/phase connects two voltages together. The magnitudes of the phase voltages at the two ends of the line are V_1 and V_2, and the angle between them is δ. Derive expressions for the complex volt-amps at V_1 and the complex volt-amps at V_2. Use your results to explain the principles of matching supply and demand for real and reactive power. [35%]

(c) It is proposed to build a wind farm with a rated total output of 400 MW and rated voltage of 11 kV. The wind farm can be modelled as a synchronous generator of negligible pu synchronous reactance, with an excitation voltage limited to 1.4 pu. Fig. 1 below 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 power factor there is maintained at unity. Find the maximum power that can be transmitted from the wind farm to the 33 kV distribution bus. Hence show that the existing grid infrastructure is inadequate. [20%]

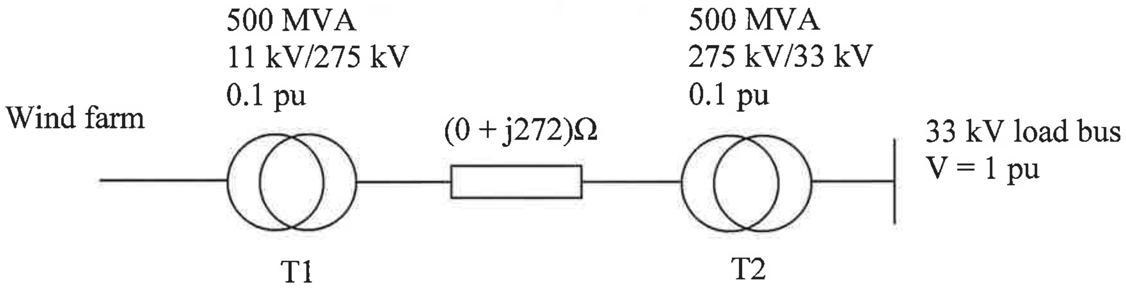

Fig. 1

(d) To overcome this problem it is proposed to upgrade the high voltage feeder from 275 kV to 400 kV. It is calculated that the transmission lines do not need to be replaced, so T1 will be replaced with a 500 MVA, 11 kV/400 kV, 0.1 pu transformer and T2 will be replaced with a 500 MVA, 400 kV/33 kV, 0.1 pu transformer. Show that the proposed upgrade will enable the system to operate as required, and find the magnitude and phase of the voltage at the wind farm when operating at the rated power output. [30%]

3 (a) Two forms of renewable generation are biomass fuelled power stations and barrages across tidal estuaries such as the River Severn. Compare these in terms of:

(i) the state of development; [10%]

(ii) the extent of the resource; [10%]

(iii) the environmental impact. [10%]

(b) Explain with the aid of diagrams the operating principles, including details of power take-off, of:

(i) shore-based tidal generation oscillating water column devices, such as the 'Limpet'; [20%]

(ii) point absorber type wave generators directly coupled to a linear generator, e.g. the Trident TE5; [20%]

(iii) offshore over topping devices, such as the 'Wave dragon'. [20%]

(c) Give two examples of applications of high voltage dc systems in conjunction with the increasing use of renewable generation. [10%]

4 (a) Give two benefits and two drawbacks of building wind turbines offshore as opposed to onshore. [10%]

(b) With the aid of a diagram explain how a slip-ring induction generator is configured in the doubly-fed mode. Why is this arrangement still the most popular for wind turbines? [40%]

(c) A medium speed drive train employing a brushless doubly-fed generator (BDFG) is proposed for a wind turbine. The three-phase power winding is rated at 690 V, 50 Hz. The pole-pair numbers of the power and control windings are 2 and 6, respectively.

(i) What is meant by the *natural speed* of a BDFG, and what is it for this machine? [10%]

(ii) The total output is to be 6 MW at a speed $^1/_3$ above natural. Find the power outputs of the power and control windings, respectively. [10%]

(iii) What is the frequency of the control winding current at maximum output power? [10%]

(iv) Suggest, with reasons, a voltage rating for the control winding. [10%]

(v) A design change requires the operating speed range to be increased up to 1 ½ times the natural speed, but with no increase in output power above 1 $^1/_3$ times the natural speed. How would this affect the design of the control winding? [10%]

Note: the synchronous speed of a BDFG is given by $N = 60 \times \left(\frac{f_1+f_2}{p_1+p_2}\right)$ where the symbols have their usual meanings

END OF PAPER