Version RAM/3

EGT3
ENGINEERING TRIPOS PART IIB

Monday 4 May 2015 9.30 to 11

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) The British Isles have a large potential renewable energy resource from both wind and marine sources. Give reasons why the practically achievable output may be substantially less than the potential resource in the case of:

(i) Onshore wind power. [10%]

(ii) Shore-line tidal generation. [10%]

(iii) Generation from marine currents. [10%]

(b) The Severn Estuary has long been recognized as a large potential source of energy. Building a barrage or using an array of marine current turbines mounted on the seabed are two possible ways of exploiting this resource. Compare these in terms of:

(i) Maturity of technology. [10%]

(ii) Constructional difficulty. [10%]

(iii) Environmental impact. [10%]

(c) Compare direct drive methods and systems using a hydraulic intermediary for marine generation, giving an example of a wave power device using each of these approaches. [30%]

(d) Under what circumstances might mooring be preferred to seabed mounting for marine generation devices? [10%]

2 (a) It is proposed to use a doubly-fed slip ring induction generator for a Marine Current Turbine (MCT). What are the attractive features of this arrangement and what are the potential drawbacks? [20%]

(b) An MCT has a maximum output of 600 kW and uses a 4-pole slip-ring induction generator. Full power is reached at an MCT shaft speed of 15 rpm, below which the output falls according to the cube law. Cut in speed is 10 rpm and cut out speed is 20 rpm. The gearbox ratio is 100:1 and the grid frequency is 50 Hz.

(i) Find the generator speed at a shaft speed of 15 rpm. [5%]

(ii) Find the range of frequencies supplied to the rotor. [10%]

(iii) Find the power flow in the rotor circuit at shaft speeds of 10, 15 and 20 rpm. [20%]

(iv) What VA ratings are needed for the machine and line side converters if the machine and line side power factors are 0.9 lagging and unity respectively. [10%]

(v) If the line-side converter is connected to a 900 V supply, explain why a DC link voltage of 1600 V is appropriate. [10%]

(vi) Suggest a suitable voltage rating for the rotor. [10%]

(vii) Outline an arrangement for connecting the MCT to the onshore grid if the voltage at the grid connection point is 275 kV. The MCT is 12 nautical miles offshore and the grid connection point is close to the shore. [15%]

The DC link voltage of a converter is related to the AC output by,

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

where the symbols have their usual meanings.

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3 (a) Describe the main differences between large-scale and small-scale wind power generation systems. With the aid of a diagram, show the main components of, and differences between, on-grid and off-grid small-scale wind power systems. [25%]

(b) 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. Sketch a typical graph of how C_p varies with the 'tip-speed ratio' λ, including the Betz criterion, and use the graph to explain why variable speed operation of wind turbines is advantageous.

Describe how rotor resistance can be used to control the speed of an induction generator and use this to explain the underlying ideas of slip energy recovery. [40%]

(c) A small farm consumes 10 MWhr of electricity per year. Consider a small-scale wind power system to supply the electricity demand of this farm with reference to the following wind speed data:

Wind speed [ms^{-1}]	2	6	8	10	14
Number of days	30	150	100	60	25

The wind turbine has a rated wind speed of 12 m/s. The cut-in and stall speeds are 5 m/s and 20 m/s, respectively. The turbine is to be operated at variable speed such that the optimum tip-speed ratio is maintained between the cut-in and rated speeds. The optimum tip-speed ratio is 8, at which C_p is 0.4. The density of air is 1.23 kg/m^3.

Determine the rated power of the generator and the output powers of the system at each wind speed. What is the capacity factor of this wind turbine installation? Determine the diameter of the turbine. [35%]

4 (a) Describe two difficulties that are often faced when integrating renewable electrical power sources into the existing UK grid infrastructure, and describe two methods for overcoming these difficulties. [20%]

(b) Derive the following equation for the *average* complex power transmitted between the two ends of a three-phase lossless transmission line of inductive reactance X Ω:

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

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.

Under normal power system operating conditions (no system faults), give the two conditions that must be met with regard to supply and demand and give the power system parameters which must be kept constant to achieve each.

Using the equation above, show how real and reactive power flow can be controlled in a power system. [40%]

(c) Under optimum wind conditions, a large wind farm produces 120 MW of real power and can produce up to ±60 MVAR of reactive power. All the generators of the wind farm are connected to the three-phase 50 Hz power system at an 11 kV bus. The 11 kV bus is connected to a 275 kV transmission line of impedance j0.5 Ω/km via an 11 kV/275 kV, 200 MVA transformer of 0.2 pu reactance. The transmission line is 300 km long. The other end of the transmission line is connected to the 33 kV load bus via a 275 kV/33 kV, 300 MVA transformer of 0.35 pu reactance. The voltage at the 33 kV load bus is maintained at exactly 33 kV.

Find the magnitude and the angle of the voltage at the wind farm bus when the load real and reactive powers are 120 MW, +30 MVAR.

Repeat the calculation for a 400 kV transmission line (with corresponding transformer voltages of 11 kV/400 kV and 400 kV/33 kV, and all other parameters remaining the same) and comment on your result. [40%]

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4B19 Numerical Answers for 2015

2(b) (i) 1500 rpm

(ii) $\pm$ 16 ⅔ Hz

(iii) - 88.9 kW, + 0, + 150 kW

(iv) 167 kVA, 150 kVA

3(c) 3.84 kW, 0, 480 W, 1152 W, 2227 W, 2840 W, 0.297, 3.39 M

4(c) 13.5 kV, 23.9°, 12.7 kV, 18.8°