Version TJF/3

EGT3
ENGINEERING TRIPOS PART IIB

Monday 8 May 2017 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.*

Write your candidate number ***not*** *your name on the coversheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed
There are no attachments

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) Explain why electrical energy storage is important for the integration of renewable electricity sources into the existing electrical network. Give three examples of electrical energy storage technologies. [20%]

(b) Power generation from the sea can exploit either sea waves or tidal flow. In the context of the UK, describe:

(i) Two main attractions of this form of power generation; [10%]

(ii) Four challenges for this form of power generation. [20%]

(c) Describe, with the use of diagrams and appropriate terminology, the following wave power devices, with respect to their usual location and power take-off system:

(i) Oscillating water column; [25%]

(ii) Buoy-type devices. [25%]

2 (a) The use of a Brushless Doubly-Fed induction Machine (BDFM) is proposed for a marine current turbine.

(i) Describe the construction and operation of a BDFM. [20%]

(ii) Describe four advantages the use of a BDFM has over a conventional induction generator. [20%]

(b) Explain why an electronic power converter might be required with a marine current turbine. [10%]

(c) The BDFM has a 4 pole/8 pole configuration and operates with a speed range of ±20% around the natural speed to give a maximum output power of 60 kW.

(i) Calculate the natural speed, N_n, of the BDFM and its operating speed range in rpm, assuming a mains frequency of 50 Hz. The rotational speed, N, of a BDFM is given by

$$N = \frac{f_p + f_c}{p_p + p_c}$$

where f_p and f_c are the frequencies of the power and control windings, respectively, and p_p and p_c are the pole-pair numbers of the power and control windings, respectively. [10%]

(ii) Calculate the VA ratings of the power and control windings, assuming that the power is delivered at a power factor of 0.8 lagging from both windings. [15%]

(d) The output of the BDFM is connected to a three-phase, full-bridge converter (inverter and rectifier). Suggest a value for the DC link voltage, with reasons, if the generator's maximum output voltage is 690 V, given that

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

Find also the VA rating of the IGBTs in the inverter, assuming a power factor of 0.8 lagging. [25%]

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3 (a) Give three advantages of the Doubly-Fed Induction Generator (DFIG) for the generation of electricity by wind turbines. Draw a schematic diagram of a DFIG connected to the three-phase grid, and explain its principles of operation. [25%]

(b) A wind turbine utilizing a DFIG is operated at its optimum tip-speed ratio of 8, at which its power coefficient is 0.4, for wind speeds between cut-in (3 ms^{-1}) and rated (10 ms^{-1}). The DFIG is mechanically coupled to the turbine via a gearbox of ratio 30. The blade diameter of the turbine is 80 m. The injected rotor voltage is zero at the most probable wind speed, which is 6 ms^{-1}. The DFIG has its stator windings star-connected to the 11 kV, 3-phase, 50 Hz grid, and its equivalent circuit parameters are: $R_1 = 0.5\ \Omega$; $R_2' = 0.4\ \Omega$; $X_1 = X_2' = 0.6\ \Omega$; R_0 and X_m are large enough to be ignored.

(i) Find the rated power of the system. [10%]

(ii) Determine the number of poles that the generator should have so that it operates optimally at the most probable wind speed. [15%]

(iii) Find the approximate slip, s, of the generator at rated wind speed. [20%]

(iv) Show that the electromagnetic torque of the DFIG is given by

$$T = 3I_2'^2 \frac{R_2'}{s\omega_s} + \frac{3V_3'I_2'}{s\omega_s}$$

where V_3' is the referred injected rotor voltage and is assumed to be in phase with the referred rotor current, I_2', and ω_s is the synchronous speed. [15%]

(v) Estimate the referred injected rotor voltage at the rated wind speed, and using the torque equation, find the generator current. [15%]

The following may be quoted without proof: $P = \frac{1}{2}C_p \rho A v^3$, $\lambda = \frac{\omega R}{v}$ and take ρ to be 1.23 kgm^{-3}.

4 (a) By giving an example, explain how increasing diversity of supply enables more sources of renewable electricity to be connected into the grid. [15%]

(b) Explain what is meant by Flexible AC Transmission Systems (FACTS), and how they are used to enhance controllability and power transmission capability of power networks, referring both to shunt and series-connected FACTS. [20%]

(c) A wind farm has a rated output power of 100 MW. 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 j50 Ω via a 200 MVA, 11 kV/275 kV transformer of 0.15 pu reactance. The other end of the transmission line is connected to the 33 kV load bus via a 275 kV/33 kV, 200 MVA transformer of 0.2 pu reactance. The voltage at the 33 kV load bus is maintained at exactly 33 kV. The power factor of the load at the load bus can vary between 0.6 lagging and 0.8 leading.

(i) Find the range of the actual line voltage at the 11 kV bus (magnitude and phase) when the wind farm is generating at its rated output power. [25%]

(ii) Explain what will happen to this voltage range when the wind farm is experiencing lower wind speeds. No calculations are necessary. [15%]

(d) In reality it is usual to operate power systems so that all bus voltages are close to their nominal values. Explain how a shunt-connected FACTS device at the 33 kV load bus can achieve this, and specify the FACTS system such that the load and wind farm bus voltages are always at their nominal value. [25%]

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Short answers

2 (c) (i) N_n = 500 rpm, speed range from 400 – 600 rpm
(ii) VA_p = 62.5 kVA, VA_c = 12 kVA (d) 1250 V, 100 kVA

3. (b) (i) 1.24 MW (ii) 18 poles (iii) -0.667 (v) -4234 V (phase), 38.9 A

4 (c) (i) 14.8 kV leading load bus voltage by 10.3^0 to 9.4 kV leading load bus voltage by 18.2^0. (d) Capacitors generating 146 MVAr at 33 kV; Inductors absorbing 62.7 MVAr at 33 kV.