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THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

AUTUMN EXAMINATIONS, 2007

B.E. DEGREE (ELECTRICAL)

ELECTRICAL AND ELECTRONIC POWER SUPPLY SYSTEMS
EE4010

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Time allowed: *3 hours*

Answer *five* questions.

All questions carry equal marks.
The use of a Casio *fx570w* or *fx570ms* calculator is permitted.

$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1} $\varepsilon_0 = 8.854 \times 10^{-12}$ F m^{-1}

1. (a) Prove that the power transmitted in a balanced three-phase sinusoidal voltage-source system is constant, independent of time, and comment on the advantages of such a system from the point of view of the large-scale generation and transmission of electrical energy.

[5]

(b) Draw a schematic diagram illustrating the operation of a typical medium head hydro-electric power generating station. Hence, derive an expression for the power available from such a station in terms of the flow rate of water Q m^3/s, the head of water H m and the overall efficiency, η, listing any assumptions which you make.

A large hydroelectric power station has a head of 300 m and an average flow rate of water of $1250\ \text{m}^3/\text{s}$. The reservoir of water behind the dam is composed of a lake covering an area of $7000\ \text{km}^2$. The overall efficiency of the power station is 85%. Calculate the available power and the number of days this power could be sustained if the level of water impounded in the dam is allowed to drop by 1 m. [Density of water = 1000 kg/m^3]

[5]

(c) Briefly describe the basic process underpinning the use of nuclear fission for the generation of electrical energy. Sketch a schematic diagram for a pressurised-water reactor (PWR) and list the relative advantages and disadvantages of this technology compared to conventional coal-based generating plant for electrical power generation in future decades.

[5]

[Q.1 continued overleaf]

(d) Describe, using appropriate diagrams, the use of solar energy for (i) direct generation of electricity, (ii) indirect generation of electricity and (iii) as a source of domestic heating. Summarise the relative advantages and disadvantages of solar energy in comparison with wind energy as potential sources of alternative energy for the future.

[5]

2. (a) Derive from first principles an expression for the theoretical maximum power available from a wind turbine in terms of the swept area of the blades, A m^2, the velocity of the wind, u m/s and the density of air at standard temperature and pressure, ρ kg/m^3. Explain why the actual output power which is achievable in practice is considerably less that this value.

Sketch an approximate power versus wind speed curve for a typical wind turbine, highlighting the different areas of operation.

List two major advantages of this type of electrical power generation and comment on the possible disadvantages of the system compared to conventional fossil-fuel-based generating stations from the perspective of the power system operator.

[10]

(b) A 400 kW, three-blade wind turbine is designed to deliver its full rated power at a rated wind speed of 15 m/s. Each blade has a length of 14 m and the rated speed of the turbine shaft is 48 rpm. The density of air at standard temperature and pressure is 1.201 kg/m^3

(i) Estimate the area swept out by the turbine blades
(ii) Evaluate the theoretical wind power available at the rated wind speed.
(iii) Calculate the ratio of the theoretical power to the rated power of the turbine.
(iv) Calculate the tip speed of the turbine blades and the ratio of this speed to the wind speed.

[10]

3. (a) Define the terms (i) *sequence voltage vector* (ii) *sequence current vector* and (iii) *sequence impedance matrix* as applied to an item of equipment in a three-phase electrical power system.

[8]

(b) Derive the positive, negative and zero sequence impedance networks for the three-phase, four-wire load with a solidly grounded star point defined by the following phase impedance matrix

$$\overline{Z}_{phase} = \begin{bmatrix} \overline{Z}_s & \overline{Z}_m & \overline{Z}_m \\ \overline{Z}_m & \overline{Z}_s & \overline{Z}_m \\ \overline{Z}_m & \overline{Z}_m & \overline{Z}_s \end{bmatrix}$$

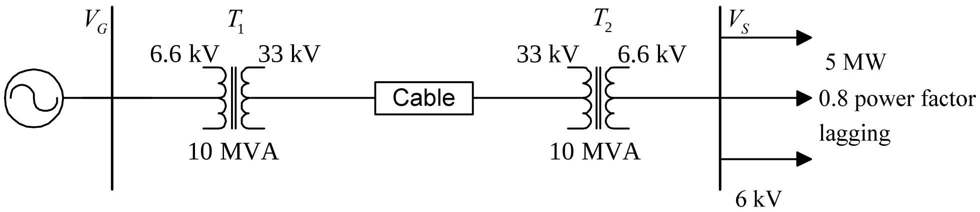
Unbalanced phase-to-ground source voltages defined by $\overline{V}_{ag} = 277\angle 0°$ V, $\overline{V}_{bg} = 260\angle -120°$ V and $\overline{V}_{cg} = 295\angle 115°$ V are applied to the three-phase load described above in which $\overline{Z}_s = (10 + j30)\ \Omega$ and $\overline{Z}_m = (5 + j20)\ \Omega$. The load star point is solidly grounded. Calculate the line current in Phase *a* of the load.

[12]

4. (a) Prove that the use of the per-unit method of analysis can eliminate the ideal transformer element from the single-phase transformer equivalent circuit model and define the conditions on the selection of base parameters under which this simplification can be achieved.

[10]

(b) A 6.6 kV/33 kV, 10 MVA, 50 Hz, star-star connected transformer T_1 is used to connect a synchronous generator to an underground cable as illustrated below. The equivalent per-phase series impedance of the transformer is $(0.08 + j0.8)\ \Omega$ referred to the low voltage winding. The magnetising branch impedances can be neglected.



The resistance of the cable per conductor is $5.0\ \Omega$ and its inductive reactance per conductor is $2.0\ \Omega$. An identical transformer T_2 is used to connect the far end of the cable to a 6.6 kV sub-station. This substation is operated at a voltage V_s of 6.0 kV and it provides power to a load of 5.0 MW at a power factor of 0.8 lagging. Calculate the voltage at the generator busbars, V_G.

[10]

5. (a) Draw the exact per-phase equivalent circuit of a three-phase, round-rotor, synchronous generator when connected to an infinite system, noting the significance of each component of the model.

Neglecting resistive losses, derive expressions for the real power P and the reactive power Q delivered by the machine to the system in terms of the terminal voltage V_t, the generated back-emf, E_f, the synchronous reactance X_s and the load angle δ.

Show that the locus of the complex power transfer derived above is a circle in the complex P/Q plane. Deduce the radius and the centre of this circle in terms of the specified parameters.

[10]

(b) A three-phase, 50 Hz, star-connected, round-rotor synchronous generator is driven by its prime mover at 1000 rpm and at this speed it develops an open circuit line voltage of 460 V when the field current is set to 16 A. The machine has a synchronous reactance of $2.0\ \Omega$ and negligible winding resistance.

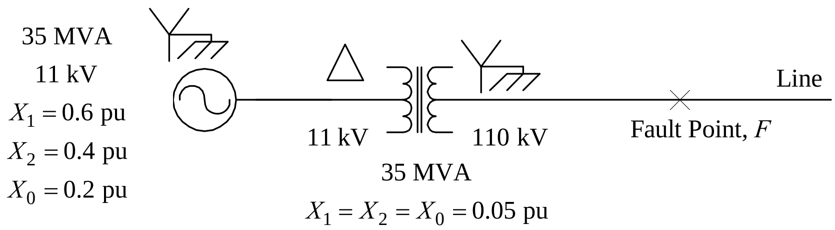
Calculate the driving torque and power required of the prime mover when the machine is supplying a current of 50 A/phase at a power factor of 0.8 lagging. Assume that the field current and the speed remain constant at 16 A and 1000 rpm, respectively. Neglect core losses and mechanical friction and windage.

[10]

6. (a) Derive an expression for the fault current when a double-phase-to-ground fault occurs at the terminals of a three-phase, star-connected synchronous generator with a solidly grounded star point. What is the effect on the fault current magnitude of a fault impedance $\overline{Z}_F$ between the two faulted lines and ground?

[8]

(b) A direct double-phase-to-ground fault occurs at the point F in the electrical power distribution system illustrated below. Draw the positive, negative and zero sequence networks for this system and calculate the fault current. The generator is initially operating unloaded at 1.0 per-unit voltage.



[12]

7. (a) Explain the operation of a single-phase, full-wave, diode-bridge rectifier and output capacitor filter circuit which is used to provide an approximately dc input voltage to switched-mode dc/dc power converters for electronic products. In your explanation, sketch and refer to typical waveforms for (i) the input line voltage, (ii) the output capacitor voltage and (iii) the input line current in this power converter.

[4]

(b) Derive a general expression for the power factor of a single-phase diode-bridge rectifier with a capacitor filter circuit in terms of the fundamental displacement power factor, *DPF*, and the total harmonic distortion, *THD*, of the input current waveform. It may be assumed that the input voltage is purely sinusoidal,

$$v_{in}(t) = \sqrt{2}\, V_{in}\, Sin(\omega_1 t)$$

while the rectifier input line current is given by

$$i_{in}(t) = \sqrt{2}\, I_{in\,1}\, Sin(\omega_1 t - \phi_1) + \sum_{k \neq 1}^{\infty} \sqrt{2}\, I_{in\,k}\, Sin(k\omega_1 t - \phi_k)\,.$$

Three of these rectifiers are connected, between live and neutral, one across each of the three phases of a balanced three-phase, four-wire sinusoidal voltage source of line voltage $\sqrt{3}\,V_{in}$. Derive an expression for the current in the neutral wire of this system.

[10]

A diode bridge rectifier and capacitor filter circuit supplies a telecommunications system which requires a power of 2 kW when operating from a mains voltage of 230 V. It is found that the fundamental current is $I_{in1} = 10$ A and the *THD* of the line current is 89%. Calculate the rms input current, the power factor and the *DPF*.

[6]