OLLSCOIL NA hÉIREANN, CORCAIGH
THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2004

B.E. DEGREE (ELECTRICAL)

ELECTRICAL AND ELECTRONIC POWER SUPPLY SYSTEMS
EE4010

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Time allowed: *3 hours*

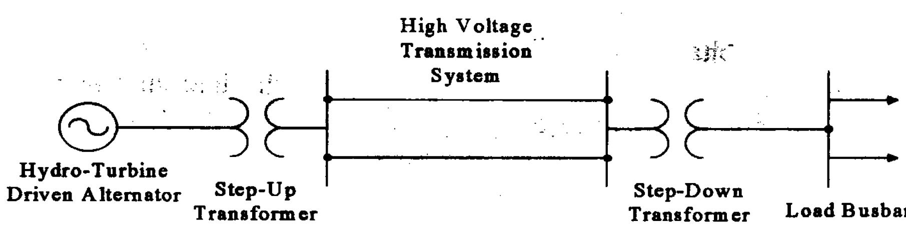
Answer *five* questions.

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. *Answer clearly and concisely any <u>four</u> of the following (5 marks each):-*

(a) The single-line diagram for a typical three-phase ac power distribution system used to connect a hydro-turbine driven alternator to a load busbar is illustrated below.



Explain briefly two of the principal advantages of this ac distribution system over a corresponding dc system.

What ***typical*** voltage ranges would you expect for the nominal generator voltage and the nominal transmission voltage in this system?

Where would you expect a high voltage dc (HVDC) transmission system to be employed in preference to the ac system shown above and list the principal components of a typical HVDC system.

(b) Electrical energy consumption in a given country is growing at a rate such that it is considered necessary to build a new power generating station. Give two arguments for, and two against, the construction of a coal-fired power station.

The typical citizen in this country consumes electrical power at an average rate of 900 W. Assuming that the projected overall efficiency of the proposed coal-fired power station is 36%, estimate the mass of coal of calorific value 30 MJ/kg required to provide this electrical power over a period of one year.

(c) Derive an expression for the power P available from a hydro-electric power station in terms of the flow rate of water Q m^3/s and the head of water H m.

A large river in Africa discharges at a constant rate of 130 km^3 of water per year. It is proposed to build a dam on the river at a point where the projected head H would be 100 m. Calculate the average flow rate Q and the average electrical output power P that could be harnessed assuming an average turbine efficiency of 92% and an average generator efficiency of 98%.

[Density of water = 1000 kg/m^3]

(d) Explain briefly, with the aid of a simplified schematic diagram, the operation of a nuclear fission Pressurised Water Reactor (PWR) nuclear power station.

Give a figure for the electrical power generating capacity of a typical PWR station and estimate the number of latest-generation wind turbines it would take to produce this level of electrical power.

(e) Describe briefly the basic concepts underlying the proposed use of thermonuclear fusion for the large-scale generation of electrical power with particular reference to the rôle of the Tokamak structure. List two advantages and two disadvantages of this technology compared to conventional nuclear fission reactors.

2. (a) A balanced, passive, three-phase load consists of three impedances of $(9 + j6)\ \Omega$ connected in delta. This load is fed from a balanced three-phase 50 Hz voltage source with a line-to-line voltage of 400 V. Taking the phase-to-neutral voltage as reference, calculate the line current in Phase A and the total three-phase apparent power. **[8]**

(b) A single-phase cable has a maximum current carrying capacity of 173 A. It supplies the following loads at a voltage of 440 V:

(a) a 5 kW lighting load at unity power factor
(b) a 10 kW heating load at unity power factor
(c) a 30 kVA motor at a power factor of 0.8 lagging.

Determine the maximum current and the kVA rating of an additional load at 0.7 power factor lagging which could be connected to the cable.

[12]

3. (a) Define the sequence components of a three-phase set of voltages and currents.

Hence derive the sequence impedance matrix of a three-phase, three-wire, star-connected unbalanced impedance load with zero mutual coupling. **[10]**

(b) A passive three-wire star-connected load with zero mutual coupling is supplied from the secondary of a delta/star connected transformer whose secondary winding star point is solidly earthed. The transformer secondary voltage is balanced and the line-to-line voltage supplied to the load is 400V. The impedance in Phase a is $10.0\angle 0° \ \Omega$, the impedance in Phase b is $10.0\angle 0° \ \Omega$ and the impedance in Phase c is $20.0\angle 0° \ \Omega$.

Using the theory of symmetrical components, calculate (i) the line current in Phase a and (ii) the voltage of the load star point with respect to earth. The phase sequence is a-b-c. The phase voltage of the supply may be taken as the reference phasor. **[10]**

4. (a) Prove that the per unit impedance of a three-phase star/delta connected transformer is the same whether computed from the star-side parameters or from the delta-side. Assume a three-phase volt-ampere rating of S VA, a line-to-line input voltage to the star side of V_L V, a turns ratio of $1{:}N$ (star/delta) and an impedance of $\overline{Z}_{phase}$ Ω per phase referred to the star-side. **[8]**

(b) A 50 Hz, 30 MVA, 13.2 kV, three-phase, synchronous generator has a positive sequence reactance of 1.5 per unit.

This synchronous generator is connected to a 35 MVA, 13.2Δ kV/115Y kV, delta/star connected, three-phase, step-up transformer bank. The transformer has a series impedance of $(0.005 + j0.1)$ per unit, based on its own thermal ratings.

Calculate the per-unit generator reactance on the transformer base.

If the load on busbars connected to the secondary terminals of the transformer bank is 25 MW at unity power factor and 115 kV, calculate (i) the transformer low-side voltage, (ii) the excitation voltage of the generator and (iii) the power factor at which the generator is operating. **[12]**

5. (a) Draw the exact per-phase equivalent circuit of a three-phase, round-rotor, synchronous generator when connected to an infinite system. **[2]**

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. **[4]**

Deduce the steady-state stability limit governing this power transfer. **[2]**

(b) A three-phase star-connected, round-rotor, synchronous generator has negligible winding resistance and a synchronous reactance of 10.0 Ω per phase.

This machine is connected to 11 kV infinite busbars and is initially delivering a per-phase current of 220 A at unity power factor.

(i) Calculate the excitation voltage and load angle of the generator in this operating condition.

(ii) If the mechanical input power to the prime mover driving the generator is maintained constant, calculate the new current and power factor at which the machine will operate when the excitation voltage is increased by 25% above that in (i).

(iii) If the excitation voltage is now held constant at the value calculated in (ii) above and the mechanical input power to the prime mover is increased, calculate the steady state stability limit of the generator in MW. **[12]**

6. (a) Derive an expression for the fault current when a single-phase-to-earth fault of impedance $\bar{Z}_f$ occurs at the terminals of a three-phase, star-connected synchronous generator with a solidly earthed star point.

What is the effect on the fault current magnitude of a grounding impedance $\bar{Z}_n$ connected between the generator star-point and earth? **[8]**

(b) A circuit breaker is to be installed to protect a three-phase, star-connected 11 kV synchronous generator. The positive, negative and zero sequence sub-transient reactances of the generator are $j10.0\,\Omega$, $j7.0\,\Omega$ and $j3.0\ \Omega$ per phase, respectively. The generator star-point is earthed via a reactance of $j1.0\ \Omega$ and the machine is initially operating at rated voltage on no-load.

(i) Calculate the fault current for a direct single-phase-to-earth fault at the terminals of the generator.

(ii) Calculate the fault MVA rating of the breaker required to protect against this fault.

(iii) Calculate the voltage of the generator star point above earth during the fault condition **[12]**

7. (a) Draw the circuit diagram of a full-wave diode-bridge rectifier and capacitor filter circuit used to provide an approximately dc input voltage to switched-mode dc/dc power converters for electronic products. **[2]**

Sketch typical waveforms for (i) the input line voltage (ii) the output capacitor voltage and (iii) the input line current. **[3]**

Briefly describe the principal disadvantages associated with this simple rectifier circuit from the perspective of both the utility company and the product manufacturer. **[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, using the usual notation, that the input voltage is purely sinusoidal,

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

while the input line current is given by

$$i_{in}(t) = \sqrt{2}\,I_{in1}\,Sin(\omega_1 t - \phi_1) + \sum_{k\neq 1}^{\infty}\sqrt{2}\,I_{in\,k}\,Sin(k\omega_1 t - \phi_k).$$

[5]

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]**