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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2003

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) Explain, with the use of a simple example, why the development of efficient transformers had such a profound impact on the evolution of large scale three-phase ac power systems.

Measurements show that 1 kg of a certain type of coal releases 30.5×10^6 J of thermal energy when incinerated in a conventional coal-fired electrical power station. Assuming a thermal energy transformation efficiency of 36.5% and an electrical generation and transmission efficiency of 90%, calculate the length of time which the energy derived from the burning of 10 kg of this type of coal will run a domestic electrical load of 5 kW.

Draw a block diagram of a pumped storage generating station and derive an expression for the power available from such a station in terms of the flow rate of water Q m^3/s and the head of water H m. Assume that the average head between two reservoirs, each of area $1.0\ km^2$, is $H = 300$ m. The station is required to produce a power output of 200 MW over 6 hours. The efficiency of the complete system is 60%. Calculate the change in reservoir water level to produce this period of output power. [Density of water = 1000 kg/m^3]

(d) Draw a simplified schematic diagram of a Pressurised Water Reactor (PWR) nuclear power station. List two advantages and two disadvantages of this form of electrical power generation compared to a conventional coal-fired station.

(e) Draw the circuit diagram of a conventional single-phase bridge rectifier/capacitor filter off-line ac/dc converter and explain briefly how it is the source of considerable harmonic pollution of the ac network.

2. (a) Define the terms complex power, real power, reactive power and apparent power in constant frequency, sinusoidal, steady-state, ac circuit analysis. **[4]**

Derive expressions for the complex power drawn by

(i) an ideal resistance, R
(ii) an ideal inductance, L
(iii) an ideal capacitance, C

when fed by a single-phase, sinusoidal voltage source of peak amplitude $\hat{V}$ and constant radian frequency ω. **[6]**

(b) The star-connected secondary winding of a three-phase transformer provides a 400 V balanced three-phase supply to a load connected via a four-conductor cable. The neutral conductor N is connected to the transformer star point which is earthed. The load consists of the following components:

between the A and N conductors: a 20 Ω resistor.
between the B and N conductors: a 20 Ω resistor.
between the C and N conductors: a 20 Ω resistor.

Connected also to the A, B, and C conductors is a three-phase induction motor which draws a balanced current of 10 A at 0.866 power factor lagging.

(i) Calculate the current and the complex power in Phase A.

(ii) If the resistor between the A and N conductors is reduced to 10 Ω and a resistor of 10 Ω is added between the A and the B conductors, calculate the current in the Phase A conductor.

[10]

3. (a) Define the sequence component transformation for three-phase voltages and currents. **[2]**

List two advantages of this transformation in power systems engineering. **[2]**

Define the sequence impedance matrix and derive the elements of this matrix in the particular case of a three-phase, three-wire, star-connected, unbalanced impedance load with zero mutual coupling. **[8]**

(b) A symmetrical, three-phase voltage source supplies an unsymmetrical, three-phase, three-wire, star-connected, impedance load with zero mutual coupling. Phase A consists of a resistance of $60\,\Omega$, phase B consists of a resistance of $30\,\Omega$ and phase C consists of a resistance of $30\,\Omega$. The supply line voltage is 400 V. Use the theory of symmetrical components to calculate the current and the power dissipation in the $60\,\Omega$ resistor in phase A.

[8]

4. (a) A particular single-phase distribution transformer has a primary voltage rating, V_p V, a primary-to-secondary turns ratio, N, and an apparent power rating, S VA. Short-circuit tests performed on the primary side of this transformer indicate that it has an equivalent series impedance of Z_p Ω. The device has negligible magnetising and core loss components. Three of these units are connected to form a three-phase, star/delta transformer bank with the primary windings connected in star. What are the primary and secondary voltage and current ratings for the three-phase bank? **[8]**

(b) A three-phase transformer bank consists of three 10 kVA, 2300/230 V, 50 Hz, single-phase power transformers. The high voltage side of the transformer bank is connected in a grounded star and the low voltage side is connected in delta. The equivalent series impedance of each single-phase transformer is $(0.12 + j0.24)$ Ω/phase referred to the low-voltage side. The transformers star-connected primary windings are fed by a high-voltage feeder line whose series impedance is $(0.5 + j5.0)$ Ω/phase.

Load busbars are connected to the transformer low-voltage side by means of a short cable whose impedance is $(0.005 + j0.01)$ Ω/phase. The load on the busbars consists of a purely resistive heating load of 2 kW/phase and a three-phase induction motor drawing 20 kVA at a lagging power factor of 0.8. The load busbars are to be maintained at 230 V line-to-line.

(i) Draw a single-line diagram of this three-phase distribution system.

(ii) Neglecting the exciting current of the transformer bank, draw the per-unit equivalent circuit of the system.

(iii) Calculate the line current and the line-to-line voltage at the sending end of the high voltage feeder. **[12]**

5. (a) Draw the exact per-phase equivalent circuit of a three-phase, round-rotor, synchronous generator when connected to an infinite system, indicating the physical reason for the existence of each component in the model. **[2]**

Neglecting resistive losses, derive expressions for the real and reactive powers delivered by the machine to the system in terms of the terminal voltage, the generated back-emf, the synchronous reactance and the load angle δ. **[4]**

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

Briefly describe one other mechanism by which this machine may lose synchronism with the infinite system. **[2]**

(b) A 2.2 MVA, 3.3 kV, 50 Hz, three-phase, star-connected, round-rotor, synchronous generator has a per-phase synchronous reactance of $j0.75$ per unit based on its own ratings. The machine is connected to 3.3 kV infinite busbars and operates at full rated load and 0.85 power factor lagging.

(i) Calculate the excitation voltage of the generator.

(ii) If the field excitation current of the generator is now slowly reduced to 45% of its original value, determine whether the machine will remain in synchronism or not and state the reason for your conclusion. **[10]**

6. (a) Derive expressions for the fault current when (i) a three-phase fault and (ii) a single-phase-to-earth fault occur at the terminals of a three-phase, star-connected synchronous generator with a solidly earthed star point. In both cases, what is the effect on the fault current magnitude of a grounding impedance $\overline{Z}_n$ connected between the generator star-point and earth? **[10]**

(b) Two identical 6.6 kV, 20 MVA, 50 Hz, star-connected, synchronous generators are connected in parallel and supply power to a small factory installation. The positive, negative and zero sequence sub-transient reactances of the generators are $j0.20$, $j0.15$ and $j0.07$ per unit, respectively based on the ratings of the generators. The system is initially operating unloaded at the rated voltage of the generators.

(i) The star point of one generator is solidly grounded while that of the second is isolated from ground. Calculate the fault current for a direct single-phase-to-ground fault at the terminals of the generators.

(ii) Re-calculate the fault current for the same direct single-phase-to-ground fault at the terminals of the generators if the grounded generator star point connection is replaced by a resistance of 0.2 Ω while the star point of the second generator remains isolated. **[10]**

7. (a) Derive an expression for the voltage transfer function of an isolated flyback dc/dc converter operating in the continuous-conduction mode assuming zero leakage inductance and winding resistance in the transformer. **[4]**

Deduce the condition on the transformer magnetising inductance to ensure a continuous current mode of operation in this converter. **[4]**

List one advantage and one disadvantage of the flyback topology compared to the conventional forward converter for isolated low voltage power supplies. **[2]**

(b) A transformer-isolated flyback converter is required to supply a dc voltage of 3.3 V_{dc} for a microcontroller board. The dc source voltage is 48 V_{dc} and the load power is 10 W. The switching frequency is 50 kHz. The primary/secondary turns ratio of the flyback transformer is 10:1 and its magnetising inductance is 1 mH referred to the higher voltage side. Leakage inductance may be neglected. The output filter capacitance is 200 μF.

(i) Calculate the duty cycle of the power switch and the maximum and minimum values of the transformer primary current.

(ii) Determine the minimum value of transformer magnetising inductance to ensure continuous current operation of this converter.

(ii) Estimate the output voltage ripple. **[10]**