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THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2007

B.E. DEGREE (ELECTRICAL)

ELECTRICAL AND ELECTRONIC POWER SUPPLY SYSTEMS
EE4010

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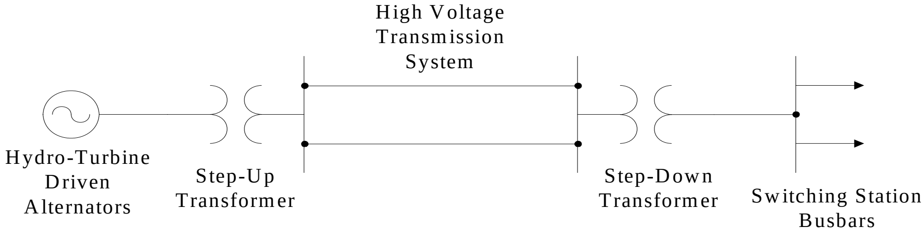
Time allowed: *3 hours*

Answer *five* questions.

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

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

1. (a) The single-line diagram for a typical three-phase ac power distribution system used to connect the busbars of a large hydro-electric power generating station to a switching station 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.

[5]

(b) Write down the formula for the ideal Carnot efficiency of a steam-based electrical power generating station in terms of the boiler temperature T_1 and condenser temperatures, T_2.

[Q 1(b) Continued overleaf]

Determine the condenser heat dissipation requirements in MW for two different electrical power generating stations producing 1000 MW of electrical output power. The first plant is a coal-fired station that has an efficiency of 40% and releases 15% of the heat produced in the furnace up the stack. The second is a pressurised-water fission reactor with an efficiency of 33%.

[5]

(c) 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.

A fuel rod of enriched uranium 235 has a mass of 22.2 kg when first inserted into the core of a PWR. If it releases an average power of 372.5 kW of thermal energy during its 19-month stay in the reactor core, calculate the total amount of heat generated by the fuel rod during this time and estimate the ideal reduction in the mass of uranium 235 required to produce this energy.

[5]

(d) Write down 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. Specify the principal approximation involved in your formula.

Calculate the diameter of a wind turbine needed to supply the 5000 kWh of electrical energy required annually by a particular household. Assume prevailing average wind conditions in which 250 kWh/m^2 of blade area is produced annually by the wind turbine.

[5]

2. (a) 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.

Distinguish between this plant and a pumped storage hydroelectric station and comment on the advantages of the pumped storage station in the context of (i) overall power system operation and (ii) the increased use of renewable energy resources in the overall power system.

[10]

(b) A lake of area 510 km^2 is fed from a drainage area of 6500 km^2 including the lake. The level of the water in the lake is 527 m at the beginning of the month (duration 720 hours) and 527.25 m at the end of the month. Over this period the total rainfall is 15.0 cm with a 38% loss due to evaporation. The only outlet from the lake is a river which supplies a hydro-electric power station, the head above the turbine being 50 m. The power loss due to friction is 3% of the total in the river.

If the overall efficiency of the turbine and generator set is 80%, calculate the average output electrical power of the station during the month.

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

[10]

3. (a) Define the terms (i) *sequence voltage vector* (ii) *sequence current vector* and (iii) *sequence impedance matrix* for a three-phase electrical load.

A three-phase, four-wire, star-connected load consists of an impedance $\overline{Z}_Y$ in each phase and an impedance $\overline{Z}_n$ between the load star-point *n* and ground, *g*. This load is fed from a set of three-phase voltages $\overline{V}_{ag}$, $\overline{V}_{bg}$ and $\overline{V}_{cg}$. Derive an expression for the phase impedance matrix $\overline{Z}_{abc}$ of this load and hence deduce the sequence impedance matrix and the associated sequence networks.

[10]

(b) A three-phase impedance load consists of a balanced, delta-connected load in parallel with a balanced, star-connected load. The impedance in each leg of the delta load is $\overline{Z}_{\Delta} = (6 + j6)\ \Omega$. The impedance in each leg of the star-connected load is $\overline{Z}_Y = (2 + j2)\ \Omega$ and the star point is grounded through a neutral impedance of $\overline{Z}_n = j1\ \Omega$.

Unbalanced line-to-ground voltages, $\overline{V}_{ag}$, $\overline{V}_{bg}$ and $\overline{V}_{cg}$, with sequence components $\overline{V}_0 = 10\angle 60°$ V, $\overline{V}_1 = 100\angle 0°$ V and $\overline{V}_2 = 15\angle 200°$ V are applied to the load.

(a) Draw the positive, negative and zero sequence impedance networks corresponding to this load.

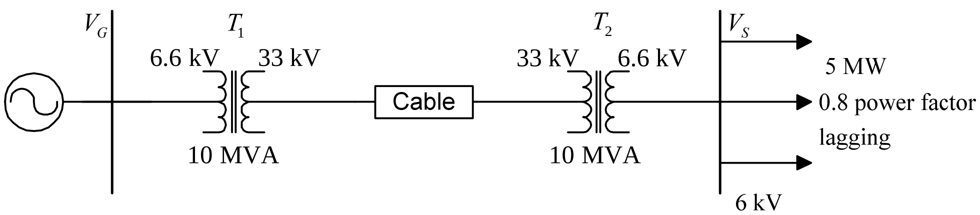
(b) Calculate the input line current to Phase *a* of the load.

[10]

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 $(0.04 + j0.4)\ \Omega$ referred to the low voltage winding. The magnetising branch can be neglected.



The resistance of the cable per conductor is $7.17\ \Omega$ 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 100 MVA, 11 kV, 50 Hz, four-pole, three-phase, star-connected, round-rotor, synchronous generator has a synchronous reactance of $j1.0\,\Omega/\text{phase}$ and negligible armature resistance. The open circuit line voltage of the machine is held constant at 12.5 kV. When connected to a set of 11 kV busbars, the machine supplies a power of 80 MW.

Calculate the load angle, the armature current and the power factor for this operating condition.

What is the theoretical maximum power which the machine could supply before losing synchronism and evaluate the armature current and the operating power factor for this limit condition.

[10]

6. (a) Derive an expression for the fault current when a single-phase-to-ground fault occurs at the terminals of a three-phase, round-rotor, star-connected synchronous generator with a solidly grounded star point. It may be assumed that the generator is initially operating at rated voltage and frequency and that it is unloaded prior to the fault.

[8]

(b) A three-phase, 25 MVA, 13.2 kV, 50 Hz, round-rotor, star-connected alternator with a solidly-earthed star-point has a per-unit positive sequence sub-transient reactance of $j\,0.25\text{ pu}$. The corresponding negative and zero sequence reactances of the machine are $j\,0.35\text{ pu}$ and $j\,0.1\text{ pu}$ respectively. The machine is initially operating on no-load at its rated voltage and frequency.

Calculate the fault current in Phase a and the line-to-line voltage V_{ab} of the machine when a bolted single-phase-to-ground fault occurs on Phase a of the alternator.

[12]

7. (a) Draw the circuit diagram 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.

Sketch typical waveforms for (i) the input line voltage (ii) the output capacitor voltage and (iii) the input line current in this power converter.

Briefly list the principal disadvantages associated with this simple rectifier circuit and describe an alternative circuit which may be used to overcome these disadvantages.

[6]

(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

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

An internet data centre has large number of server computers each of which will draw a line current similar to that described above. In general, these loads are distributed approximately evenly across the three phases of the power distribution system. Explain the consequences for the neutral conductor of (a) an equal number of computer loads in each phase and (b) an uneven distribution of computer loads across the three phases.

[8]

A diode bridge rectifier and capacitor filter circuit supplies a switched mode power supply which requires a power of 2.75 kW when operating from a single-phase mains voltage of 230 V. It is found that the fundamental current is $I_{in1} = 13\text{ A}$ and the THD of the line current is 97.5%. Calculate the *DPF*, the power factor and the rms input current.

[6]