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COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

AUTUMN EXAMINATIONS, 2005

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) Give two advantages and two disadvantages of the use of coal to generate electrical energy.

The typical citizen of a particular country consumes electrical power at an average rate of 0.9 kW. Assuming that the projected overall efficiency of a proposed coal-fired power station is 36.5%, estimate the mass of coal of calorific value 30.6 MJ/kg required to provide this electrical power over a period of one year.

[5]

(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 during the month.

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

[5]

(Question 1 continued overleaf)

(c) Sketch a schematic diagram of a Pressurised-Water nuclear fission Reactor, (PWR). Describe the fundamental difference between the PWR and the Fast Breeder Reactor (FBR) and list the relative advantages and disadvantages of these technologies for electrical power generation in future decades.

[5]

(d) A three-phase load may be represented as three balanced impedances of $(900 + j600)\ \Omega$ connected in delta. This load is fed from a balanced three-phase 50 Hz voltage source with a line-to-line voltage of 10 kV. Taking the phase-to-neutral voltage as reference, calculate the line current in Phase *a* and the total three-phase apparent power.

[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.

Sketch an approximate power versus wind speed curve for a typical wind turbine. Explain why the actual output power which is achievable in practice is considerably less than this value.

[8]

(b) A small wind generator is designed to generate 75 kW of electrical output power at a wind velocity of 12.5 m/s. Calculate the required blade diameter D assuming that the turbine can achieve a practical operating efficiency of 59% of the maximum theoretical value. The density of air at standard temperature and pressure is 1.201 kg/m^3.

If the wind speed were to vary between 17.5 km/hour and 65 km/hour, determine the range of available output power.

List two major advantages of this type of electrical power generation and comment on the relative merits of the system compared to a nuclear-based generating station from the perspective of the power system operator.

[12]

3. (a) State the sequence component transformation for three-phase voltages and currents and hence develop the general expression for the sequence impedance matrix $\overline{Z}_s$ in terms of the phase impedance matrix $\overline{Z}_p$.

An unbalanced, three-phase, star-connected, sinusoidal voltage source, with phase-to-star-point voltages defined by the phasors $\overline{V}_{ag}$, $\overline{V}_{bg}$ and $\overline{V}_{cg}$, has a solidly grounded star point. This unbalanced voltage source is connected to a three-phase, balanced, star-connected impedance load of $\overline{Z}_Y$ Ω/phase. The star point of the load is grounded via an impedance $\overline{Z}_n$. Derive from first principles an expression for the line current in Phase *a* of this system in terms of the sequence components, $\overline{V}_0$, $\overline{V}_1$ and $\overline{V}_2$, of the source voltage.

[10]

(b) Unbalanced phase-to-ground source voltages defined by $\bar{V}_{ag} = 230\angle 0° \text{ V}$, $\bar{V}_{bg} = 250\angle -130° \text{ V}$ and $\bar{V}_{cg} = 175\angle 110° \text{ V}$ are applied to a balanced three-phase load consisting of a star-connected impedance of $\bar{Z}_Y = (16 + j20)\ \Omega$ per phase. The load star point is solidly grounded.

(i) Calculate the line current in Phase *a* of the load.

(ii) Determine the line current in Phase *a* of the load if the load star-point to ground connection is open circuited

[10]

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. Open-circuit and short-circuit tests performed on the primary side of this transformer indicate that it has negligible magnetising and core loss components and an equivalent series impedance of $\bar{Z}_p\ \Omega$.

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 transformers. The high voltage side of the transformer bank is connected in a grounded star and the low-voltage side is connected in delta.

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

The equivalent series impedance of each single-phase transformer is $(0.12 + j0.24)\,\Omega$/phase referred to the low-voltage side. The transformers themselves are fed by a high-voltage feeder line whose series impedance is $(0.5 + j5.0)\,\Omega$/phase.

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

(ii) Neglecting the exciting current of the transformer bank, derive a 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 line.

[12]

5. (a) Draw the per-phase equivalent circuit of a three-phase, round-rotor, synchronous generator.

Derive expressions for the real and reactive power transfer from the machine in terms of the terminal voltage V_t, the generated voltage E_f, the synchronous reactance, X_s, and the load angle δ. It may be assumed that the armature winding resistance is negligible.

Deduce also the steady-state stability limit governing this power transfer.

[8]

(b) A steam-turbine driven, three-phase, round-rotor, synchronous generator with negligible phase winding resistance and a synchronous reactance of $4.0\,\Omega$/phase is connected to an infinite busbar operating at 10.0 kV. The generator delivers 120 A at 0.8 power factor lagging. Calculate the open-circuit phase voltage of the generator and the real power transferred to the busbars.

The steam supply to the turbine is now increased and the load angle δ of the synchronous generator is increased by $10°$. Calculate the new load current delivered by the machine and the power factor at which it is operating.

The excitation current of the generator is now increased while the steam supply is held constant until the power factor of the current is again 0.8 lagging. Calculate the load current now delivered by the alternator.

[12]

6. (a) Derive expressions for (i) the fault current and (ii) the voltage above ground of the healthy line 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 of Figure 1. Draw the positive, negative and zero sequence networks for this system and calculate the fault current. The generator is initially unloaded at 1.0 per-unit voltage.

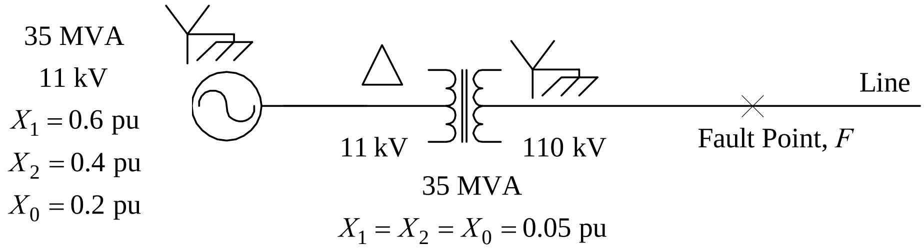

Figure 1: The electrical power distribution system of Q.6.

[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 describe the principal disadvantages associated with this simple rectifier circuit from the perspective of both the utility company and the product manufacturer.

[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,

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

while the input line current is given by

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

Derive also an expression for the neutral current if one of these converters is connected between live and neutral in each phase of a balanced three-phase star-connected system.

[8]

A diode bridge rectifier and capacitor filter circuit supplies a switched mode power supply which requires a power of 2.2 kW when operating from a mains voltage of 230 V. It is found that the fundamental current is $I_{in1}=11\,\text{A}$ and the THD of the line current is 93%. Calculate the *DPF*, the power factor and the rms input current.

[6]