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THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2009

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 approved calculators is permitted.

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

1. (a) Define the terms *per-unit growth rate, α*, and *doubling time, t_d* of energy consumption in a national electrical power system which demonstrates exponential growth. Hence derive an expression for the doubling time in terms of the growth rate.

The electrical energy consumption curve over time in a given electrical power system is such that the per-unit growth rate increases from an average of 2.5% per annum to 9.5% per annum. Calculate the doubling times corresponding to these growth rates and comment on the likely consequences of the higher level of growth if it is sustained over a number of years.

[5]

(b) Draw a schematic diagram illustrating the operation of a typical coal-fired electrical power generating station. Give approximate values for boiler inlet and outlet temperatures and estimate the ideal efficiency of such a process.

The coal yard for a coal-fired electrical power station can store 113×10^3 tonnes of black coal with a calorific value of 28 MJ/kg. The coal is used to feed a burner/boiler to raise steam for a turbo-generator system producing an average electrical output power of 95 MW. The efficiency of the system is 38%. Determine how many days the store can be used to operate the synchronous generator at its rated output power.

[5]

[Q.1 Continued overleaf]

(c) 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.

Estimate the number of wind turbines required to produce the equivalent of 600 MW of electrical power from a combined cycle gas plant. Assume that the average wind speed is 14 m/s, the blade diameter is 90 m and the overall efficiency is 30%. [Density of air at STP = 1.225 kgm^{-3}]

[5]

(d) List two advantages and two disadvantages of a Pressurised Water Reactor (PWR) nuclear power station 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]

2. (a) Explain the advantages of employing hydroelectric power generation in the operation of a national electrical power system. Comment, in particular, on the use of a pumped storage facility as part of the generation assets available to the system operator.

Draw a detailed system diagram of a pumped storage hydro-electric station and hence derive an expression for the generated 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 generating efficiency, η_G.

This pumped storage system has an efficiency η_P while pumping. Derive an expression for the ratio of the energy supplied to the grid while generating to that consumed during the corresponding pumping period.

[10]

(b) A large pumped storage system is constructed using an upper reservoir with a total volume of 9.2×10^6 m^3 of water, of which 6.7×10^6 m^3 is usefully transferred between the upper and lower reservoirs during an operational cycle. Power generation consists of 6 synchronous machines, each with a rated generating capacity of 300 MW. The average head between the two reservoirs is 536 m and the efficiency of the system in generating mode is 85.8%.

The total electrical energy generated by the station in a typical year is 1450 GWh while the total electrical energy consumed is 1860 GWh.

(i) Calculate the stored electrical energy capacity of the station in MWh and estimate how long the station can deliver its rated output power to the grid.
(ii) Calculate the flow rate of water to each generator for rated power output during generating mode.
(iii) Evaluate the overall annual efficiency of the pumped storage station.

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

[10]

3. (a) State the sequence component transformation and its inverse for three-phase voltages and currents.

A balanced, three-phase, star-connected load consists of an impedance $\bar{Z}_s\ \Omega$ in each phase. The star point of the load is grounded via an impedance $\bar{Z}_n\ \Omega$. Derive the zero, positive and negative sequence impedance networks corresponding to this load.

Hence, or otherwise, deduce the zero, positive and negative sequence impedance networks for a balanced delta connected load with an impedance of $\bar{Z}_\Delta\ \Omega$ connected between each phase.

[10]

(b) A three-phase balanced star-connected load is in parallel with a balanced delta-connected capacitor bank. The star-connected load has an impedance of $\bar{Z}_s = (3 + j4)\ \Omega\text{/phase}$ and its neutral is grounded via an inductive reactance of $X_n = 2\ \Omega$. The capacitor bank has a reactance of $X_\Delta = 30\ \Omega\text{/phase}$.

Draw the zero, positive and zero sequence networks corresponding to this load.

A system fault results in unbalanced phase-to-ground voltages being applied to this parallel load. If the zero, positive and negative sequence components of the phase-to-ground voltages are measured as $\bar{V}_0 = 32.7\angle 30.0°$ V, $\bar{V}_1 = 188.3\angle 7.6°$ V and $\bar{V}_2 = 44\angle -109.8°$ V, calculate the current which flows in Phase *a*

[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.

[8]

(b) A three-phase electrical power distribution system consisting of a synchronous generator, step-up transformer, transmission line, step-down transformer and load is illustrated in Figure 1 below. The parameters of the system are as specified in the figure and the impedance on the load busbars can be represented as a resistance of $300\ \Omega$. The generator is operated at a line voltage of 13.2 kV. Calculate the current in the generator zone and the voltage at the load busbars.

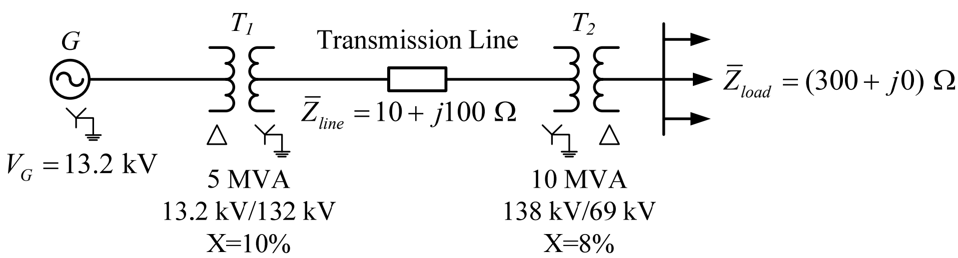

Figure 1. The three-phase distribution system of Q.4.

[12]

5. (a) The excitation system of a three-phase, round-rotor, synchronous generator is adjusted to give an internal emf of E_f V per phase when connected to a set of infinite busbar of line voltage $\sqrt{3}\,V_t$ V. The synchronous reactance of the machine is measured to be $X_s\,\Omega$. Neglecting resistive losses, derive expressions for the real power P and the reactive power Q delivered by this machine to the infinite busbar system in terms of the load angle δ. Assume a lagging power factor mode of operation.

Prove also 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 round-rotor synchronous generator delivers 1.0 pu current at 1.0 pu terminal voltage and a power factor of 0.8 lagging to a set of infinite three-phase busbars. The synchronous reactance of the generator is 1.0 pu and the phase winding resistance may be neglected.

(i) Calculate the internal emf of the machine, the load angle of the machine and the real and reactive power transfers to the set of infinite busbars.

(ii) If the excitation is now increased by 20% relative to that in (i), calculate the new load angle, the new armature current and the new operating power factor. The output power from the prime mover remains constant.

(iii) If the excitation is reduced again to that of Case (i), and the mechanical output power from the primer mover is increased by 20%, calculate the new values of the generator load angle, the armature current and the operating power factor of the machine.

[10]

6. (a) Derive an expression for the per unit fault volt-amperes arising from a symmetrical fault in a three-phase system in which $X_{T\,pu}$ is the total per-unit per-phase reactance up to the fault point.

Explain the object of sectionalising the busbars of a large generating station and connecting reactors between the sections. Sketch (i) the tie-bar configuration and (ii) the ring reactor configuration for interconnecting three sectionalised busbars in a power station.

[8]

(b) A power generating station has four busbar sections, *A, B*, *C* and *D* to each of which is connected a three-phase synchronous generator with a rating of 30 MVA and a reactance of 12 per cent based on this rating. Each busbar section is connected to a common tie-bar via a reactor of reactance *x* per unit based on the rated MVA of the generators.

(i) Calculate the per unit value of the tie-bar reactance *x* to limit the fault volt-amperes on a generator busbar section to 425 MVA.

(ii) Using this value of tie-bar reactance, calculate the maximum value of MVA fed into the fault on a busbar section if the number of similar busbar sections where increased to infinity.

[12]

7. (a) Derive an expression for the fault current when a line-to-line-to-ground short circuit 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) The single line diagram of a three-phase power distribution system is illustrated in Figure 2 below. In this system, the generator *G* is providing power over a three-phase transmission line to a large synchronous motor *M*.

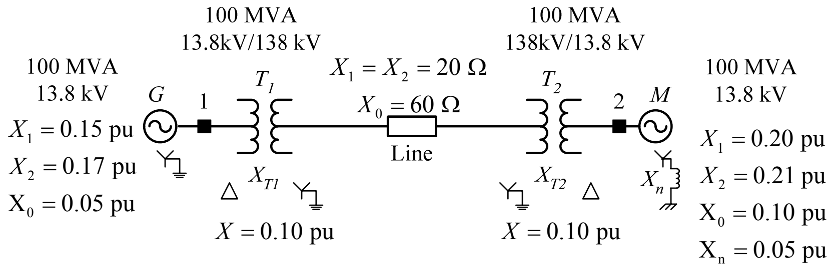

Figure 2. Power distribution system for Q.7.

(i) Deduce the per unit zero, positive and negative sequence networks for this system on a 100 MVA, 13.8 kV base in the generator zone.

(ii) Derive the corresponding zero, positive and negative sequence Thevenin equivalent networks as viewed from Busbar 2 at the motor terminals.

(iii) Calculate the fault current to earth for a zero-impedance, line-to-line-to-ground short circuit on Busbar 2. It can be assumed that the pre-fault current is negligible and that the pre-fault voltage is 1.05 per unit.

[12]