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B.E. Degree (Electrical)

Electrical & Electronic Power Supply Systems (EE4010)

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Attempt **FIVE** Questions

3 Hours

Q. 1. Answer clearly and concisely any *three* of the following.

(a) Prove that the total instantaneous power delivered by a three-phase sinusoidal voltage source operating under balanced conditions is a constant. Explain the significance of this result in the context of the generation and distribution of large scale electrical power.

(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 = $993 \text{ kg} / \text{m}^3$]

(c) Describe the characteristics of a three-phase synchronous machine designed for steam-turbine driven applications and contrast the construction of this machine with that of an alternator employed in hydro-electric generating stations.

(d) Sketch schematic diagrams for (i) a pressurised-water reactor nuclear fission reactor and (ii) a liquid metal fast breeder reactor. List the relative advantages and disadvantages of these technologies for electrical power generation in future decades.

(e) Define the term power quality. Describe two types of ac mains borne interference and comment on the measures that must be taken in off-line power supply designs to minimise the impact of these disturbances.

Q.2. A balanced, three-phase, star-connected, sinusoidal voltage source, with phase-to-star-point voltages defined by the phasors $\overline{V}_{Ag}$, $\overline{V}_{Bg}$ and $\overline{V}_{Cg}$, is connected to a three-phase, three-wire, unbalanced, star-connected impedance load. Two phases of the star-connected load, A and C, consist of impedances $\overline{Z}\,\Omega$ whilst the impedance in Phase B is zero. Derive from first principles an expression for the line current in the A phase of this system.

A voltage source such as that described above, with $\overline{V}_{AB} = 400\angle 0°$, is applied to an unbalanced delta-connected load as shown in Figure 1 below. The delta-connected impedance is $(18 + j10)\,\Omega$/phase but note that one phase of the delta, that between A and C, is open-circuited. Determine the line current $\overline{I}_A$ as well as its positive, negative and zero sequence components. Determine also the load current $\overline{I}_{BC}$.

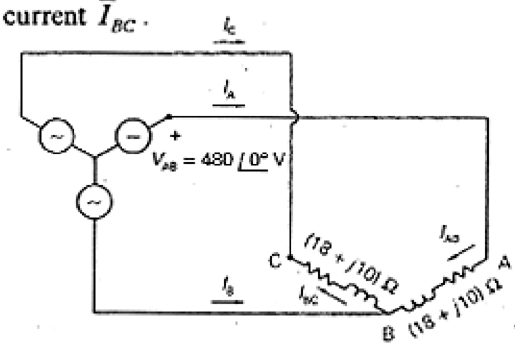

Figure 1. Unbalanced three-phase system of Question 2.

Q.3. Describe the advantages of employing the per-unit method of analysis in power systems engineering, proving, in particular, that the ideal transformer element in the full per-phase transformer model can be eliminated.

A 300 MVA, 20 kV, three-phase, star-connected, synchronous generator, with its star point grounded through a reactance, has a sub-transient reactance of 0.20 per unit. This generator supplies two synchronous motors over a 64 km transmission line having transformers at both ends as illustrated in the single-line diagram of Figure 2. The motors are both star-connected and are rated at 13.2 kV. The neutral of one motor, M_1, is grounded through a reactance while the neutral of the second motor, M_2,, is not connected to ground. The ratings of the motors are 200 MVA for motor M_1 and 100 MVA for M_2. Both motors have a sub-transient reactance of 0.20 per unit. The three-phase transformer, T_1, is rated at 350 MVA, 20kV/230kV with a leakage reactance of 0.10 per unit. Transformer, T, is made up of three single-phase transformers, each rated at 100 MVA, 127 kV/13.2 kV, with a leakage reactance of 0.10 per unit. The series reactance of the transmission line is $0.5\,\Omega$/km.

(a) Draw the per-unit equivalent circuit of this system using the generator ratings as base.

(b) If the motors M_1 and M_2 are have input powers of 120 kW and 60 kW respectively at 13.2 kV and both operate at unity power factor, find the voltage at the terminal of the generator.

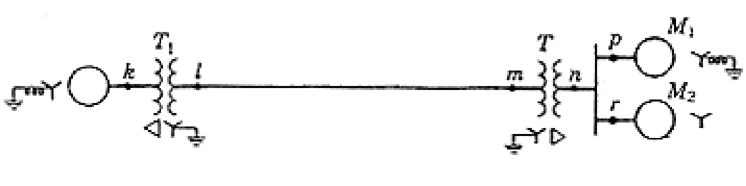

Figure 2. Power distribution system of Question 3. .

Q.4 Explain concisely the fundamental principle of operation of a three-phase, round-rotor, synchronous machine when supplying power to an infinite grid. Draw the per-phase equivalent circuit of the machine and 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.

A three-phase, star-connected, 11 kV, four-pole, 50 Hz, round rotor, synchronous generator has a synchronous reactance of $j1.0\,\Omega/\text{phase}$ and an open-circuit voltage of 12.5 kV. The machine is driven by a steam turbine and it is connected to 11 kV busbars. The steam supply to the turbine is adjusted until the generator supplies 80 MW of power to the busbars. Calculate the Calculate the armature current, power factor and the load angle of the machine when operating under these conditions.

Evaluate the theoretical maximum power which the machine can supply to the busbars without losing synchronism, calculate the power factor of the machine at this point and sketch the corresponding phasor diagram.

Q.5. Prove, listing all relevant assumptions, that the per-unit fault volt-amperes for a symmetrical fault in a three-phase system is given approximately by

$$VA_{f\,pu} = \frac{1}{X_{T\,pu}}$$

where $X_{T\,pu}$ is the total per-unit phase reactance up to the fault point. Explain the use of current limiting reactors in electrical power systems and describe a method of connecting such reactors in a large multi-generator power station.

A power station operating at 33 kV is divided into sections *A* and *B*. Section *A* consists of three generators rated at 15 MVA, each having a reactance of 15%. Section *B* is fed from the national grid through a transformer rated at 75 MVA and having a reactance of 8%. The circuit breakers on the load feeder lines from Section *A* have a breaking capacity of 750 MVA.

(a) Determine the reactance of a reactor connected between *A* and *B* to prevent the breakers being overloaded in the event of a three-phase symmetrical short circuit occurring on an outgoing feeder line connected to section *A*.

(b) A 750 MVA breaker is also used at section *B* to protect an outgoing feeder line supplied directly from this section. Is this breaker overloaded in the event of a three-phase symmetrical short circuit on this outgoing feeder line, and, if so, suggest some possible solutions to the problem.

Q.6. Derive expressions for the fault current when a single-phase-to-earth fault 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 connected between the generator star-point and earth?

A three-phase synchronous generator is rated at 20 MVA, 13.8 kV and has a direct-axis, sub-transient reactance of 0.25 per unit. The corresponding negative-sequence and zero-sequence reactances are 0.35 per unit and 0.10 per unit respectively. The neutral of the generator is solidly grounded. Determine the sub-transient fault current in the generator and the line-to-line voltages when a single-line-to-ground fault occurs at the generator terminals with the generator initially operating unloaded at rated voltage. Resistance may be neglected.

Q.7. Derive an expression for the voltage transfer function of a isolated flyback dc/dc converter operating in the continuous-conduction mode assuming zero leakage inductance and winding resistance in the transformer. Deduce also the condition on the transformer magnetising inductance to ensure a continuous current mode of operation. Describe the fundamental difference in operation between the transformer used in this topology and that the transformer used in a forward converter.

A flyback converter is required to supply 100 W at 3.3 V_{dc} from a 320 V_{dc} dc voltage source. The switching frequency is 200 kHz and the primary/secondary turns ratio of the transformer is 60:1. Calculate the duty cycle of the power switch, the minimum transformer primary magnetising inductance to ensure continuous current operation and the peak switch blocking voltage.