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B.E. Degree (Electrical)

Electrical & Electronic Power Supply Systems (EE4010)

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Attempt **FIVE** Questions

The use of approved electronic calculators is permitted.

3 Hours

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

(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. In a certain country, the electrical energy consumption curve over time is such that the per-unit growth rate increases from an average of 2.45% per annum to 7.5% per annum. Comment on the impact which this increase in growth rate has on the doubling time.

(b) Derive an expression for the electrical output power P available from a hydroelectric power station in terms of the flow rate of water Q m^3/s, the head of water H m and the overall efficiency η. A river-based hydroelectric power station has a mean head of 28.5 m. The minimum average flow rate of water in summer is 180 m^3/s and this increases to a maximum of 400 m^3/s in winter. Calculate the maximum and minimum generating capacities of the station assuming an overall efficiency of 92%.

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

(c) Briefly describe the basic process underpinning the use of nuclear fission for the generation of electrical energy. Sketch schematic diagrams for (i) a pressurised-water reactor and (ii) a liquid metal fast breeder reactor and list the relative advantages and disadvantages of these technologies for electrical power generation in future decades.

(d) A balanced, positive sequence, star-connected voltage source has a line voltage of 400V and a solidly grounded star point. This three-phase voltage source is applied via a transmission line to a balanced, star-connected load with $\overline{Z}_{star} = 10\angle 40°\ \Omega$ per phase. The star point of the load is grounded through an impedance of $\overline{Z}_{ground} = 5\angle 90°\ \Omega$. The impedance of the transmission line between the source and load is $\overline{Z}_{line} = 1\angle 85°\ \Omega$ per phase. Calculate the line current in Phase *a* of the transmission line.

(e) Draw the circuit diagram of an off-line rectifier-fed flyback dc/dc converter. Using this circuit as an example, define the distinction between the *differential mode current* and the *common mode current* drawn by a switched mode off-line power converter. Draw the circuit diagram of a typical power line filter used at the input of such converters and explain the use of each of the constituent components.

Q.2. Define the terms (i) *sequence voltage vector* (ii) *sequence current vector* and (iii) *sequence impedance matrix* as applied to an item of equipment in a three-phase electrical power system. Define also what is meant by a *symmetrical load* in a three-phase system.

A three-phase, four-wire load with a solidly grounded star point is defined by the following phase impedance matrix

$$\overline{Z}_{phase} = \begin{bmatrix} \overline{Z}_s & \overline{Z}_m & \overline{Z}_m \\ \overline{Z}_m & \overline{Z}_s & \overline{Z}_m \\ \overline{Z}_m & \overline{Z}_m & \overline{Z}_s \end{bmatrix}.$$

Derive the positive, negative and zero sequence impedance networks corresponding to this load.

Unbalanced phase-to-ground source voltages defined by $\overline{V}_{ag} = 277\angle 0°$ V, $\overline{V}_{bg} = 260\angle -120°$ V and $\overline{V}_{cg} = 295\angle 115°$ V are applied to the three-phase load described above in which $\overline{Z}_s = (10 + j30)\ \Omega$ and $\overline{Z}_m = (5 + j20)\ \Omega$. The load star point is solidly grounded. Calculate the line current in Phase *a* of the load.

Q.3. Prove that the per unit impedance of a three-phase star/delta connected transformer is the same whether computed from the star-side parameters or from the delta-side. Assume a three-phase volt-ampere rating of *S* VA, a line-to-line input voltage to the star side of V_L V, a turns ratio of *1:N* (star/delta) and an impedance of $\overline{Z}_{phase}$ Ω per phase referred to the star-side.

The one-line schematic diagram of a three-phase power transmission system is illustrated in Figure 1 below.

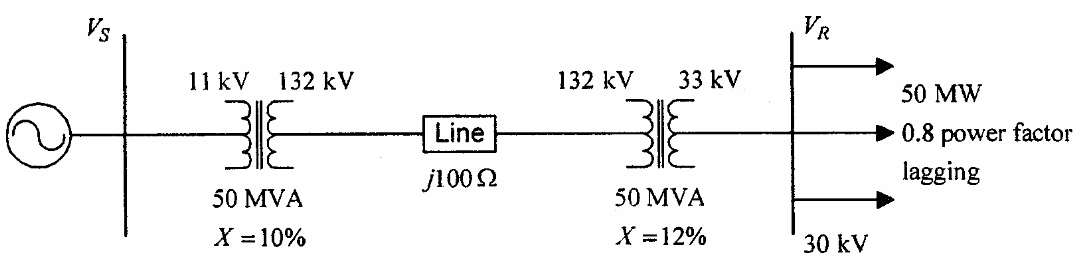

Figure 1: Power transmission system of Q.3.

The ratings and reactances of the various components are as shown together with the nominal line voltages. The specified per-unit values are based on the given ratings. The three-phase transformers are connected in delta on the low voltage side and in a grounded star on the high voltage side. A load of 50 MW at 0.8 power factor lagging is taken from the 33 kV busbar which is to be maintained at $V_R = 30\text{kV}$. Calculate the line voltage V_S at the terminals of the synchronous generator.

Q.4. Explain the origin of the two rotating magnetic fields in the air gap of a three-phase, round-rotor synchronous machine when supplying power to an infinite grid. Hence, construct the corresponding phasor diagram assuming balanced three-phase operation of the machine. From the resultant per-phase equivalent circuit, 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, 50 Hz, round rotor, synchronous generator has a synchronous reactance of $j8.5\,\Omega/\text{phase}$ and negligible resistance. The machine is synchronised onto 11 kV infinite busbars and it is initially delivering a per-phase armature current of 180 A at 0.9 power factor lagging. Calculate the internal emf of the machine. If the steam turbine mechanical output power is held constant while the generator field excitation is increased by 25%, calculate the new armature current and power factor for this operating condition.

The field excitation current is now maintained constant at the new value and the turbine mechanical power is steadily increased. Compute the value of electrical output power at which the synchronous generator loses synchronism.

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.

An industrial power distribution system is illustrated in the one-line diagram of Figure 2 below.

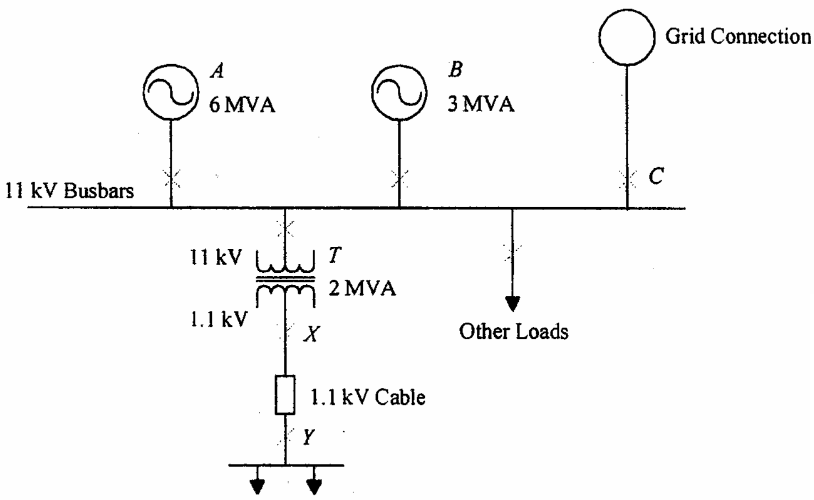

Figure 2: The industrial power distribution system of Q.5.

The reactance of generator A is 0.3 per-unit and that of generator B is 0.35 per-unit. The transformer T has a reactance of 0.07 per-unit. All reactances are based on the ratings of the particular unit. The reactance of the cable is $X_{cable} = 0.019\,\Omega$ and its resistance is negligible. The circuit breaker at C is initially open. Calculate the fault MVA levels in the system at points X and Y.

The circuit breaker at C is now closed. The supply authority system fault level at point C is 100 MVA when the generators A and B are isolated from the network. Compute the fault MVA level at C when generators A and B are on-line and the circuit breaker at C is closed.

Q.6. Derive an expression for the fault current 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?

A direct double-phase-to-ground fault occurs at the point F in the electrical power distribution system of Figure 3. 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.

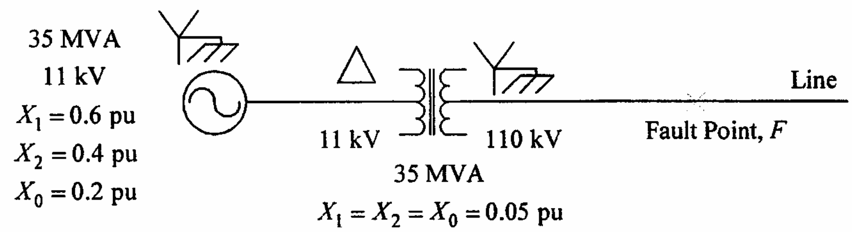

Figure 3: The electrical power distribution system of Q.6.

Q.7. The circuit of Figure 4 shows a forward dc/dc converter used in an off-line switched mode power supply. Explain the basic operation of the circuit and derive an expression for the steady state dc voltage gain $\frac{V_o}{V_i}$ of this converter assuming that the output inductor current is continuous and that the switching frequency is fixed. Deduce also the critical condition on the output filter inductance to ensure continuous current operation.

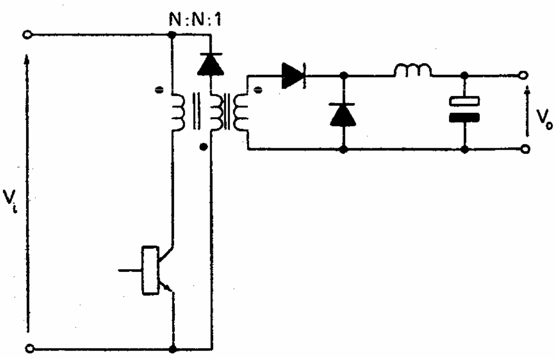

Figure 4. The forward dc/dc converter circuit for Q.7.

A forward dc/dc converter for a telecommunications system operates from an input voltage of 48 V_{dc}. The load can be represented as a fixed resistance of 10 Ω. The primary-to-secondary turns ratio is 1.5:1 while the primary-to-reset winding turns ratio is 1:1. At a particular operating point, the duty cycle is 0.4, the switching frequency is 35 kHz and the output filter inductance is 400 μH.

Calculate the dc output voltage, the input power and the maximum and minimum filter inductor currents. Also, if the transformer magnetising inductance is 5 mH, verify that the primary magnetising current is reset to zero during each switching cycle.