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The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2013-14 (2.0 hours)

EE341 Electrical Power Systems

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1.

a. State the definition of 'infinite bus-bar' in relation to an electrical power system and list the main conditions to be satisfied to synchronise a wound field synchronous machine to an infinite bus-bar system. **(2)**

b. A 3-phase synchronous motor which has negligible winding resistance is connected to an infinite busbar system. The motor is initially on no-load and is idling on the system with negligible current flow through its terminals. Using a suitable equivalent circuit model and phasor diagrams of the steady-state conditions explain the following:

(i) the initial operating conditions of the machine **(2)**

(ii) what happens when the machine excitation is increased whilst it remains on no-load? **(2)**

(iii) what happens when the excitation remains unchanged from the idling conditions in part **(i)** but a mechanical load is applied to the shaft? **(2)**

c. A 15kV star-connected 3-phase synchronous motor has a synchronous reactance of 10Ω per phase and negligible resistance. The motor is to be used in a factory with a general load requirement of 20MVA at 0.75 power factor lagging. When the motor is installed it will be used to provide an **additional** 3MW of mechanical power and also to correct the total power factor of the factory to a value of 0.95 lagging.

(i) Calculate the MVA rating and the power factor at which the synchronous motor must operate. **(5)**

(ii) Calculate the motor line current, excitation emf and the load angle at which the motor will be operating. **(4)**

(iii) If the mechanical load on the synchronous machine reduces to 2.4MW calculate the new load angle at which the motor will operate assuming the excitation emf is unchanged. **(3)**

2.

a. Describe what in general is meant by the per-unit value of any quantity. **(1)**

b. Briefly describe, with suitable diagrams where appropriate, methods for limiting fault levels in interconnected power systems. **(5)**

c. Figure 2.1 shows a line diagram of a 3-phase power system consisting of two 11kV busbars linked by a fault limiting busbar reactor of 0.12Ω. The two 132kV feeders supply passive loads, and the Grid Infeed can supply 500MVA into a symmetrical 3-phase fault.

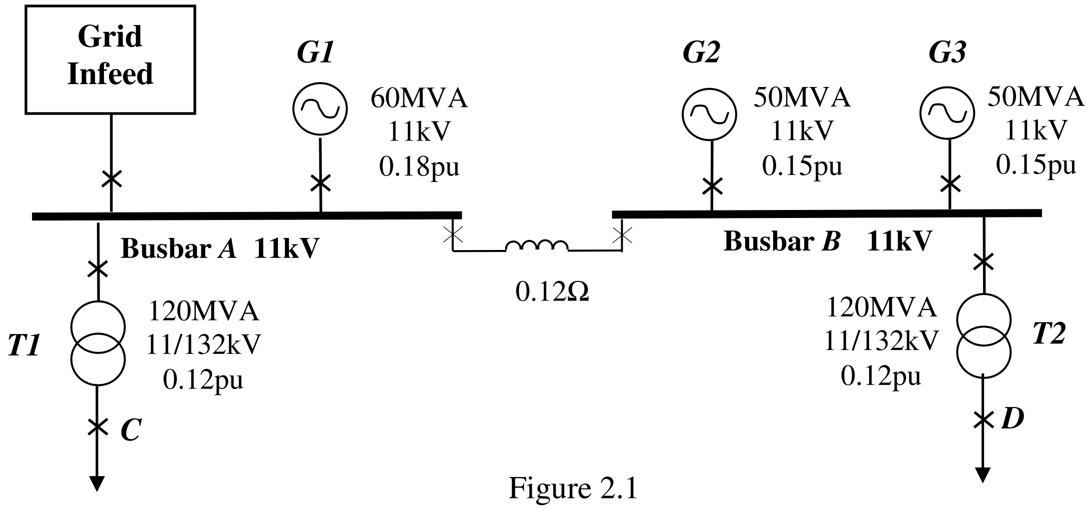

Figure 2.1

(i) Using a reference base of 50MVA calculate the required MVA rating of the circuit breakers at points ***C*** and ***D*** on each of the feeders. **(7)**

(ii) For a 3-phase symmetrical fault at point *D*, calculate the rms phase current which flows in Generator *G2* (Assume *G2* is star-connected). **(3)**

(iii) Assuming faults may occur at any point in the system, calculate the maximum fault current rating of the busbar reactor. **(4)**

3.

A 3-phase, star-connected load is supplied via a balanced 415V, 3-phase, 3-wire supply, of phase sequence ABC. The 3-phase load consists of three single-phase loads of (10 – j4) Ω, (4 + j6) Ω and (5 + j16) Ω, connected between phases *A, B, C* and the load star point respectively, as illustrated in Figure 3.1.

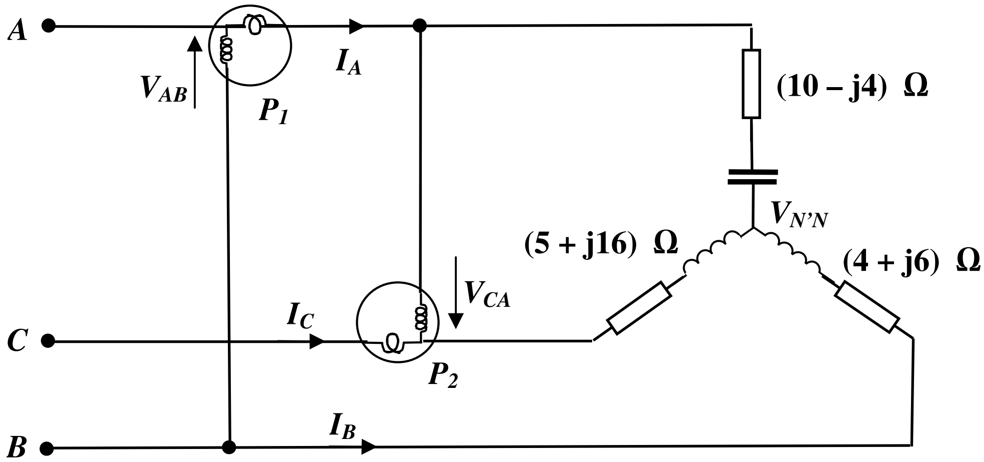

Figure 3.1

a. Using Millman's theorem, or otherwise:

(i) calculate the voltage across each phase of the load **(8)**

(ii) hence calculate the three line currents **(2)**

b. During installation, the wattmeters, P_1 and P_2, were not correctly connected as shown in Figure 3.1:

(i) sketch the phasor diagram for the system showing the three phase and line voltages, the three line currents and their relevant angles. **(3)**

(ii) hence, calculate the readings on the two wattmeters and the sum of the two wattmeter readings. **(2)**

c. **(i)** Describe how P_2 may be reconnected to correctly measure the power in the unbalanced load and calculate the new reading for P_2. **(2)**

(ii) Verify that the sum of the power readings on the two wattmeters measures the true power dissipated in the unbalanced 3-phase load. **(1)**

(iii) If the star point of the load was connected to the neutral point of the supply would the sum of the power readings on the two wattmeters still measure the true power? Explain your answer. (Assume the neutral conductor has zero impedance and that the Wattmeters are correctly connected). **(2)**

4.

a. State two major benefits and two drawbacks of induction machines over synchronous machines, connected to an infinite bus-bar system, for wind generation applications. **(2)**

b. Figure 4.1 shows a per-phase equivalent circuit of a 3-phase induction machine. Explain what each of the components represents. **(2)**

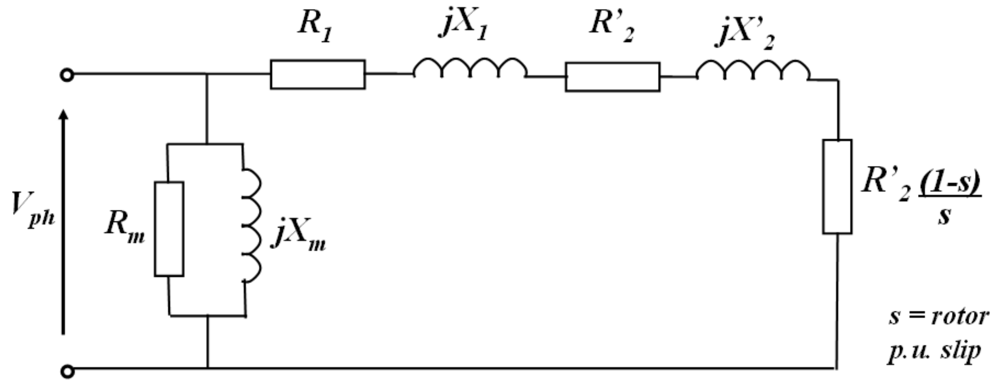

Figure 4.1

c. A small factory has a typical base load demand of 50MVA at 0.72pf lagging. To reduce their annual energy requirements, the company installed a wind turbine. The turbine drives a 3-phase, star-connected, 8-pole induction machine generating into an 11kV, 50Hz, infinite bus-bar system. The machine can be modelled via a simplified, per phase equivalent circuit, as illustrated in Figure 4.1 which has the equivalent circuit parameters as detailed in Table 4.1

R_1 = 0.25Ω	**R'_2 = 1.2Ω**	**R_m = 280Ω**
jX_1 = j 2.6Ω	**jX'_2 = j 2.5Ω**	**jX_m = j 65Ω**

Table 4.1. Equivalent circuit parameters

(i) Calculate the apparent power at the machine terminals and hence the net electrical real and reactive power generation if the rotor speed is 870rpm. **(7)**

(ii) For this operating condition, calculate the turbine mechanical power input and hence the efficiency of the induction generator. **(2)**

(iii) By combining the output of the induction generator with the base load demand of the factory, calculate and comment on the resultant real and reactive power drawn from the supply. **(3)**

(iv) Calculate the value of capacitance per phase of a star-connected capacitor bank, connected in parallel with the factory base load and the induction generator to improve the overall power-factor to 0.95 lagging. Assume the induction generator is at the operating condition of part **(c)(i).** **(3)**

(v) If the capacitor bank is permanently connected, calculate the power-factor of the factory when the wind turbine is not in operation. **(1)**

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