Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-16 (2.0 hours)

EEE341 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. Sketch a typical torque-speed characteristic for an induction machine identifying both motoring and generating regions, the synchronous speed and any critical operating points from a generator perspective. **(3)**

b. A chemical processing company has a base load demand of 15MVA at 0.7 power-factor lagging which it draws from an 11kV, 50Hz, infinite busbar supply. To reduce its carbon footprint, the company decides to use waste steam from one of the production processes to operate a steam turbine which drives a 6-pole, 3-phase, star-connected induction generator. The induction generator can be modelled using a simplified, per phase equivalent circuit, as shown in Figure 1.1. The equivalent circuit parameters of the machine are given in Table 1.1

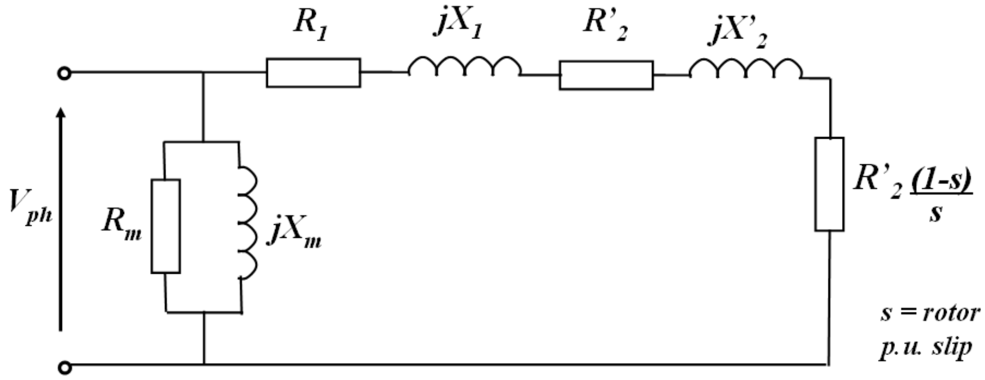

Figure 1.1

$R_1 = 0.9\ \Omega$	$R'_2 = 1.7\ \Omega$	$R_m = 850\ \Omega$
$jX_1 = j\ 8\ \Omega$	$jX'_2 = j\ 6.5\ \Omega$	$jX_m = j\ 200\ \Omega$

Table 1.1. Equivalent circuit parameters

(i) Calculate the apparent power at the terminals of the induction machine and hence the net electrical real and reactive power generation if the speed of the steam turbine is 1080rpm. **(6)**

(ii) For this operating condition, calculate the turbine mechanical power input and hence the efficiency of the induction generator. Check your answer by performing an audit of the machine losses. **(3)**

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

c. The company decide to install a permanent, delta-connected, capacitor bank in parallel with the incoming supply. The capacitor bank has a capacitance of 50µF per phase. Calculate the apparent power and operating power factor of the company when at base load and:

(i) the steam turbine is not in operation **(2)**

(ii) when the steam turbine is operating at 1080 rpm, as in part **b (i)** **(1)**

d. Comment on the factory's real and apparent power consumption for the two scenarios **c (i)** and **(ii)** above. **(2)**

2.

a. Given that the real power transfer through a transmission line can be approximated by:

$$P = \frac{V_S V_R}{X} \sin(\delta)$$

Briefly discuss methods for increasing the power flow through the line and any problems associated with these methods. **(3)**

b. Briefly outline three methods which can be used to limit fault levels in power systems. **(3)**

c. Figure 2.1 shows a line diagram of a 3-phase power system consisting of two 20kV busbars linked by a fault limiting reactor of 1.5Ω. The Grid Infeed can supply 250MVA into a symmetrical 3-phase fault.

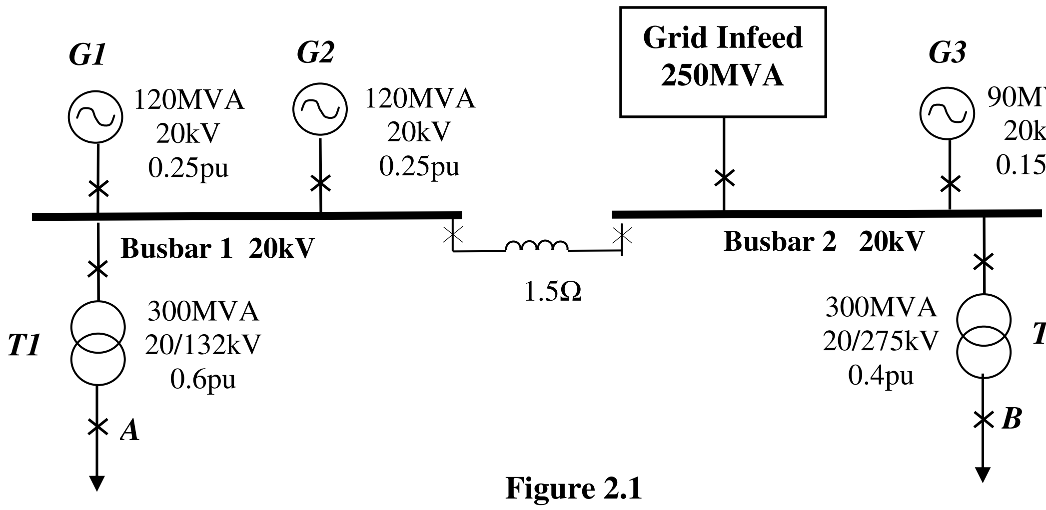

Figure 2.1

(i) Using a reference base of 120MVA calculate the required MVA rating of the circuit breakers at points *A* and *B*. **(7)**

(ii) For a 3-phase symmetrical fault at point *B*, calculate the rms phase current which flows in Generator *G1* (Assume *G1* is delta-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 star-connected load is supplied via a balanced 400V, 3-phase, 4-wire supply of phase sequence *ABC*. The 3-phase load consists of three single phase loads of $(10 - j3)\Omega$, $(7 + j12)\Omega$ and $(9 + j5)\Omega$, connected between lines *A,B,C*, and the neutral respectively as shown in Figure 3.1. All the supply lines and the neutral wire have negligible impedance.

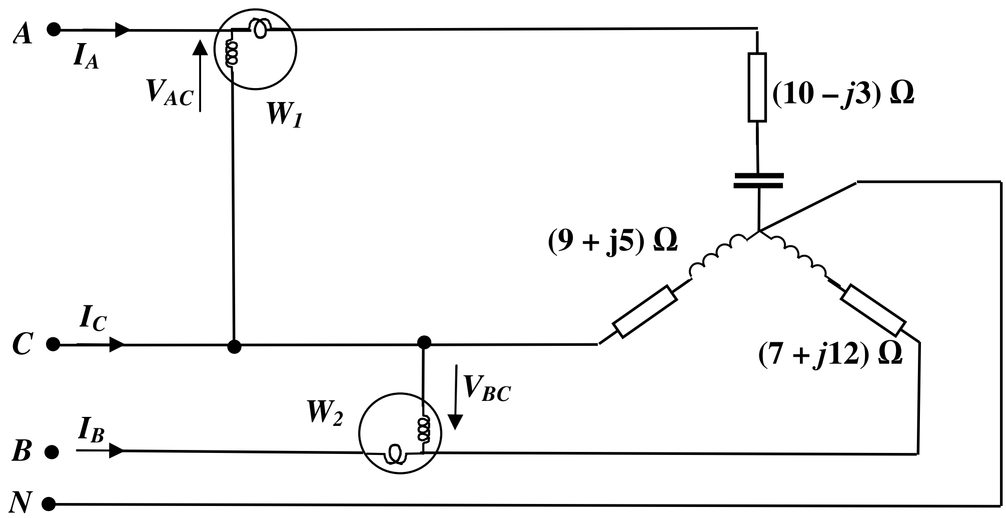

Figure 3.1

a. Calculate the magnitude and phase of the three line currents and the neutral current. State which voltage you have taken as reference. **(2)**

b. Two wattmeters are installed to measure the total input power to the load. One is connected with its current coil in line *A* and its voltage coil between lines *A* and *C*, the other with its current coil in line *B* and voltage coil between lines *B* and *C*, as illustrated in Figure 3.1.

(i) Sketch a phasor diagram showing the voltages and currents which are measured by the two wattmeters and their respective phase angles. **(3)**

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

(iii) What percentage error, if any, would be incurred if it was assumed that the sum of the two wattmeter readings gave the total input power to the system? **(2)**

(iv) Briefly describe a more appropriate method of measuring the total 3-phase power. **(1)**

c. Due to poor installation the neutral wire has become disconnected at the supply and is open circuit.

(i) Using a star-delta transformation or otherwise calculate the three line currents and the voltage across each phase for this condition. State which voltage you have taken as reference. **(7)**

(ii) Hence, calculate the readings on the two wattmeters. **(2)**

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

4.

a. Write down the circuit equations of a synchronous machine (for operation as both a motor and a generator) and use them to derive phasor diagrams for the machine operating as a generator on leading power-factor and as a motor on lagging power-factor. **(3)**

b. A synchronous machine is operated as a motor and is connected to an infinite bus-bar. The machine has a fixed mechanical output power and the resistance of the armature winding can be neglected.

Initially, the excitation, E, is set so that it is much greater than the system voltage, V (i.e. $E_1 > V$). The mechanical output power is then kept constant and the field current is gradually reduced until the excitation, E, is less than the voltage, V (i.e. $E_2 < V$). Graphs are then plotted of the line current magnitude and power-factor against field current.

By the use of the relevant phasor diagrams, and by carefully explaining the changing operating conditions, explain what happens to the line current magnitude and power-factor as the excitation is decreased from E_1 to E_2. Hence, plot the expected form of the two graphs. **(5)**

c. A small manufacturing company has an existing general load requirement of 6MVA at 0.8 power-factor lagging. The company plans to expand and obtains an 11kV, three-phase star-connected synchronous motor, having a synchronous reactance of 12Ω per phase and negligible resistance, to provide the **additional** 1MW of mechanical power required. The motor will also be used to improve the overall power-factor of the company from 0.8 lagging to a value of 0.98 lagging.

(i) Calculate the MVA rating and the power factor at which the synchronous motor must operate. **(4)**

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

(iii) Overnight the load on the motor falls to 800kW and the excitation emf is adjusted to 7kV. Calculate the new phase current and power factor of the motor. **(3)**

d. Briefly comment on the reasons for employing the synchronous machine to improve the total company power-factor. **(1)**

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