The University Of Sheffield.

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DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (3.0 hours)

EEE338 Power Engineering

Answer **FIVE QUESTIONS** comprising **AT LEAST TWO** each from **part A** and **part B. No marks will be awarded for solutions to a sixth question, or if you answer more than three questions from parts A or B.** 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.**

Part A

A1.

A three-phase, star-connected load is supplied via a balanced 6.6kV, three-phase, 3-wire supply, of phase sequence ABC. The three-phase load consists of three single-phase loads of (25 + j60) Ω, (15 + j20) Ω and (40 – j25) Ω, connected between phases *A, B, C* and the load star point respectively, as shown in Figure A1.1.

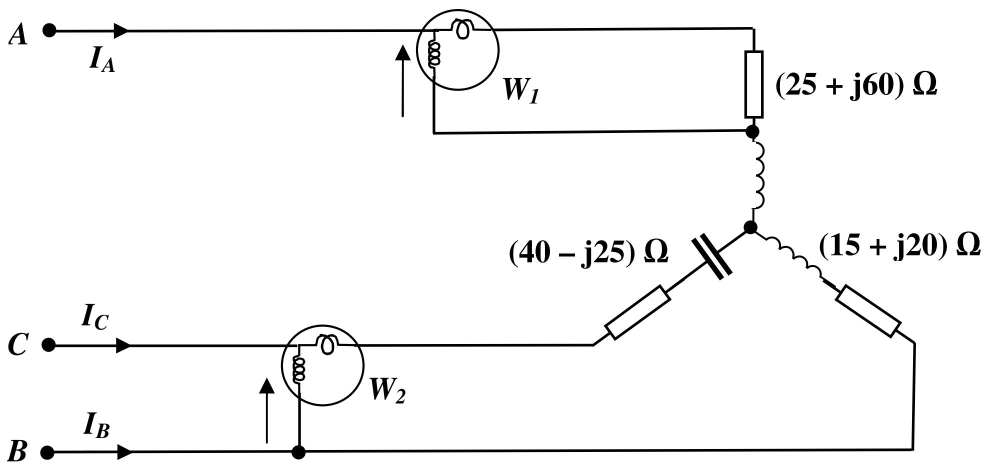

Figure A1.1

a. Using the star to delta transformation, or otherwise:

(i) calculate the current in each phase of the load **(7)**

(ii) hence calculate the voltage across each phase of the load **(2)**

b. Two wattmeters, W_1 and W_2 are to be used to measure the input power to the load. However, during installation the wattmeters were incorrectly connected as shown in Figure A1.1:

(i) sketch the phasor diagram for the system showing the three line and phase voltages of the supply, the voltages across the wattmeter voltage measuring coils, the three line currents and their relevant angles. **(4)**

(ii) hence, calculate the readings on the two wattmeters. Comment on the relevance of the readings on W_1 and W_2. **(3)**

c. (i) Describe how W_1 may be reconnected to correctly measure the power in the unbalanced load and calculate the new reading for W_1. **(2)**

(ii) Verify that the sum of the power readings on the two wattmeters measures the true power dissipated in the unbalanced three-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? (Assume the neutral conductor has zero impedance and that the Wattmeters are correctly connected). **(1)**

A2.

a. Briefly explain and illustrate the operation of the Arc Chute and Blow-out Coil types of plain air break circuit breakers. **(3)**

b. Describe what in general is meant by the per-unit value of any quantity. How is this general definition usually applied in 3-phase systems? **(2)**

c. Figure A2.1 shows a line diagram of a three-phase network in which it is proposed to link the 66kV busbar ***B*** to the 132kV system at ***A*** via an overhead line and a 100 MVA transformer (*T3*) as shown.

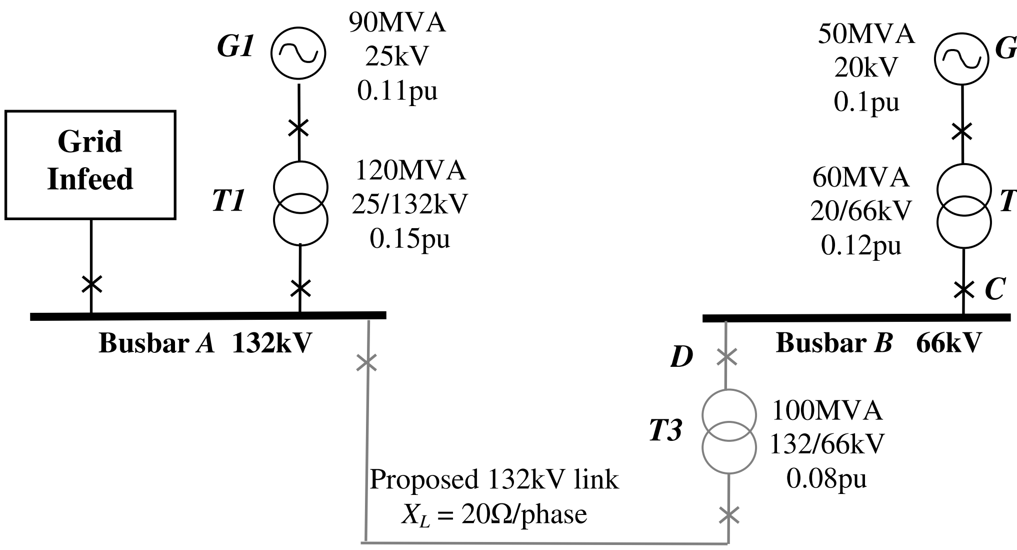

Figure A2.1

(i) Calculate the fault level at busbar *B* before the 132 kV system is linked in. **(3)**

(ii) If the Grid Infeed can feed 300 MVA into a symmetrical fault at busbar A calculate the new fault level at *B* when the 132kV link is connected. Hence calculate the rms fault current through circuit breakers *C* and *D* for a fault on busbar *B*. **(7)**

(iii) For the fault at busbar *B* described in part **(ii)** above, calculate the rms phase current which flows in generator *G1*. (Assume *G1* is star-connected). **(2)**

(iv) If the new fault level at busbar *B* has to be limited to 500MVA calculate the required per-unit series reactance which must be inserted in the 132kV line linking busbars *A* and *B*. **(3)**

A3.

a. **(i)** Draw the equivalent circuit of a three-phase synchronous machine and explain the physical significance of the various voltages, currents and impedances. **(3)**

(ii) Describe what tests would be used to characterise a synchronous machine and obtain the parameters for the equivalent circuit. **(3)**

(iii) Write down the circuit equation for the machine acting as a motor and use this to derive phasor diagrams for operation at leading, lagging and unity power-factor. (You can assume the machine is connected to an infinite busbar system). **(4)**

b. A star-connected three-phase **generator** is connected to a 50kV (line voltage) infinite busbar system and has a synchronous reactance of 8Ω per phase and negligible armature resistance.

(i) Calculate the excitation voltage required for operation at 8MVA and 0.75 power-factor lagging. What is the percentage regulation for this condition? **(3)**

(ii) The excitation is kept constant at the value calculated in part **b(i)** and the mechanical input power increased until the generator operates at unity power factor. Calculate the new input power and the load angle. **(3)**

(iii) If the power input to the generator is kept at the same level as part **b(i)**, calculate the output phase current and power-factor if the excitation is decreased to a value which would give a 12% lower open-circuit voltage. **(4)**

A4.

a. What conditions would be preferred when operating transformers in parallel, and explain the consequences of deviations from these ideal conditions. **(3)**

b. Explain, with the aid of suitable circuit and voltage phasor diagrams, what the designations Dy11 and Dy1 indicate on a transformer nameplate. **(4)**

c. The existing electrical supply to an industrial company is taken via an 8MVA, 66:11kV, 3-phase transformer, *T1*, which has a per-unit impedance of $(0.03 + j\ 0.06)$. The company adds a new assembly line which increases the maximum demand from 8MVA to 10MVA at a power-factor of 0.7 lagging. As a short-term solution, the supply authority arranges for a second supply to the company to be taken via a 4MVA, 66:11kV transformer, *T2*, having a per-unit impedance of $(0.05 + j\ 0.15)$, and connected in parallel with the existing 8MVA transformer, as shown in Figure A4.1.

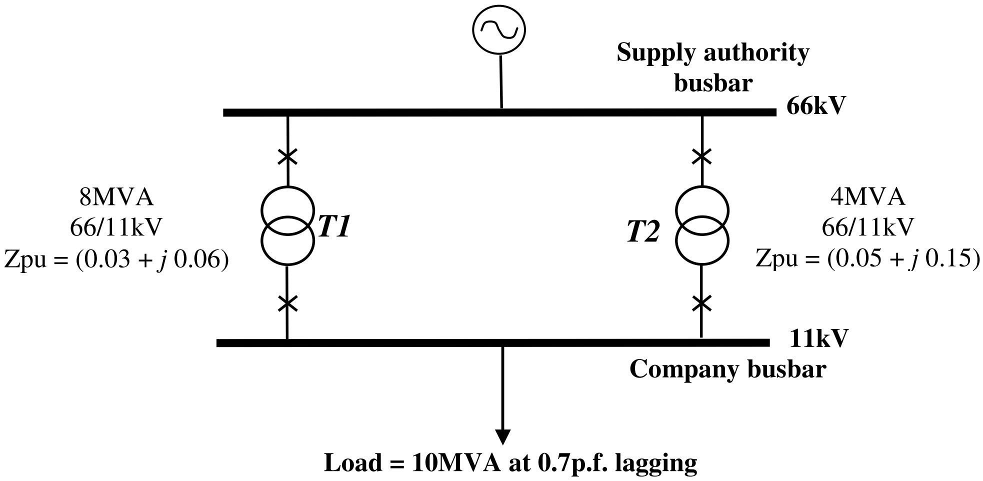

Figure A4.1

(i) Calculate the load and power-factor of each transformer when they are operating in parallel and supplying the demand of 10MVA at 0.7 p.f. lagging. **(5)**

(ii) Comment on the suitability of this solution in terms of transformer load share. **(1)**

d. An in-line reactor is connected in series with one of the transformers in Figure A4.1 to apportion the transformer loadings relative to their respective MVA ratings.

(i) Explain where you would connect the in-line reactor and calculate its per-unit impedance and MVA rating. **(3)**

(ii) Calculate the new loadings taking into account the reactor, to give evidence that the reactor has achieved load sharing. **(2)**

e. To meet future production needs it is proposed to add a 4MVA synchronous motor, operating at 0.8 p.f. leading, in addition to the existing 10MVA load in Figure A4.1. Calculate the new overall demand of the factory and decide whether the two transformers (including the in-line reactor) could still cope without being overloaded. **(2)**

Part B

B1.

a. What is meant by a synchronous machine "losing synchronisation". Explain why this is undesirable. **(2)**

b. A 200MVA generator is connected to an infinite busbar via a transformer and a pair of identical overhead transmission lines, each having negligible resistance and a reactance of *j*0.2 pu as shown in Figure B1.1. The generator voltage is 1.1 pu and the voltage of the infinite busbar is 1.0 pu.

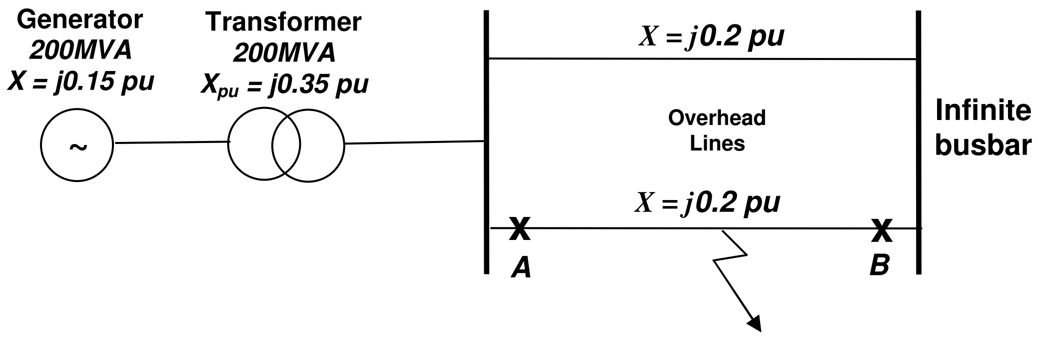

Figure B1.1 Generator and transmission system.

(i) Determine the power-load angle equation for the system. If the generator is delivering 180MW, calculate its load angle. **(3)**

(ii) When a 3-phase short-circuit occurs at the middle of one of the overhead transmission lines, between *A* and *B,* the effective system reactance becomes j1.9pu. Determine the power-load angle equation for the system under fault conditions. **(1)**

(iii) The short-circuit is then cleared by the simultaneous opening of the circuit breakers, *A* and *B* at each end of the faulted line. Determine the new power-load angle equation for the system. **(1)**

(iv) Sketch the power transfer curves for before, during, and after the fault. Mark on the sketch the accelerating area, decelerating area, and the critical load angle. **(3)**

(v) By deriving an analytical expression or otherwise, determine the critical switching angle at which the fault must be cleared in order to ensure system stability. **(5)**

c. If the circuit breakers clear the fault in 0.2s determine if this is sufficient to maintain system stability if the inertia constant of the generator, $M = 2.5 \times 10^{-4}$ pu. Use a time interval, $\Delta t = 0.05$s in conjunction with the swing equation.

(Use may be made of the equation: $\Delta\delta_n = \Delta\delta_{n-1} + \frac{(\Delta t)^2}{M} P_{a(n-1)}$) **(5)**

B2.

Figure B2.1 shows the single-line diagram of a power system comprising three 132kV busbars, *Bus 1, Bus2* and *Bus 3*, connected together by overhead transmission lines, *L1* and *L2*. Each busbar is supplied by a generator via a step-up transformer. Generator, *G2,* has its star point earthed through a reactor, X_N, of j0.3Ω, all other star points in the system are solidly earthed. A single phase to earth fault occurs on one end of *L2*, as shown.

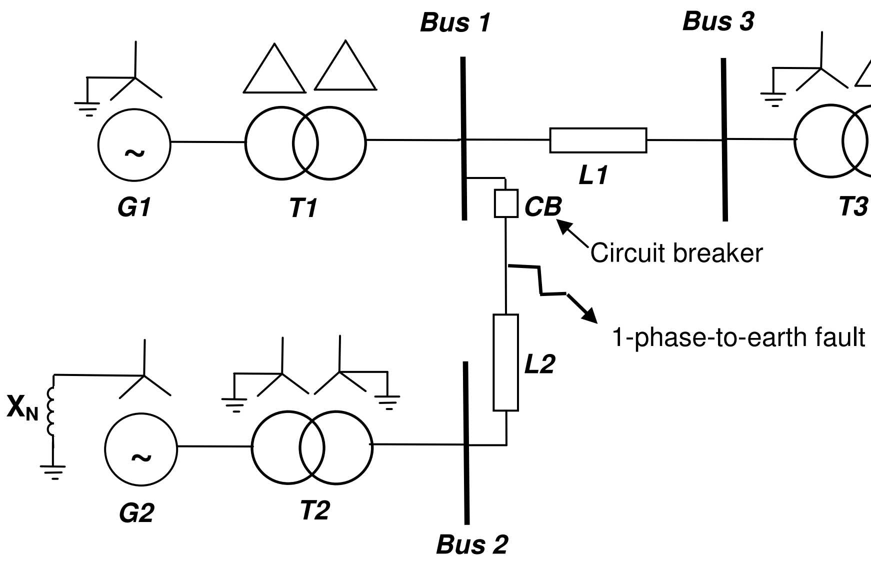

Figure B2.1 Line diagram of power system

	Rating MVA	Voltage kV	X_+	X_-	X_0
G1	100	25	j0.1 pu	j0.1 pu	j0.08 pu
G2	120	25	j0.15 pu	j0.18 pu	j0.14 pu
G3	80	19.5	j0.08 pu	j0.08 pu	j0.06 pu
T1, T2	120	25/132	j0.12 pu	j0.12 pu	j0.12 pu
T3	80	20/132	j0.06 pu	j0.06 pu	j0.06 pu
L1, L2	-	132	j8Ω	j8Ω	j30Ω

a. Calculate all the per-unit reactances of the system using a reference base of 120MVA. **(6)**

b. Draw the positive, negative and zero sequence diagrams for the system and determine Z_+, Z_- and Z_0. **(7)**

c. Determine the total fault current when a single phase-to-earth fault occurs at one end of line, *L2*, as shown in Figure B2.1. **(3)**

d. If each phase of circuit breaker *CB* is set to trip on an over-current of 2500A explain whether circuit breaker *A* is adequately rated for this type of fault. **(4)**

B3.

a. Give two examples of the sources of short circuits in power systems and explain why protection is required. **(2)**

b. **(i)** Sketch a diagram showing the main components of an induction relay and explain its operation. **(3)**

(ii) Describe a type of protection relay which may be used to detect faults in an oil-filled transformer and explain its operation. **(3)**

c. **(i)** Explain what is meant by time and current grading in relation to power system protection. **(5)**

(ii) Describe, with the aid of a suitable diagram, how protection may be achieved for a 2 source system using directional relays. **(3)**

d. **(i)** Explain why a current transformer should never be operated without a load. **(2)**

(ii) A 5A current transformer is used to monitor a busbar carrying a maximum current of 15000A. If the reluctance of the core is 3×10^{5} H^{-1} and the frequency is 50Hz, estimate the typical emf produced if the load on the secondary winding is accidentally removed. **(2)**

B4.

a. Show that, if skin effect is neglected, the component of self-inductance due to the magnetic field within a solid circular conductor is independent of the radius of the conductor. **(5)**

b. Show that the geometric mean radius of the 7-strand conductor shown in Figure B4.1, in which the radius of each strand is 1.5mm, is approximately 3.27mm.

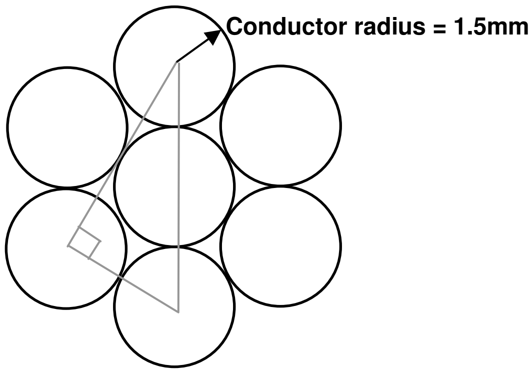

Figure B4.1: 7-strand conductor **(6)**

c. A three phase, 50Hz transmission line has its phases arranged in a flat, horizontal formation. The spacing between phases is 1.4m, and the phases are fully transposed, determine the reactance per kilometre if:

(i) the line has one solid conductor of 4mm radius per phase **(3)**

(ii) the line has a 7-strand conductor, as described in part (**b**), per phase **(1)**

(You may assume the inductance per metre for the fully transposed line is given by:

$$L = 2\times 10^{-7} \ln\left(\frac{D_g}{R_g}\right) \text{ H/m}$$

where D_g is the geometric mean distance between conductors, and R_g is the geometric mean radius of the conductors).

d. If the transmission line using the stranded conductors (see part **c(ii)** above) is 20km long and supplies a 11kV, 400kW load at 0.8 power factor lagging, calculate the line voltage at the sending end of the line. The resistance of the stranded conductor is 0.25Ω/km. **(4)**

e. Suggest two mechanisms by which the voltage at the receiving end of the line could be regulated. **(1)**

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