The University Of Sheffield.

Data Provided: Linear graph paper

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-16 (2.0 hours)

EEE301 Power Systems Engineering

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. **(i)** Describe why electrical power systems require protection. **(1)**

(ii) Draw a diagram showing the key components of a simple protection system and briefly describe their function. **(3)**

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

c. Explain why tap changing transformers are used in a power system and describe the difference between an off-load and an on-load tap changing transformer. What is meant by an "off-nominal transformer"? **(3)**

d. Figures 1.1 and 1.2 show a per-phase circuit of a tap-changing transformer and an equivalent 'π' network respectively. By consideration of the no-load voltage transformation ratios and short circuit impedances, show that the parameters A, B and C may be represented as:

$$A = \frac{Z_{HL}}{(1-k)} \qquad B = \frac{Z_{HL}}{k(k-1)} \qquad C = \frac{Z_{HL}}{k}$$

(3)

e. A 200MVA 275kV/132kV, star/delta transformer, with the star winding solidly earthed, has a nominal tap impedance (Z_{HL_NOM}) of j0.09 pu. The tap changer is assumed to be on the 275kV winding. Draw the equivalent circuits for the nominal tap and the +12% tap setting. (Assume the impedances Z_H and Z_L are proportional to the square of the number of turns on the winding concerned). **(4)**

f. A 3-phase symmetrical fault occurs on the low voltage side of the transformer when it is operating on the +12% tap setting. Calculate the fault current on the high voltage side of the transformer if the fault level on the high voltage side is 900MVA. **(3)**

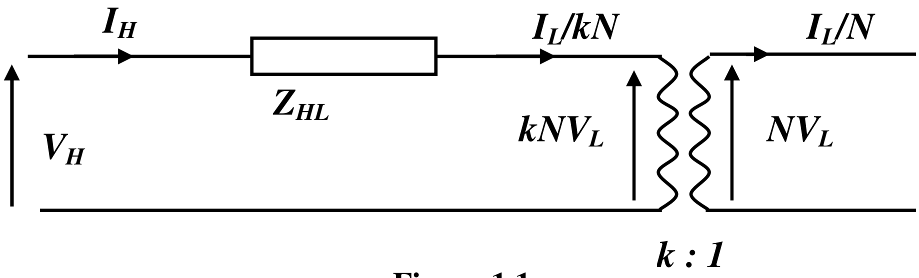

Figure 1.1

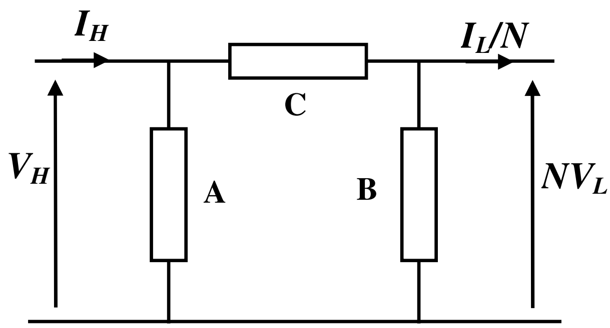

Figure 1.2

2.

a. **(i)** Explain the advantage of using bundled conductors on high voltage overhead transmission lines. **(2)**

(ii) Explain why the conductors of long overhead transmission lines are transposed. **(2)**

(iii) 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. **(4)**

b. A 11kV 50Hz, fully transposed 3-phase transmission line is proposed to connect a new wind turbine to a local sub-station. The line will use the 6-strand bundled conductor shown in Figure 2.1 and will have a phase layout as shown in Figure 2.2. The length of the line is 15km.

(i) Show that the geometric mean radius of the 6-strand conductor shown in Figure 2.1, in which the radius of each strand is 4 mm, is 8.4 mm. **(6)**

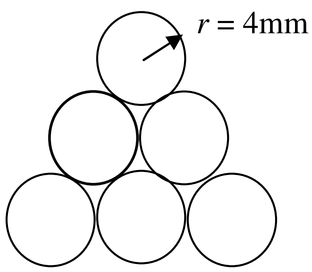

Figure 2.1 Layout of Strands

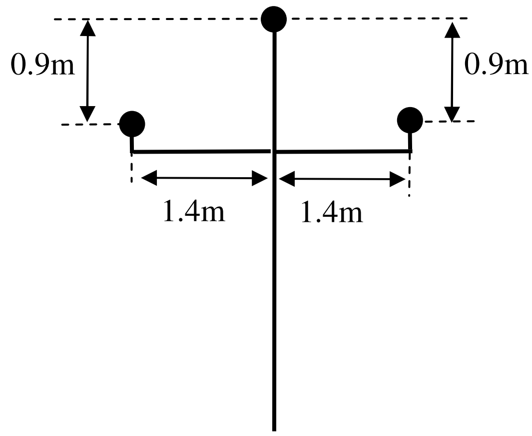

Figure 2.2 Layout of Phases

(ii) Calculate the geometric mean distance between phases for the layout shown in Figure 2.2, and hence calculate the reactance of the 15km line.
(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). **(2)**

(iii) If the line has a phase resistance of 0.1 Ω/km and the wind turbine is supplying 4MW at 0.8 power-factor lagging, determine the voltage at which the wind turbine must operate if the voltage at the sub-station is 11kV. **(3)**

(iv) If the real power supplied remains constant at 4MW, but the power-factor increases to 0.9, explain briefly whether the voltage of the wind turbine would need to be increased or decreased to maintain the 11kV at the sub-station. **(1)**

3.

a. A synchronous motor is connected to an infinite busbar system by a short transmission line. Initially the system is stable and the motor is providing constant power to a mechanical load. With the aid of a suitable diagram explain what would happen to the rotor load angle when there is a sudden increase in the mechanical load, and the conditions required to ensure the motor would not lose synchronism. **(4)**

b. A synchronous motor connected to an infinite grid system is operating at 25% of its maximum rated power. If the load on the motor is doubled calculate the maximum load angle during swinging around the new equilibrium condition. **(4)**

c. Figure 3.1 shows a 150MVA Combined Heat and Power (CHP) generator connected to a grid system by a pair of overhead lines. The per-unit reactances of the various components are given for a common base of 150MVA.

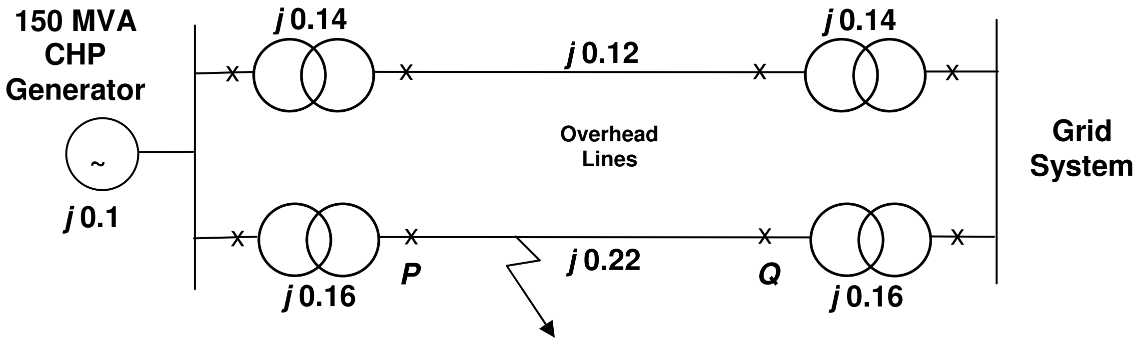

Figure 3.1 CHP Generator System

(i) If the terminal voltage is 1.0pu throughout the system determine the power-load angle equation for the system. If the generator is delivering 120MW calculate its load angle. **(2)**

(ii) When a 3-phase fault occurs on one of the overhead lines the effective system reactance becomes j1.10pu. Determine the power-load angle equation for the system under fault conditions. **(1)**

(iii) The fault is then cleared by the simultaneous opening of the circuit breakers, *P* and *Q* 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 clearance angle. **(3)**

(v) 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, $M = 0.00025$ 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)**

4.

Figure 4.1 shows the single-line diagram of a power system comprising two 132kV busbars, *A* and *B*, connected together by an overhead transmission line. Each busbar is supplied from a generator via a step-up transformer. The star points of generators *G1* and *G2* and transformers *T1* and *T2* are all solidly earthed. A single phase to earth fault occurs on busbar *B*.

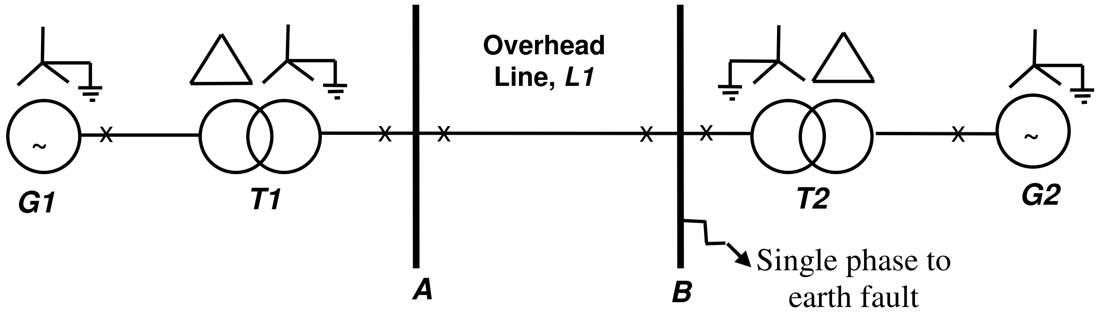

Figure 4.1 Line diagram of Power System

	Rating MVA	Voltage kV	X_+	X_-	X_0
G1	90	22	0.21 pu	0.21 pu	0.075 pu
G2	80	12	0.2 pu	0.2 pu	0.06 pu
T1	90	22/132	0.12 pu	0.12 pu	0.075 pu
T2	110	13/132	0.11 pu	0.11 pu	0.11 pu
L1		132	8 Ω	8 Ω	25 Ω

a. Calculate all the per-unit reactances of the system using a reference base of 90MVA. **(4)**

b. Draw the positive, negative and zero sequence diagrams for the system. **(6)**

c. Determine the total fault current when a single phase to earth fault occurs at busbar B. **(4)**

d. Hence calculate the current which flows in each phase of the 132kV overhead transmission line during fault conditions. **(5)**

e. The power system is upgraded and the star point of generator *G1* is now connected to ground through an earthing reactor (instead of being solidly earthed) and generator *G2* is replaced by a machine having delta connected windings (the MVA rating, voltage rating and per-unit reactances remain the same). Comment on the effect this would have on the level of fault current for the system and type of fault shown in figure 4.1. Briefly justify your answer. **(1)**

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