Data Provided: Linear graph paper

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2013-14 (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 3-phase 50Hz, fully transposed, transmission line, shown in Figure 1.1 has the horizontal formation shown in Figure 1.2.

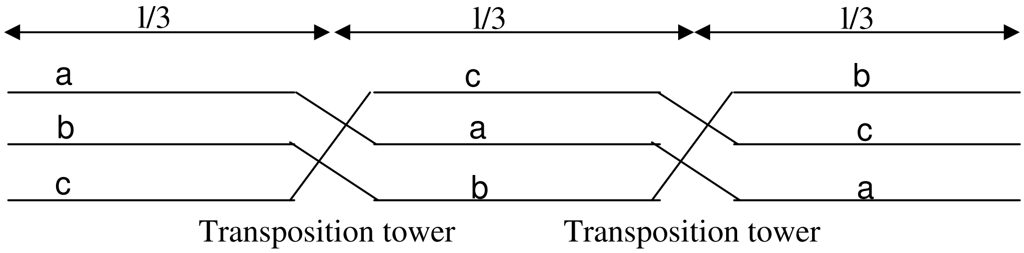

Figure 1.1 Transposed Transmission Line

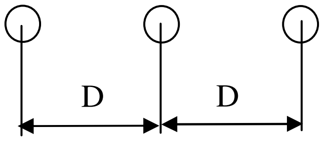

Figure 1.2 Horizontal Conductor Layout

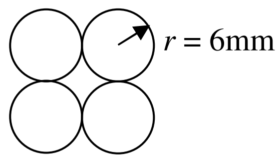

Figure 1.3 Layout of Strands

a. If the line carries symmetrical currents and has one conductor per phase, show that the inductance per phase is given by:

$$\boldsymbol{L} = \frac{\mu_0}{2\pi}\ln\left(\frac{\sqrt[3]{2}\boldsymbol{D}}{\boldsymbol{r}'}\right)$$

where $\boldsymbol{r}' = \boldsymbol{e}^{-0.25}\boldsymbol{r} = 0.7788\boldsymbol{r}$ and r is the conductor radius.
You may assume that:

- the flux linking a conductor, λ_p, to an external point P, at a distance D_P from the conductor, due to a current I flowing in the conductor itself is:

$$\lambda_P = \frac{\mu_0}{2\pi} I \ln\left(\frac{D_P}{r'}\right)$$

- the total flux linkage between two external points at distances D_1 and D_2 from a conductor carrying a current I is:

$$\lambda_P = \frac{\mu_0}{2\pi} I \ln\left(\frac{D_2}{D_1}\right)$$

(6)

b. The distance between the conductor centres is 1.5m (distance D in Figure 1.2). Calculate the inductance per phase for a 20km long line, if:

(i) the line has one solid conductor per phase having a radius of 12mm **(4)**

(ii) the line uses stranded conductors with each conductor comprising 4 strands of radius 6mm, arranged as shown in Figure 1.3. **(4)**

c. If the transmission line using the stranded conductors (see part **b(ii)**) supplies a 33kV, 900kW load at 0.9 power factor lagging, calculate the voltage at the sending end of the line. The resistance of the conductor is 0.04Ω/km. **(4)**

d. Explain briefly why it is necessary to use bundled conductors on high voltage lines. **(2)**

2.

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. Describe a type of protection relay which may be used to detect faults in an oil-filled transformer 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 on-load tap changing transformer with relevance to a power distribution transformer. **(2)**

d. Figures 2.1 and 2.2 show a per-phase circuit of a tap-changer 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:

$$A = \frac{Z_{HL}}{(1-k)} \qquad B = \frac{Z_{HL}}{k(k-1)} \qquad C = \frac{Z_{HL}}{k}$$ **(4)**

e. A 100MVA 132kV/66kV, star/delta transformer, with the star point solidly earthed, has a nominal tap impedance (Z_{HL_NOM}) of j0.08 pu. The tap changer is assumed to be on the 132kV winding. Draw the equivalent circuits for the nominal tap and the +10% 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 +10% tap setting. Calculate the fault current on the high voltage side of the transformer if the fault level on the high voltage side is 1000MVA. **(3)**

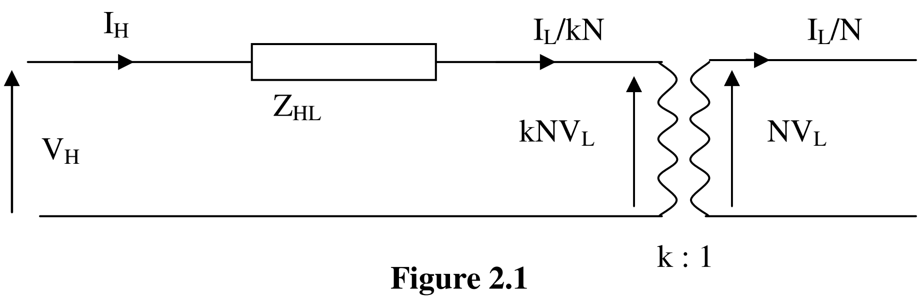

Figure 2.1

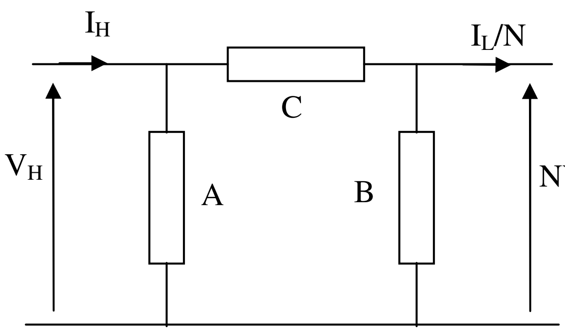

Figure 2.2

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 50MVA gas turbine driven synchronous machine, having a synchronous reactance of j0.3 pu, delivers 40MW over a double-circuit transmission line to a large power system which may be regarded as an infinite busbar. The transmission system has negligible resistance, and each line has a reactance of j0.25 pu as shown in Figure 3.1. The generator voltage is 1.1 pu and the voltage of the infinite busbar is 1.0 pu.

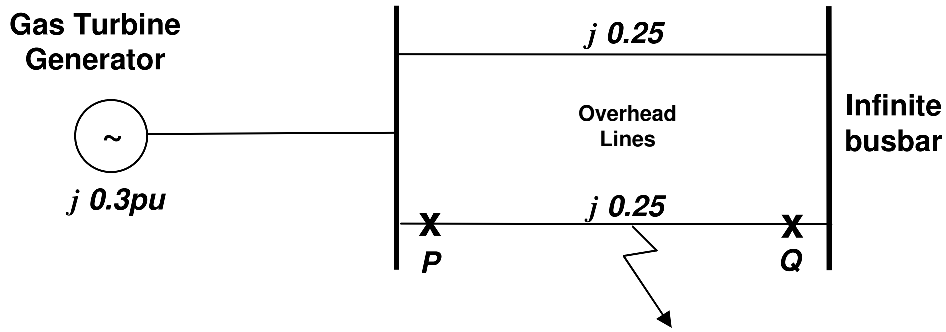

Figure 3.1 Gas Turbine driven generator and transmission system.

(i) Determine the power-load angle equation for the system and the load angle of the generator. **(3)**

(ii) When a 3-phase short-circuit occurs at the middle of one of the overhead transmission lines, between *P* and *Q,* the effective system reactance becomes j1.2pu. 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, *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. **(4)**

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

c. Explain briefly how the transient stability of the power system could be improved. **(2)**

4. Figure 4.1 shows a single line diagram of a power system in which both the generators operate at rated voltage. Generator *A* is directly connected to a 15kV busbar, *Bus 1*, which supplies a pair of overhead transmission lines, *D* and *E*, through step-up transformers *B* and *C* respectively. The other ends of the overhead lines are connected to a 132kV busbar, *Bus 2*, which is also supplied by Generator *G* through a step-up transformer, *F*. All star points in the system are solidly earthed.

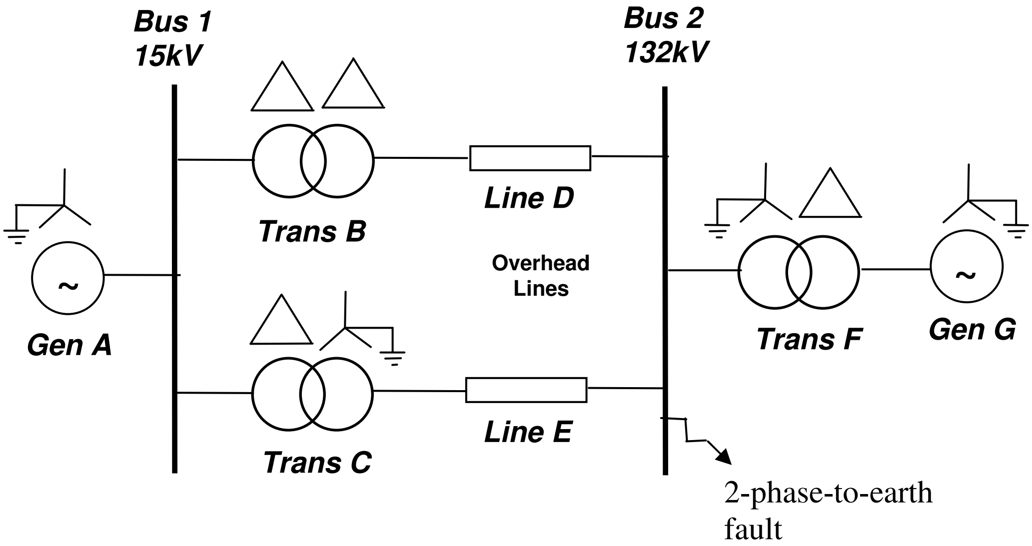

Figure 4.1 Line diagram of power system

	Rating	Voltage	X_+	X_-	X_0
Gen A	30 MVA	15 kV	j0.1pu	j0.1 pu	j0.08 pu
Gen G	50 MVA	22 kV	j0.1 pu	j0.08 pu	j0.05 pu
Trans B	30 MVA	15/132 kV	j0.3 pu	j0.3 pu	j0.4 pu
Trans C	40 MVA	15/132 kV	j0.3 pu	j0.3 pu	j0.3 pu
Trans F	30 MVA	25/132 kV	j0.08 pu	j0.08 pu	j0.04 pu
Line D	-	132 kV	j20Ω	j20Ω	j30Ω
Line E	-	132 kV	j20Ω	j20Ω	j30Ω

a. Calculate all the per-unit reactances of the system using a reference base of 30MVA. **(4)**

b. Draw the positive, negative and zero sequence diagrams for the system and calculate the equivalent positive, negative and zero sequence reactances. **(7)**

c. Determine the total fault current, and the line to line voltages at the fault, when a double phase-to-earth fault occurs on phases *B* and *C* at the 132kV busbar, *Bus 2*, as shown in Figure 4.1. **(8)**

d. If the star point of Generator A was connected to ground through an earthing reactor (instead of being solidly earthed), 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. **(1)**

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