UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: October 2019

Module Number: EE7203 **Module Name: Power System Analysis**

[Three Hours]

[Answer **all questions**, each question carries **10 marks**]

Q1 a) i) What are the different types of reactance exhibit by a synchronous machine when it experiences a short circuit fault?

ii) Briefly explain the types of faults occur in a power system.

[2 Marks]

b) Figure Q1 (b.1) shows a single line diagram of a three phase power system. Each of the generators, G1 and G2, is rated at 100 MVA, 11 kV and has a sub-transient reactance of 0.2 per unit. Each of the transformer is rated at 125 MVA, 11/132 kV and has a leakage reactance of 0.06 per unit. Find:

i) Short circuit MVA at bus 5.

ii) Three phase fault current at bus 5 in kA.

Note: Star to delta and delta to star conversion of a three phase load is given in Figure Q1 (b.2).

[3 Marks]

c) i) What is the principle of voltage control in a power system?

ii) What are the sources and sinks of reactive power in a power system?

iii) State four methods of voltage control in a power system.

[2 Marks]

d) Figure Q1 (d) shows a Thevenin equivalent circuit of a grid as seen from the point of common coupling (PCC). A Static Var System (SVS) is connected to this point. At certain operating condition, the Thevenin equivalent voltage $E_{th} = 132.0$ kV and the Thevenin equivalent impedance $X_{th} = 5\ \Omega$. The reactive current (I_s) of the SVS at this operating point is set to zero. The slope reactance of the SVS is 0.12 Ω. Because of the changes in the operating condition, the Thevenin equivalent voltage of the grid increases by 10 kV. However, the Thevenin equivalent impedance remain unchanged. Calculate the voltage at PCC after the change in the operating point.

[3 Marks]

Q2 a) i) The phase voltages across a three phase unbalanced load are given as;

$$V_a = (176 - j132)\text{ V}$$
$$V_b = (-128 - j96)\text{ V}$$
$$V_c = (-160 + j100)\text{ V}.$$

Compute positive, negative and zero sequence components of the phase a load voltage.

ii) Starting from the boundary condition, derive the sequence network connection diagram for a single line to ground fault through a fault impedance Z_f.

[4 Marks]

b) Two generators are operating in parallel and supplying a synchronous motor as shown in single line diagram in Figure Q2. Power ratings, voltage ratings and per unit sequence reactances of the system elements are shown in the figure. Synchronous motor is drawing 60 MW of power at 0.8 power factor lagging at 6 kV when a single line to ground fault occur at the middle of the line through a fault resistance of 4 Ω.

i) Selecting the base MVA of 100 and base voltage at the generator bus as 11 kV, derive the positive sequence, negative sequence and zero sequence networks of the system.

ii) Calculate the per unit pre-fault voltage at the fault point.

iii) Obtain the Thevenin's equivalent circuit of the positive sequence, negative sequence and zero sequence networks as seen from the fault point.

iv) Calculate the fault current in kA.

[6 Marks]

Q3 a) i) Define the term "stability" with regard to power system operation.

ii) Briefly explain the three categories of stability in a power system.

iii) What measures can be employed to improve the transient stability limit of a power system.

[4 Marks]

b) Figure Q3 shows the single line diagram of a three phase, 60 Hz, synchronous generator connected through a transformer and two parallel transmission lines to an infinite bus. All reactances are given in per unit on a common system base. The generator is initially operating in the steady state supplying 1.0 per unit real power at 0.95 lagging power factor to the infinite bus when a permanent three phase to ground bolted short circuit fault occurs on line 1-3 at bus 3.

i) Determine the pre-fault internal generated voltage of the synchronous generator.

ii) The fault is cleared by opening the circuit breakers at the ends of the line 1-3 and line 2-3. These circuit breakers remain opened. Calculate the critical clearing angle.

[6 Marks]

Q4 a) Figure Q4 (a) shows an interconnected power system with three buses. The system consists of two hydro generating units. The system is designed such that the changing load is shared by two generating units.

i) What are the types of governors which are suitable for each generator unit in this system?

ii) Draw the schematic diagram(s) and the characteristic(s) of the type(s) of governor(s) you have mentioned in part a) i).

iii) Initially, the system is in the steady-state operating condition with system frequency 50 Hz. After sometime, the load on bus-3 suddenly drops by 30%. What will happen to the frequency of the generators after the load drop? Draw the frequency variation at bus-1 over the time if only the primary frequency regulation is active in this power system and there hasn't been any changes in the governor characteristics.

[4 Marks]

b) The rated load on the system shown in Figure Q4 (a) is 140 MW. The power ratings of generators G_1 and G_2 are 70 MW and 80 MW, respectively. The system design at ***rated loading condition*** is as follows.

- The system frequency is 49.5 Hz.
- The no-load frequencies of generators G_1 and G_2 are 51.4 Hz and 52.0 Hz, respectively.

The generators share the system load in proportional to their power ratings.

i) Calculate the droop coefficients of governors of generator G_1 and G_2.

ii) Calculate the steady state frequency of the system and the power generated by two generators when the system load is 60% of the rated system load.

iii) In this system, generator G_1 is responsible for maintaining the system frequency at 50 Hz when the load changes. How can this generator maintain the system frequency at 50 Hz when the load changes?

iv) Suppose generator G_1 restore the system frequency to 50 Hz at 60% loading condition mentioned in part b) ii). Calculate the power outputs of two generators for this operating condition.

[6 Marks]

Q5 a) i) What are the basic components of a protection scheme in power system?

ii) What are the appropriate protection schemes for the following power system apparatus?

- Transmission line
- Radial distribution line
- Transformer
- Bus bar

iii) Explain the relaying logic of a directional over-current relay.

[4 Marks]

b) Consider the radial distribution line shown in Figure Q5 (b). The bus loads and the fault currents of this system are listed in Table Q5 (b). The suggested locations of the relays along with the circuit breakers of an over-current protection scheme are shown in the figure. All relays are IDMT type and the plug settings of them have been set to 100%.

Operating time of an IDMT relay is given by

$$T_{op} = \frac{0.14 \times TMS}{PSM^{0.02} - 1}$$

i) What are the primary and back-up relays of each line sections? What is the purpose of using back-up relays?

ii) Calculate pick-up current settings and TMS settings of all the relays in the system. Consider the TMS of relay R_1 is 0.02 s and the coordination time interval (CTI) is 0.3 s.

iii) Suppose there is a fault with fault current of 1200 A in the line section CB as shown in Figure Q5 (b). If primary protection works properly, which customers will lose the power? Calculate the operating time of the primary protection relay.

iv) Suppose due to a malfunction in primary protection relay of the line section CB, that relay is not able to isolate the fault. In that case, calculate the operating time of the back-up relay.

[6 Marks]

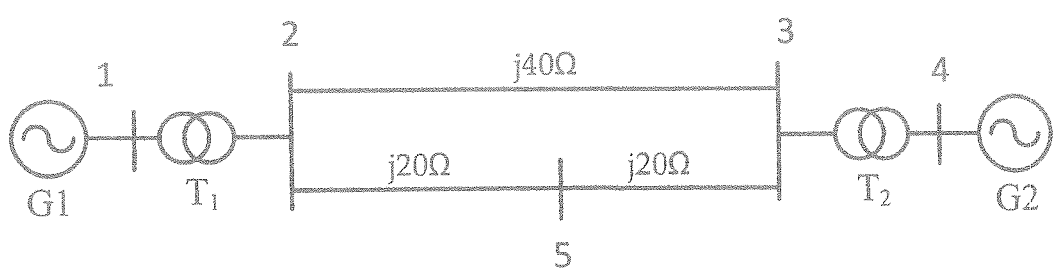
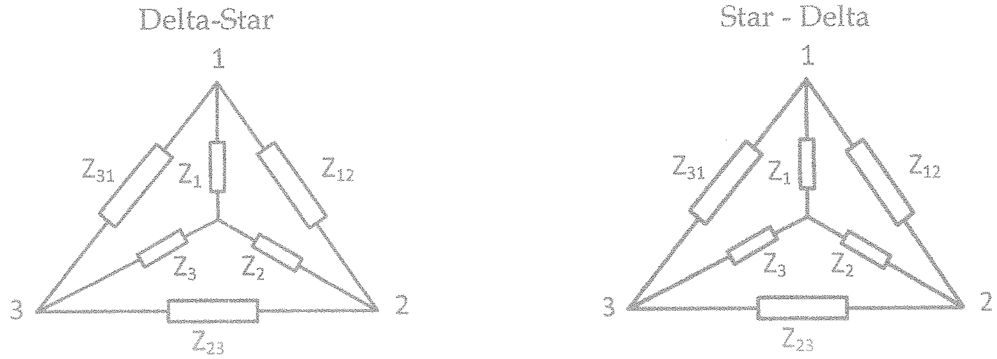


Figure Q1 (b.1)



$$Z_1 = \frac{Z_{12}Z_{23}}{Z_{12}+Z_{23}+Z_{31}}$$

$$Z_{12} = Z_1 + Z_2 + \frac{Z_1 Z_2}{Z_3}$$

Figure Q1 (b.2)

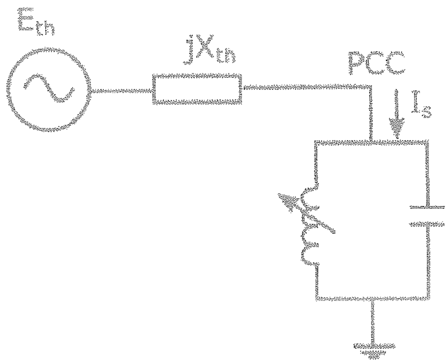


Figure Q1 (d)

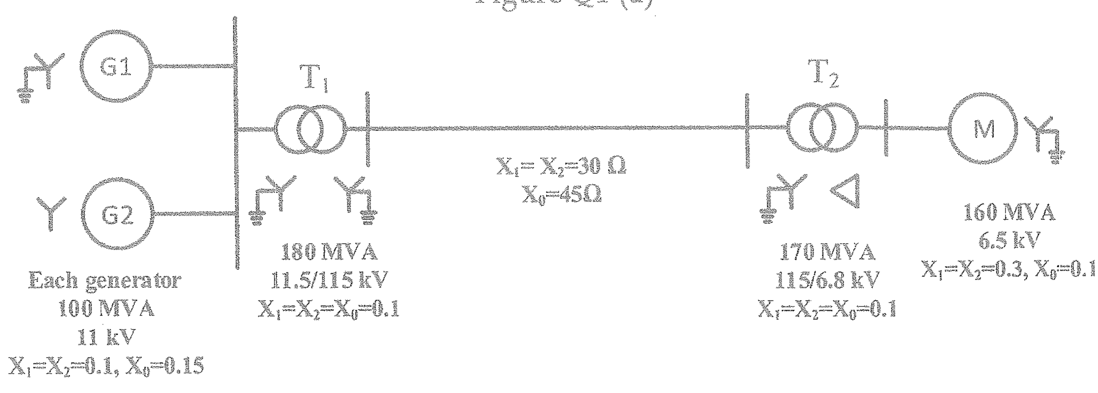


Figure Q2

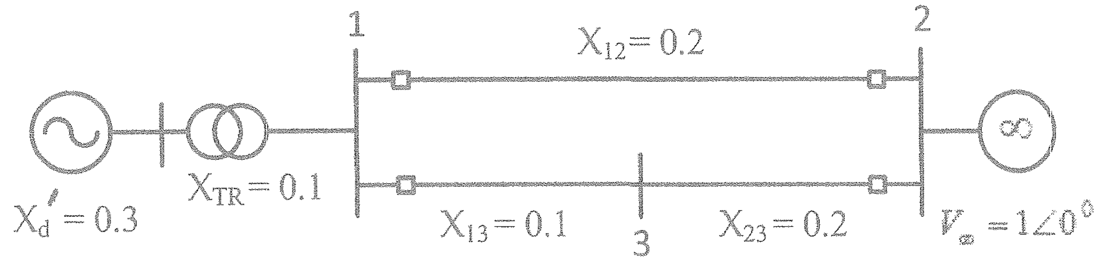


Figure Q3

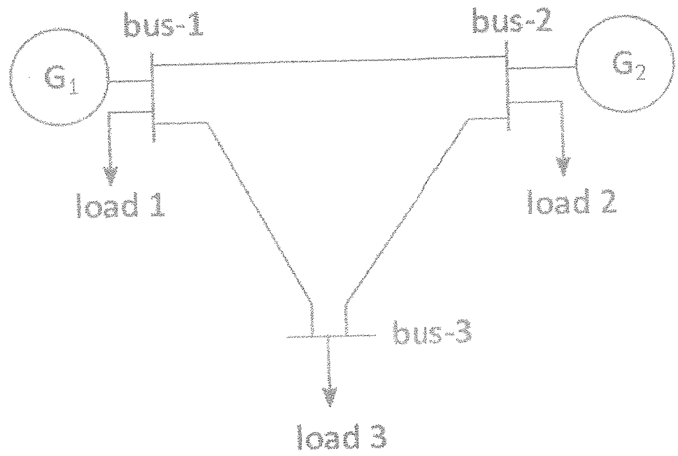


Figure Q4 (a)

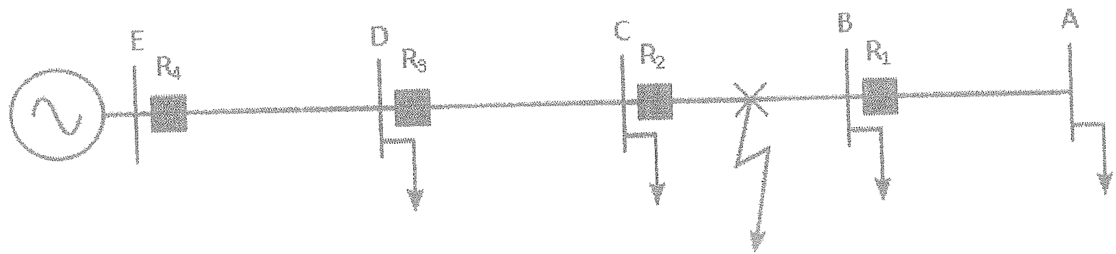


Figure Q5 (b)

Table Q5 (b)

Bus	Maximum load [A]	Minimum fault current [A]	Maximum fault current [A]
A	60	300	600
B	50	600	900
C	80	900	1500
D	60	1500	3200