UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: January 2022

Module Number: EE6207 **Module Name: Power System Analysis**

[Three Hours]

[Answer **all questions**, each question carries **12 marks**]

Q1. a) i) State three assumptions made when calculating the fault currents of a three-phase short-circuit fault in a power system.

ii) Illustrate the variation of symmetrical short-circuit current of a synchronous machine indicating different regions in a graph.

iii) Discuss the advantages and disadvantages of using current limiting reactors in a power system.

[4.0 Marks]

b) Single line diagram of a three-phase power system is shown in Figure Q1. The two generators (G_1 and G_2) rated 30 MVA, 15 kV and 20 MVA, 14.5 kV with sub-transient reactances of 0.12 pu and 0.10 pu respectively are connected to busbar *A*. The two transformers (T_1 and T_2) rated 60 MVA, 14/132 kV and 55 MVA, 132/33 kV have leakage reactances of 0.15 pu and 0.18 pu respectively. The transmission line between busbar *B* and busbar *C* has a series reactance of 20 Ω. The system is under no-load and voltage at busbar *A* is maintained at 14.85 kV.

i) Draw the per-unit reactance diagram for the power system taking the base voltage as 15 kV and base power as 50 MVA at G_1.

ii) Calculate the sub-transient fault current in Amperes if a three-phase short circuit fault occurs at busbar *D*.

iii) Determine the fault level for each busbar. Comment on your answers.

iv) Two generator reactors with each having a reactance of X_R in ohms are connected between each generator and busbar *A* to reduce the fault level at busbar *D* by 20%. Determine the value of X_R.

[8.0 Marks]

Q2. a) Briefly explain the use of symmetrical components.

[1.5 Marks]

b) Determine the symmetrical components of the unbalanced system of the following voltages in per-unit; $1\angle 0^o$, $2\angle -120^o$ and $3\angle 90^o$.

[2.5 Marks]

c) Prove that for a line to ground (L-G) fault on a generator, the sequence networks should be connected in series during the network analysis.

[3.0 Marks]

d) Consider a 22 kV, 144 MVA star-connected three-phase generator. This generator is running on no-load at the rated terminal voltage. A single line to ground fault occurs on phase A of this generator. It has positive, negative and zero sequence reactances of 0.7 pu, 0.3 pu and 0.08 pu respectively. Assume that the generator neutral is grounded through a reactance of 5 Ω. Calculate the fault current.

[5.0 Marks]

Q3. a) Briefly explain the behavior of the Rotor Angle (δ_r) under normal operating conditions, during any disturbance and after a possible oscillatory period.

[3.0 Marks]

b) Two 50 Hz generating units operate in parallel within the power plant and they have the following ratings.

- Generator 1: 750 MVA, 0.9 PF lag, 20 kV, 1800 rpm, inertia constant = 6 MWs/MVA
- Generator 2: 1000 MVA, 0.8 PF lag, 22 kV, 3600 rpm, inertia constant = 5.5 MWs/MVA

Determine the equivalent single machine inertia constant.

[3.0 Marks]

c) A generating unit operating at 50 Hz delivers 1 pu power to an infinite busbar through a network having negligible resistance. A fault occurs in the network reducing the maximum power transferable to 0.4 pu. Before the fault, maximum power transferable is 1.7 pu and after clearing the fault it is 1.4 pu. Using equal area criterion, determine the critical clearing angle.

[6.0 Marks]

Q4. a) i) State three reasons for close regulation of frequency in power systems.

ii) Draw a schematic diagram to illustrate the operation of load frequency control (LFC) and automatic voltage regulator (AVR) of a synchronous generator.

iii) Briefly describe the characteristics of an isochronous governor.

iv) Explain the operation of a brushless AC excitation system using a schematic diagram.

[5.0 Marks]

b) A single area consists of two 25 MW generators which are operating in parallel and sharing four frequency-independent loads. Details related to the power demand of each load is given in Table Q4. Generator 1 (G_1) has a no-load frequency of 50.5 Hz and a slope of 15 MW/Hz, and generator 2 (G_2) has a no-load frequency of 51.5 Hz and a slope of 10 MW/Hz.

i) Calculate the system frequency and the real power outputs of G_1 and G_2.

ii) Determine the maximum real power demand that can be fulfilled without exceeding the power ratings of the generators and the corresponding system frequency.

iii) What is the maximum real power that can be delivered with the contribution of only one generator?

iv) Suddenly the load 2 is disconnected from the system and no-load frequency of G_2 is adjusted to bring the system frequency to 50 Hz. Determine the new no-load frequency stetting and corresponding power output of G_2.

[7.0 Marks]

Q5. a) i) What is meant by voltage stability in a power system?

ii) State three methods that can be used to minimize the possibility of a voltage collapse in a power system.

iii) 'V-Q sensitivity of any given bus of a power system should be positive for voltage stability.' Briefly discuss whether you agree or disagree with the above statement.

iv) Discuss the similarities and differences between a static var compensator (SVC) and a static synchronous compensator (STATCOM).

[4.5 Marks]

b) Consider the 2-bus system shown in Figure Q5. Its generator bus voltage is $E\angle\delta$ and load bus voltage is $V\angle 0^0$. The line reactance is X and line resistance is negligible. The load consumes an active power of P and a reactive power of Q. All parameters are given in SI units. Take the base voltage as E and base impedance as X for the system.

i) Starting from the first principles, show that maximum per-unit real power (p_{MAX}) that can be delivered to the load bus can be expressed by

$$p_{MAX} = \frac{\sqrt{k^2+1}}{2} - \frac{k}{2}$$

where, $k = \tan\theta$ and θ is the impedance angle of the load.

ii) Calculate the p_{MAX} for the load power factors of 0.8 lagging and 0.8 leading.

iii) Sketch the P-V curves for the two cases in part ii) and highlight the important regions.

[4.5 Marks]

c) A load of 15 MVA at a power factor of 0.85 lagging is supplied by a three-phase line and its voltage needs to be maintained at 33 kV at both ends. If the line resistance and reactance per phase are 4.2 Ω and 8.6 Ω respectively, calculate the capacity of the synchronous condenser required for the above purpose.

[3.0 Marks]

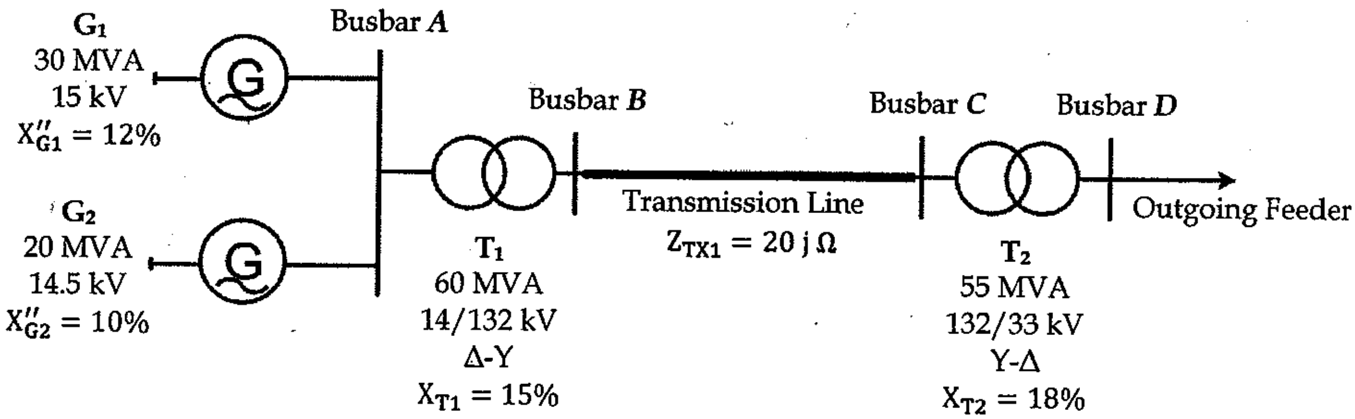

Figure Q1

Table Q4

Load	Apparent Power (MVA)	Real Power (MW)	Reactive Power (MVar)	Power Factor
Load 1	5.0	-	2.5	-
Load 2	-	10.5	-	0.8 lagging
Load 3	6.5	-	-	0.9 leading
Load 4	-	-	3.0	0.9 lagging

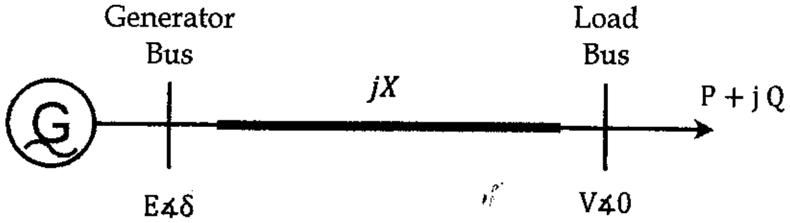

Figure Q5