# UNIVERSITY OF RUHUNA

## Faculty of Engineering

### End-Semester 6 Examination in Engineering: November 2022

**Module Number: EE6207** **Module Name: Power System Analysis (C/18)**

**[Three Hours]**

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

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Q1 a) i) State two advantages of per unit computations.

ii) List four ways of fault occurrence in a power system.

iii) Represent the per unit equivalent circuit of the single-phase transformer shown in Figure Q1.a).

[4 Marks]

b) Single line diagram of a three-phase power system is shown in Figure Q1.b). A three-phase symmetrical short circuit fault occurs at the 110 kV bus bar as indicated. Assume the system base is 25 MVA. Transmission line has a reactance of 0.085 pu. The manufacturer's nominal ratings of the power system components are given as follows:

| Device | $S_n$ (MVA) | $U_{(L-L)n}$ (kV) | $X_n$ |
|---|---|---|---|
| G1 | 20 | 11 | 14.0% |
| G2 | 25 | 11 | 15.0% |
| G3 | 25 | 11 | 15.0% |
| T1 | 125 | 11/110 | 12.5% |
| T2 | 100 | 11/110 | 12.0% |

i) List the key steps in calculating a symmetrical fault in a power system.

ii) Draw the single-phase per unit equivalent reactance diagram of the power system shown in Figure Q1.b). Mention all the assumptions you made.

iii) Calculate the fault current and fault level of the three-phase symmetrical short circuit fault occurring at 110 kV bus bar.

iv) Does the fault current increase/decrease at the 11 kV bus bar compared to that of the 110 kV bus bar? Justify your answer?

[8 Marks]

Q2 a) Starting from the first principles, develop the sequence network diagrams for,

i) Line to Line (LL) fault

ii) Line to Line to ground (L-L-G) fault

[6Marks]

b) A single-line diagram of a power system is shown in Figure Q2. The neutrals of the generator and the transformer T1 are solidly grounded.

i) Draw the per unit sequence network diagrams of the power system shown in Figure Q2.

ii) Calculate the fault current, for a line to line to ground (L-L-G) fault from phase 'b' to phase 'c' to the ground at point F in the power system shown in Figure Q2. Assume that the pre-fault per unit voltage (Vf) at the generator is 1.2 with zero phase shift.

[6 Marks]

Q3 a) i) State the Swing equation and the use of the Swing curve in power system calculations.

ii) Define the critical clearing angle.

iii) Starting from the Swing equation, derive the equation for critical clearing time at a three-phase fault.

[ 4 Marks]

b) A 150 MVA synchronous generator transformer unit with overall reactance of 0.3 pu is delivering 1.0 pu active power to an infinite bus through a parallel transmission line of 220 kV as shown in Figure Q3. Both the terminal voltage and the infinite bus voltage are 1.0 pu. A three-phase fault occurs midway along one of the transmission lines which has reactance of 0.31 pu. Faulted transmission line is disconnected to stabilize the system.

i) Determine the power angle equation of the system applicable to the given operating conditions.

ii) Calculate the maximum swing angle and the time taken by the generator to clear the fault without loss of stability. The H of the machine is 5 MJ/MVA, and the frequency is 50 Hz.

[ 8 Marks]

Q4 a) i) List four sources of sinks of reactive power applied for the voltage control in a power system.

ii) Draw the characteristic of a practical Static Var System (SVS) and briefly describe the effect of SVS with the voltage variation in the system. Assume the system stabilized at the voltage ($V_o$) initially.

[4 Marks]

b) Figure Q4 shows two generators supplying a load. Generator 1 has a no-load frequency of 61.5 Hz and a 1 MW/Hz slope. Generator 2 has a no-load frequency of 61 Hz and a 1 MW/Hz slope. The two generators supply a real load of 2.5 MW at 0.8 PF lagging.

i) Sketch the resulting system power frequency (house) diagram.

ii) At what frequency is this system operating and how much power is being supplied by each of the two generators?

iii) Suppose an additional 1 MW load is attached to this power system. What will be the new system frequency and how much power will generator 1 and generator 2 supply now?

iv) With the system configuration described in part iii), what will the system frequency and generator powers be if the governor set point (no load frequency) on generator 2 is increased by 0.5 Hz?

[8 Marks]

Q5 a) i) State a difference between voltage stability and rotor angle stability in a power system.

ii) Explain the cause of voltage instability in a power system.

iii) List four measures that can be taken to prevent voltage collapse in a power system.

[4 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 P, Q basic equations derive the QV relationship given below.

$$Q = \sqrt{\left(\frac{EV}{X}\right)^2 - P^2} - \frac{V^2}{X}$$

ii) From the equation obtained in part (i), find the maximum value for Q that can be supplied to the load by the source. (Hint: So that $P_L$= 0)

iii) Sketch the QV curve and indicate the maximum MVAR utilization before a voltage collapse.

[5 Marks]

c) Consider the same 2-bus system in Figure Q5. The maximum per-unit real power ($P_{MAX}$) that can be delivered to the load bus can be expressed as

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

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

i) Calculate the $P_{MAX}$ for the load power factors of 0.8 lagging and 0.8 leading.

ii) Sketch the P-V curves for the two cases in part i) and indicate the stable and unstable regions.

[3 Marks]

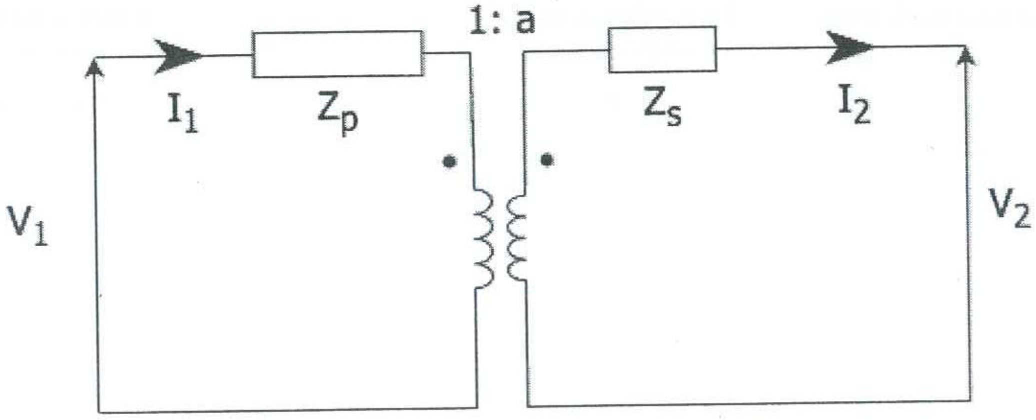


Figure Q1.a) Representation of a Single-Phase Transformer.

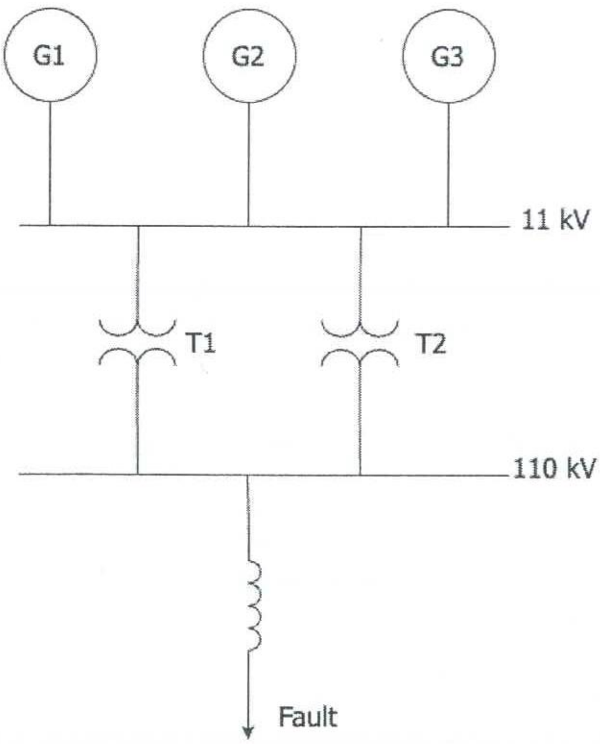


Figure Q1.b) Single Line Diagram.

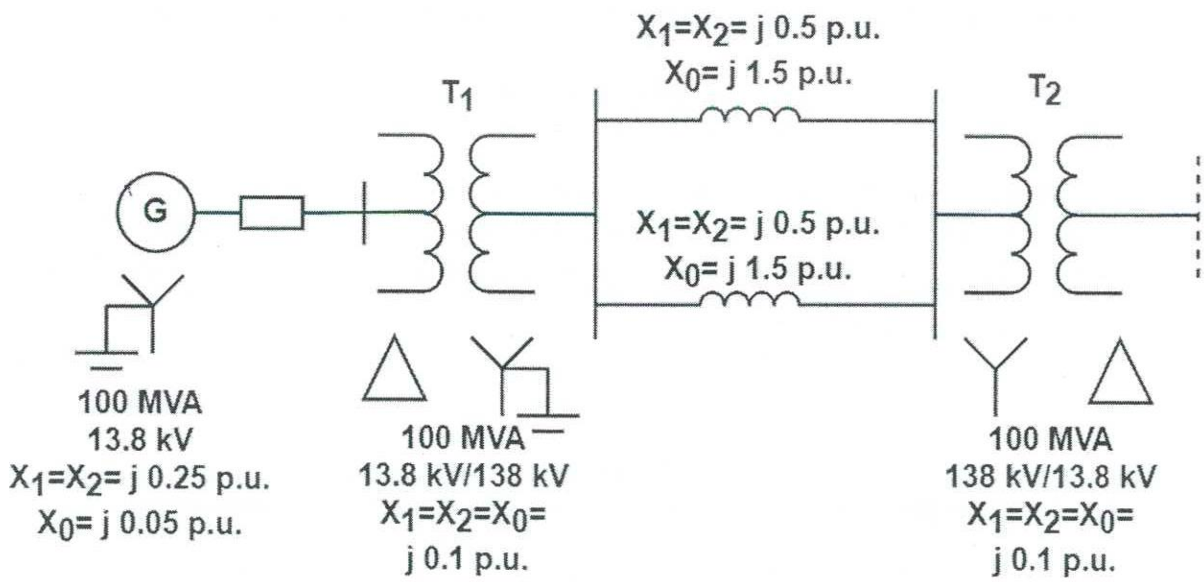


Figure Q2. A single-line diagram of a power system.

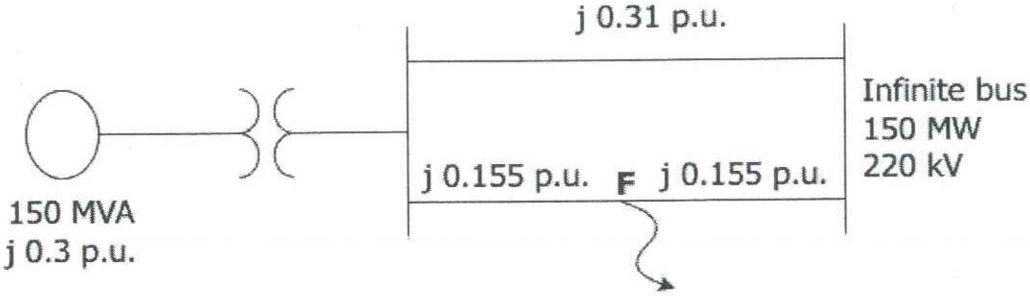


Figure Q3. Single Line Diagram.

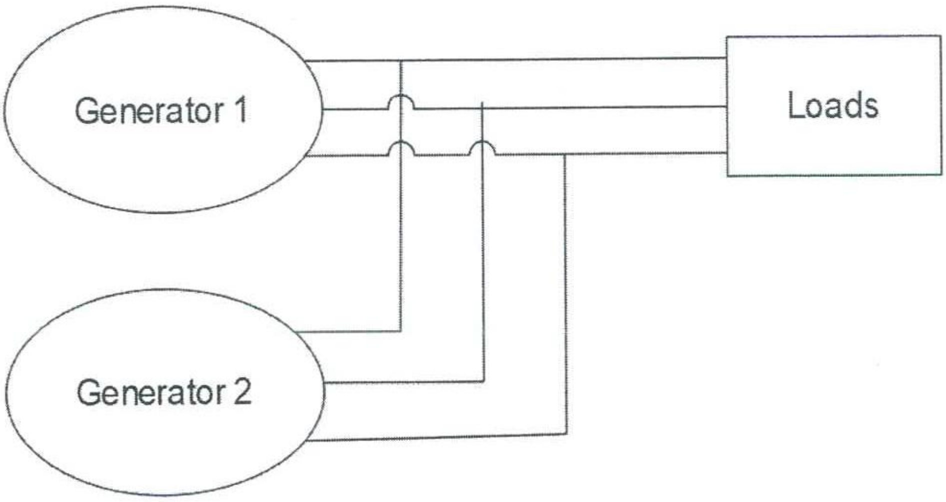


Figure Q4. Two generators supplying a load.

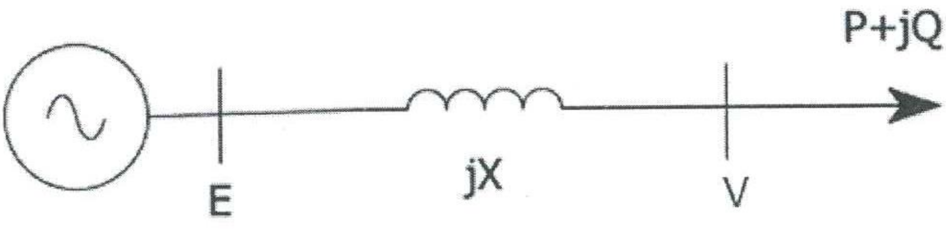


Figure Q5. 2-bus system