



UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: March 2026

Module Number: EE5305

Module Name: Power Systems (C-23)

[Three Hours]

[Answer all questions, each question carries 10 marks]

- Q1 a) A country is expanding its interconnected national power grid to supply electricity to a newly developed coastal industrial zone. A newly commissioned two power stations have been integrated into the national network. The generated power must be transmitted over long distances to reach major load centers. As part of the planning and analysis for this expansion, you are tasked with modeling a section of the power system for load flow and fault studies.
- List and briefly explain **two essential characteristics** of a well-designed power system that must be preserved during this grid expansion.
 - State **two reasons** why high voltage transmission is preferred in modern power systems.
 - Explain the role of **power transformers** and **instrument transformers** in this grid expansion.
 - Draw the impedance diagram for the power system shown in Figure Q1 and calculate all impedances in per unit on a common 100 MVA base. Use 20 kV base voltage for the generator G_1 . The three-phase power and line ratings are given below:
Generator G_1 : 90 MVA, 20 kV, $x_{g1} = 9\%$
Generator G_2 : 90 MVA, 18 kV, $x_{g2} = 9\%$
Transformer T_1 : 80 MVA, 20/200 kV, $x_{t1} = 16\%$
Transformer T_2 : 80 MVA, 200/20 kV, $x_{t2} = 20\%$
Transmission Line: 200 kV, $x_{line} = 120 \Omega$
Load: 200 kV, $S = (48 + j64) \text{ MVA}$

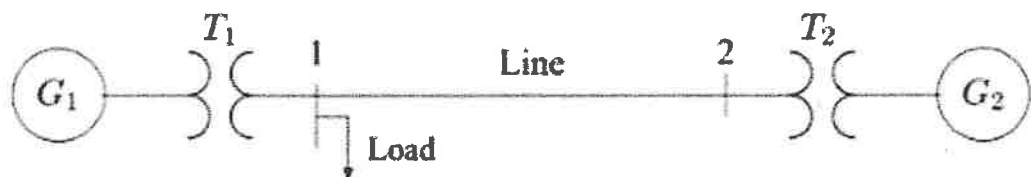


Figure Q1.

[5.0 marks]

- b) The village Riverside is getting a new, dedicated microgrid to ensure a reliable power supply. The project involves a small, dedicated distribution transformer (11 kV/400 V) that will supply a school, a community health center, and five residential homes. The project site is located in a land with a history of being a riverbed. A soil sample taken from the land is identified as **Clayey sand with slight plasticity**. The microgrid is intended to be designed and commissioned with a **TN-C-S earthing arrangement**.

- i) List **two** primary reasons why a proper power system earthing is crucial for this new microgrid.
- ii) Draw a clear and properly labelled connection diagram of the earthing system from the transformer secondary up to one consumer installation.
- iii) For the transformer neutral, it was decided to use a Single Earth Rod Electrode. If you use a copper rod of **3 m** length and **2 cm** diameter, calculate the earth resistance. Note that the earth resistance R_n is given by

$$R_n = \frac{\rho}{2\pi L} \left[\ln \left(\frac{8L}{d} \right) - 1 \right]$$

where, all the symbols have their usual meaning. Assume that the soil resistivity is $60 \Omega\text{m}$.

- iv) To achieve the desired earth resistance of less than 5Ω , it was decided to use **multiple**, same size **earth rod electrodes**, in parallel, arranged in a straight line with a spacing (S) of **6 m** between them. Calculate the minimum number of earth rod electrodes to achieve the requirement of the earth resistance. Assume the soil resistivity remains $60 \Omega\text{m}$. Then, the earth resistance R_n is given by

$$R_n = \frac{1}{n} \frac{\rho}{2\pi L} \left[\ln \left(\frac{8L}{d} \right) - 1 + \frac{\lambda L}{S} \right]$$

where,

$$\lambda = 2 \times \sum_{r=2}^n \left(\frac{1}{r} \right)$$

- v) To measure the final earth resistance of the multiple-rod electrode system, it was decided to use the **Fall of Potential Method**. Explain the procedure for this test. In your explanation, the critical considerations for placing the current and potential probes and how you determine the final earth resistance value from the readings.

[5.0 marks]

- Q2 a) The voltage induced in the armature of a salient-pole synchronous generator is given by

$$E_f = V + I_a R_a + jX_{sa} I_d + jX_{sq} I_q$$

where, all symbols have their usual meanings.

- i) Draw the phasor diagram for a lagging load with power factor $\cos \theta$ for the following cases:
 - Including armature resistance
 - Neglecting armature resistance
- ii) By neglecting armature resistance, derive an expression for the load angle (δ) in terms of I_a , X_{sq} , θ , and V .
- iii) A three-phase, Y-connected salient-pole synchronous generator delivers a line-to-line voltage of 1.5 kV to a load of 15 kVA at 0.9 power factor lagging. The synchronous reactances are $X_{sd} = 4.67 \Omega$ and $X_{sq} = 2.85 \Omega$. The armature resistance is negligible. Calculate the no-load voltage of the generator.

[5.0 Marks]

- b) A microgrid consists of two synchronous generators, G1 and G2, operating in parallel to supply a common load. The generators have identical voltage ratings but different power ratings and droop characteristics as given in Table Q2. Initially, the load supplied by two generators is 10 MW, the microgrid frequency is 50 Hz, and the no-load frequency set point of G1 is set to 51.0 Hz.

Table Q2: Generators' characteristics.

Generator	Power Rating	Frequency droop
G1	10 MVA	5 MW/Hz
G2	6 MVA	4 MW/Hz

- i) Calculate the initial power outputs of two generators and the no-load frequency set point of G2.
- ii) Suddenly, the load is increased to 14 MW. Determine the frequency of the microgrid and the power outputs of the two generators.
- iii) Calculate the new no-load set points, and the power outputs of two generators if the no-load set points of both generators are adjusted by Δf to recover the microgrid frequency back to 50 Hz.
- iv) The microgrid is decided to be connected to the main grid which can be assumed as an infinite grid with frequency 50 Hz. What are the output power of the two generators when they connected to the infinite grid with the setpoints in part iii).
- v) If the two generators want to change their outputs to 60% of their rated MVA when connected to the infinite grid, calculate the required no-load set points of the two generators.

[5.0 Marks]

- Q3 a) i) Define the following types of buses in a power system for load flow analysis, stating the specified and unknown quantities for each bus.
- Slack bus
 - Load bus
 - PV bus

- ii) State the key properties and assumptions of a power system that are utilized in the Fast Decoupled Load Flow (FDLF) method to reduce computational complexity compared to the Newton-Raphson method.

[3.0 Marks]

- b) Consider the three-bus power system shown in Figure Q3. Bus 1 is the slack bus, Bus 2 is a PQ bus, and Bus 3 is a PV bus. The line impedances and bus data are provided in the figure. All quantities are expressed in per unit on a common base of 100 MVA.

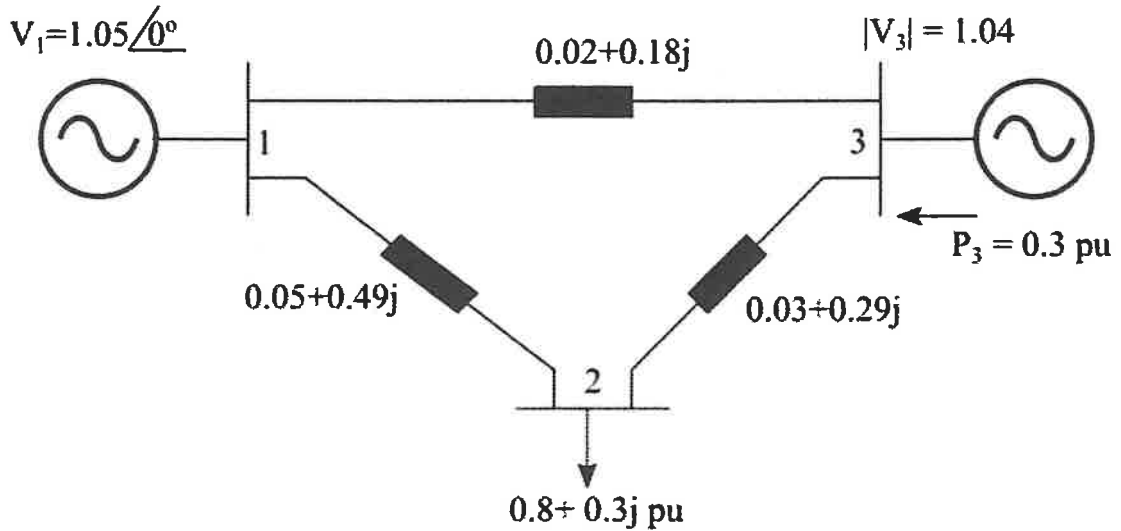


Figure Q3.

- i) Using the Gauss-Seidel load flow method, perform one iteration and determine:

- The voltage magnitude and angle at Bus 2
- The voltage angle at Bus 3

Clearly show all calculation steps. Assume a flat start (i.e., initial voltages of $1 \angle 0^\circ$ p.u. for all buses except the slack bus, and PV bus whose voltage magnitudes are specified).

- ii) During the iterative process, it is observed (e.g., at the 10th iteration) that the reactive power generated at the Bus 2 exceeds its specified limits. Explain how this situation is handled in load flow analysis.
- iii) Explain how the choice of the pre-specified tolerance (convergence criterion) affects the convergence rate and the accuracy of the final solution.
- iv) After convergence, the solution yields the following bus voltages:
- $V_2 = 0.961 \angle -0.158$ rad
 - $V_3 = 1.04 \angle -0.028$ rad

Using these values, calculate the active and reactive power supplied by the slack bus.

- v) Determine the total real power loss in the transmission lines of the system.

[7.0 Marks]

Q4 a) The **method of symmetrical components**, introduced by Dr. Charles LeGeyt Fortescue in 1918, provides a systematic approach to analyze unbalanced three phase systems by decomposing phase quantities into three balanced sets.

- Write the transformation equations relating phase voltages (V_a, V_b, V_c) to sequence voltages (V_0, V_1, V_2)
- Show that for a balanced abc sequence system, only the +ve sequence components exist.
- An unbalanced three-phase system is described by
 $I_a = 12\angle 0^\circ \text{ A}, I_b = 6\angle -90^\circ \text{ A}, I_c = 8\angle 150^\circ \text{ A}.$
 Calculate the symmetrical components I_0, I_1, I_2 in polar form.

[4.0 marks]

b) Equipment ratings for the four-bus power system shown in Figure Q4 are as follows:

Generator G1: 500 MVA, 13.8 kV, $X'' = 0.20 \text{ pu}$

Generator G2: 750 MVA, 18 kV, $X'' = 0.18 \text{ pu}$

Generator G3: 1000 MVA, 20 kV, $X'' = 0.17 \text{ pu}$

Transformer T1: 500 MVA, 13.8 kV (Δ)/500 kV (Y), $X = 0.12 \text{ pu}$

Transformer T2: 750 MVA, 18 kV (Δ)/500 kV (Y), $X = 0.10 \text{ pu}$

Transformer T3: 1000 MVA, 20 Δ /500 Y kV, $X = 0.10 \text{ pu}$

Each 500-kV line: $X_1 = 50 \Omega$

A three-phase bolted short circuit fault occurs at bus 1, where the pre-fault voltage is 525 kV. The pre-fault load current is negligible.

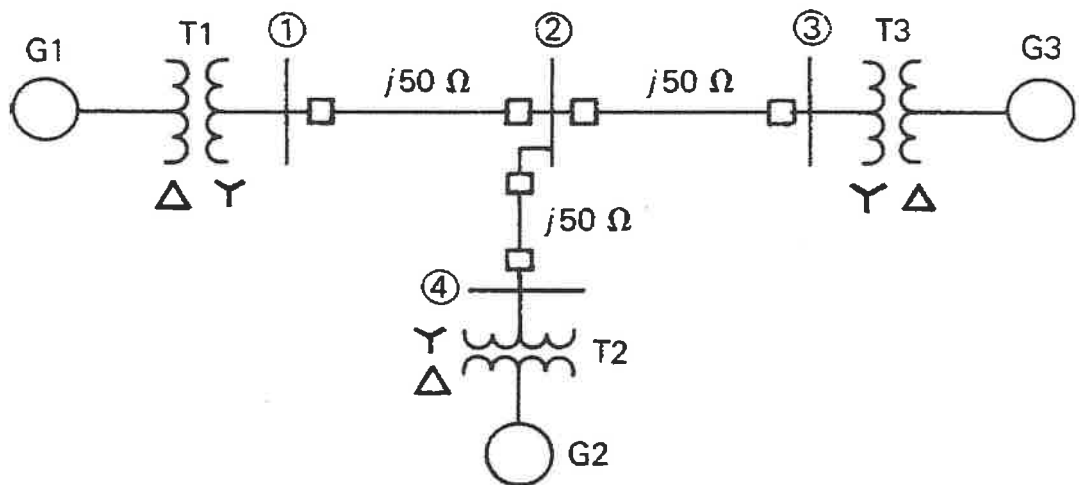


Figure Q4: The four bus power system.

- Draw the positive-sequence reactance diagram in per-unit on a 1000 MVA, 20 kV base, in the zone of generator G3.
- Determine the sub transient fault current in per-unit and in kA rms.
- Find contributions to the fault current from generator G1 and from line 1-2.

[6.0 marks]

- Q5 a) In a three-phase power system, unbalanced operating conditions frequently arise due to unsymmetrical faults such as single line-to-ground (SLG), line-to-line (LL), and double line-to-ground (LLG) faults. Direct phase-domain analysis of such systems is mathematically complex because the three phases become coupled under unbalanced conditions.
- Starting from the first principles, develop the sequence network diagram for SLG fault.
 - Derive an expression for the SLG fault current.

[4.0 marks]

- b) Equipment ratings for the same four-bus power system shown in Figure Q4 are given as follows:

Generator G1: 500 MVA, 13.8 kV, $X'' = X_2 = 0.20$ pu, $X_0 = 0.10$ pu

Generator G2: 750 MVA, 18 kV, $X'' = X_2 = 0.18$ pu, $X_0 = 0.09$ pu

Generator G3: 1000 MVA, 20 kV, $X'' = 0.17$ pu, $X_2 = 0.20$ pu, $X_0 = 0.09$ pu

Transformer T1: 500 MVA, 13.8 kV (Δ) / 500 kV (Y), $X = 0.12$ pu

Transformer T2: 750 MVA, 18 kV (Δ) / 500 kV (Y), $X = 0.10$ pu

Transformer T3: 1000 MVA, 20 kV (Δ) / 500 kV (Y), $X = 0.10$ pu

Each line: $X_1 = 50 \Omega$, $X_0 = 150 \Omega$

The inductor connected to the neutral of generator G3 has a reactance of 0.028Ω . A bolted single line to ground fault occurs at bus 1, where the pre-fault voltage is 1.0 per unit. The pre-fault load current and Δ -Y phase shifts are negligible.

- Draw the zero, positive, and negative-sequence reactance diagrams using a 1000 MVA, 20 kV base, in the zone of generator G3.
- Determine the sub-transient fault current in **per-unit and in kA**. State the assumptions you made for the calculations.

[6.0 marks]