UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 4 Examination in Engineering: January 2022

Module Number: EE4305 **Module Name: Power Systems (N/C)**

[Three Hours]

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

Q1 a) Three three-phase loads that are connected in parallel across an 11 kV, 50 Hz three-phase supply are given below.

Load 1: 20 kVA three phase induction motor operating at 0.8 power factor lagging

Load 2: 15 kW three phase heater operating at unity power factor

Load 3: Star connected constant impedance load with $2 + j3$ kΩ impedance per phase

(i) Find the line current drawn by each load.

(ii) Find the total current drawn from the supply.

(iii) Find the overall power factor of the load.

(iv) A star-connected capacitor bank is expected to be connected in parallel with the loads in order to improve the overall power factor to 0.98 lagging. Calculate the capacitance of a capacitor of the required capacitor bank.

[6 Marks]

b) Draw the per unit impedance diagram for the electric power system shown in Figure Q1 giving all impedances in per unit on a 50 MVA base. G is a generator, T1 and T2 are transformers, and M is a motor. Choose 9 kV as the voltage base for generator G. The three-phase power rating, the line to line voltage rating and the reactance of the power system elements are given below.

G:	20 MVA	9 kV	X = 9%
T1:	30 MVA	11/33 kV	X = 10%
M:	15 MVA	11 kV	X = 9%
T2:	30 MVA	33/11 kV	X = 10%
Line 1-2:		33 kV	X = 11.0 Ω
Line 2-3:		33 kV	X= 7.3 Ω
Line 3-1:		33 kV	X= 4.4 Ω
Load:	$11\angle 38^0$ MVA	33 kV	

[6 Marks]

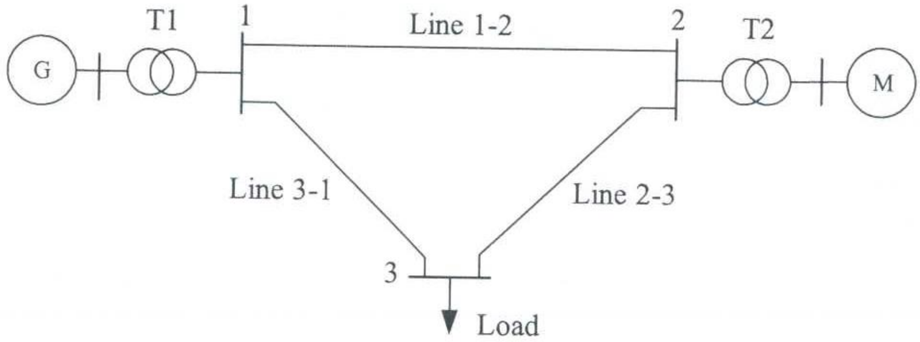

Figure Q1

Q2 a) $ABCD$ parameters of a two port network model of a long transmission line in usual notation are given as

$A = \cosh(\gamma l) = D$

$B = Z_C \sinh(\gamma l)$

$C = \frac{1}{Z_C}\sinh(\gamma l)$, where $\gamma = \sqrt{zy} = \alpha + j\beta$ and $Z_C = \sqrt{\frac{z}{y}}$.

(i) Obtain the $ABCD$ parameters of a two port network model of a lossless line. Hint: $\cosh(jx) = \cos(x)$; $\sinh(jx) = j\sin(x)$

(ii) Show that the voltage at any point along a loss less transmission line remains constant if the line is terminated by the surge impedance.

[6 Marks]

b) A 200 km, 400 kV, 50 Hz three-phase loss less transmission line has a per phase series impedance of $z = j\,0.25\ \Omega$ per km and a per phase shunt admittance of $y = j\,3.8 \times 10^{-6}$ siemens per km.

(i) Calculate the two port network model parameters ($ABCD$ parameters) of the above transmission line.

(ii) Find the sending end voltage, sending end current and sending end power if the line supplies a 250 MVA at 0.8 power factor lagging at 400 kV.

[6 Marks]

Q3 a) A typical bus of a power system (bus-i) is shown in Figure Q3 (a) in which the transmission lines are represented by their per unit admittances on a common MVA base. Show that in the iterative process of calculating the bus bar voltages, the i^{th} bus bar voltage at $(k+1)$ iteration can be given as

$$V_i^{k+1} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^{*(k)}} + \sum_{j=1}^{n} y_{ij} V_j^{(k)}}{\sum_{j=0}^{n} y_{ij}} \qquad j \neq i$$

All notations have their usual meanings.

[4 Marks]

b) The single-line diagram of a three-bus power system with generation at buses 1 and bus 3 is shown in Figure Q3 (b). The magnitude of voltage at bus 1 is adjusted to 1.05 per unit. The magnitude of voltage at bus 3 is fixed at 1.04 per unit with a real power generation of 200 MW. A load consisting of 400 MW and 250 MVar is taken from bus 2. The per unit reactance of the lines on a 100 MVA base are given in Table Q3. The line resistance and the charging susceptance can be neglected.

(i) Using Gauss-Seidel method and initial estimates of $V_2^{(0)} = 1.0 + j\,0$ and $V_3^{(0)} = 1.04 + j\,0$, perform one iteration in the process of calculating the voltages at bus 2 and bus 3. The expected accuracy of the bus bar voltages is up to four decimal places.

(ii) Assume that after several iterations, voltages at bus 2 and bus 3 converge to $0.9617\angle{-2.7^0}$ and $1.04\angle{-0.5^0}$ per unit respectively. Determine the active and reactive power supplied from the generator at bus 1.

[8 Marks]

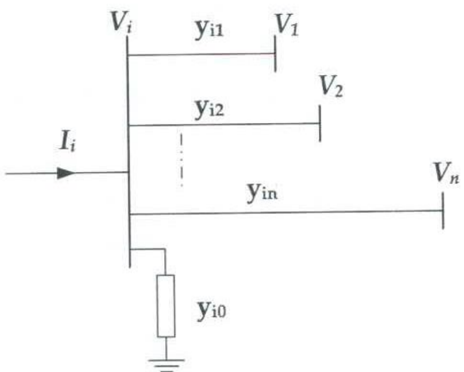

Figure Q3 (a)

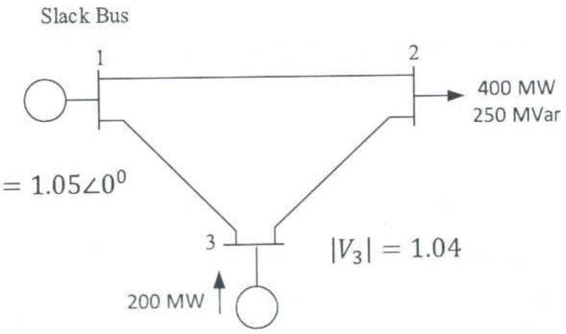

Figure Q3 (b)

Table Q3: Line data (in per unit)

Bus (from-to)	Reactance
1-2	j 0.04
1-3	j 0.04
2-3	j 0.025

Q4 a) Starting from the first principles, obtain the coordination equations to be solved in order to obtain the economic load dispatch among the thermal generators when the transmission line losses are also coordinated among the generators.

[4 Marks]

b) Fuel cost curves of two thermal plants of a simple two-plant network are given as

$$F_1 = 4 + 2P_1 + 0.006{P_1}^2 \quad \text{Rs/hr}$$
$$F_2 = 3 + 1.5P_2 + 0.0075{P_2}^2 \quad \text{Rs/hr}$$

where P_1 and P_2 are the generation of the two plants in MW.

The total system losses of the above network is given by

$$P_L = 0.0015{P_1}^2 + 0.0025{P_2}^2 - 0.0005P_1P_2 \text{ MW}$$

The total demand of the network is 160 MW.

(i) Using the equal incremental cost criteria and neglecting the transmission line losses, find the optimum load distribution among the two plants.

(ii) Using the Lambda iteration method, perform three iteration of the process of finding the economic scheduling of the two plants. Take $\lambda = 3.0$ as the initial estimate and 1 MW of power mismatch as the acceptable tolerance. Stop the above process in case you get the answer in your second iteration.

[8 Marks]

Q5 a) A fully transposed three-phase line consisting of three-conductor bundles is shown in Figure Q5. The conductors have a diameter of 2.18 cm and a GMR of 0.88 cm and the space between the conductors is 45 cm in the bundle. The line has a flat horizontal configuration with a spacing of 14 m as measured from the center of the bundle as shown in Figure Q5.

(i) Determine the inductance per phase per km of the line.

(ii) If the line is 200 km long, calculate the charging capacitance per phase with respect to neutral.

(iii) If the operating voltage of the line is 220 kV (line to line), calculate the line charging current.

[6 Marks]

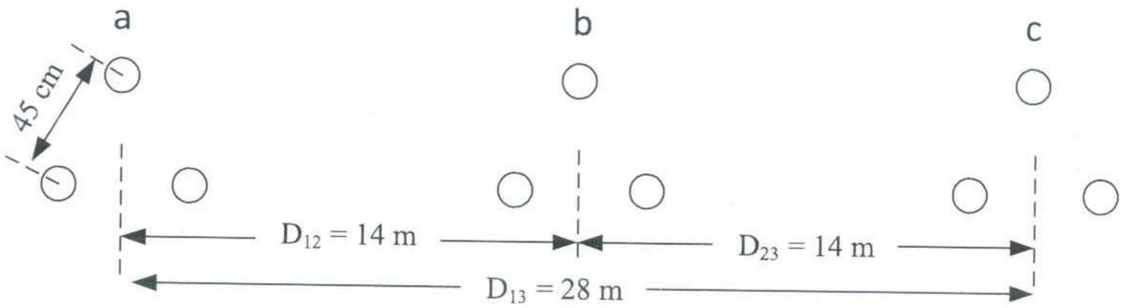

Figure Q5

b) Bundle conductors of the transmission line shown in Figure Q5 have been replaced by solid conductors with 25mm diameter. It has been suspended freely from two towers at the same elevation and has taken the form of a catenary curve. The span between the two towers is 250 m, and the weight of the bundle conductor is 0.85 N/m. The ultimate breaking strength of the bundle conductor is 3000 N. Each bundle conductor is subjected to a horizontal wind pressure of 40 N/m^2. Assume a factor safety of 2 and a single 3 core cable for the bundle conductor.

(i) State the equation of the catenary curve which describes the shape of the transmission line strung between two towers by defining each of the symbols used.

(ii) Hence, find the deflected sag of the above transmission line.

(iii) Use the approximated parabolic equation to calculate the deflected sag of the transmission line and estimate the deviation of the result compared to the value obtained in part (ii) above.

(iv) Calculate the length of the transmission line between the two towers.

[6 Marks]