Problem Set 3

1. A three-phase transmission line operating at 33 kV and having a resistance and reactance of 5 Ω and 20 Ω respectively is connected to a generating station busbar through a 5 MVA 6.6 / 33 kV step up transformer which has a reactance of 6 %. Connected to the busbar are two alternators, one of 10 MVA, 6.6 kV having 10 % reactance and another of 5 MVA, 6.6 kV having 7.5 %. Calculate the short circuit MVA when a three phase fault occurs at (i) the high voltage terminals of the transformer (ii) load end of the transmission line.

2. A 25 MVA, 13.8 kV alternator with X_d'' = 15 % is connected through a transformer to a busbar that supplies four identical synchronous motors. Each motor has X_d'' = 20 % on a base of 5 MVA and 6.9 kV. The three-phase ratings of the transformer are 25 MVA, 13.8 / 6.9 kV with a leakage reactance of 10 %. The bus voltage at the motors is 6.9 kV when a symmetrical three phase fault occurs at the terminals of one of the motors. Determine

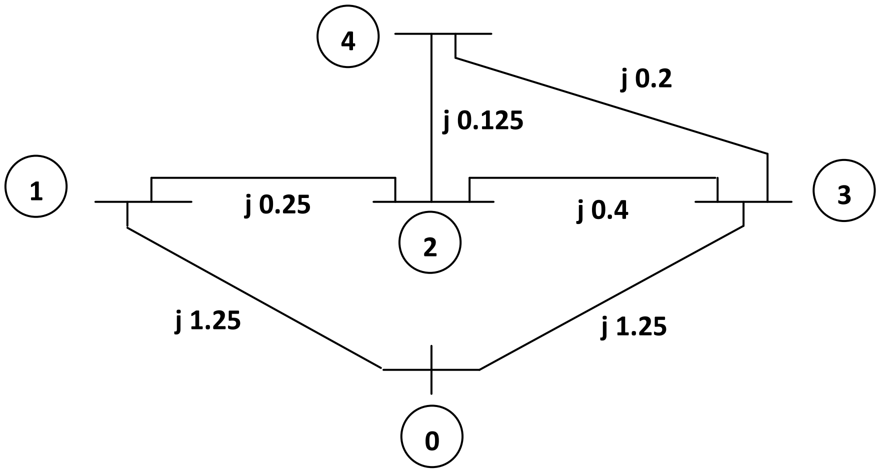
i) the subtransient current in the fault

ii) the subtransient current flowing in the circuit breaker connected between the faulted motor and 6.9 kV busbar.

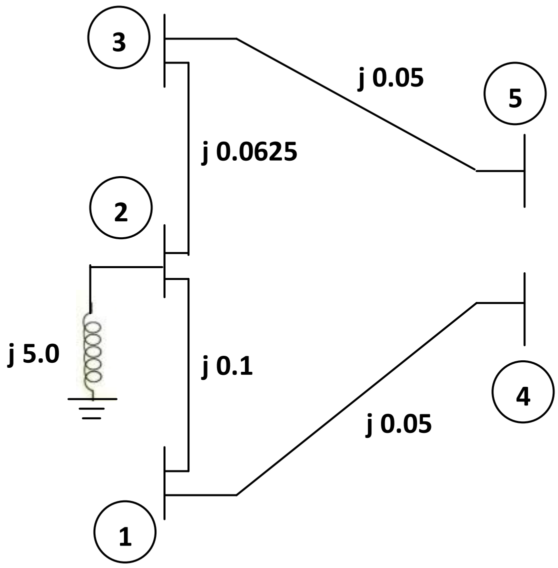
3. For the network with the following data construct the bus impedance matrix.

Element No.	Between buses		p.u. impedance
1	0	1	j 0.3
2	2	3	j 0.5
3	4	1	j 0.44
4	0	3	j 0.3
5	2	1	j 0.6
6	1	3	j 0.4

4. **Consider the power network shown. Values marked are p.u. impedances. Determine its bus impedance matrix.**



5. **Calculate the impedance matrix of the network shown.**



6. **A power system has the following transmission line data**

From bus	To bus	Line impedance in p.u.
1	2	j 0.1
2	3	j 0.0625
3	5	j 0.05
1	4	j 0.05

4	5	j 0.08

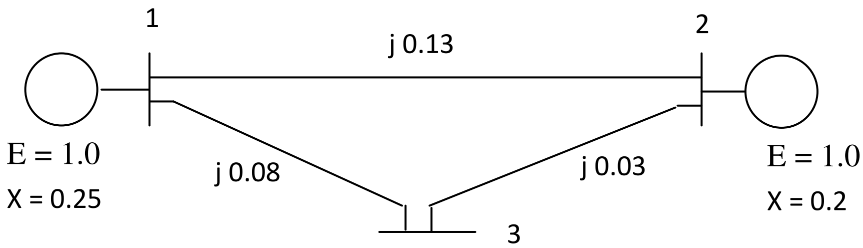
Generator 1 with reactance j 0.1 p.u. is connected at bus 2. Generator 2 having reactance j 0.125 p.u. is connected at bus 5. Using building algorithm, construct the bus impedance matrix of the generator-transmission network.

7. The bus impedance matrix of a four bus power system, with values in p.u., is given by

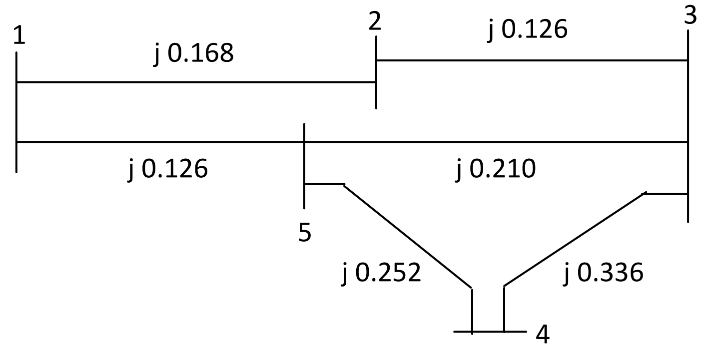
$$
Z_{bus} = j \quad \begin{array}{c c} & \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \end{array} & \begin{bmatrix} 0.15 & 0.08 & 0.07 & 0.04 \\ 0.08 & 0.15 & 0.09 & 0.06 \\ 0.07 & 0.09 & 0.12 & 0.05 \\ 0.04 & 0.06 & 0.05 & 0.13 \end{bmatrix} \end{array}
$$

Generators are connected to buses 1 and 2 and their subtransient reactances were included while computing Z_{bus}. A three phase fault occurs at bus 3 with a fault impedance of j 0.08 p.u. Find the subtransient current in the fault. If the subtransient reactance of the generator in bus 2 is 0.2 p.u., determine the subtransient fault current supplied by the generator. Also find the voltage at bus 4.

8. For the system shown below, find the fault current in all the branches, when a three phase fault with fault impedance j 0.0785 p.u. occurs at bus 2. Mark the currents in the one-line diagram. All the reactances and voltages are in p.u.



9. A 5 bus transmission network is shown below. Marked values are the line impedances in per unit on a 100 MVA system base.



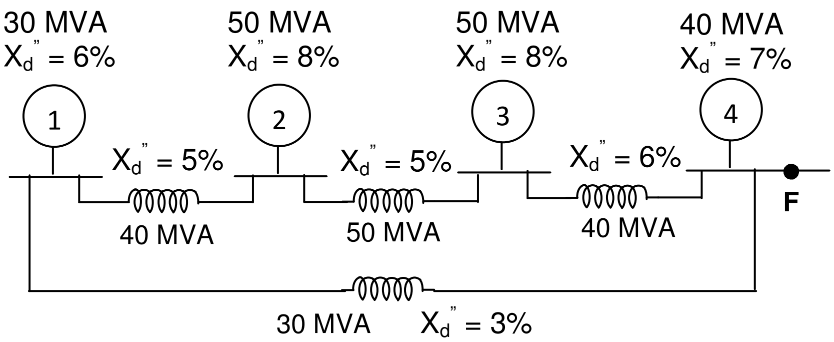
Generators are connected at buses 1 and 3 and rated 270 and 225 MVA respectively. The generator subtransient reactances plus the reactances of the transformers connecting them to the buses are each 0.3 p.u. on the generator rating as base. The turns ratios of the transformers are such that the voltage base in each generator circuit is equal to the voltage rating of the generator. Using the bus impedance matrix, find the subtransient current in a three phase fault at bus 4 and the current coming to the faulted bus over each line.

10. In the power system described in Problem 5, symmetrical three phase fault occurs at bus 4. Using the bus impedance matrix, calculate the fault current, voltages at all the buses and the currents in all the elements.

11. A generating station has two alternators of 3 MVA, 7% subtransient reactance and 4.5 MVA, 8 % subtransient reactance. The circuit breaker in the outgoing feeder is rated for 150 MVA. It is intended to extend the system by including one more alternator of 7.5 MVA, 7.5 % subtransient reactance. Find the reactance necessary which should be connected in series with the third alternator to protect the system. Assume the system voltage as 3.3 kV.

12. A generating station has three generators each of 10 MVA capacity with 10% subtransient reactance. Generators are connected to a common busbar through reactors of 8%. If symmetrical three phase fault develops on the busbar of one of the generators, calculate the short circuit MVA and compare it with the case when there are no external reactors used.

13. Four generators in a power station are arranged in a ring busbar with suitable reactors as shown. Calculate the short circuit MVA if there is symmetrical three phase fault at point F. All the reactances are referred to their respective MVA rating. Select 600 MVA as the base value.



<u>ANSWERS</u>

1. (i) 55.556 MVA (ii) 27.278 MVA

2. (i) 16720 A (ii) 14640 A

3.

$$
Z_{bus} = j \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array}
\begin{array}{c}
\begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\
\begin{bmatrix}
0.19925 & 0.1455 & 0.1007 & 0.19925 \\
0.1455 & 0.4231 & 0.1545 & 0.1455 \\
0.1007 & 0.1545 & 0.19925 & 0.1007 \\
0.19925 & 0.1455 & 0.1007 & 0.63925
\end{bmatrix}
\end{array}
$$

4.

$$Z_{bus} = j \quad \begin{array}{cc} & \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \end{array} & \begin{bmatrix} 0.71660 & 0.60992 & 0.53340 & 0.58049 \\ 0.60992 & 0.73190 & 0.64008 & 0.69659 \\ 0.53340 & 0.64008 & 0.71660 & 0.66951 \\ 0.58049 & 0.69659 & 0.66951 & 0.76310 \end{bmatrix} \end{array}$$

5.

$$Z_{bus} = j \quad \begin{array}{cc} & \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} & \begin{bmatrix} 5.1 & 5.0 & 5.0 & 5.1 & 5.0 \\ 5.0 & 5.0 & 5.0 & 5.0 & 5.0 \\ 5.0 & 5.0 & 5.0625 & 5.0 & 5.0625 \\ 5.1 & 5.0 & 5.0 & 5.15 & 5.0 \\ 5.0 & 5.0 & 5.0625 & 5.0 & 5.1125 \end{bmatrix} \end{array}$$

6.

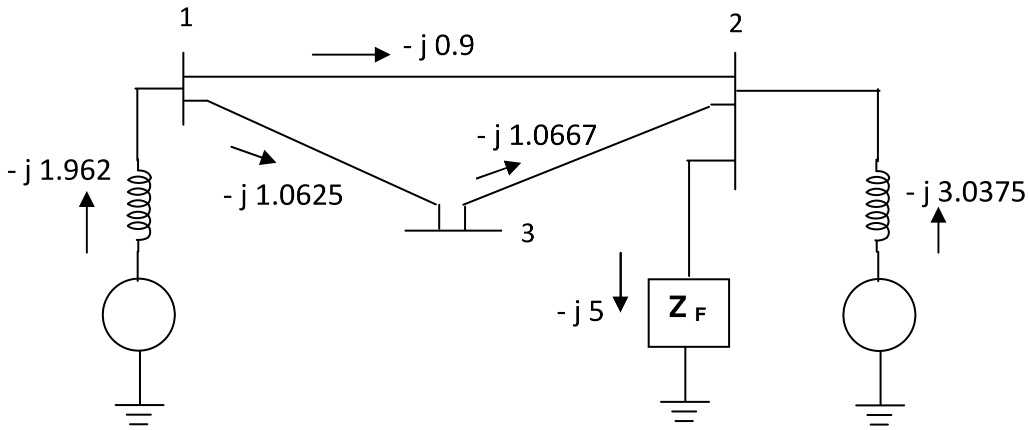
$$Z_{bus} = j \quad \begin{array}{cc} & \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} & \begin{bmatrix} 0.112082 & 0.055798 & 0.55494 & 0.090224 & 0.055251 \\ 0.055798 & 0.066727 & 0.052762 & 0.050333 & 0.041591 \\ 0.055798 & 0.052762 & 0.084031 & 0.056861 & 0.059046 \\ 0.090224 & 0.050333 & 0.056861 & 0.110170 & 0.062083 \\ 0.055252 & 0.041591 & 0.059046 & 0.062083 & 0.073011 \end{bmatrix} \end{array}$$

7. **Subtransient current in the fault $I_f'' = -j\,5.0$ p.u.**

Current supplied by the generator in bus 2 = - j 2.25 p.u.

$V_{4\,(F)}$ = 0.75 p.u.

8.



9. Subtransient current in the fault = - j 4.30885 p.u.

i_{3-4} = - j 2.05324 p.u.; i_{5-4} = - j 2.25563 p.u.

10. $V_{1\,(F)}$ = 0.181047 p.u.; $V_{2\,(F)}$ = 0.543133 p.u.

$V_{3\,(F)}$ = 0.483879 p.u.; $V_{4\,(F)}$ = 0 $V_{5\,(F)}$ = 0.436480 p.u.;

i_{2-1} = - j 3.62086 p.u.; i_{2-3} = - j 0.94806 p.u. i_{3-5} = - j 0.94798 p.u.

i_{1-4} = - j 3.62094 p.u.; i_{5-4} = - j 5.456 p.u.

$i_{g\,1}$ = - j 4.56867 p.u.; $i_{g\,2}$ = - j 4.5081 p.u.

11. 0.105 Ω

12. 158.73 MVA 300 MVA

13. 1370.8 MVA

PROBLEM SET 4

1. In an unbalanced circuit the three line currents are measured as

   $I_a = 7.0311\angle 59.85^0$
   $I_b = 4.3733\angle 203.84^0$
   $I_c = 2.6810\angle 160.75^0$

   Obtain the corresponding sequence components of currents and draw them to scale.

2. For the sequence components calculated in Problem 1, find the corresponding phase components of line currents and verify the results graphically.

3. A three phase transmission line has the phase impedance of

$$z_{a,b,c} = j\begin{bmatrix} 21 & 6 & 6 \\ 6 & 21 & 6 \\ 6 & 6 & 21 \end{bmatrix}$$

   Calculate its sequence impedances.

4. A 20 MVA, 13.8 kV alternator has the following reactances:

   $X_1 = 0.25$ p.u. $X_2 = 0.35$ p.u. $X_{g0} = 0.04$ p.u. $X_n = 0.02$ p.u.

   A single line to ground fault occurs at its terminals. Draw the interconnections of the sequence networks and calculate

   i) the current in each line

   ii) the fault current

   iii) the line to neutral voltages

   iv) the line to line voltages

   Denoting the neutral point as n and the ground as o, draw the phasor diagram of line to neutral voltages.

5. Repeat Problem 4 for line to line fault.

6. Repeat Problem 4 for double line to ground fault.

7. Repeat Problem 4 for symmetrical three phase fault.

8. Consider the alternator described in Problem 4. It is required to limit the fault current to 2500 A for single line to ground fault. Find the additional reactance necessary to be introduced in the neutral.

9. Two synchronous machines are connected through three-phase transformers to the transmission line as shown.

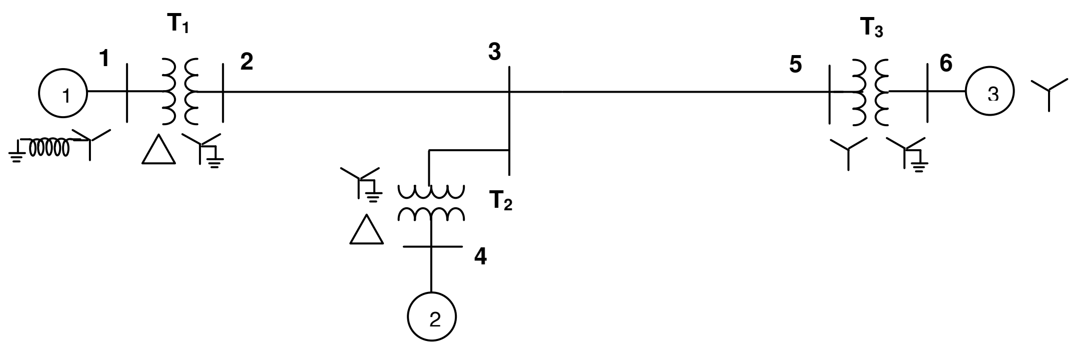
The ratings and reactances of the machines and transformers are:

Machines 1 and 2: 100 MVA, 20 kV, $X_1 = X_2 = 20$ %, $X_{m0} = 4$ %, $X_n = 5$ %

Transformers T_1 and T_2: 100 MVA, 20 Δ / 345 Y kV, X = 8 %

On a chosen base of 100 MVA, 345 kV in the transmission line circuit, the line reactances are $X_1 = X_2 = 15$ % and $X_0 = 50$ %. Draw each of the three sequence networks and find Z_{bus}^0, Z_{bus}^1 and Z_{bus}^2.

10. The one-line diagram of a power system is shown below.



The following are the p.u. reactances of different elements on a common base.

Generator 1: $X_{g0} = 0.075$; $X_n = 0.075$; $X_1 = X_2 = 0.25$

Generator 2: $X_{g0} = 0.15$; $X_n = 0.15$; $X_1 = X_2 = 0.2$

Generator 3: $X_{g0} = 0.072$; $X_1 = X_2 = 0.15$

Transformer 1: $X_0 = X_1 = X_2 = 0.12$

Transformer 2: $X_0 = X_1 = X_2 = 0.24$

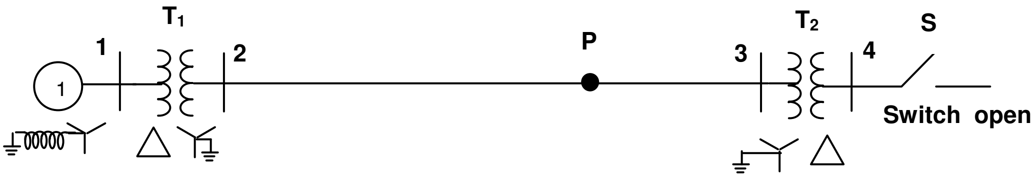
Transformer 3: $X_0 = X_1 = X_2 = 0.1276$

Transmission line 2 – 3 $X_0 = 0.5671$; $X_1 = X_2 = 0.18$

Transmission line 3 – 5 $X_0 = 0.4764$; $X_1 = X_2 = 0.12$

Draw the three sequence networks and determine Z_{bus}^0, Z_{bus}^1 and Z_{bus}^2.

11. The single line diagram of a small power system is shown below.



Generator: 100 MVA, 20 kV, $X_1 = X_2 = 20$ %, $X_{g0} = 4$ %, $X_n = 5$ %

Transformers T_1 and T_2: 100 MVA, 20 Δ / 345 Y kV, X = 10 %

On a chosen base of 100 MVA, 345 kV in the transmission line circuit, the line reactances are:

From T_1 to P: $X_1 = X_2 = 20$ %; $X_0 = 50$%

From T_2 to P: $X_1 = X_2 = 10$ %; $X_0 = 30$%

A bolted single lone to ground occurs at P. Determine

i) fault current I_{fA}, I_{fB} and I_{fC}.

ii) currents flowing towards P from T_1.

iii) currents flowing towards P from T_2.

iv) current supplied by the generator.

Note that the positive sequence current in Δ winding of transformer lags that in Y winding by 30^0; the negative sequence current in Δ winding leads that in Y winding by 30^0.

12. In the power system described in Problem 10, a single line to ground fault occurs at bus 2 with a fault impedance of j0.1. Determine the bus currents at the faulted bus and the voltages at buses 1 and 2.

ANSWERS

1. $I_{a0} = I_{b0} = I_{c0} = 2\angle 120^0$; $I_{a1} = 3.5\angle 30^0$; $I_{b1} = 3.5\angle 270^0$; $I_{c1} = 3.5\angle 150^0$

   $I_{a2} = 3\angle 60^0$; $I_{b2} = 3\angle 180^0$; $I_{c2} = 3\angle 300^0$

2. $I_a = 7.0311\angle 59.85^0$; $I_b = 4.3733\angle 203.84^0$; $I_c = 2.681\angle 160.75^0$

3. $Z_0 = j33$; $Z_1 = Z_2 = j15$

4. I_a = -j 3586.1 A I_b = 0 I_c = 0 I_f = -j 3586.1 A

   V_a = 0 V_b = 8.0694 $\angle -102.22^0$ kV V_c = 8.0694 $\angle 102.22^0$ kV

   V_{ab} = 8.0694 $\angle$ 77.78^0 kV; V_{bc}= 15.7724 $\angle -90^0$ kV; V_{ca}= 8.0694 $\angle 102.22^0$ kV

5. I_a = 0 I_b = -2415.5 A I_c = 2415.5 A I_f = -2415.5 A

   V_a = 9.2948 kV V_b = -4.6474 kV V_c = -4.6474 kV

   V_{ab} = 13.9422 kV V_{bc} = 0 V_{ca} = 13.9422 $\angle 180^0$ kV

6. I_a = 0 I_b = 4020.95 $\angle 132.22^0$ A I_c = 4020 $\angle 47.78^0$ A I_f = 5956.08 $\angle 90^0$ A

   V_a = 5.6720 kV V_b = 0 V_c = 0

   V_{ab} = 5.6720 kV V_{bc} = 0 V_{ca} = 5.6720 $\angle 180^0$ kV

7. I_a = 3347 $\angle -90^0$ A I_b = 3347 $\angle 150^0$ A I_c = 3347 $\angle 30^0$ A

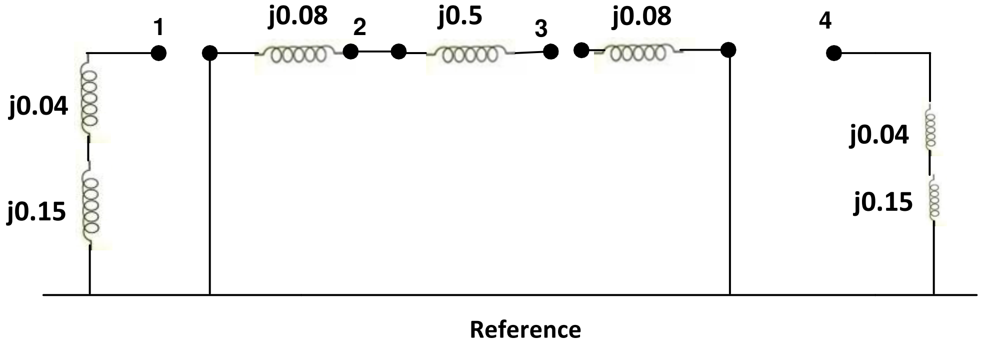
   I_f = 3347 $\angle -90^0$ A

   $V_a = V_b = V_c = 0$

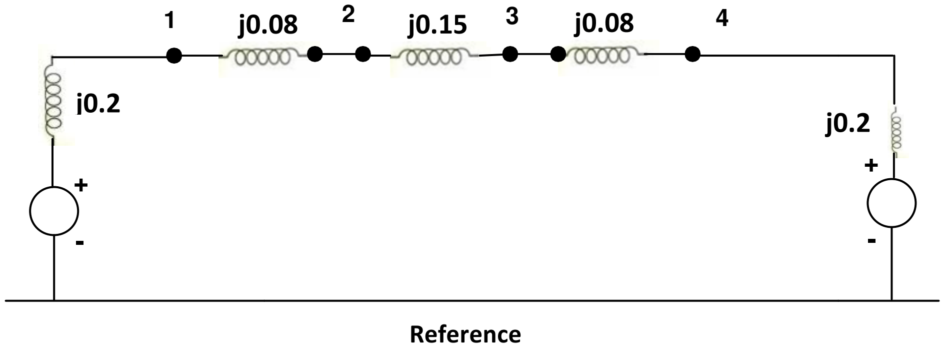
   $V_{ab} = V_{bc} = V_{ca} = 0$

8. 0.9655 Ω

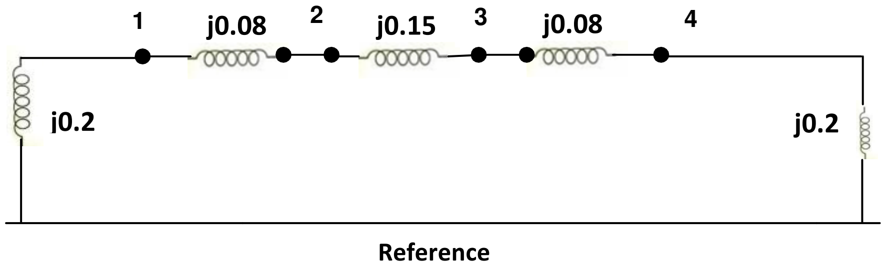
9. Zero sequence network:



Positive sequence network:



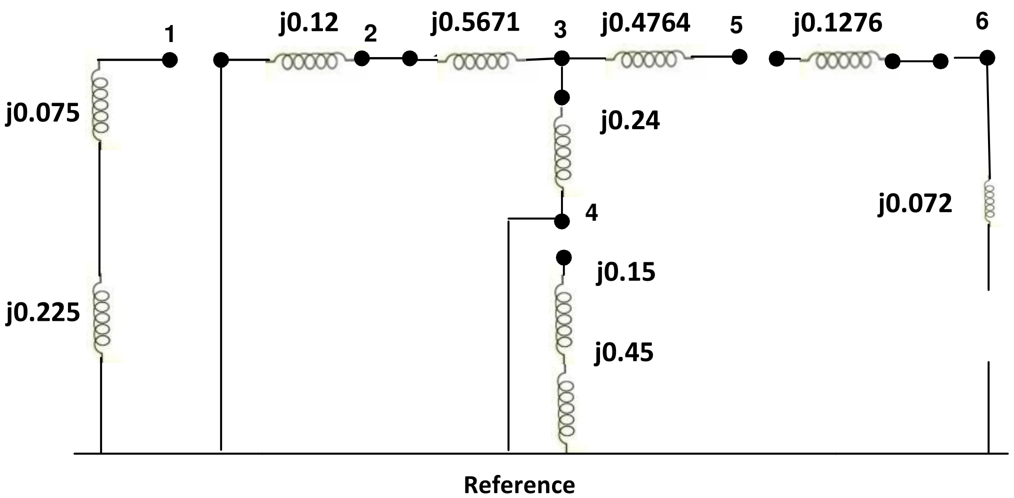
Negative sequence network:



$$Z_{bus}^{0} = i \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \begin{bmatrix} 0.19 & 0 & 0 & 0 \\ 0 & 0.08 & 0.08 & 0 \\ 0 & 0.08 & 0.58 & 0 \\ 0 & 0 & 0 & 0.19 \end{bmatrix} \end{array}$$

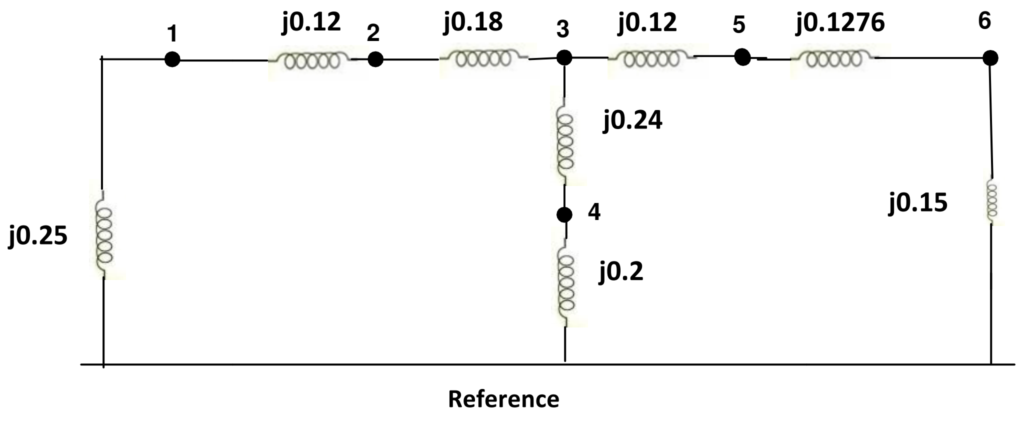
$$Z_{bus}^{1} = Z_{bus}^{2} = i \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \begin{bmatrix} 0.1437 & 0.1211 & 0.0789 & 0.0563 \\ 0.1211 & 0.1696 & 0.1104 & 0.0789 \\ 0.0789 & 0.1104 & 0.1696 & 0.1211 \\ 0.0563 & 0.0789 & 0.1211 & 0.1437 \end{bmatrix} \end{array}$$

10. **Zero sequence network:**



$$
\begin{array}{c c}
 & \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\
Z_{bus}^{0} = j \quad \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} & \begin{bmatrix} 0.3 & 0 & 0 & 0 & 0 \\ 0 & 0.104468 & 0.031065 & 0 & 0.031065 \\ 0 & 0.031065 & 0.177871 & 0 & 0.177871 \\ 0 & 0 & 0 & 0.6 & 0 \\ 0 & 0.031065 & 0.177871 & 0 & 0.654271 \end{bmatrix}
\end{array}
$$

Negative sequence network:



$Z_{bus}^{1} = Z_{bus}^{2} =$

$$\begin{array}{cc} & \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ j \quad \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} & \begin{bmatrix} 0.167640 & 0.128108 & 0.068808 & 0.031276 & 0.048041 & 0.025959 \\ 0.128108 & 0.189500 & 0.101836 & 0.046289 & 0.071101 & 0.038419 \\ 0.068808 & 0.101836 & 0.151377 & 0.068808 & 0.105690 & 0.057109 \\ 0.031276 & 0.046289 & 0.068808 & 0.140367 & 0.048041 & 0.025959 \\ 0.048041 & 0.071101 & 0.105690 & 0.048041 & 0.157574 & 0.085145 \\ 0.025959 & 0.038419 & 0.057109 & 0.025959 & 0.085145 & 0.114956 \end{bmatrix} \end{array}$$

11. $I_{fA} = -j\,2.4195$ p.u.; $I_{fB} = 0$; $I_{fC} = 0$

$I_A = -j\,1.9356$ p.u.; $I_B = j\,0.4839$ p.u.; $I_C = j\,0.4839$ p.u.

$I_A = -j\,0.4839$ p.u.; $I_B = -j\,0.4839$ p.u.; $I_C = -j\,0.4839$ p.u.

$I_a = -j\,1.3969$ p.u.; $I_B = j\,1.4969$ p.u.; $I_C = 0$

12. $I_{2a} = j\,3.828162$ p.u.; $I_{2b} = 0$; $I_{2c} = 0$

$V_{2a} = 0.382815$ p.u.; $V_{2b} = 0.950352 \angle 245.68^0$ p.u.

$V_{2c} = 0.950352 \angle 114.32^0$ p.u.

$V_{1a} = 0.673054$ p.u.; $V_{1b} = 0.929112 \angle 248.76^0$ p.u.

$V_{1c} = 0.929112 \angle 111.236^0$ p.u.

PROBLEM SET 5

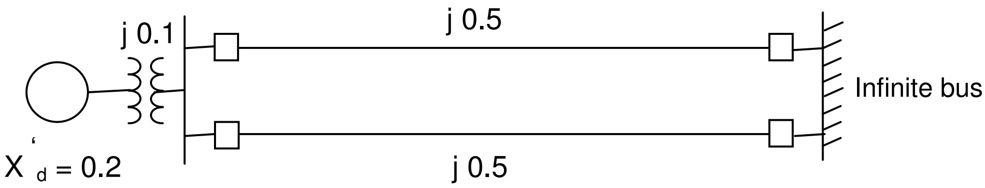
1. A 60-Hz four pole turbogenerator rated 500 MVA, 22 kV has an inertia constant of H = 7.5 MJ / MVA. The electrical power developed is 400 MW when the input less the rotational losses is 740000 hp. Find (a) the kinetic energy stored in the rotor at synchronous speed and (b) the angular acceleration in elec. deg. / s^2 and rpm / s^2.

[3750 MJ   437.76 elec. deg. / s^2 36.48 rpm / s^2]

2. If the acceleration computed for the generator described in Prob. 1 is constant for a period of 15 cycles, find the speed in rpm at the end of 15 cycles and the change in δ in electrical degrees in that period. Assume that the generator is synchronized with a large system and has no acceleration torque before the 15-cycle period begins.

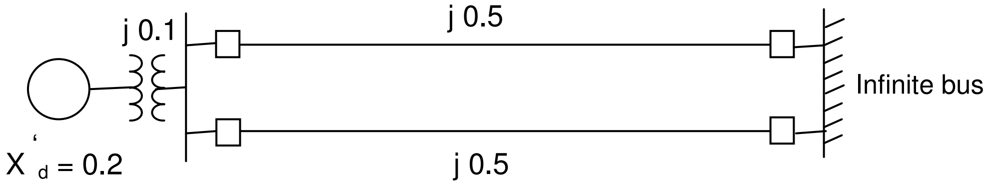
[1809.12 rpm;   13.68 elec. deg.]

3. The single-line diagram shows a generator connected through parallel transmission lines to an infinite bus. The machine is delivering 0.8 per unit power and both the terminal voltage and infinite bus voltages are 1.0 per unit. (i) Calculate the machine's internal voltage (ii) Find the operating rotor angle. (iii) Determine the power angle equation for the system.



[1.0353 $\angle 25.16^0$; 25.16^0 ; P_e = 1.8824 sin δ]

4. The single-line diagram shows a generator connected through parallel transmission lines to an infinite bus. The machine with $|E'|$ = 1.0352 is delivering 0.8 p.u. A three-phase fault occurs at a point on one of the transmission lines at a distance of 30% of the line length away from the sending end terminal. Inertia constant of the machine is 5.0 MJ / MVA. For the faulted condition determine the power angle equation and the swing equation.



[$P_e = 0.5752 \sin \delta$; $\dfrac{d^2\delta}{dt^2} = 36 f \ (0.8 - 0.5752 \sin \delta)$]

5. A 60 Hz generator having H = 6.0 MJ / MVA is delivering power of 1.0 p.u. to an infinite bus through a purely reactive network when the occurrence of a fault reduces the generator output power to zero. The maximum power that could be delivered is 2.5 p.u. When the fault is cleared the original network condition again exist. Determine the critical clearing angle and critical clearing time.

[$\delta_{cc} = 89.374^0 = 1.5599$ rad.; $t_{ccT} = 0.2704$ sec.]

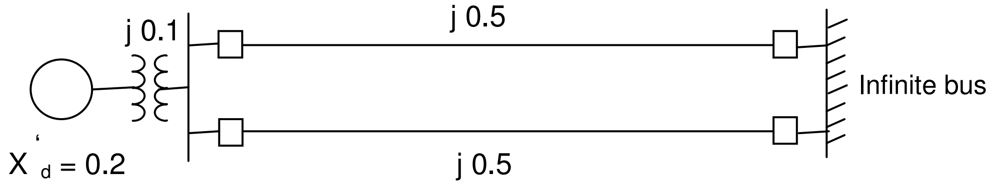
6. A synchronous generator is supplying 60% of P_{max} to an infinite bus through a reactive network. A fault occurs which increases the reactance of the network between the generator internal voltage and the infinite bus by 400%. When the fault is cleared the maximum power that can be delivered is 80% of the original maximum value. Determine the critical clearing angle.

[61.68^0]

7. If the synchronous generator of Prob. 6 has an inertia constant of H = 6 MJ / MVA and P_m (equals to 0.6 P_{max}) is 1.0 p.u., find the critical clearing time. Use Δt = 0.05 sec to plot the necessary swing curve.

[0.194 s]

8. A 60 Hz single generator having inertia constant of 5 MJ / MVA is connected to an infinite bus through transformer and transmission system as shown. Input to the generator = 0.8 p.u.



Before the fault generator has voltage $|E'|$ = 1.0352p.u. and maximum power output is 1.882 p.u. During fault generator output power is 0.575 sin δ. The fault that occurs in one of the transmission is cleared at 4.5 cycles by the simultaneous opening of breakers at both ends.(i) Determine the power angle equation for the post fault period. (ii) Obtain the swing curve up to 0.25 s taking Δt = 0.05 s.

8. A 60 Hz synchronous generator having inertia constant H = 4 MJ / MVA is connected to infinite bus through transformer and a transmission network. Mechanical input power is 1.0 p.u. Its prefault and during fault maximum power output are 1.6667 p.u. and 0.4167 p.u. respectively. Using Modified Euler's method obtain its swing curve up to 0.2 s taking time step of 0.05 s.

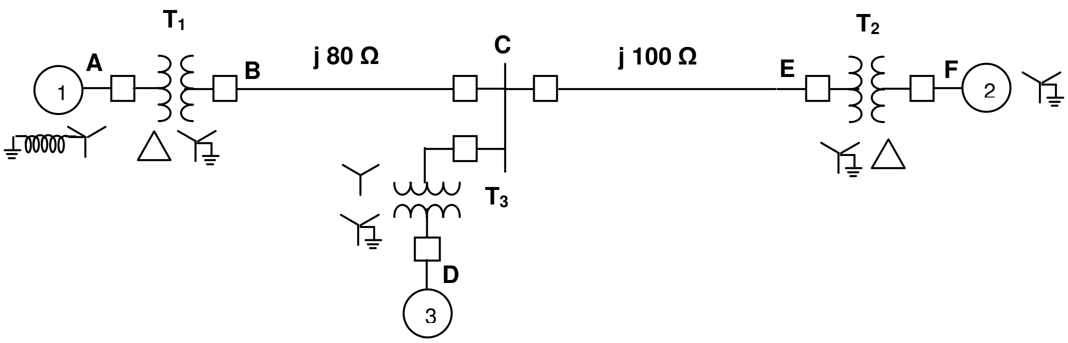
[0, 36.87^0 0.05,37.88^0 0.1,45.46^0 0.15,57.82^0 0.2,74.24^0]

9. Repeat Problem 8 using 4^{th} order RK method.

[0, 36.87^0 0.05,39.40^0 0.1,46.87^0 0.15,59.03^0 0.2,76.66^0]

Problem Set 1

1. A 120 MVA, 19.5 kV generator has X_s = 0.15 per unit and is connected to a transmission line by a transformer rated 150 MVA, 230 Y/18Δ kV with X = 0.1 per unit. If the base to be used in the calculation is 100 MVA, 230 kV for the transmission line, find the per unit values to be used for the transformer and the generator reactances.
2. A transformer's three phase rating is 5000 kVA, 115/13.2 kV, and its impedance is 0.007 + j0.075 per unit. The transformer is connected to a short transmission line whose impedance is 0.02 + j0.1 per unit on a base of 10 MVA, 13.2 kV. The line supplies a three phase load rated 3200 kW, 13.2 kV with a lagging power factor of 0.8. Draw the per unit impedance diagram taking the base as 10 MVA, 13.2 kV at the load. If the high tension voltage is maintained at 115 kV, find the per unit and the actual load voltage.
3. The one-line diagram of an unloaded power system is shown below.



Reactances of the two sections of transmission line are shown in the diagram. The generators and transformers are rated as follows:

Generator 1: 20 MVA, 13.8 kV, X'' = 0.2 per unit

Generator 2: 30 MVA, 18 kV, X'' = 0.2 per unit

Generator 3: 30 MVA, 20 kV, X'' = 0.2 per unit

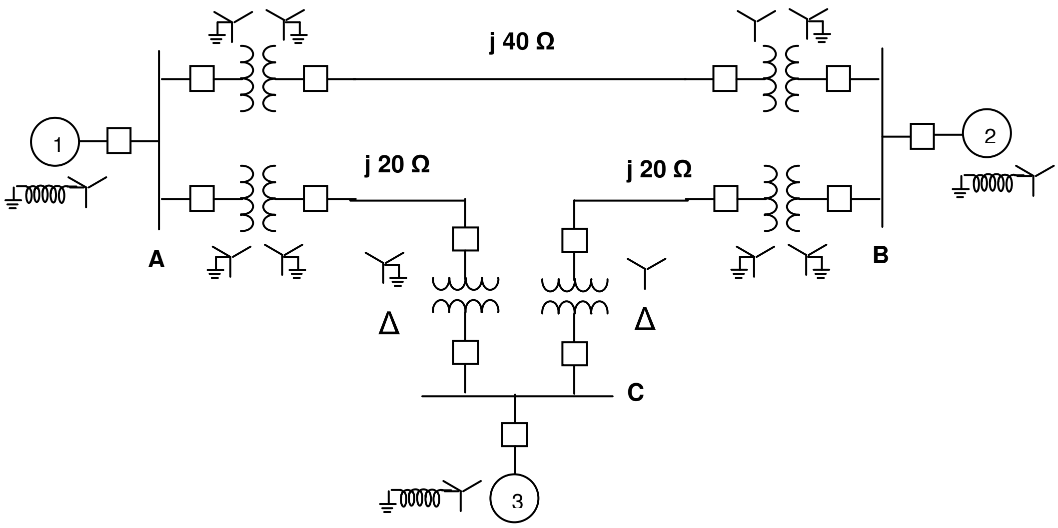
Transformer T_1: 25 MVA, 220Y/13.8Δ kV, X = 10%

Transformer T_2: Single-phase units each rated 10 MVA, 127/18 kV, X = 10%

Transformer T_3: 35 MVA, 220Y/22Y kV, X = 10%

Draw the reactance diagram with all reactances marked in per unit and with letters to indicate points corresponding to the one-line diagram. Choose a base of 50 MVA, 13.8kV in the circuit of generator 1.

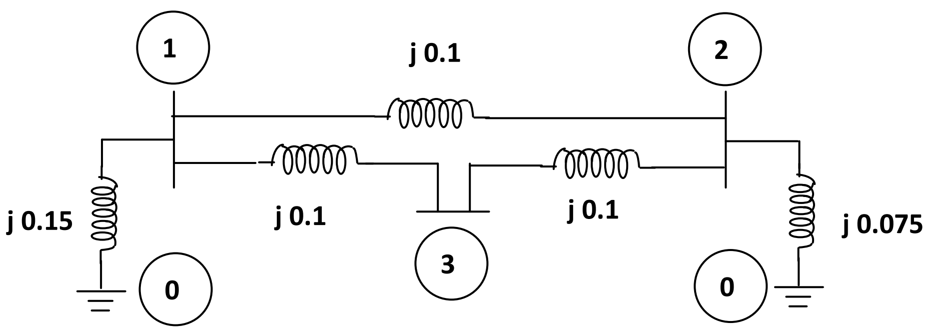
4. Draw the impedance diagram of the power system shown below.



Mark impedances in per unit. Neglect resistance and use a base of 50 MVA, 138 kV in the 40-Ω line. The ratings of the generator, motors and transformers are:

Generator 1:	**20 MVA,18 kV, X" = 20%**
Generator 2:	**20 MVA,18 kV, X" = 20%**
Synchronous motor 3:	**30 MVA, 13.8 kV, X" = 20%**
Three phase Y-Y transformers:	**20 MVA, 138Y/20Y kV, X = 10%**
Three phase Y- Δ transformers:	**15 MVA, 138Y/13.8 Δ kV, X = 10%**

5. The p.u. impedance diagram of a power system is shown below.



Compute its bus admittance matrix.

6. For the network with the following data determine the bus admittance matrix.

Element No.	Between buses		p.u.impedance
1	0	1	j 0.3
2	2	3	j 0.5
3	4	1	j 0.44
4	0	3	j 0.3
5	2	1	j 0.6
6	1	3	j 0.4

7. For the network shown in Fig. 1.21, neglect the mutual coupling and compute Y_{bus} matrix using the bus incidence matrix and the primitive admittance matrix. Take the orientation of elements as from 1 to 2; from 3 to 1; from 3 to 2; from 4 to 2; from 3 to 4; from 0 to 1 and from 0 to 4.

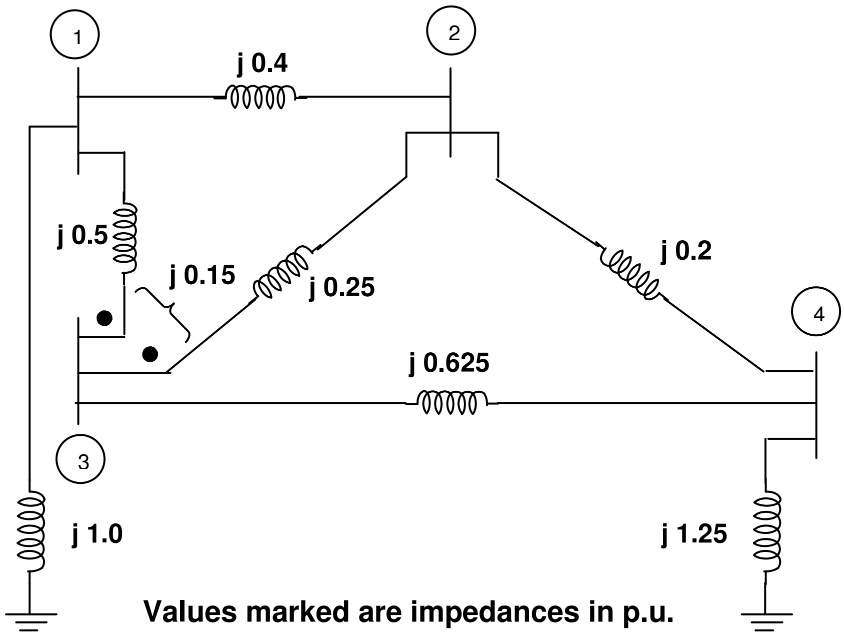


Fig. 1.21 One-line diagram of a 4-bus power system

8. For the network shown in Fig. 1.21, neglect the mutual coupling and compute Y_{bus} matrix by adding one element at a time.

9. For the network shown in Fig. 1.21, neglect the mutual coupling and compute Y_{bus} matrix using the rules for Y_{ii} and Y_{ij} elements.

10. For the network shown in Fig. 1.21, include the mutual coupling and compute Y_{bus} matrix using the bus incidence matrix and the primitive admittance matrix. Take the orientation of elements as from 1 to 2; from 3 to 1; from 3 to 2; from 4 to 2; from 3 to 4; from 0 to 1 and from 0 to 5.

11. Consider the network shown in Fig. 1.21. Find the bus admittance matrix corresponding to the coupled group; compute the bus admittance matrix of the network excluding the coupled group and hence find the Y_{bus} matrix of the full network.

12. i) Determine the bus admittance corresponding to the off-nominal tap setting transformer.

ii) Obtain the bus admittance matrix of the transmission system with the following data.

<u>Line data</u>

Line No.	Between buses	Line Impedance	HLCA	Off nominal turns ratio
1	4 – 3	j 0.125	0	0.95
2	1 – 6	j 0.5	j 0.015	---
3	2 – 3	j 1.2	0	---
4	2 – 5	j 0.75	0	---
5	1 – 4	j 0.32	j 0.01	---
6	4 – 6	j 0.4	j 0.075	---
7	6 – 5	j 0.25	0	---

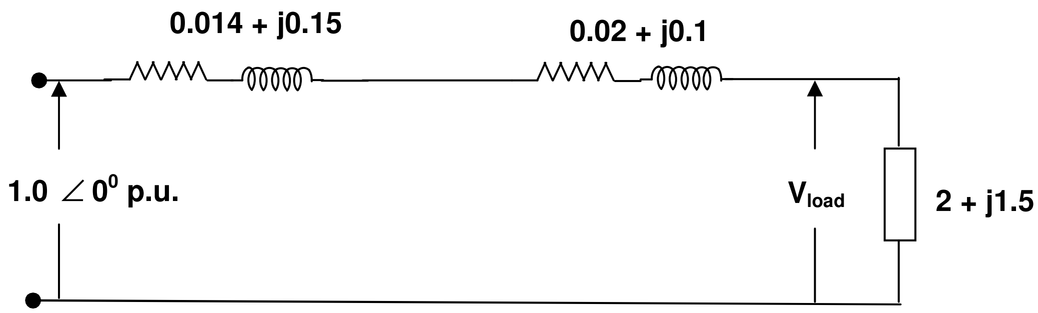
Shunt capacitor data

Bus No. 4 Admittance j 0.05

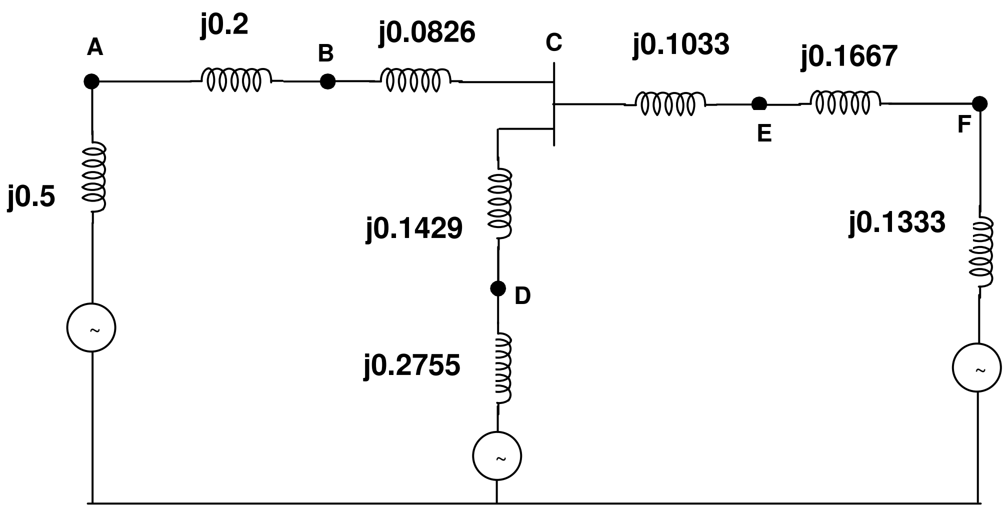
ANSWERS

1. **0.06667 p.u.; 0.1467 p.u.**

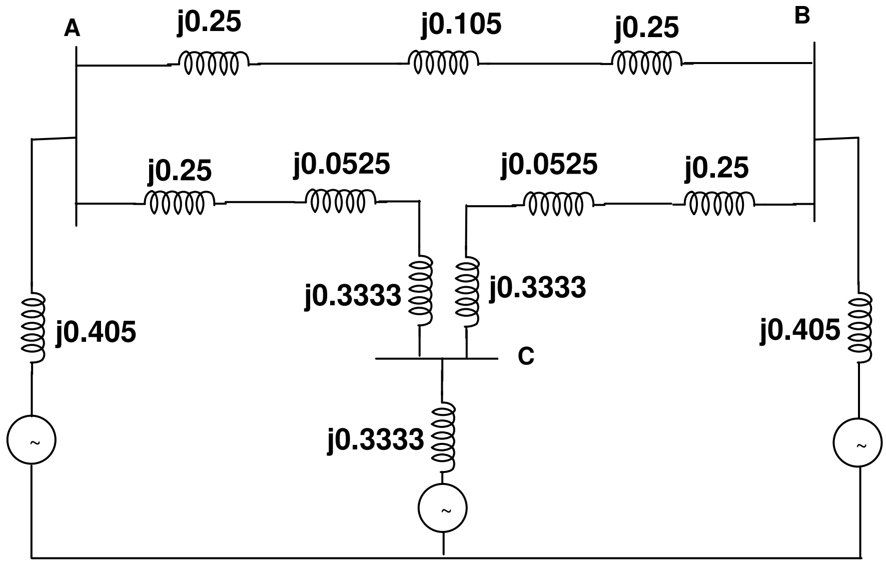
2. **0.9317 p.u.; 12.2984 kV**



3.



4.



5. $$Y_{bus} = \begin{bmatrix} -j26.6667 & j10 & j10 \\ j10 & -j33.3333 & j10 \\ j10 & j10 & -j20 \end{bmatrix}$$

6. $$Y_{bus} = \begin{bmatrix} -j9.7727 & j1.6667 & j2.5 & j2.2727 \\ j1.6667 & -j3.6667 & j2 & 0 \\ j2.5 & j2 & -j7.8333 & 0 \\ j2.2727 & 0 & 0 & -j2.2727 \end{bmatrix}$$

7 to 9: $$Y_{bus} = \begin{bmatrix} -j5.5 & j2.5 & j2 & 0 \\ j2.5 & -j11.5 & j4 & j5 \\ j2 & j4 & -j7.6 & j1.6 \\ 0 & j5 & j1.6 & -j7.4 \end{bmatrix}$$

10 and 11 $$Y_{bus} = \begin{bmatrix} -j5.9390 & j3.9634 & j0.9756 & 0 \\ j3.9634 & -j12.3780 & j3.4146 & j5 \\ j0.9756 & j3.4146 & -j5.9902 & j1.6 \\ 0 & j5 & j1.6 & -j7.4 \end{bmatrix}$$

12.

$$
Y_{bus} = \begin{array}{cc} & \begin{array}{cc} 3 & 4 \end{array} \\ \begin{array}{c} 3 \\ 4 \end{array} & \begin{bmatrix} -j8 & j8.4211 \\ j8.4211 & -j8.8643 \end{bmatrix} \end{array}
$$

$$
Y_{bus} = \begin{bmatrix} -j5.1 & 0 & 0 & j3.125 & 0 & j2 \\ 0 & -j2.1667 & j0.8333 & 0 & j1.3333 & 0 \\ 0 & j0.8333 & -j8.8333 & j8.4211 & 0 & 0 \\ j3.125 & 0 & j8.4211 & -j14.3543 & 0 & j2.5 \\ 0 & j1.3333 & 0 & 0 & -j5.3333 & j4 \\ j2 & 0 & 0 & j2.5 & j4 & -j8.41 \end{bmatrix}
$$

Problem Set 2

1. Fig. 2.7 shows the one-line diagram of a simple three-bus power system with generation at bus 1. The voltage at bus 1 is $V_1 = 1.0 \angle 0^0$ per unit.The scheduled load at buses 2 and 3 are marked on the diagram. Line impedances are marked in per unit on a 100-MVA base.

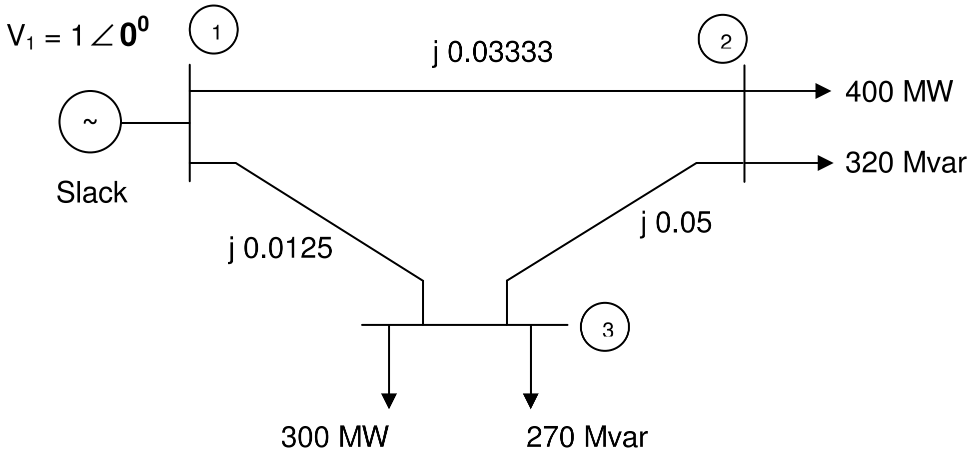


Fig. 2.7 One-line diagram for Problem 1

(a) Assuming a flat start using Gauss-Seidel method determine V_2 and V_3. Perform two iterations. Take acceleration factor as 1.2.

(b) If after several iterations the bus voltages converge to $V_2 = (0.9 - j\,0.1)$ pu and $V_3 = (0.95 - j\,0.05)$ pu determine the line flows, line losses, transmission loss and the slack bus real and reactive power. Construct a power flow diagram and show the direction of the line flows.

2. Fig. 2.9 shows the one-line diagram of a simple three-phase power system with generation at buses 1 and 3. The voltage at bus 1 is $V_1 = 1.025 \angle 0^0$ per unit. Voltage magnitude at bus 3 is fixed at 1.03 pu with a real power generation of 300 MW. A load consisting of 400 MW and 200 Mvar is taken from bus 2. Line impedances are marked in per unit on a 100-MVA base.

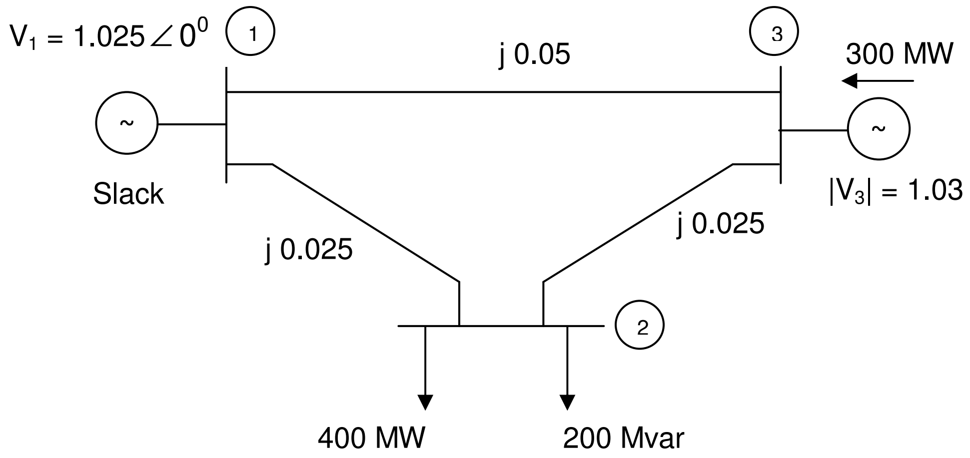


Fig. 2.8 One-line diagram for Problem 2

3. Consider the two-bus system shown in Fig. 2.9. Base = 100 MVA. Starting with flat start, using Newton-Raphson method, obtain the voltage at bus 2 at the end of first and second iteration.

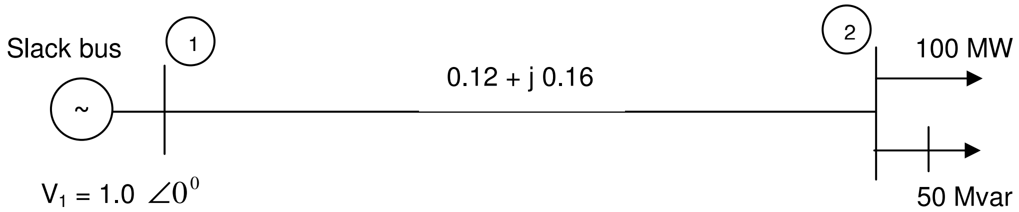


Fig. 2.9 One-line diagram for Problem 3

4. Consider the power system with the following data. Perform power flow analysis for the power system with the data given below, using Newton Raphson method, and obtain the bus voltages at the end of first two iterations.

Line data (p.u. quantities)

Line No.	Between buses	Line impedances
1	1–2	0 + j0.1
2	2–3	0 + j0.2
3	1–3	0 + j0.2

Bus data (p.u. quantities)

Bus No	Type	Generator		Load		$\|V\|$	δ	Q_{min}	Q_{max}
		P	Q	P	Q				
1	Slack	---	---	0	0	1.0	0	---	---
2	P - V	5.3217	---	0	---	1.1	---	0	3.5
3	P - Q	0	0	3.6392	0.5339	---	---	---	---

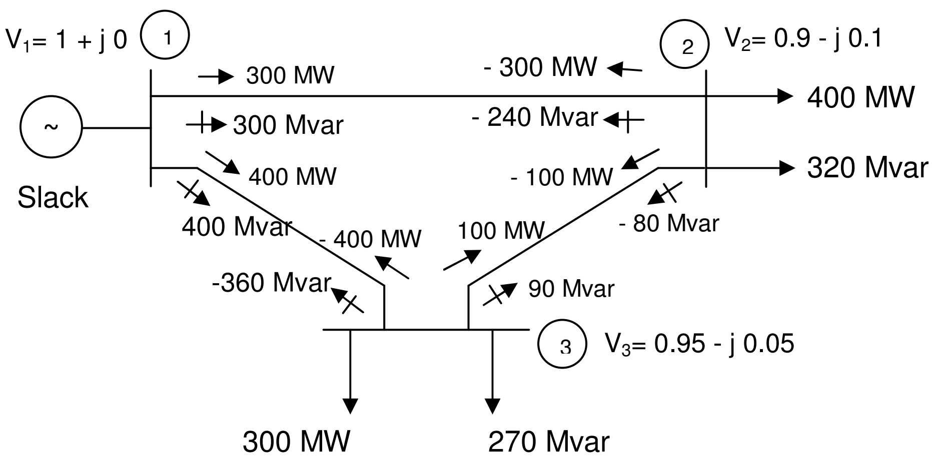
5. Redo the problem using Fast Decoupled Power Flow method.

ANSWERS

1. (a) $V_2^{(1)} = 0.9232 - j\,0.096$; $V_3^{(1)} = 0.9491 - j\,0.0590$

$V_2^{(2)} = 0.8979 - j\,0.1034$; $V_3^{(2)} = 0.9493 - j\,0.0487$

(b)



Transmission loss = $S_{L\,1\text{-}2} + S_{L\,1\text{-}3} + S_{L\,2\text{-}3}$ = j 0.6 + j 0.4 + j 0.1 = j 1.1 pu

i.e. 110 Mvar

Slack bus power $S_L = S_{12} + S_{13}$ = (3 + j 3) + (4 + j 4) = (7 + j 7) pu

i.e. 700 MW and 700 Mvar

2. At the end of first iteration

$V_1 = 1.025 + j\,0$; $V_2 = 1.0025 - j\,0.05$; $V_3 = 1.02989 + j\,0.01521$

At the end of second iteration

$V_1 = 1.025 + j\,0$; $V_2 = 1.00008 - j\,0.0409$; $V_3 = 1.02978 + j\,0.0216$

3. At the end of first iteration $|V_2| = 1 - 0.2 = 0.8$ and $\delta_2 = 0 - 0.1 = -0.1$

$V_2 = 0.8 \angle -5.73^0$

At the end of second iteration $|V_2| = 0.8 - 0.07736 = 0.7226$

$\delta_2 = -0.1 - 0.035 = -0.135$

Thus $V_2 = 0.7226 \angle -7.735^0$

4.

At the end of first iteration $V_1 = 1.0\angle 0^0$ $V_2 = 1.1\angle 14.37^0$ $V_3 = 0.9964\angle -12.33^0$

At the end of second iteration

$V_1 = 1.0\angle 0^0$ $V_2 = 1.1\angle 14.943^0$ $V_3 = 0.912\angle -14.456^0$

5. At the end of first iteration, bus voltage

$V_1 = 1.0\angle 0^0$
$V_2 = 1.1\angle 13.84^0$
$V_3 = 0.9186\angle -13.93^0$

At the end of second iteration, bus voltages

$V_1 = 1.0\angle 0^0$
$V_2 = 1.1\angle 14.79^0$
$V_3 = 0.9799\angle -14.57^0$