CLASS TEST

S.No. : 02SKEE_EFGHIJK_310823

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POWER SYSTMS-2

ELECTRICAL ENGINEERING

Date of Test : 31/08/2023

ANSWER KEY

1. (c)	7. (a)	13. (b)	19. (a)	25. (c)
2. (c)	8. (d)	14. (c)	20. (c)	26. (b)
3. (b)	9. (b)	15. (a)	21. (a)	27. (d)
4. (a)	10. (b)	16. (b)	22. (b)	28. (b)
5. (d)	11. (c)	17. (c)	23. (b)	29. (d)
6. (a)	12. (c)	18. (a)	24. (b)	30. (a)

DETAILED EXPLANATIONS

1. **(c)**

The rating of the machine, G = 100 MVA

Inertia constant, H = 10 MJ/MVA

Accelerating power, P_a = 90 MW – 60 MW = 30 MW

$$\text{Angular momentum, } M = \frac{GH}{180f} = \frac{100 \times 10}{180 \times 50} = \frac{1}{9} \text{ MJ-s/electrical degree}$$

$$\text{Acceleration, } \alpha = \frac{P_a}{M} = \frac{30}{1/9} = 270 \text{ elec. degree/s}^2$$

2. **(c)**

Assuming one-generator bus as slack bus

Number of slack bus-1

Number of PQ bus-2

Number of PV bus-1

Number of simultaneous equation to be solved is 2 (No. of PQ bus) + No. of PV bus

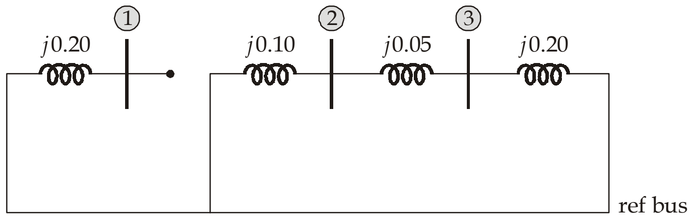
= 2 × 2 + 1 = 5

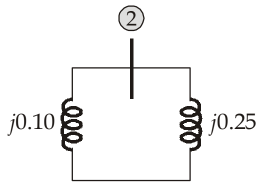
3. **(b)**

$$Y_{13} = j40$$
$$y_{13} = -j40$$
$$\frac{1}{Z_{13}} = -j40$$
$$Z_{13} = 0.025\,j \text{ p.u.}$$

4. **(a)**

The zero sequence network of the above single line diagram is as shown below,





$$Z_0 = (j0.10) \,||\, (j0.25)$$
$$= \frac{0.10j \times 0.25j}{0.10j + 0.25j} = 0.0714j$$

∴ The zero sequence driving point reactance of bus-2 is 0.0714.

5. (d)

$$I_f = \frac{\sqrt{3}E_a}{X_1 + X_2} = \frac{\sqrt{3}}{0.2+0.2} = 4.33 \text{ p.u.}$$

$$I_f = 4.33 \times \frac{25\times 10^3}{\sqrt{3}\times 11} = 5.68 \text{ kA}$$

6. (a)

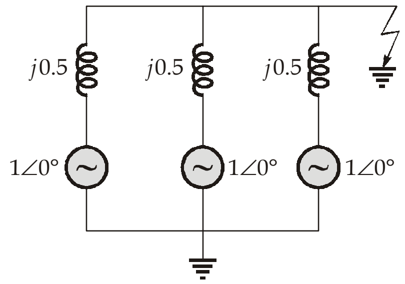
$$\text{Fault current (kA)} = \text{Base current} \times \text{Fault current (p.u.)}$$

$$\text{Base current} = \frac{\text{MVA}}{\sqrt{3}\times\text{KV}}\times 1000 \text{ A} = \frac{100}{\sqrt{3}\times 132}\times 1000 = 437.4 \text{ A}$$

$$\text{Fault current} = 437.4 \times 5 = 2.187 \text{ KA}$$

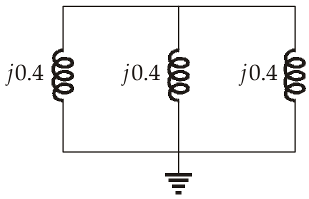
7. (a)

Positive sequence reactance diagram:



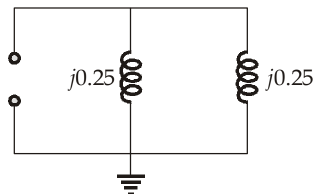
$\Rightarrow$ $$Z_{01} = j\frac{0.5}{3}$$

Negative sequence reactance diagram:



$\Rightarrow$ $$Z_{02} = j\frac{0.4}{3}$$

Zero sequence reactance diagram:



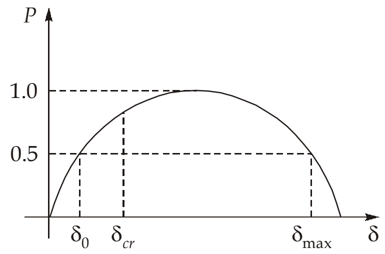
$\Rightarrow$ $$Z_{00} = j\frac{0.25}{2}$$

$$I_f = 3\left(\frac{E}{Z_{01}+Z_{02}+Z_{00}}\right) = 3\left(\frac{1}{j0.425}\right)$$

$$I_f = -j7.058 \text{ p.u.}$$

$\Rightarrow$ $$|I_f| = 7.058 \text{ p.u.}$$

8. (d)



$$P_m = P_{max} \sin \delta_0$$
$$\sin \delta_0 = 0.5$$
$$\delta_0 = 30° \text{ or } \frac{\pi}{6} \text{ rad}$$

and $$\delta_{max} = \pi - \delta_0 = \pi - \frac{\pi}{6} = \frac{5\pi}{6} \text{ rad or } 150°$$

$$\cos \delta_{cr} = \frac{P_m}{P_{max}}(\delta_{max} - \delta_0) + \cos\delta_{max} = \frac{0.5}{1}\left(\frac{5\pi}{6} - \frac{\pi}{6}\right) + \cos(150°)$$

The critical clearing angle,
$$\delta_{cr} = \cos^{-1}(0.18117) = 79.562°$$

9. (b)

Sum of the line currents in a Δ is always zero
$$I_a + I_b + I_c = 0$$
$$I_b = -I_a$$
$$I_{a1} = \frac{1}{3}\left[I_a + \alpha I_b + \alpha^2 I_c\right] = \frac{1}{3}[I_a - \alpha I_a]$$
$$= \frac{I_a(1 - 1\angle 120°)}{3} = \frac{(10\angle 0°)(1 - 1\angle 120°)}{3}$$
$$I_{a1} = 5.77\angle -30° \text{ A}$$

10. (b)

This method is not directly applicable to multi-machine system.

11. (c)

Only Y_{22}, Y_{24}, Y_{42}, Y_{44} will change because transmission line is connected between 2nd and 4th buses.

$$Y_{22} = -j60 + \frac{1}{Z_{se}} + \frac{Y_{sh}}{2}$$
$$= -j60 + \frac{1}{j0.1} + j20 = -j60 - j10 + j20 = -j50$$
$$Y_{24} = Y_{42} = 0 - \frac{Y_{sh}}{2} = -j20$$
$$Y_{44} = -j25 + \frac{1}{Z_{se}} + \frac{Y_{sh}}{2} = -j25 + \frac{1}{j0.1} + j20 = -j25 - j10 + j20$$
$$Y_{44} = -j15$$

12. (c)

Inertia constant, $H = 4$ MW-sec/MVA

$= 4$ MJ/MVA

No load voltage, $V_1 = 1.2$ p.u.

Infinite bus voltage, $V_2 = 1$ p.u.

Total reactance, $X = X_G + X_L$

$= 0.25 + 0.15$

$= 0.4$ p.u.

Angular momentum, $M = \frac{GH}{\pi f} = \frac{1 \times 4}{\pi \times 50} = 0.0254$

For 80% loading,

$$\sin \delta_0 = \frac{80}{100} = 0.8$$

$$\cos \delta_0 = \sqrt{1 - 0.8^2} = 0.6$$

$$\frac{dP_c}{d\delta} = \frac{V_1 V_2}{X} \cos \delta_0 = \frac{1.2 \times 1}{0.4} \times 0.6 = 1.8$$

$$f_n = \sqrt{\frac{\left.\frac{dP_e}{d\delta}\right|_{\delta_0}}{M}} = \sqrt{\frac{1.8}{0.0254}} = 8.41 \text{ rad/sec} = 1.34 \text{ Hz}$$

13. (b)

Full load current of each alternator,

$$= \frac{20 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 1.05 \text{ kA}$$

Since the two identical alternators are operating in parallel

$$Z_1 = \frac{j0.18}{2} = j0.09 \text{ p.u.}$$

$$Z_2 = \frac{j0.15}{2} = j0.075 \text{ p.u.}$$

$$Z_0 = j0.10 + 3R_n$$

$$= j0.1 + 3 \times \frac{2 \times 20}{11^2} = j0.1 + 0.992$$

For an L-G fault,

fault current, $I_f = 3I_{a1} = \frac{3E_a}{Z_1 + Z_2 + Z_0} = \frac{3}{j0.09 + j0.075 + j0.1 + 0.992}$

$= 2.92\angle -14.96°$ p.u.

fault current, $I_f = 2.92 \times 1.05 = 3.066$ kA

Voltage drop across grounding resistor

$= 3.066 \times 2 = 6.132$ kV

14. (c)

Voltage magnitude at bus-2,

$$V_2 = 1 - \frac{Z_{12}}{Z_{11}} = 1 - Z_{12} I_{f1} \qquad \left(\therefore I_{f1} = \frac{1}{Z_{11}}\right)$$

$$0.9 = 1 - Z_{12} \times 12.5$$

$$Z_{12} = \frac{0.1}{12.5} = 0.008 \text{ p.u.}$$

and voltage magnitude at bus-1,

$$V_1 = 1 - \frac{Z_{12}}{Z_{22}} = 1 - Z_{12} \cdot I_{f2}$$

$$= 1 - 0.008 \times 10$$

$$= 1 - 0.08$$

$$V_1 = 0.92 \text{ p.u.}$$

15. (a)

$$\text{Base MVA} = 2 \text{ MVA}$$

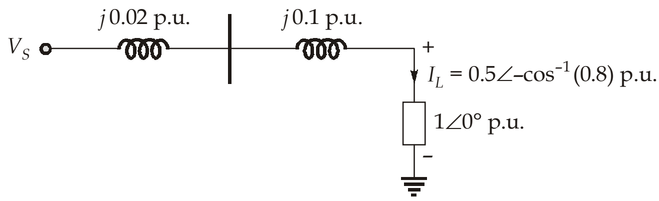
The p.u. reactance of 2 MVA transformer is $j0.1$ p.u.

The p.u. reactance of 10 MVA transformer,

$$X_{\text{p.u. (new)}} = X_{\text{p.u.(old)}} \times \frac{2}{10}$$

$$= 0.1 \times \frac{2}{10} = 0.02 \text{ p.u.}$$

The load current is 0.5 p.u. for 2 MVA base



KVL in the loop:

$$V_S = I_L Z + V\angle 0°$$

$$= [(0.5\angle -36.87°)(j0.12)] + (1\angle 0°)$$

$$= 1.037\angle 2.65° \text{ p.u.}$$

$$V_S = 1.037 \times 33 = 34.22 \text{ kV}$$

16. (b)

Natural frequency of oscillations is,

$$f_n = \sqrt{\frac{\left.\left(\frac{\partial P_e}{\partial \delta}\right)\right|_{\delta_0}}{M}}$$

$$\text{GH} = \frac{1}{2} M\omega$$

$$M = \frac{GH}{\pi f} = \frac{1 \times 3}{\pi \times 50} = 0.019$$

$$P_e = \frac{|E||V|}{X}\sin\delta_0$$

$$0.6\ P_{max} = P_{max}\ \sin\ \delta_0$$

$$\delta_0 = \sin^{-1}(0.6) = 36.87°$$

$$\left.\frac{\partial P_e}{\partial \delta}\right|_{\delta_0} = P_e \cos\delta_0 = \frac{1.1}{0.5}\cos(36.87°) = 1.76 \text{ p.u.}$$

$$f_n = \sqrt{\frac{1.76}{0.019}} = 9.62 \text{ rad/sec}$$

$$f_n = \frac{9.62}{2\pi} = 1.53 \text{ Hz}$$

17. (c)

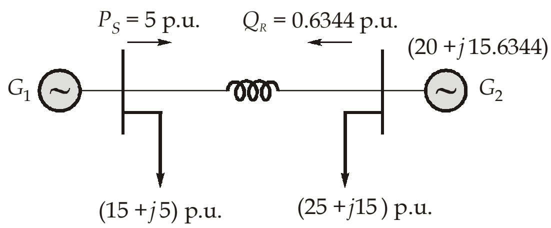
By equalizing the station,

$$P_{G_1} = P_{G_2} = 20 \text{ p.u.}$$

Now,

$$5 = \frac{|E||V|}{|X|}\sin\delta = \frac{1\times 1}{0.05}\sin\delta$$

$$\delta = 14.47°$$



$$Q_R = \frac{|V_1||V_2|}{X}\cos\delta - \frac{|V_1|^2}{X} = -0.6344 \text{ p.u.}$$

Total load on station 2 $= (25 + j15) + (-5 + j0.6344)$

$= (20 + j15.6344)$

Power factor of station 2 $= \cos\left(\tan^{-1}\left(\frac{15.6344}{20}\right)\right)$

$= 0.78$ lagging

18. (a)

$$I_{f\,3\text{-}\phi} = \frac{E_f}{X_1}$$

$$I_{f\,\text{L-G}} = \frac{3E_f}{X_1 + X_2 + X_0}$$

$$\frac{I_{f\,3-\phi}}{I_{f\,L-G}} = \frac{X_1 + X_2 + X_0}{3X_1}$$

$$= \frac{0.30 + 0.30 + 0.10}{3\times 0.30} = 0.778$$

19. (a)

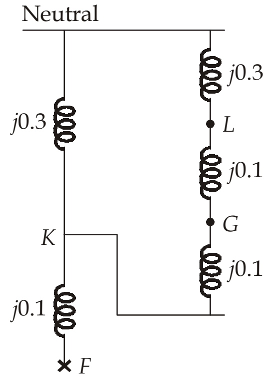
Let base MVA = 10 MVA

Per unit reactance of each generator is 0.3 p.u.

Per unit reactance of each reactor is 0.1 p.u.

Per unit reactance of each transformer on the base MVA

$$= \frac{5}{100} \times \frac{10}{5} = 0.1 \text{ p.u.}$$



Total per unit impedance from generator neutral upto fault point F

$$= 0.1 + [(0.3) \,||\, (0.5)]$$

$$= 0.1 + \frac{(0.3)(0.5)}{(0.3)+(0.5)} = 0.2875 \text{ p.u.}$$

$$\text{Short circuit MVA} = \frac{\text{Base MVA}}{\text{Per unit fault reactance}} = \frac{10}{0.2785} = 34.78 \text{ MVA}$$

20. (c)

The rating of the machine, G = 100 MVA

Inertia constant, H = 5 kW-s/kVA

= 5 KJ/KVA = 5 MJ/MVA

Kinetic energy stored in the rotating parts of generator and turbine at synchronous speed (f = 50 Hz)

= HG = 5 × 100 = 500 MJ

Excess power input to the generator shaft before the steam valve begins to close,

= 100 – 60 = 40 MW

Excess energy transferred to rotating parts in 0.5 sec

= 40 × 0.5 = 20 MJ

Since, Kinetic energy, $K.E. \propto (\text{speed})^2 \propto f^2$

So, frequency at the end of 0.5 sec

$$f_2 = f_1\sqrt{\frac{\text{Total energy stored in 0.5 sec}}{\text{Energy stored at synchronous speed}}}$$

$$f_2 = 50\sqrt{\frac{500+20}{500}} = 50 \times 1.02 \approx 51 \text{ Hz}$$

Change in frequency $= f_2 - f_1$

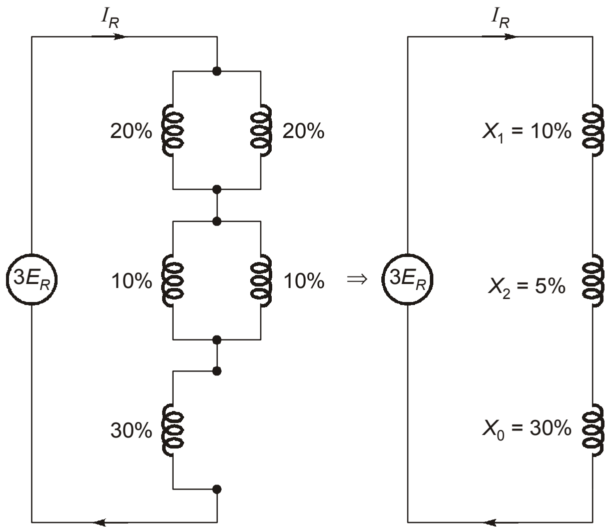
= 51 – 50 ≈ 1 Hz

21. (a)

The earth fault is assumed to occur on the red phase. Taking red phase as the reference, its phase e.m.f.

$$E_R = \frac{11\times1000}{\sqrt{3}} = 6351 \text{ V}$$

For line to ground fault the equivalent circuit will be



The percentage reactances can be converted into ohmic values as under :

$$\%\ X = \frac{Z\,(MVA_b)}{(KV)^2}\times100$$

$$Z = \frac{\%X\times(KV)^2}{(MVA_b)\times100}$$

$$X_1 = \frac{10\times(11)^2}{20\times100} = 0.605\ \Omega$$

$$X_2 = \frac{5\times11^2}{20\times100} = 0.3025\ \Omega$$

$$X_0 = \frac{30\times11^2}{20\times100} = 1.815\ \Omega$$

Fault current $$\vec{I_R} = \frac{3\,\vec{E_R}}{X_1+X_2+X_0} = \frac{3\times6351}{j0.605+j0.3025+j1.815}$$

$$\vec{I_R} = -j\,6998 \text{ A}$$

$$|I_R| = 6998 \text{ A}$$

22. (b)

For 3-ϕ transmission line we can use relation,

$$X_1 = X_s - X_m \quad ...(1)$$

$$X_0 = X_s + 2X_m \quad ...(2)$$

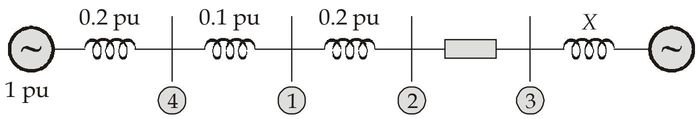
Also given, $X_0 = 32\ \Omega$ and $X_1 = 16\ \Omega$

∴ Solving (1) and (2) simultaneously,

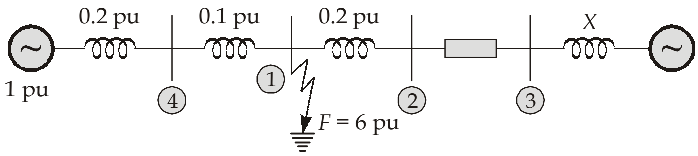
$$X_s - X_m = 16$$
$$X_s + 2X_m = 32$$
$$(-) \quad (-) \qquad (-)$$
$$-3X_m = -16$$
$$X_m = \frac{16}{3} \simeq 5.33\ \Omega$$

23. **(b)**

Drawing single line diagram, assuming system B reactance be X,



If fault occurs at bus 1 after reactance,



Thevenin impedance, $Z_{th} = (0.2 + 0.1) \,||\, (0.2 + X)$

$$= \frac{(0.3)(0.2+X)}{0.5+X}$$

Also, per unit fault current $= \dfrac{1}{Z_{th}} = 6$ pu

$$\therefore \quad \frac{1}{6} = \frac{(0.3)(0.2+X)}{0.5+X}$$

$$0.5 + X = (1.8)(0.2 + X)$$
$$0.8\,X = 0.5 - 0.36 \text{ or } X = 0.175 \text{ pu}$$

Now using $X = 0.175$ pu, finding fault level at bus 3 after interconnection

New, $$Z_{th\ pu} = \frac{(0.5)(0.175)\text{ pu}}{0.675} = 0.1296 \text{ pu}$$

$$I'_f = \frac{1}{Z_{th\,pu}} = 7.71 \text{ pu}$$

24. **(b)**

For the power system finding admittance value,

$$y_{10} = \frac{1}{Z_{10}} = \frac{1}{0.3} = \frac{10}{3}$$

$$y_{12} = \frac{1}{Z_{12}} = \frac{1}{0.5} = 2$$

$$\therefore \quad y_{20} = \frac{1}{Z_{20}} = \frac{1}{0.5} = 2$$

Admittance matrix, $$Y_{bus} = \begin{bmatrix} 10/3+2 & -2 \\ -2 & 4 \end{bmatrix} = \begin{bmatrix} 5.33 & -2 \\ -2 & 4 \end{bmatrix}$$

∴ Impedance matrix,

$$Z_{bus} = [Y_{bus}]^{-1} = \frac{1}{(5.33\times 4)-(2\times 2)} \times \begin{bmatrix} 4 & 2 \\ 2 & 5.33 \end{bmatrix}$$

$$= 0.0577 \times \begin{bmatrix} 4 & 2 \\ 2 & 5.33 \end{bmatrix} = \begin{bmatrix} 0.230 & 0.115 \\ 0.115 & 0.308 \end{bmatrix}$$

25. (c)

$$v = 100\sin(100\pi t + 15°)$$

It will be maximum when,

$$(100\pi t + 15°) = 90°$$

$$100\,\pi t = \frac{75 \times \pi}{180}$$

$$t = \frac{75}{100 \times 180} = 4.16 \text{ ms}$$

Now short circuit current is given by

$$i = \frac{V_{max}}{Z}\sin(\omega t + \alpha - \phi) + \frac{V_{max}}{Z}\sin(\phi - \alpha)e^{-t/\tau}$$

Where τ is time constant,

Now, $$Z = \sqrt{R^2 + X^2} = \sqrt{5^2 + (100\pi \times 0.1)^2} = 31.81\ \Omega$$

$$V_{max} = 100 \text{ Volts}$$

$$\alpha = 15°$$

$$\phi = \tan^{-1}\left(\frac{100\pi \times 0.1}{5}\right) = 80.96°$$

$$\tau = \frac{L}{R} = \frac{0.1}{5} = \frac{1}{50}$$

So, $$i = \frac{100}{31.81}\sin(100\pi t + 15 - 80.96°) + \frac{100}{31.81}\sin(80.96 - 15)e^{-50t}$$

$$= \underbrace{3.1435\sin(100\pi t - 65.96°)}_{\text{Particular}} + \underbrace{2.871e^{-50t}}_{\text{Complementary}}$$

(d) at t = 4.16 ms

$$i = 3.1435\sin\left(\left(\frac{100\pi}{\pi} \times 180 \times 4.16 \times 10^{-3}\right) - 65.96°\right) + 2.871e^{-50\times 4.16\times 10^{-3}}$$

$$= 0.4874 + 2.3318 = 2.819 \text{ Amp}$$

26. (b)

$$X_{1\,eq} = \frac{j0.18}{2} = j0.09 \text{ p.u.}$$

$$X_{2\,eq} = \frac{j0.15}{2} = j0.075 \text{ p.u.}$$

$$Z_{0\,eq} = j0.1 + \frac{3 \times 2}{11^2} \times 20 = (0.9917 + j0.1) \text{ p.u.}$$

$$\text{Fault current, } I_f = \frac{3E_f}{j(X_1) + jX_2 + Z_{0eq}}$$

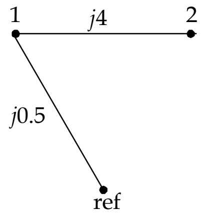
$$= \frac{3 \times 1\angle 0°}{1.0265\angle 14.96°} = 2.922\angle -14.96° \text{ A}$$

Current in grounding resistor,

$$I_f = 2.922 \times \frac{20}{11\sqrt{3}} = 3.07 \text{ kA}$$

27. (d)

Existing system and bus matrix is



$$Z_{Bus} = \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j4.5 \end{bmatrix}$$

Modifying line with reactance $j2$ is equivalent to adding a line in parallel with impedance $j4$. Thus it is type-4 modification.

$$[Z_{new}] = [Z_{old}] - \frac{1}{Z_{11} + Z_{22} - 2Z_{12} + Z_s} \begin{bmatrix} \text{subtract} \\ 2^{\text{old}} \text{column} \\ \text{to first column} \end{bmatrix} [\text{Transpose}]$$

$$[Z_{Bus}]_{new} = \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j4.5 \end{bmatrix} - \frac{1}{j0.5 + j4.5 - 2(j0.5) + j4} \begin{bmatrix} j0 \\ -j4 \end{bmatrix} \begin{bmatrix} j0 & -j4 \end{bmatrix}$$

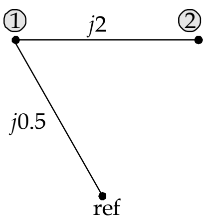
$$= \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j4.5 \end{bmatrix} - \frac{1}{j8} \begin{bmatrix} 0 & 0 \\ 0 & -16 \end{bmatrix}$$

$$= \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j4.5 \end{bmatrix} - \begin{bmatrix} 0 & 0 \\ 0 & -\frac{16}{j8} \end{bmatrix}$$

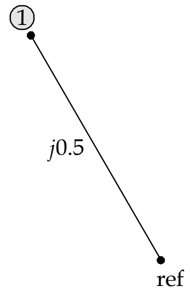
$$= \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j4.5 - \frac{j16}{8} \end{bmatrix} = \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j2.5 \end{bmatrix}$$

Alternative :

New system will

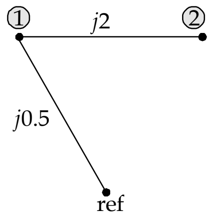


First branch :



$$Z = [\,j0.5]$$

Type – 2 modification



$$Z = \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j0.5 + j2 \end{bmatrix} = \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j2.5 \end{bmatrix}$$

28. (b)

For single line to ground fault , fault current is

$$I_f = 3I_a^{(0)}$$

and
$$I_a^{(0)} = \frac{-V_a^{(0)}}{Z_{g0}}$$

$$V_a^{(0)} = \frac{1}{3}[V_a + V_b + V_c] = \frac{1}{3}[0 + 1.013\angle -102.25° + 1.013\angle 102.25°]$$

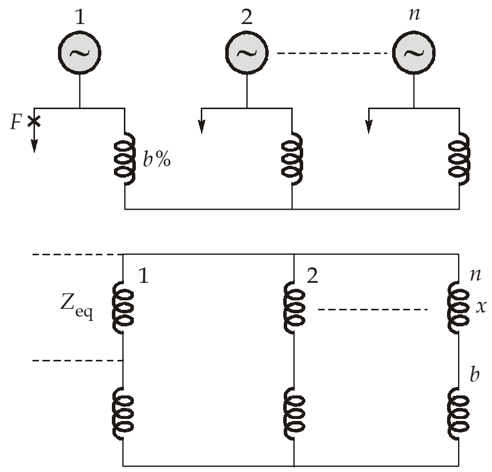
$$= -0.1433 \text{ p.u.}$$

$$I_a^{(0)} = -\left(\frac{-0.1433}{j0.1}\right) = -j1.43 \text{ p.u.}$$

$$I_f = 3 \times (-j1.43) = -j4.29 \text{ p.u.}$$

$$I_f = -j4.29 \times \left(\frac{20000}{\sqrt{3} \times 13.8}\right) = -j3.59 \text{ kA}$$

29. (d)



Equivalent impedance Z_{eq} between the zero potential bus and the fault point is

$$\left(\frac{b+x}{n-1}+b\right) \| x = \left(\frac{bn+x}{n-1}\right) \| x$$

$$\frac{1}{Z_{eq}} = \frac{1}{x}+\frac{n-1}{bn+x}$$

$$\text{SC kVA} = \frac{8}{Z_{eq}} \times 100$$

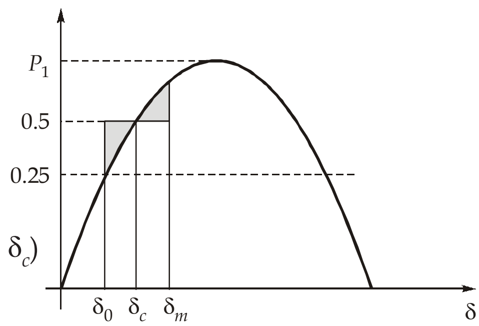
$$= 8\left[\frac{1}{x}+\frac{n-1}{bn+x}\right] \times 100$$

If n is very large.

$$\text{Short circuit kVA} = 8\left[\frac{1}{x}+\frac{1}{b}\right]$$

30. (a)

$$\delta_0 = \sin^{-1}(0.25)$$
$$= 14.48°$$
$$\delta_c = \sin^{-1}(0.5)$$
$$= 30°$$



$$\int_{\delta_0}^{\delta_c} (0.5-\sin\delta)d\delta = \int_{\delta_c}^{\delta_m} (\sin\delta - 0.5)d\delta$$

$$\Rightarrow 0.5\,(\delta_c - \delta_0) + \cos\delta_c - \cos\delta_0 = \cos\delta_c - \cos\delta_m - 0.5\,(\delta_m - \delta_c)$$

$$0.5\,(\delta_m - \delta_0) = \cos 14.48° - \cos\delta_m$$

$$0.5\,\delta_m + \cos\delta_m = 1.0945$$

$$\delta_m = 46.41°$$

■■■■