CLASS TEST

S.No. : 02 SK_EFSGHI_090822

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POWER SYSTMS-2

ELECTRICAL ENGINEERING

Date of Test : 09/08/2022

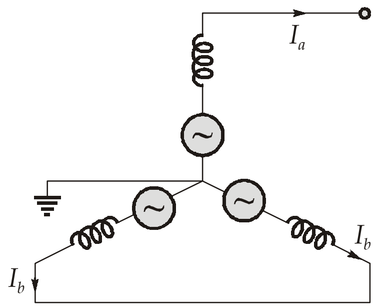
ANSWER KEY

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

DETAILED EXPLANATIONS

1. (b)

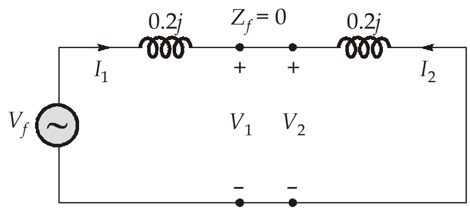
Line-to line fault occurs on b and c phases of generator,



$$I_f = I_b = -I_c$$

and $$I_a = 0$$

The sequence network for line to line fault is



$$I_1 = \frac{V_f}{z_1 + z_2}$$

$\Rightarrow$ $$I_f = I_b = (\alpha^2 - \alpha)I_1 = -j\sqrt{3}I_1 = \frac{-j\sqrt{3}V_f}{z_1 + z_2}$$

and $$I_{f\,\text{p.u.}} = \frac{-j\sqrt{3}\times 1}{j0.2 + j0.2}$$

$$|I_{f\,\text{p.u.}}| = \frac{\sqrt{3}}{0.4} = 4.33 \text{ p.u.}$$

$$\text{Base current} = \frac{25\times 10^3}{\sqrt{3}\times 11} = 1312.16 \text{ A}$$

$$\text{Fault current, } I_f = 4.33 \times 1312.16 = 5.68\text{kA}$$

2. (b)

For the fully transposed transmission line,

Positive sequence impedance $Z_1 = Z_s - Z_m$

Negative sequence impedance $Z_2 = Z_s - Z_m$

Zero sequence impedance, $Z_s = Z_s + 2Z_m + 3Z_n$

Where, Z_s = Self impedance/ph

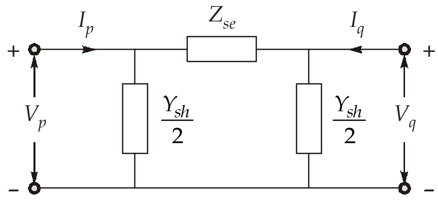
Z_m = Mutual impedance/ph

If the system voltages are unbalanced, we have a neutral current, I_n flowing through the neutral (ground) having impedance Z_n.
From above equations, we can say
1. Positive and negative sequence impedance are equal.
2. Zero sequence impedance is much larger than the positive or negative sequence impedance.

$\therefore$ Statement (I) is true and statement (II) is false.

3. (b)

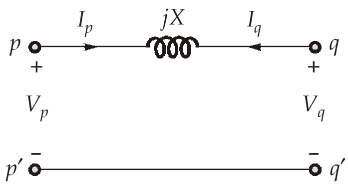
Y-bus matrix for the π equivalent circuit.



$$Y_{\text{bus}} = \begin{bmatrix} \frac{1}{Z_{se}} + \frac{Y_{\text{sh}}}{2} & -\frac{1}{Z_{se}} \\ -\frac{1}{Z_{se}} & \frac{1}{Z_{se}} + \frac{Y_{\text{sh}}}{2} \end{bmatrix}$$

Here, $Z_{\text{se}} = jX;\ Y_{\text{sh}} = 0$

The above circuit diagram becomes,



$$\therefore \quad Y_{\text{bus}} = \begin{bmatrix} \frac{1}{jX} & \frac{-1}{jX} \\ \frac{-1}{jX} & \frac{1}{jX} \end{bmatrix}$$

4. (a)

Total Kinetic energy of the two machines,

$$= G_1H_1 + G_2H_2$$
$$= 400 \times 4 + 1600 \times 2$$
$$= 4800 \text{ MJ}$$

The equivalent H on the base of 200 MVA,

$$= \frac{4800 \text{ MJ}}{200 \text{ MVA}}$$
$$= 24 \text{ MJ/MVA}$$

5. (c)

Minimum number of equations $= 2n - m - 2$

$$= 2(112) - 20 - 2$$
$$= 202$$

6. (d)

We know that, $(Z_{p.u.})_{new} = (Z_{p.u.})_{old} \times \frac{(MVA)_{new}}{(MVA)_{old}} \times \frac{(kV)^2_{old}}{(kV)^2_{new}}$

For G_1 and M_1:

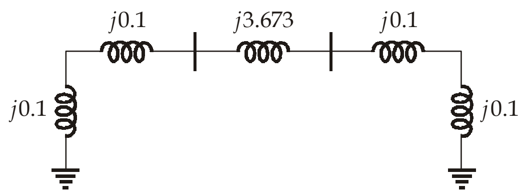
$$(X_{p.u.})_{new} = 0.05 \times \frac{80}{40} \times \left(\frac{11}{11}\right)^2 = j\,0.1 \text{ p.u.}$$

For line:

$$(X_\Omega)_{base} = \frac{(kV)^2}{MVA} = \frac{33^2}{80} = 13.6125\ \Omega$$

$$(X_{p.u.})_{line} = \frac{\text{Actual value}}{\text{Base value}} = \frac{50}{13.6125}$$

$$= j\,3.673 \text{ p.u.}$$



7. (b)

3-ϕ fault current:

Let system is under no load condition before fault,

∴ $E = 1\angle 0°$ p.u.

3-ϕ fault current, $I_f = \frac{E}{X_1}$

⇒ $X_1 = \frac{1}{-j5} = j0.2\,\text{p.u.}$

Line-line fault current:

$$I_f = \frac{\sqrt{3}E}{X_1 + X_2}$$

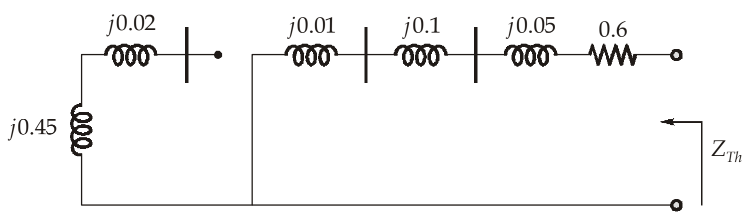
⇒ $X_1 + X_2 = \frac{\sqrt{3}}{-j2.5}$

⇒ $j\,0.2 + X_2 = j\,0.69$ p.u.

⇒ $X_2 = j\,0.49$ p.u.

8. (b)

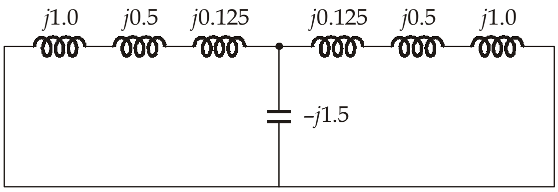
The zero sequence impedance network from point P and ground



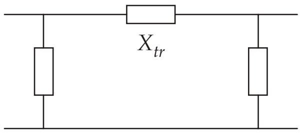
The Thevenin's equivalent zero sequence impedance

$$Z_{Th} = (0.6 + j\,0.16) \text{ p.u.}$$

9. (a)



Converting star into delta:



The transfer reactance, $X_{tr} = j1.625 + j1.625 + \dfrac{j1.625 \times j1.625}{-j1.5}$

$= 1.48$ p.u.

10. (d)

$$Z_{Bus\,(new)} = \begin{bmatrix} 0.3 & 0.3 \\ 0.3 & 0.3+0.5 \end{bmatrix} = \begin{bmatrix} 0.3 & 0.3 \\ 0.3 & 0.8 \end{bmatrix}$$

11. (b)

Let the base kVA be 500 kVA and base voltage be 2.5 kV,

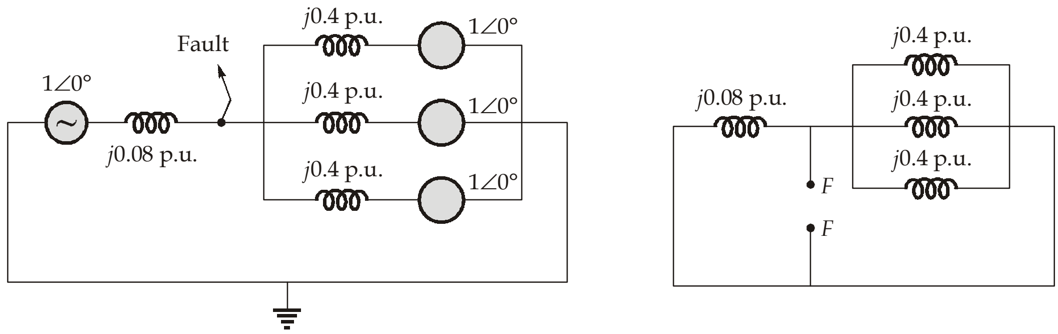
Per unit transient reactance of generator,

$$X_g' = \frac{j8}{100} = j0.08 \text{ p.u.}$$

Per unit subtransient reactance of each motor,

$$X_m'' = j0.2 \times \frac{500}{250} = j0.4 \text{ p.u.}$$

Per unit reactance diagram is shown below,



Thevenin reactance when viewed from fault terminals,

$$X_{th} = \frac{\frac{j0.4}{3} \times j0.08}{\frac{j0.4}{3} + j0.08} = j0.05 \text{ p.u.}$$

At fault location V_{th} = rated voltage,

$$\text{Fault current at } F,\ I_f = \frac{1}{j0.05} = -j20 \text{ p.u.}$$

The generator contribution is,

$$I_g = -j20 \times \frac{j\frac{0.4}{3}}{j\frac{0.4}{3} + j0.08}$$

$$I_g = -j12.5 \text{ p.u.}$$

Contribution of motors,

$$3I_m = I_f - I_g = -j20 - (-j12.5)$$

$$3I_m = -j7.5$$

$$I_m = -j2.5 \text{ p.u.}$$

12. (c)

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

$$Y_{22} = -j60 + \frac{1}{Z_{se}} + \frac{Y_{sh}}{2}$$

$$= -j60 + \frac{1}{j0.1} + j20 = -j60 - j10 + j20 = -j50$$

$$Y_{24} = Y_{42} = 0 - \frac{Y_{sh}}{2} = -j20$$

$$Y_{44} = -j25 + \frac{1}{Z_{se}} + \frac{Y_{sh}}{2} = -j25 + \frac{1}{j0.1} + j20 = -j25 - j10 + j20$$

$$Y_{44} = -j15$$

13. (c)

Reactive power supplied by capacitor to bus-1,

$$Q_{21} = \frac{|V_2|^2}{X} - \frac{|V_2||V_1|}{X}\cos\delta$$

Given that, $Q_{21} = 0$

$$\frac{|V_2|^2}{X} = \frac{|V_2||V_1|}{X}\cos\delta$$

$$|V_2| = |V_1|\cos\delta$$

Given that, $|V_1| = 1$ p.u.

$$|V_2| = \cos\delta \qquad \text{...(i)}$$

Since load demand at bus 2 is 1 p.u. (real power). This real power can be supplied by generator S_{G1} only. So this power should flow through transmission line from bus 1 to bus 2

$\therefore \quad P_{12} = 1$ p.u.

$\therefore$ real power flow from bus 1 to bus 2,

$$P_{12} = \frac{|V_1||V_2|}{X}\sin\delta$$

$$1 = \frac{1 \cdot \cos\delta}{0.5} \cdot \sin\delta$$

$$0.5 = \frac{\sin 2\delta}{2}$$

$$\sin 2\delta = 1$$

$$2\delta = 90°$$

$$\delta = 45°$$

$\therefore$ from equation (i),

$$|V_2| = \cos\delta = \cos 45° = \frac{1}{\sqrt{2}}$$

Voltage at bus-2, $V_2 = \frac{1}{\sqrt{2}}\angle -45°$

14. (b)

Given, before fault,

$$0.6\ P_{m\,1} = P_{m\,1} \sin \delta_0$$

$\therefore$ $\delta_0 = 36.86°$ (or) 0.643 radian

During fault,

$$P_{m\,2} = 0.25\ P_{m\,1} \text{ as } X_2 = 4X_1$$

After fualt,

$$P_{m\,3} = 0.75\ P_{m\,1} \text{ (given)}$$

$\therefore$

$$\delta_{max} = 180 - \sin^{-1}\left(\frac{0.6P_{m1}}{0.75P_{m1}}\right)$$

$$= 126.86° \text{ (or) } 2.214 \text{ radian}$$

Since,

$$\cos\delta_{cr} = \frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_m - P_{m2}\cos\delta_0}{P_{m3} - P_{m2}}$$

$$\cos\delta_{cr} = \frac{0.6P_{m1}[2.214 - 0.643] + 0.75P_{m1}\cos(126.86) - 0.25P_{m1}\cos(36.86)}{0.75P_{m1} - 0.25P_{m1}}$$

$$= \frac{0.6(2.214 - 0.643) + 0.75\cos(126.86) - 0.25\cos(36.86)}{0.75 - 0.25}$$

$$\cos\delta_{cr} = 0.585$$

$$\delta_{cr} = 54.2°$$

15. (b)

The reactance in p.u. $= Z_{\text{p.u.}} = Z_{\Omega} \times \frac{\text{MVA}_{(b)}}{(\text{kV})_b^2}$

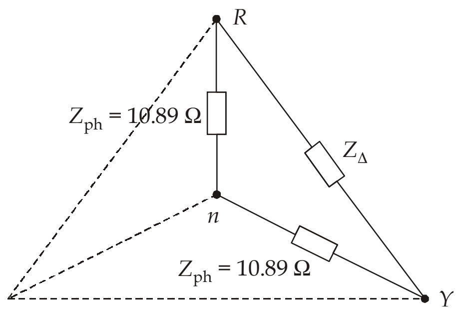
$$Z_{\Omega} = Z_{\text{p.u.}} \times \frac{(kV_b)^2}{(\text{MVA})_b}$$

$$= 0.10 \times \frac{(33)^2}{10} = 10.89\ \Omega$$

So reactance per phase $= Z_{ph} = 10.89\ \Omega$

$$Z_{\Delta} = 3 \times Z_{ph} = 3 \times 10.89$$

$$Z_{\Delta} = 32.67\ \Omega$$



16. (b)

$$S_{D2} = (0.8 + j0) \text{ p.u.}$$

This 0.8 p.u. active power is supplied by the generator G_1

$$\therefore \quad 0.8 = \frac{1\times 1}{0.5}\sin\delta$$

$$\delta = \sin^{-1}\left(\frac{0.8}{2}\right) = 23.58°$$

$$Q_R = \frac{|V_1|\times|V_2|}{X}\cos\delta - \frac{|V_1|^2}{X}$$

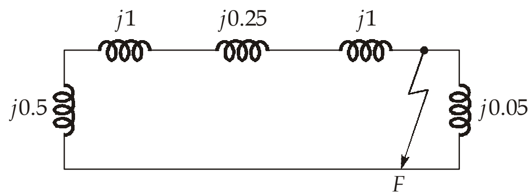
$$= \frac{1}{0.5}\cos(23.58°) - \frac{1}{0.5}$$

$$Q_R = -0.167 \text{ p.u.}$$

The VAR rating of the capacitor = 0.167 p.u.

17. (a)

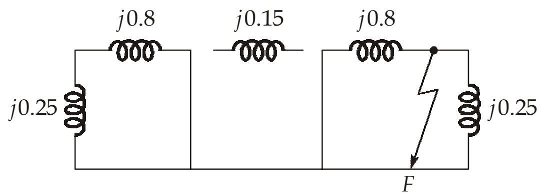
Positive and negative sequence reactance diagram:



$$Z_1 = Z_2$$

$$= j\,2.75 \,||\, j\,0.5 = j\,0.423 \text{ p.u.}$$

Zero sequence reactance diagram:



$$Z_0 = j\,0.8 \,||\, j\,0.25 = j\,0.19 \text{ p.u.}$$

Considering system at no load before fault

i.e. $\quad E = 1.0\angle 0° \text{ p.u.}$

$$(I_F) = 3\left(\frac{E}{Z_1+Z_2+Z_0}\right) = 3\left(\frac{1}{j0.423+j0.423+j0.19}\right)$$

$$I_f = -j2.896 \text{ p.u.}$$

18. (a)

$$|I''| = \frac{E}{|X_d''|} = \frac{1}{0.22} = 4.54 \text{ p.u.}$$

$$I_{\text{base}} = \frac{\text{MVA}_b}{\sqrt{3}(\text{kV}_b)} = \frac{100\times 10^6}{\sqrt{3}\times 11\times 10^3} = 5248.6 \text{ A} = 5.248 \text{ kA}$$

The magnitude of initial symmetrical rms current

$$= 4.54 \times 5.248 = 23.82 \text{ kA}$$

19. (a)

$$\vec{I_R} = 100\angle 0°\text{A} \quad ; \quad \vec{I_Y} = 100\angle -120°\text{A} \quad ; \quad \vec{I_B} = 100\angle -240°\text{A}$$

$$I_{R0} = \frac{1}{3}\left(\vec{I}_R + \vec{I}_Y + \vec{I}_B\right)$$

$$\vec{I}_{Ro} = \frac{1}{3}[100\angle 0° + 100\angle 240° + 100\angle 120°] = 0 \text{ A}$$

$$\vec{I}_{R1} = \frac{1}{3}\left[\vec{I}_R + a\vec{I}_Y + a^2\vec{I}_B\right]$$

$$= \frac{1}{3}(100\angle 0° + (1\angle 120°)(100\angle -120°) + (1\angle 240°)(100\angle -240°))$$

$$= 100 \text{ A}$$

$$\vec{I}_{R2} = \frac{1}{3}\left[\vec{I}_R + a^2\vec{I}_Y + a\vec{I}_B\right]$$

$$= \frac{1}{3}(100\angle 0° + (1\angle 240°)(100\angle -120°) + (1\angle 120°)(100\angle -240°)) = 0 \text{ A}$$

20. (b)

$$\delta_0 = \sin^{-1}\left(\frac{P_e}{P_m}\right) = \sin^{-1}(0.5) = 30°$$

$$P_e = \frac{EV}{X}\sin\delta_0$$

$$\frac{dP_e}{d\delta} = \frac{EV}{X}\cos\delta_0 = \frac{1.2 \times 1}{1.8}\cos 30°$$

$$= 0.577 \text{ MW (p.u.)/elec. rad}$$

$$M = \frac{GH}{\pi f} = \frac{1 \times 4}{\pi \times 50} = 0.025 \text{ s}^2/\text{elec. rad}$$

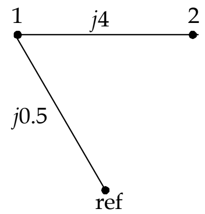
$$\omega = \left(\frac{\left(\frac{dP_e}{d\delta_0}\right)}{M}\right)^{1/2} = \left(\frac{0.577}{0.025}\right)^{1/2} = 4.8 \text{ rad/sec}$$

Frequency of natural oscillation,

$$f = \frac{\omega}{2\pi} = 0.764 \text{ Hz}$$

21. (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.

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

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

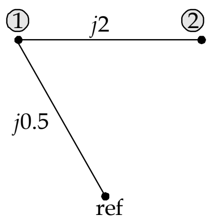
$$= \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j4.5 \end{bmatrix} - \frac{1}{j8}\begin{bmatrix} 0 & 0 \\ 0 & -16 \end{bmatrix}$$

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

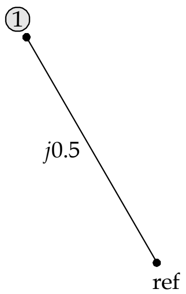
$$= \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j4.5 - \frac{j16}{8} \end{bmatrix} = \begin{bmatrix} j0.5 & j0.5 \\ j0.5 & j2.5 \end{bmatrix}$$

Alternative :

New system will

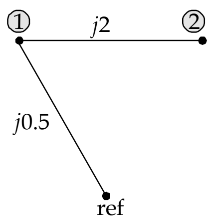


First branch :



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

Type – 2 modification



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

22. **(b)**

For single line to ground fault , fault current is

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

and

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

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

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

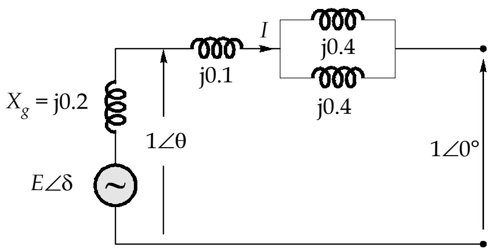
$$I_a^{(0)} = -\left(\frac{-0.1433}{j0.1}\right) = -j1.43 \text{ p.u.}$$

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

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

23. **(b)**

Reactance diagram of the system is



$$\text{Terminal voltage } V_t = 1\angle\theta$$

$$\text{Power supplied} = \frac{|1||1|}{X}.\sin\theta$$

$$X = j0.1 + \left(\frac{j0.4}{2}\right) = j(0.1 + 0.2) = j0.3$$

$$1.0 = \frac{1}{0.3}\sin\theta$$

$$\theta = \sin^{-1}(0.3) = 17.46°$$

$$\text{Current, } \vec{I} = \frac{1\angle\theta - 1\angle 0°}{j0.3}$$

$$\vec{I} = \frac{1\angle 17.46° - 1\angle 0°}{j0.3} = 1.0118\angle 8.73° \text{p.u.}$$

$$\text{Excitation emf, } \vec{E} = \vec{V} + jX\vec{I} = 1\angle 17.46° + (j1.0118\angle 8.73°)(0.2)$$

$$\vec{E} = 1.05\angle 28.44° \text{ p.u.}$$

$$\text{Power angle equation} = \frac{EV}{X}\sin\delta = \frac{(1.05)(1)}{0.5}\sin\delta = 2.1 \sin\delta$$

24. **(b)**

We know that, $$f_n = \sqrt{\frac{\left(\frac{\partial P_e}{\partial \delta}\right)_{\delta_0}}{M}}$$

$$\left(\frac{\partial P_e}{\partial \delta}\right)_{\delta=\delta_0} = P_{max} \cos \delta_0 = \frac{|E||V|}{|X|}\cos\delta_0$$

$$0.5\ P_{max} = P_{max} \sin \delta_0$$

$$\delta_0 = 30°$$

$$\left.\frac{\partial P_e}{\partial \delta}\right|_{\delta=\delta_0} = \frac{1.05\times 1}{0.8}\cos 30° = 1.1366 \text{ p.u.}$$

$$M = \frac{GH}{\pi f} = \frac{1\times 5}{\pi \times 50} = 0.0318$$

Natural frequency of Oscillations

$$f_n = \sqrt{\frac{1.1366}{0.0318}} = 5.9787 \text{ rad}$$

$$f_n = 0.9515 \text{ Hz}$$

25. **(d)**

$$M = \frac{GH}{\pi f} = \frac{100\times 8}{50\times 180} = \frac{4}{45}\text{ MJ-s/elec. degree}$$

$$\frac{Md^2\delta}{dt^2} = (P_m - P_e)$$

$$\frac{d^2\delta}{dt^2} = 30\times\frac{45}{4}$$

$$\frac{d^2\delta}{dt^2} = 337.5 \text{ elec deg/s}^2$$

$$\frac{d\delta}{dt} = 337.5t$$

$$\frac{d\delta}{dt} = 337.5\times\frac{10}{50}\times\frac{60}{360}\times\left(\frac{2}{4}\right) = 5.625 \text{ rpm}$$

$$\omega_m = \omega_{m0} + \frac{d\delta}{dt}$$

$$N_m = \frac{120\times 50}{4} + 5.625 = 1505.625 \text{ rpm}$$

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,

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

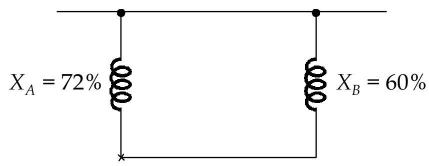
27. (a)

Let the base MVA be 45 MVA.

$$\%\ \text{Reactance of alternator } A \text{ at the base MVA}(\%X_A) = \frac{45}{25}\times 40 = 72\%$$

$$\%\ X_B = 60\%$$

% reactance of alternator B,



$$I_{base} = \frac{MVA}{\sqrt{3}\,kV} = \frac{45\times 10^6}{\sqrt{3}\times 15\times 10^3} = 1732.05\text{ A}$$

Total % reactance from generator neutral to fault point is

$$\%X = X_A \,||\, X_B = \frac{60\times 72}{60+72} = 32.72\%$$

P.u. short circuit current,

$$I_{SC} = \frac{1}{0.3272} = 3.0562\text{ p.u.}$$

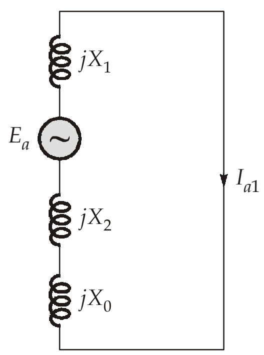
$$I_{SC\ actual} = I_{SC\ p.u.}\times I_{base} = 5293\text{ A} = 5.29\text{ kA}$$

28. (c)

For a line to ground fault,
Positive sequence current,

$$I_{a1} = \frac{E_a}{Z_1 + Z_2 + Z_0}$$

$$I_{a1} = \frac{1}{j0.25 + j0.35 + j0.1} = -j1.428$$



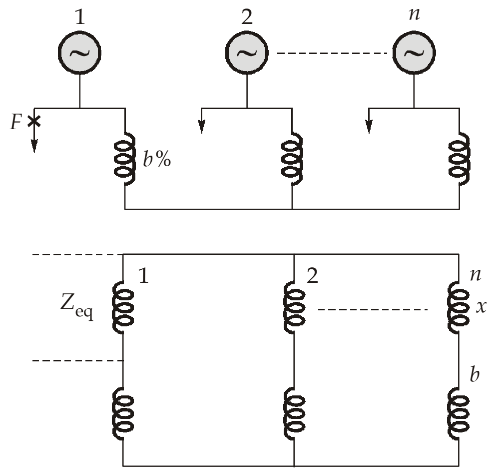
Base current, $$I_B = \frac{25\times 1000\times 10^3}{\sqrt{3}\times 13.2\times 10^3} = 1093.46\text{ A}$$

Fault current, $$I_f = 3I_{a1}\times I_b$$

$$= 3\times 1.428\times 1093.46$$

$$= 4684.38\text{ A}$$

29. (d)



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

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

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

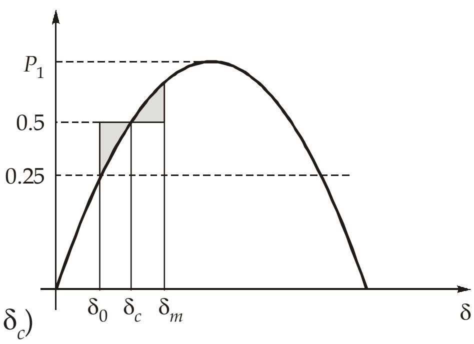
$$\text{SC kVA} = \frac{8}{Z_{eq}} \times 100$$

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

If n is very large.

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

30. (a)



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

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

$$\Rightarrow 0.5\,(\delta_c - \delta_0) + \cos\delta_c - \cos\delta_0 = \cos\delta_c - \cos\delta_m - 0.5\,(\delta_m - \delta_c)$$
$$0.5\,(\delta_m - \delta_0) = \cos 14.48° - \cos\delta_m$$
$$0.5\,\delta_m + \cos\delta_m = 1.0945$$
$$\delta_m = 46.41°$$

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