ESE GATE PSUs

State Engg. Exams

MADE EASY

# Workbook 2025

## Detailed Explanations of Try Yourself *Questions*

# ELECTRICAL ENGINEERING

## Power Systems

MADE EASY PUBLICATIONS

# 1 Power Generation Concepts

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

(d)

Maximum demand, MD = 40 MW

Capacity factor = 0.5

Utilization factor = 0.8

$$\text{Load factor} = \frac{\text{Capacity factor}}{\text{Utilization factor}} = \frac{0.5}{0.8} = 0.625$$

$$\text{Plant capacity} = \frac{\text{Maximum demand}}{\text{Utilization factor}} = \frac{40}{0.8} = 50 \text{ MW}$$

Reserve capacity = plant capacity – maximum demand

= 50 – 40 = 10 MW

**T2 : Solution**

$$\text{Average load} = \frac{\text{Energy generated per annum}}{24 \times 365} = \frac{438 \times 10^4}{24 \times 365} = 500 \text{ KW}$$

$$\text{Maximum demand, MD} = \frac{\text{Average load}}{\text{Load factor}}$$

$$= \frac{500}{0.2} = 2.5 \text{ MW}$$

$$\text{plant capacity} = \frac{\text{Average load}}{\text{Capacity factor}} = \frac{500}{0.15} = 3.333 \text{ MW}$$

Reserve capacity = Installed capacity – maximum demand

= 3.333 – 2.5

= 0.833 MW

**T3 : Solution**

$$\text{Maximum demand} = 20\text{ MW}$$
$$\text{Connected load} = 23\text{ MW}$$
$$\text{Units generated} = 61.5 \times 10^6\text{ kWh}$$

$$\text{Average load} = \frac{\text{Units generated per annum in kWh}}{24 \times 365}$$

$$= \frac{61.5 \times 10^6}{24 \times 365} = 7{,}020\text{ kW}$$

(a) $$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}} = \frac{20}{23} = 0.869$$

(b) $$\text{Average demand} = 7020\text{ kW}$$

(c) $$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum demand}} = \frac{7020}{20 \times 1000} = 35.1\%$$

**T4 : Solution**

**(c)**

Let maximum efficiency be at a load of $x$ MW.

So, $$\text{output} = x \times 1000 \times 3600 = 3.6 \times 10^6 x\text{ kJ/hour}$$

$$\text{Input} = (18 + 12x \times 0.5x^2) \times 10^6 \times 4.18\text{ kJ/hour}$$

Efficiency, $$\eta = \frac{\text{output}}{\text{input}} = \frac{3.6 \times 10^6 x}{(18 + 12x + 0.5x^2) \times 10^6 \times 4.18}$$

$$\eta = \frac{0.86x}{18 + 12x + 0.5x^2}$$

differentiating both sides of above equation with respect to $x$, we have,

$$\frac{d\eta}{dx} = \frac{(18 + 12x + 0.5x^2) \times 0.86 - 0.86x(12 + x)}{(18 + 12x + 0.5x^2)^2}$$

$$= \frac{15.48 - 0.43x^2}{(18 + 12x + 0.5x^2)^2}$$

Efficiency $\eta$ will be maximum when $\frac{d\eta}{dx} = 0$

$$= 15.48 - 0.43x^2 = 0$$

$$x = 6\text{ MW}$$

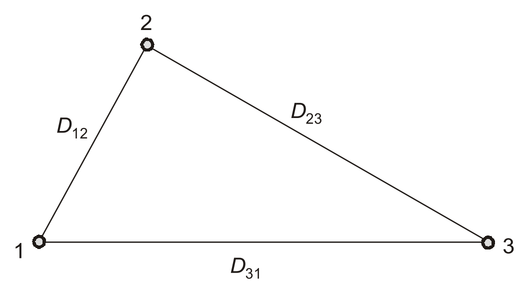
■■■■

# 2 Transmission

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

(c)




The above figure shows three conductors of a 3-phase line placed at the corners of a triangle of sides $D_{12} = 2$ m, $D_{23} = 2.5$ m and $D_{31} = 4.5$ m.

The conductor radius $r = \frac{1.24}{2} = 0.62$ cm

Equivalent equilateral spacing,

$$D_m = \sqrt[3]{D_{12} \times D_{23} \times D_{31}}$$

$$= \sqrt[3]{2 \times 2.5 \times 4.5}$$

$$= 2.82 \text{ m} = 282 \text{ cm}$$

$$D_s = \text{GMR} = 0.7788 \times r' = 0.7788 \times 0.62$$

$$= 0.4828$$

$$\text{Inductance/phase/meter} = 2 \times 10^{-7} \, l\text{og}_e\left(\frac{D_m}{D_s}\right)$$

$$= 2 \times 10^{-7} \, l\text{og}_e\left(\frac{282}{0.4828}\right)$$

$$= 1.27 \, \mu\text{H/phase/m}$$

**T2 : Solution**

(c)

Considering the effect of earth and neglecting non uniformity of charge distribution

$$C_n = \frac{0.0242}{\log\left(\dfrac{D}{r\left(1+\dfrac{D^2}{4h^2}\right)^{1/2}}\right)} = \frac{0.0242}{\log\left(\dfrac{300}{0.3345}\right)}$$

$$= \frac{0.0242}{2.9527} = 0.0082\ \mu\text{F/km}$$

**T3 : Solution**

(a)

The mutual GMD between sides $A$ and $B$ is

$$D_M = \sqrt[6]{(D_{14}.D_{15})(D_{24}.D_{25})(D_{34}.D_{35})}$$

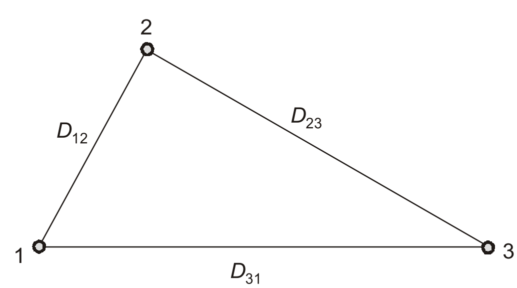
From the figure it is obvious that, $D_{14} = D_{24} = D_{25} = D_{35} = \sqrt{8^2+2^2} = \sqrt{68}$ m

$$D_{15} = D_{34} = \sqrt{8^2+6^2} = \sqrt{64+36} = 10 \text{ m}$$

$$D_M = \sqrt[6]{(68)^2 \times 100} = 8.793 \text{ m} \approx 8.8 \text{ m}$$

**T4 : Solution**

(c)




The above figure shows three conductors of a 3-phase line placed at the corners of a triangle of sides $D_{12}$ = 2 m, $D_{23}$ = 2.5 m and $D_{31}$ = 4.5 m.

The conductor radius $\quad r = \dfrac{1.24}{2} = 0.62$ cm

Equivalent equilateral spacing, $\quad D_m = \sqrt[3]{D_{12} \times D_{23} \times D_{31}} = \sqrt[3]{2 \times 2.5 \times 4.5}$

$$= 2.82 \text{ m} = 282 \text{ cm}$$

$$D_s = \text{GMR} = 0.7788 \times r' = 0.7788 \times 0.62 = 0.4828$$

$$\text{Inductance/phase/meter} = 2 \times 10^{-7}\, log_e\left(\frac{D_m}{D_s}\right)$$

$$= 2 \times 10^{-7}\, log_e\left(\frac{282}{0.4828}\right) = 1.27\ \mu\text{H/phase/m}$$

**T5 : Solution**

(d)

Receiving-end phase voltage,

$$V_R = \frac{100 \times 1000}{\sqrt{3}} = 63508 \text{ V}$$

Magnitude of receiving-end current,

$$|I_R| = \frac{\text{Load in MW} \times 10^6}{\sqrt{3}\, V_{RL} \cos\phi_R} = \frac{30 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.8}$$

$$= 196.82 \text{ A}$$

Taking receiving-end phase voltage as reference phasor,

we have $V_R = 63508 \angle 0° \text{ V}$

Receiving-end current,

$$I_R = 196.82 \angle -36.87° \text{ A}$$

Sending-end phase voltage,

$$V_s = AV_R + BI_R$$

$$= 0.96 \angle 1.0° \times 63508 \angle 0° + 100 \angle 80° \times 196.82 \angle -36.87°$$

$$= 76709.6 \angle 10.91° \text{ V}$$

Magnitude of sending-end line voltage,

$$|V_{SL}| = \sqrt{3} \times 76709.6 = 132865 \text{ V or } 132.865 \text{ kV}$$

$$\text{Voltage regulation} = \frac{|V_{SL}| - |V_{RL}|}{|V_{RL}|} \times 100 = \frac{132.865 - 110}{110} \times 100 = 20.786\%$$

**T6 : Solution**

For the given values of sending end and receiving end voltages, the power transfer will be maximum for $\delta = \beta$.

where $\delta$ is the phase angle between sending end and receiving end voltage.

$$A = A\angle\alpha = 0.96\angle 1.0°$$

$$B = B\angle\beta = 100\angle 80° \ \Omega$$

The maximum power transmitted is given by

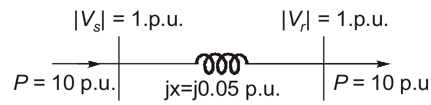
$$P_{R,\max} = \frac{|V_S||V_R|}{|B|} - \frac{|A||V_R|^2}{|B|}\cos(\beta - \alpha)$$

$$= \frac{120 \times 110}{100} - \frac{0.96\,(110)^2}{100}\cos(79°)$$

$$P_{R,\max} = 109.83 \text{ MW}$$

**T7 : Solution**




$$P = \frac{|V_s||V_r|}{X}\sin\delta$$

$$\sin^{-1}\left(\frac{10\times 0.05}{1}\right) = \delta$$

$$\delta = 30°$$

Reactive power flow at sending end through the line is given by

$$Q_s = \frac{|V_s^2|}{X} - \frac{|V_s||V_r|}{X}\cos\delta = \frac{1}{0.05} - \frac{1}{0.05}\cos 30°$$

$$Q_s = 2.68 \text{ p.u.}$$

Reactive power flow at receiving end through the line is given by

$$Q_r = \frac{|V_s||V_r|}{X}\cos\delta - \frac{|V_s|^2}{X} = -2.68 \text{ p.u.}$$

So, reactive power flow through line is

$$Q_s - Q_r = 2.68 - (-2.68) = 5.36 \text{ p.u.}$$

**T8 : Solution**

(a)

Reactive power consumed by shunt inductor at rated voltage and frequency is

$$Q = \frac{V_{ph}^2}{X_L} = \frac{V_{ph}^2}{2\pi f L}$$

New reactive power, $Q' = \dfrac{(0.96)^2 V_{ph}^2}{(1.04)(2\pi f L)} = 0.886Q$

Change in $Q$ = 11.4% low

**T9 : Solution**

(b)

The percentage voltage regulation % $\dfrac{V' - V_R}{V_R}\times 100$

$$V' = \frac{V_s}{A}$$

$$A = 1 + \frac{YZ}{2}$$

$$Y = j\omega C = j2\pi f\times\frac{1}{\pi}\times 10^{-6} = j100\times 10^{-6}\ ℧$$ [∵ assumed $f$ = 50 Hz)

$$Z = R + j\omega L = 0 + j2\pi f\times\frac{4}{\pi} = j400\ \Omega$$

$$A = 1+\frac{YZ}{2} = \frac{1+(j100\times10^{-6})(j400)}{2} = 0.98$$

$$V' = \frac{V_s}{A} = \frac{220}{0.98} = 234.693 \text{ kV}$$

$$\%V_R = \frac{234.693-220}{22}\times100 = 6.678 \simeq 6.8\%$$

**T10 : Solution**

Number of units, $n = 3$

Ratio of shunt capacitance to mutual capacitance,

$$K = \frac{0.1C}{C} = 0.1$$

Voltage across bottom most unit, $V_3$ = Safe working voltage of the unit = 20 KV

So voltage across top most unit, $V_1 = \dfrac{V_3}{1+3K+K^2} = \dfrac{20}{1+0.3+0.01} = 15.267$ KV

Voltage across middle unit, $V_2 = V_1(1+K) = 15.267 + 1.1 = 16.794$ KV

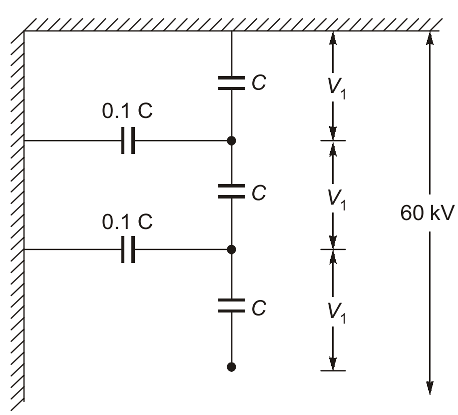
Maximum safe working voltage of the string,

$$V = V_1 + V_2 + V_3$$
$$= 15.267 + 16.794 + 20 = 52 \text{ KV}$$

$$\text{String efficiency} = \frac{V}{nV_n}\times100 = \frac{52}{3\times20}\times100$$
$$= 86.67\ \%$$

**T11 : Solution**

(d)




$$V_3 = (k^2 + 3k + 1)\,V_1$$
$$V_2 = (k + 1)\,V_1$$

$\therefore$
$$V_1 + V_2 + V_3 = 60 \text{ kV}$$
$$V_1 + (k+1)\,V_1 + (k^2 + 3k + 1)\,V_1 = 60 \text{ kV}$$
$$V_1(k^2 + 4k + 3) = 60 \text{ kV}$$

also given,

$$k = \frac{0.1C}{C} = 0.1$$

$$V_1 = \frac{60}{0.1^2 + 0.4 + 3} = 17.5953 \text{ kV}$$

$$V_3 = (k^2 + 3k + 1)\ V_1$$

$$= (0.1^2 + 0.3 + 1)\ 17.5953$$

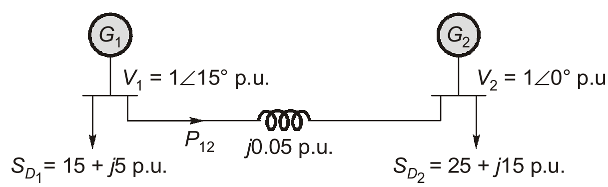
$$= 23.05 \text{ kV} ;\ 23.1 \text{ kV}$$

■■■■

# 3 Voltage and Frequency Control

## Detailed Explanation of Try Yourself Questions

### T1 : Solution




$$P_{12} = \left|\frac{V_1 \times V_2}{X_L}\right| \sin\delta$$

$$P_{12} = \left|\frac{1 \times 1}{0.05}\right| \sin 15° = 5.176 \text{ p.u.}$$

∴ Total active power at generating station 1 is,

$$= 15 + 5.176 = 20.176 \text{ p.u.}$$

### T2 : Solution

**(c)**

Since two machines are working in parallel the percent drop in frequency from the machines due to different loading mustbe same.

Let $x$ be power supplied by 60 MW alternator,

$$\frac{5x}{60} = \frac{4}{80}(120 - x)$$

$$0.0833\,x = 6 - 0.05\,x$$

$$0.1333\,x = 6$$

$$x = 45 \text{ MW}$$

The other alternator share, $(120 - 45) = 75$ MW

So, the answer is 45 and 75 MW.

■■■■

# 4 Distribution and Power Cables

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

Length of cable, $l = 5 \text{ km} = 5000 \text{ m}$

Cable insulation resistance, $R = 0.4 \text{ M}\Omega = 0.4 \times 10^6 \ \Omega$

Conductor radius, $r_1 = \frac{20}{2} = 10 \text{ mm}$

Internal sheath radius, $r_2 = \frac{50}{2} = 25 \text{ mm}$

$\therefore$ Insulation resistance of the cables is

$$R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$$

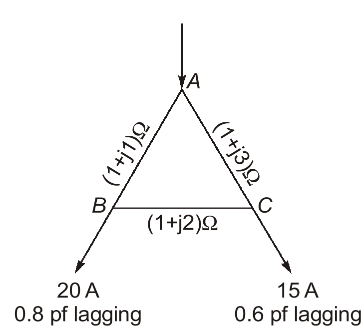
$$0.4 \times 10^6 = \frac{\rho}{2\pi \times 5000} \times \log_e \frac{25}{10}$$

$\therefore$ the resistivity of the insulating material is,

$$\rho = 1.37 \times 10^{10}$$
$$= 13.71 \text{ G}\Omega\text{ - m}$$

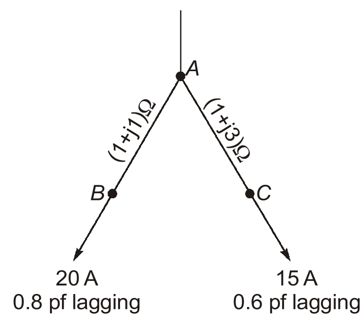
**T2 : Solution**

The given ring distributor is shown below,



to obtain the current in section $BC$, assume that feeder $BC$ is removed.
Current in section $AB$ is,

$$I_{AB} = 20(0.8 - j0.6)$$
$$= (16 - j12)\text{A}$$




Current in section $AC$ is,

$$I_{AC} = 15(0.6 - j0.8)$$
$$= (9 - j12)\text{A}$$

Voltage drop in section $AB$ is,

$$V_{AB} = I_{AB} Z_{AB}$$
$$= (16 - j12)(1 + j1)$$
$$= (28 + j4)\text{ V}$$

Voltage drop in section $AC$ is,

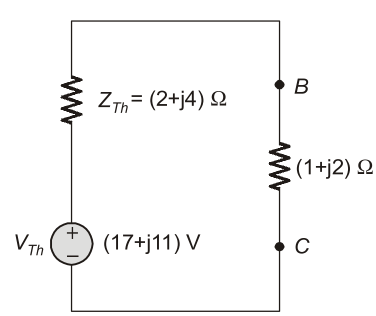
$$V_{AC} = I_{AC} Z_{AC}$$
$$= (9 - j12)(1 + j3)$$
$$= (45 + j15)\text{ V}$$

Potential drop between terminals $B$ and $C$, $B$ being at higher potential than $C$.

$$V_{BC} = (45 + j15) - (28 + j4)$$
$$= (17 + j11)\text{ V}$$

This is Thevenin's equivalent emf = $V_{Th} = (17 + j11)\text{V}$
Impedance of the network looking back from the terminals $B$ and $C$ i.e.
Thevenin's equivalent impedance,

$$Z_{Th} = (1 + j1) + (1 + j3)$$
$$= (2 + j4)\ \Omega$$




∴ Current in section $BC$,

$$I_{BC} = \frac{V_{Th}}{Z_{Th} + Z_{BC}} = \frac{(17 + j11)}{(2 + j4) + (1 + j2)}$$
$$I_{BC} = (2.6 - j1.5)\text{ A}$$

**T3 : Solution**

(d)

Specific resistance of insulation,

$$\rho = 8 \times 10^{12}\ \Omega\text{-m}$$

Length of Cable $l = 5\text{ km} = 5000\text{ m}$

Core radius, $r_1 = 12.5\text{ mm}$

Internal sheath radius, $r_2 = 12.5 + 9 = 21.5\text{ mm}$

We know that,

Insulation Resistance, $R_{ins} = \dfrac{\rho}{2\pi l} ln \dfrac{r_2}{r_1}$

$$= \frac{8 \times 10^{12}}{2\pi \times 5000} ln \frac{21.5}{12.5} = \frac{8 \times 10^{12}}{2\pi \times 5000} \times 0.5423$$

$$= 1.381 \times 10^8$$

$$R_{ins} = 138.1\text{ M}\Omega \approx 138\text{ M}\Omega$$

■■■■

# 5 Load Flow Studies

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

(b)

The network has two buses.

Therefore, $Y_{BUS}$ matrix is a 2 × 2 matrix

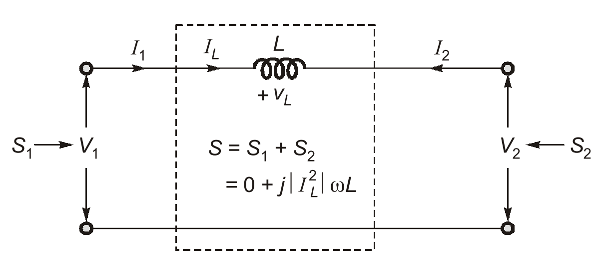
$$Y_{11} = \text{Sum of all admittances terminating at bus 1}$$
$$= -j0.45 + (-j0.75) = -j1.2$$
$$Y_{22} = \text{Sum of all admittances terminating at bus 2}$$
$$= -j0.6 + (-j0.75) = -j1.35$$
$$Y_{12} = Y_{21} = -y_{12} = -(-j0.75) = j0.75$$
$$[Y_{BUS}] = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} -j1.2 & j0.75 \\ j0.75 & -j1.35 \end{bmatrix}$$

**T2 : Solution**

(c)

$$Y_{11} = y_{11} + y_{12} + y_{13} = -j\,2.86$$
$$Y_{22} = y_{12} + y_{22} + y_{23} = -j\,6$$
$$Y_{33} = y_{13} + y_{23} + y_{33} = -j\,8.86$$
$$Y_{12} = Y_{21} = -y_{12} = 0$$
$$Y_{13} = Y_{31} = -y_{13} = j\,2.86$$
$$Y_{23} = Y_{32} = -y_{23} = j\,2$$

**T3 : Solution**



$$S_1 = V_1 I_1^* = P_1 + jQ_1$$

$$S_2 = V_2 I_2^* = P_2 + jQ_2$$

Complex power absorbed by the circuit (inductor) in the box

$$S = S_1 + S_2 = (P_1 + P_2) + j(Q_1 + Q_2)$$

$$= 0 + j\left|I_L^2\right|\omega L$$

From above equation,

$$P_1 + P_2 = 0 \quad \Rightarrow \quad P_1 = -P_2$$

Also, $\quad I_1 = I_L, \quad I_2 = -I_L \qquad$ (From the circuit)

$\Rightarrow \quad |I_1| = |I_L|, \quad |I_2| = |I_L|$

$\Rightarrow \quad |I_1| = |I_2|$

If $\quad |V_1| = |V_2| \qquad$ (Given)

$\Rightarrow \quad |S_1| = |S_2|$

$$P_1^2 + Q_1^2 = P_2^2 + Q_2^2$$

Since, $\quad P_1 = -P_2 \quad \Rightarrow \quad P_1^2 = P_2^2$

Hence, $\quad Q_1^2 = Q_2^2 \quad \Rightarrow \quad Q_1 = Q_2$

Now, $\quad S_2 = P_2 + jQ_2$

$$= -P_1 + jQ_1$$

$$S_2 = -(P_1 - jQ_1)$$

$$S_2 = -S_1^*$$

**T4 : Solution**

(b)

To eleminate $L_2$ which has per unit impedance of $j0.3$ we can add an impedance of $-j0.3$ p.u. between the bus 1 and 2.

**Type 4 modification:**

$$Z_{new} = Z_{old} - \frac{1}{Z_{ii} + Z_{KK} - 2Z_{iK} + Z_s}\begin{bmatrix} j0.06 \\ -j0.06 \end{bmatrix}\begin{bmatrix} j0.06 & -j0.06 \end{bmatrix}$$

$$= \begin{bmatrix} j0.18 & j0.12 \\ j0.12 & j0.18 \end{bmatrix} - \frac{1}{j0.18 + j0.18 - j0.24 - j0.3}\begin{bmatrix} j0.06 \\ -j0.06 \end{bmatrix}\begin{bmatrix} j0.06 & -j0.06 \end{bmatrix}$$

$$= \begin{bmatrix} j0.18 & j0.12 \\ j0.12 & j0.18 \end{bmatrix} + \begin{bmatrix} j0.02 & -j0.02 \\ -j0.02 & j0.02 \end{bmatrix}$$

$$Z_{\text{bus modified}} = \begin{bmatrix} j0.2 & j0.1 \\ j0.1 & j0.2 \end{bmatrix}$$

■■■■

# 6 Fault Analysis

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

(d)

$$P_{3\text{-}\phi} = 400 \text{ MW}$$

$$P_{3\text{-}\phi\text{pu}} = \frac{400}{500} = 0.8 \text{ pu}$$

$$P_{3\text{-}\phi\text{pu}} = V_{\text{pu}} I_{\text{pu}} \cos\theta$$

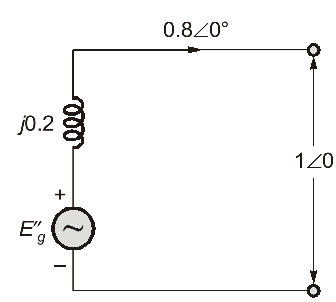
$$= 1 \times I_{\text{pu}} \times 1 \qquad (V_{\text{pu}} = 1, \cos\theta = 1)$$

$$I_{\text{pu}} = 0.8$$

$$E_g'' = 1\angle 0° + (j0.2)(0.8\angle 0°)$$

$$= 1.01\angle 9.09° \text{ pu}$$

$$I_F'' = \frac{E_g''}{X_d''} = \frac{1.01\angle 9.09°}{j0.2} = 5.06\angle -80.91° \text{ p.u.}$$




**T2 : Solution**

(b)

$$\text{Rated current} = 1 \text{ pu}$$

$$I_{f_{LG}} = \frac{3 \times 1\angle 0°}{3R \times j0.3 + j0.4 + j0.05}$$

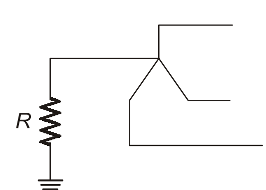
It is required that $|I_{f_{LG}}| = 1 \text{ pu}$

$$\frac{3}{\sqrt{9R^2 + (0.75)^2}} = 1$$

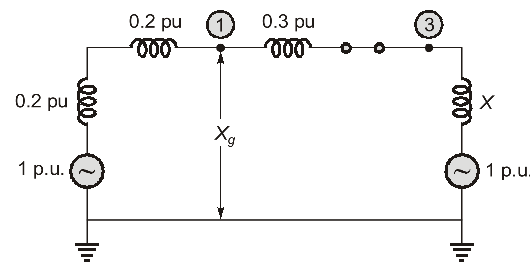
$$9R^2 + 0.75^2 = 9$$

$$R = 0.96$$

$$R = 0.96 \times \frac{13.8^2}{10}\ \Omega = 18.4\ \Omega$$



**T3 : Solution**




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

At bus (1),

$$X_1 = \frac{(0.4)(0.3+X)}{(0.4)+(0.3+X)}$$

$$\frac{E_f}{X_1} = 5 \text{ pu} \quad \text{(given)}$$

or $\quad X + 0.7 = 2(0.3 + X)$

$\Rightarrow \quad X = 0.1$ pu

Now at bus (3)

$$X_{1\,eq} = \frac{(0.2+0.2+0.3)\times 0.1}{(0.2+0.2+0.3+0.1)} = \frac{0.7\times 0.1}{0.8}$$

$$\therefore \quad I_f = \frac{1\text{pu}}{X_{eq}} = \frac{0.8}{0.1\times 0.7} = 11.4285 \text{ pu}$$

**T4 : Solution**

(a)
We use switch diagram to draw the zero-sequence network.

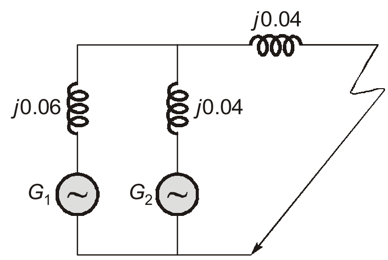
**T5 : Solution**

(c)
Let, Common base MVA = 10
Base voltage for LT side of the transformer = 11 kV
Base votlage for HT side of the transformer = 220 kV

$$X_{G1(new)} = j0.03 \times \frac{10}{5} = j0.06 \text{ pu}$$

$$X_{G2(new)} = j0.02 \times \frac{10}{5} = j0.04 \text{ pu}$$

$\therefore$ The reactance diagram will be as shown below.




Equivalent reactance,

$$X = \left(\frac{j0.06 \times j0.04}{j0.06 + j0.04}\right) + j0.04$$

$$X = j0.064 \text{ pu}$$

$$\text{Base current on LT side} = \frac{10 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 524.86 \text{ A}$$

$$\text{Fault current in p.u.} = \frac{1}{0.064} = 15.625 \text{ p.u}$$

$$\text{Fault current in LT side} = \text{Base current in LT side} \times \text{Fault current in p.u}$$

$$= 524.86 \times 15.625$$

$$\text{Fault current in LT side} = 8200.93 \text{ A} \approx 8.2 \text{ KA}$$

Using current division formula, fault current of generator-1 is

$$I_{fG_1} = \frac{0.04}{0.10} \times 8.2 = 3.28 \text{ KA}$$

Also, $I_{fG_2}$ = 4.92 KA so that total fault current on LT side

$$= I_{fG_1} + I_{fG_2} = 8.2 \text{ KA}$$

■■■■

# 7 Stability Analysis

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

(c)
The swing equatin is

$$M\frac{d^2\delta}{dt^2} = P_S - P_E$$

**T2 : Solution**

(a)

The rating of the machine, $G = 100$ MVA
Inertia constant, H = 5 kW - second/KVA = 5 MJ/MVA
Kinetic energy stored in the rotating parts of the generator and turbine at synchronous speed ($f$ = 50 Hz)

$$= HG = 5 \times 100 = 500 \text{ MJ}$$

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

$$= 100 - 50 = 50 \text{ MW}$$

Excess energy transferred to rotating parts in 0.4 second

$$= 50 \times 0.4 = 20 \text{ MJ}$$

Since kinetic energy, $KE \propto (\text{speed})^2 \propto (\text{frequency})^2$
so, frequency at the end of 0.4 sec

$$f_2 = f_1 \times \sqrt{\left(\frac{\text{total energy stored in 0.4 second}}{\text{energy stored at synchronous speed}}\right)}$$

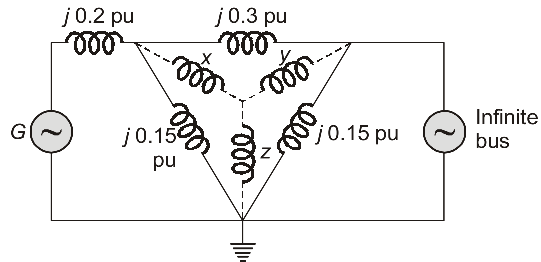
$$= 50 \times \sqrt{\frac{500+20}{500}} = 51 \text{ Hz}$$

$$\text{Change in frequency} = f_2 - f_1 = 51 - 50 = 1 \text{ Hz}$$

**T3 : Solution**

(c)

The per unit reactance diagram that appears between generator and infinite bus is,



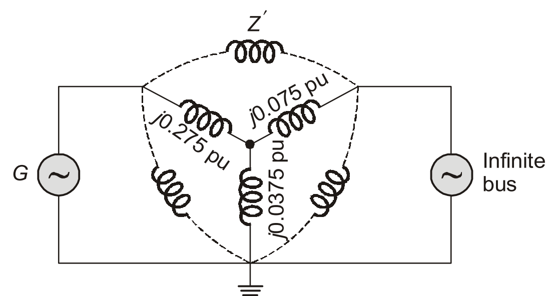

Converting the delta into star,

$$X = \frac{j0.3 \times j0.15}{j0.6} = j0.075 \text{ pu}$$

$$Y = \frac{j0.3 \times j0.15}{j0.6} = j0.075 \text{ pu}$$

$$Z = \frac{j0.15 \times j0.15}{j0.6} = j0.0375 \text{ pu}$$

The reactance diagram can be redrawn as,



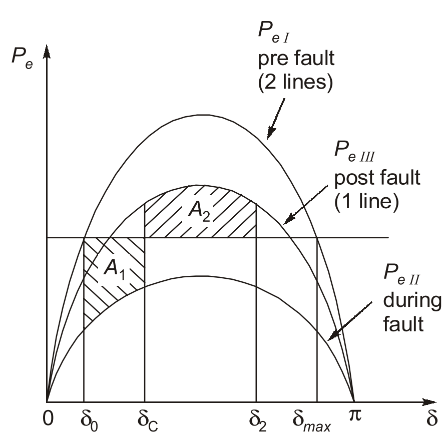

by again converting star to delta, $Z' = j0.275 \times j0.075 + \left(\frac{j0.275 \times j0.075}{j0.0375}\right) = j0.9 \text{ pu}$

Neglecting the shunt reactances,

∴ The per unit transfer reactance is $= j0.9$ pu

**T4 : Solution**

(b)



$$P_{\max I} = 2.0 \text{ pu},$$
$$P_{\max II} = 0.5 \text{ pu},$$
and, $$P_{\max III} = 1.5 \text{ pu}$$
Initial loading, $$P_m = 1.0 \text{ pu}$$

$$\delta_0 = \sin^{-1}\left(\frac{P_m}{P_{\max I}}\right) = \sin^{-1}\frac{1}{2} = 0.523 \text{ rad}$$

$$\delta_{\max} = \pi - \sin^{-1}\left(\frac{P_{\max}}{P_{\max III}}\right) = \pi - \sin^{-1}\left(\frac{1}{1.5}\right) = 2.41 \text{ rad}$$

$$\cos\delta_{cr} = \frac{P_m(\delta_{\max} - \delta_0) - P_{\max II}\cos\delta_0 + P_{\max III}\cos\delta_{\max}}{P_{\max III} - P_{\max II}}$$

$$\cos\delta_{cr} = \frac{1.0(2.41 - 0.523) - 0.5\cos 0.523 + 1.5\cos 2.41}{1.5 - 0.5}$$
$$= 1.887 - 0.433 - 1.116$$
$$\delta_{cr} = 70.3°$$

**T5 : Solution**

$$\text{Accelerating power} = 25 \text{ MW} - 22.5 \text{ MW}$$
$$= 2.5 \text{ MW}$$

$$H = \frac{200}{50} = 4 \text{ sec.}$$

According to swing equation,

$$\frac{2 \times 4}{2 \times 3.14 \times 60} \times \underset{\uparrow \text{ Acceleration}}{\frac{d^2\delta}{dt^2}} = \frac{2.5}{50}$$

$$\text{Acceleration} = 2.356 \text{ ele.rad/sec}^2$$

■■■■

# 8 Switch Gear and Protection

## Detailed Explanation *of* Try Yourself Questions

**T1 : Solution**

(a)

Since the LT side is delta connected, the CTs on that side will be star connected. Therefore, if 400 A is line current, the CT secondary current is 5 A. The line current on the star side of the power transformer will be

$$400 \times \frac{6.6}{33} = 80 \text{ A}$$

The CTs on the star side are delta connected and the current required on the relay side of the CT is 5 A.

Therefore, the current in the CT secondary (phase current) is $\frac{5}{\sqrt{3}}$.

The CT ratio on the HT side will be $80 : \frac{5}{\sqrt{3}}$.

**T2 : Solution**

The phase voltage of the alternator $= \frac{10000}{\sqrt{3}} = 5773$ V

Let $x$% be the percent winding which remains unprotected. The voltage of the unprotected portion of the winding

$$= 5773 \times \frac{x}{100} \times \frac{1}{10} \text{ A}$$

The current in the pilot wires will be with a CT of $\frac{1000}{5}$ amps ratio

$$= 5773 \times \frac{x}{100} \times \frac{1}{10} \times \frac{5}{1000} = 1.8$$

$$5773x = 3.6 \times 10^5$$

$$x = \frac{3.6 \times 10^5}{5773} = 62.36\%$$

**T3 : Solution**

(c)
Voltage across breaker contacts at chopping is

$$e = i\sqrt{\frac{L}{C}}$$

Here, $i$ = 7 A, L = 35.2 H and C = 0.0023 μF

$$e = 7\sqrt{\frac{35.2}{0.0023 \times 10^{-6}}}\, V = 866 \text{ KV}$$

**T4 : Solution**

(a)
Rated secondary current of C.T. = 5 A
pick up current = 5 × 1.25 = 6.25 A

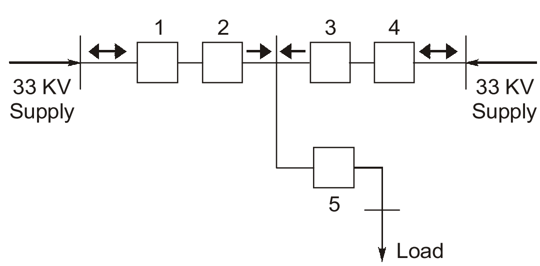
$$\text{fault current in relay coil} = 4000 \times \frac{5}{400} = 50 \text{ A}$$

$$\text{plug setting multiplier (P.S.M.)} = \frac{50}{6.25} = 8$$

Corresponding to the plug setting multiplier of 8, the time of operation is 3.5 seconds.
∴ Actual relay operating time = 3.5 × Time setting = 3.5 × 0.6 = 2.1 sec

**T5 : Solution**

(b)




Since there are two source ends we require two non directional relays there, as shown above.
At the point of 2 and 3 directional over current relays are required because, when a fault occur at some point between 2 and 3, there should be no power flow in the direction opposite to the mentioned one.
At point 5 since it is only load there is no case of reverse flow of power.

**T6 : Solution**

(c)

$$\text{Characteristic impedance of cable} = \sqrt{\frac{0.3}{0.4}} = 0.866\ \Omega$$

$$\text{Characteristic impedance of overhead line} = \sqrt{\frac{1.5}{0.012}} = 11.18\ \Omega$$

$$\text{Voltage rise due to surge} = 15 \text{ k} \times \frac{2 \times 11.18}{11.18 + 0.866} = 27.87 \text{ kV}$$

■■■■