

ESE GATE PSUs

State Engg. Exams

MADE EASY
WORKBOOK 2024



**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,

$$MD = 40 \text{ MW}$$

$$\text{Capacity factor} = 0.5$$

$$\text{Utilization factor} = 0.8$$

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

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

$$\begin{aligned} \text{Reserve capacity} &= \text{plant capacity} - \text{maximum demand} \\ &= 50 - 40 = 10 \text{ MW} \end{aligned}$$

T2 : Solution

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

$$\begin{aligned} \text{Maximum demand, MD} &= \frac{\text{Average load}}{\text{Load factor}} \\ &= \frac{500}{0.2} = 2.5 \text{ MW} \end{aligned}$$

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

$$\begin{aligned} \text{Reserve capacity} &= \text{Installed capacity} - \text{maximum demand} \\ &= 3.333 - 2.5 \\ &= 0.833 \text{ MW} \end{aligned}$$

T3 : Solution

Maximum demand = 20 MW

Connected load = 23 MW

Units generated = 61.5×10^6 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) Demand factor = $\frac{\text{Maximum demand}}{\text{Connected load}} = \frac{20}{23} = 0.869$

(b) Average demand = 7020 kW

(c) 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,

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

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

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,

$$\begin{aligned} \frac{d\eta}{dx} &= \frac{(18 + 12x + 0.5x^2) \times 0.86 - 0.86x(12 + x)}{(18 + 12x + 0.5x^2)^2} \\ &= \frac{15.48 - 0.43x^2}{(18 + 12x + 0.5x^2)^2} \end{aligned}$$

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

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

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



2

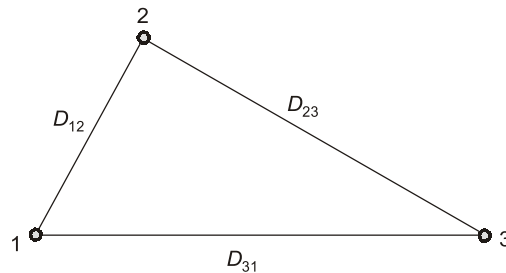
Transmission



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,

$$\begin{aligned} D_m &= \sqrt[3]{D_{12} \times D_{23} \times D_{31}} \\ &= \sqrt[3]{2 \times 2.5 \times 4.5} \\ &= 2.82 \text{ m} = 282 \text{ cm} \end{aligned}$$

$$\begin{aligned} D_s = \text{GMR} &= 0.7788 \times r' = 0.7788 \times 0.62 \\ &= 0.4828 \end{aligned}$$

$$\begin{aligned} \text{Inductance/phase/meter} &= 2 \times 10^{-7} \log_e \left(\frac{D_m}{D_s} \right) \\ &= 2 \times 10^{-7} \log_e \left(\frac{282}{0.4828} \right) \\ &= 1.27 \text{ } \mu\text{H/phase/m} \end{aligned}$$

T2 : Solution

(c)

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

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

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

T3 : Solution

(a)

The mutual GMD between sides A and B is

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

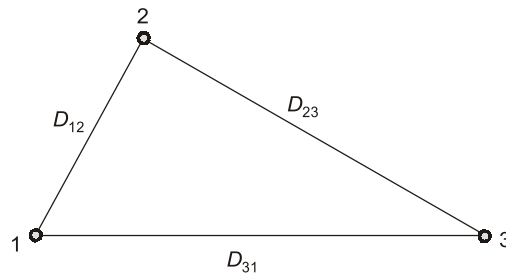
From the figure it is obvious that, $D_{14} = D_{24} = D_{25} = D_{35} = \sqrt{8^2 + 2^2} = \sqrt{68} \text{ m}$

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

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

T4 : Solution

(c)



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

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

Equivalent equilateral spacing, $D_m = \sqrt[3]{D_{12} \times D_{23} \times D_{31}} = \sqrt[3]{2 \times 2.5 \times 4.5}$
 $= 2.82 \text{ m} = 282 \text{ cm}$

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

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

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

T5 : Solution

(d)

Receiving-end phase voltage,

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

Magnitude of receiving-end current,

$$\begin{aligned} |I_R| &= \frac{\text{Load in MW} \times 10^6}{\sqrt{3} V_{RL} \cos \phi_R} = \frac{30 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.8} \\ &= 196.82 \text{ A} \end{aligned}$$

Taking receiving-end phase voltage as reference phasor,

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

Receiving-end current,

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

Sending-end phase voltage,

$$\begin{aligned} V_s &= AV_R + BI_R \\ &= 0.96 \angle 1.0^\circ \times 63508 \angle 0^\circ + 100 \angle 80^\circ \times 196.82 \angle -36.87^\circ \\ &= 76709.6 \angle 10.91^\circ \text{ V} \end{aligned}$$

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 δ is the phase angle between sending end and receiving end voltage.

$$A = A \angle \alpha = 0.96 \angle 1.0^\circ$$

$$B = B \angle \beta = 100 \angle 80^\circ \Omega$$

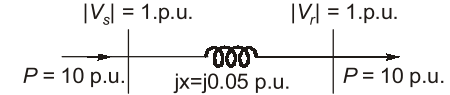
The maximum power transmitted is given by

$$\begin{aligned} P_{R,\max} &= \frac{|V_S| |V_R|}{|B|} - \frac{|A| |V_R|^2}{|B|} \cos(\beta - \alpha) \\ &= \frac{120 \times 110}{100} - \frac{0.96 (110)^2}{100} \cos(79^\circ) \\ P_{R,\max} &= 109.83 \text{ MW} \end{aligned}$$

T7 : Solution

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

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

$$\delta = 30^\circ$$


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

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

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

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

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

$$\text{New reactive power, } Q' = \frac{(0.96)^2 V_{ph}^2}{(1.04)(2\pi fL)} = 0.886 Q$$

$$\text{Change in } Q = 11.4\% \text{ low}$$

T9 : Solution

(b)

$$\text{The percentage voltage regulation \%} = \frac{V' - V_R}{V_R} \times 100$$

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

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

$$Y = j\omega C = j2\pi f \times \frac{1}{\pi} \times 10^{-6} = j100 \times 10^{-6} \text{ } \Omega^{-1} \quad [\because \text{assumed } f = 50 \text{ Hz}]$$

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

$$A = 1 + \frac{YZ}{2} = \frac{1 + (j100 \times 10^{-6})(j400)}{2} = 0.98$$

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

$$\%V_R = \frac{234.693 - 220}{22} \times 100 = 6.678 \approx 6.8\%$$

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,

$$V_3 = \text{Safe working voltage of the unit} = 20 \text{ kV}$$

So voltage across top most unit,

$$V_1 = \frac{V_3}{1 + 3K + K^2} = \frac{20}{1 + 0.3 + 0.01} = 15.267 \text{ kV}$$

Voltage across middle unit,

$$V_2 = V_1(1 + K) = 15.267 + 1.1 = 16.794 \text{ kV}$$

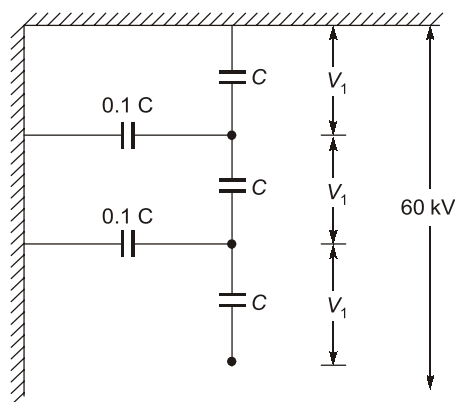
Maximum safe working voltage of the string,

$$\begin{aligned} V &= V_1 + V_2 + V_3 \\ &= 15.267 + 16.794 + 20 = 52 \text{ kV} \end{aligned}$$

$$\begin{aligned} \text{String efficiency} &= \frac{V}{nV_n} \times 100 = \frac{52}{3 \times 20} \times 100 \\ &= 86.67\% \end{aligned}$$

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,

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

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

$$\begin{aligned} V_3 &= (k^2 + 3k + 1) V_1 \\ &= (0.1^2 + 0.3 + 1) 17.5953 \\ &= 23.05 \text{ kV ; } 23.1 \text{ kV} \end{aligned}$$

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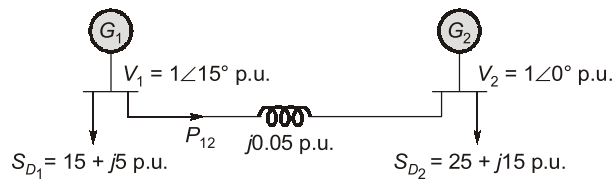
3

Voltage and Frequency Control



Detailed Explanation of Try Yourself Questions

T1 : Solution



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

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

∴ 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 must be same.

Let x be power supplied by 60 MW alternator,

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

$$0.0833x = 6 - 0.05x$$

$$0.1333x = 6$$

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

The other alternator share, $(120 - 45) = 75 \text{ MW}$

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

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

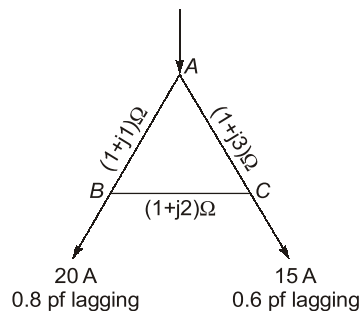
$$0.4 \times 10^6 = \frac{\rho}{2\pi \times 5000} \times \log_e \frac{25}{10}$$

\therefore the resistivity of the insulating material is,

$$\begin{aligned} \rho &= 1.37 \times 10^{10} \\ &= 13.71 \text{ G}\Omega \cdot \text{m} \end{aligned}$$

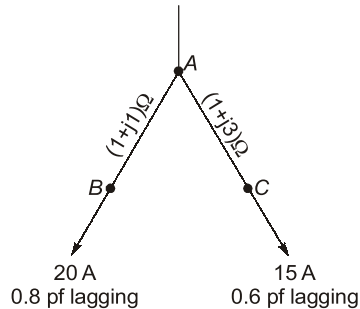
T2 : Solution

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,

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



Current in section AC is,

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

Voltage drop in section AB is,

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

Voltage drop in section AC is,

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

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

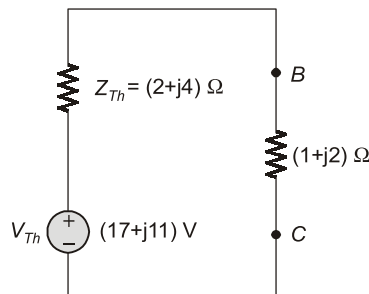
$$\begin{aligned} V_{BC} &= (45 + j15) - (28 + j4) \\ &= (17 + j11)\text{V} \end{aligned}$$

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,

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



\therefore Current in section BC ,

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

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,

$$\begin{aligned} \text{Insulation Resistance, } R_{\text{ins}} &= \frac{\rho}{2\pi l} \ln \frac{r_2}{r_1} \\ &= \frac{8 \times 10^{12}}{2\pi \times 5000} \ln \frac{21.5}{12.5} = \frac{8 \times 10^{12}}{2\pi \times 5000} \times 0.5423 \\ &= 1.381 \times 10^8 \\ R_{\text{ins}} &= 138.1 \text{ M}\Omega \approx 138 \text{ M}\Omega \end{aligned}$$

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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)

$$Y_{11} = y_{11} + y_{12} + y_{13} = -j 2.86$$

$$Y_{22} = y_{12} + y_{22} + y_{23} = -j 6$$

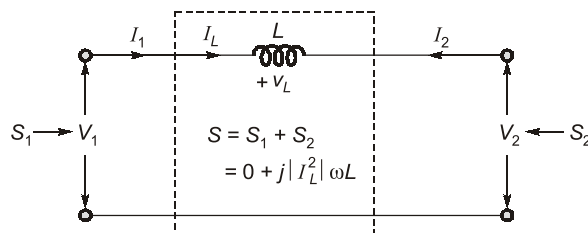
$$Y_{33} = y_{13} + y_{23} + y_{33} = -j 8.86$$

$$Y_{12} = Y_{21} = -y_{12} = 0$$

$$Y_{13} = Y_{31} = -y_{13} = j 2.86$$

$$Y_{23} = Y_{32} = -y_{23} = j 2$$

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

$$\begin{aligned} S &= S_1 + S_2 = (P_1 + P_2) + j(Q_1 + Q_2) \\ &= 0 + j|I_L|^2 \omega L \end{aligned}$$

From above equation,

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

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

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

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

$$\text{If } |V_1| = |V_2| \quad (\text{Given})$$

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

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

$$\text{Since, } P_1 = -P_2 \Rightarrow P_1^2 = P_2^2$$

$$\text{Hence, } Q_1^2 = Q_2^2 \Rightarrow Q_1 = Q_2$$

$$\begin{aligned} \text{Now, } S_2 &= P_2 + jQ_2 \\ &= -P_1 + jQ_1 \\ S_2 &= -(P_1 - jQ_1) \\ S_2 &= -S_1^* \end{aligned}$$

T4 : Solution

(b)

To eliminate 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:

$$\begin{aligned} Z_{\text{new}} &= Z_{\text{old}} - \frac{1}{Z_{ii} + Z_{KK} - 2Z_{iK} + Z_s} \begin{bmatrix} j0.06 \\ -j0.06 \end{bmatrix} \begin{bmatrix} j0.06 & -j0.06 \end{bmatrix} \\ &= \begin{bmatrix} j0.18 & j0.12 \\ j0.12 & j0.18 \end{bmatrix} - \frac{1}{j0.18 + j0.18 - j0.24 - j0.3} \begin{bmatrix} j0.06 \\ -j0.06 \end{bmatrix} \begin{bmatrix} j0.06 & -j0.06 \end{bmatrix} \\ &= \begin{bmatrix} j0.18 & j0.12 \\ j0.12 & j0.18 \end{bmatrix} + \begin{bmatrix} j0.02 & -j0.02 \\ -j0.02 & j0.02 \end{bmatrix} \\ Z_{\text{bus modified}} &= \begin{bmatrix} j0.2 & j0.1 \\ j0.1 & j0.2 \end{bmatrix} \end{aligned}$$



6

Fault Analysis

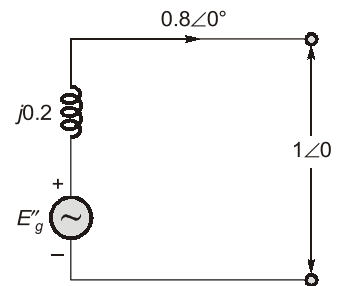


Detailed Explanation of Try Yourself Questions

T1 : Solution

(d)

$$\begin{aligned}
 P_{3-\phi} &= 400 \text{ MW} \\
 P_{3-\phi \text{ pu}} &= \frac{400}{500} = 0.8 \text{ pu} \\
 P_{3-\phi \text{ pu}} &= V_{\text{pu}} I_{\text{pu}} \cos \theta \\
 &= 1 \times I_{\text{pu}} \times 1 \quad (V_{\text{pu}} = 1, \cos \theta = 1) \\
 I_{\text{pu}} &= 0.8 \\
 E_g'' &= 1 \angle 0^\circ + (j0.2)(0.8 \angle 0^\circ) \\
 &= 1.01 \angle 9.09^\circ \text{ pu} \\
 I_F'' &= \frac{E_g''}{X_d''} = \frac{1.01 \angle 9.09^\circ}{j0.2} = 5.06 \angle -80.91^\circ \text{ p.u.}
 \end{aligned}$$



T2 : Solution

(b)

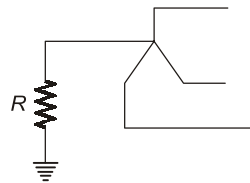
Rated current = 1 pu

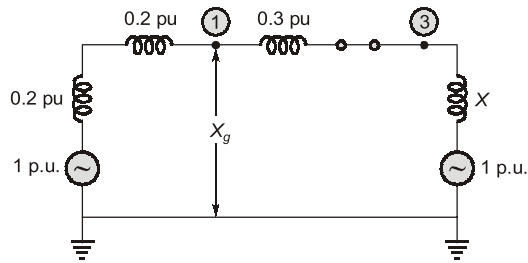
$$I_{fLG} = \frac{3 \times 1 \angle 0^\circ}{3R \times j0.3 + j0.4 + j0.05}$$

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

$$\begin{aligned}
 \frac{3}{\sqrt{9R^2 + (0.75)^2}} &= 1 \\
 9R^2 + 0.75^2 &= 9 \\
 R &= 0.96
 \end{aligned}$$

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



T3 : Solution


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

At bus (1),

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

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

$$\text{or } X + 0.7 = 2(0.3 + X)$$

$$\Rightarrow X = 0.1 \text{ pu}$$

Now at bus (3)

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

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

T4 : Solution

(a)

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

T5 : Solution

(c)

Let, Common base MVA = 10

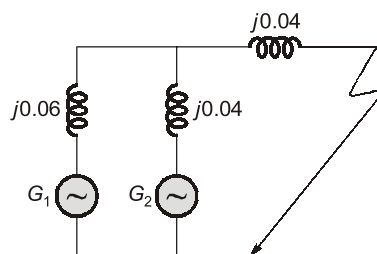
Base voltage for LT side of the transformer = 11 kV

Base voltage for HT side of the transformer = 220 kV

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

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

\therefore The reactance diagram will be as shown below.



Equivalent reactance,

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

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

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

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

$$\begin{aligned} \text{Fault current in LT side} &= \text{Base current in LT side} \times \text{Fault current in p.u.} \\ &= 524.86 \times 15.625 \end{aligned}$$

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

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,

$$\begin{aligned} I_{fG_2} &= 4.92 \text{ KA so that total fault current on LT side} \\ &= I_{fG_1} + I_{fG_2} = 8.2 \text{ KA} \end{aligned}$$

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7

Stability Analysis



Detailed Explanation of Try Yourself Questions

T1 : Solution

(c)

The swing equation is

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

T2 : Solution

(a)

The rating of the machine, $G = 100 \text{ MVA}$

Inertia constant, $H = 5 \text{ kW - second/KVA} = 5 \text{ MJ/MVA}$

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

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

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

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

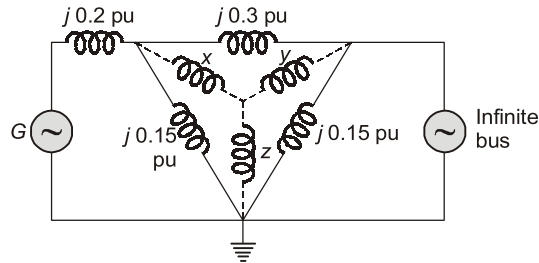
$$= 50 \times \sqrt{\frac{500 + 20}{500}} = 51 \text{ Hz}$$

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

T3 : Solution

(c)

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



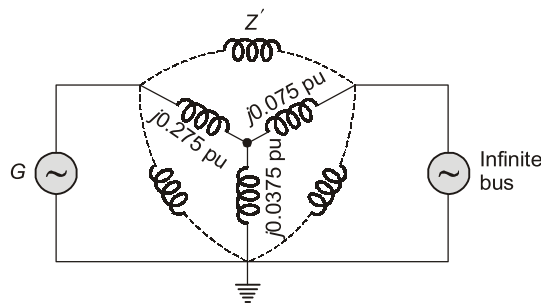
Converting the delta into star,

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

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

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

The reactance diagram can be redrawn as,



by again converting star to delta,

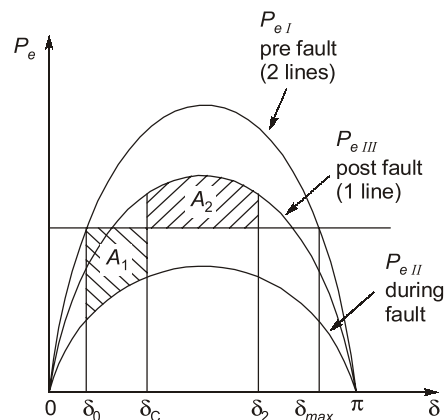
$$Z' = j0.275 \times j0.075 + \left(\frac{j0.275 \times j0.075}{j0.0375} \right) = j0.9 \text{ pu}$$

Neglecting the shunt reactances,

\therefore The per unit transfer reactance is $= j0.9 \text{ pu}$

T4 : Solution

(b)



and,
Initial loading,

$$\begin{aligned} P_{\max I} &= 2.0 \text{ pu,} \\ P_{\max II} &= 0.5 \text{ pu,} \\ P_{\max III} &= 1.5 \text{ pu} \\ P_m &= 1.0 \text{ pu} \end{aligned}$$

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

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

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

$$\cos \delta_{cr} = \frac{1.0(2.41 - 0.523) - 0.5 \cos 0.523 + 1.5 \cos 2.41}{1.5 - 0.5}$$

$$= 1.887 - 0.433 - 1.116$$

$$\delta_{cr} = 70.3^\circ$$

T5 : Solution

$$\begin{aligned} \text{Accelerating power} &= 25 \text{ MW} - 22.5 \text{ MW} \\ &= 2.5 \text{ MW} \end{aligned}$$

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

According to swing equation,

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

↑
Acceleration

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

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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 = $\frac{10000}{\sqrt{3}} = 5773 \text{ V}$

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 $C = 0.0023 \mu\text{F}$

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

T4 : Solution

(a)

Rated secondary current of
pick up current

$$\text{C.T.} = 5 \text{ A}$$

$$= 5 \times 1.25 = 6.25 \text{ A}$$

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

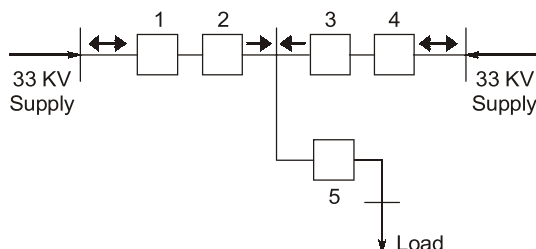
$$\text{plug setting multiplier (P.S.M.)} = \frac{50}{6.25} = 8$$

Corresponding to the plug setting multiplier of 8, the time of operation is 3.5 seconds.

$$\therefore \text{Actual relay operating time} = 3.5 \times \text{Time setting} = 3.5 \times 0.6 = 2.1 \text{ sec}$$

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)

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

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

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

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