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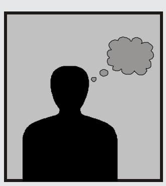

## Detailed Explanations of Try Yourself *Questions*

# ELECTRICAL ENGINEERING

## Power Electronics & Drives

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# 1 Power Semiconductor Devices

## Detailed Explanation *of* Try Yourself Questions

**T1 : Solution**

(c)

Devices mentioned in figure 2 and 4 allow current flow in both direction.

**T2 : Solution**

(d)

$$\left(\frac{di}{dt}\right)_{max} = \left(\frac{V_{s_{max}}}{L}\right)$$

$$= \frac{\sqrt{2}\times 230}{15\times 10^{-6}} = 21.685 \text{ A/}\mu\text{s}$$

$$\left(\frac{dv}{dt}\right)_{max} = R_s\left(\frac{di}{dt}\right)_{max} = 10\times 21.685$$

$$= 216.85 \text{ V/}\mu\text{ sec}$$

**T3 : Solution**

(d)

KVL in the loop is, $-V + L\dfrac{di}{dt} = 0$

$$V = L\frac{di}{dt}$$

$$dt = \frac{L}{V}di$$

Integrating on both sides, $\int dt = \int \dfrac{L}{V}di$


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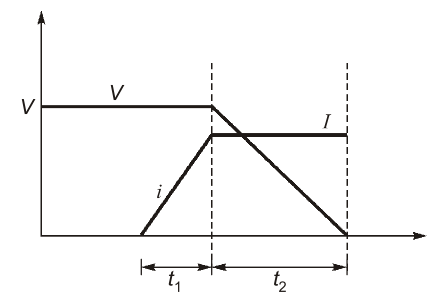
$$t_{min} = \frac{0.1}{100} \times 4 \times 10^{-3} = 4\ \mu s$$

∴ The minimum width of the gating pulse required to properly turn on the SCR is 4 μs.

## T4 : Solution

(a)

During interval $t_2$, voltage starts decreasing and becomes zero and current starts increasing and becomes constant ($I$), so transition is turn on.




$$\int dt = \int \frac{L}{V} di$$

During $t_1$ interval,

power loss = $vi$

$$E_1 = \text{Energy loss} = \int vidt = V\int idt$$

$V$ is constant during this period, $v = V$

$\int idt$ represents area under i-t curve

$$\int idt = \frac{1}{2} \times I \times t_1$$

$$E_1 = V\int idt = \frac{1}{2}VIt_1 \quad \text{...(i)}$$

During $t_2$ interval, Power loss = $vi$

$$E_2 = \text{Energy loss} = \int vidt = I\int vdt$$

$i$ is constant during this period $i = I$

$\int vdt$ represents are under v-t curve

$$\int vdt = \frac{1}{2}VIt_2$$

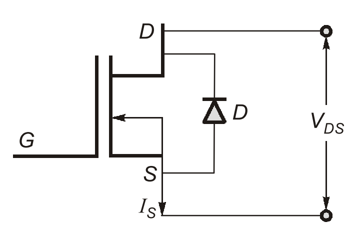
$$E_2 = I\int vdt = \frac{1}{2}VIt_2 \quad \text{...(ii)}$$

Total energy lost during the transition

$$E = E_1 + E_2 = \frac{1}{2}VIt_1 + \frac{1}{2}VIt_2$$

## T5 : Solution

(b)




When reverse current flows through diode D.

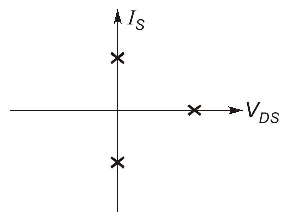
So, $I_S < 0$ and $V_{DS} = 0$

When MOSFET is in ON state,

$$I_S > 0 \text{ and } V_{DS} = 0$$

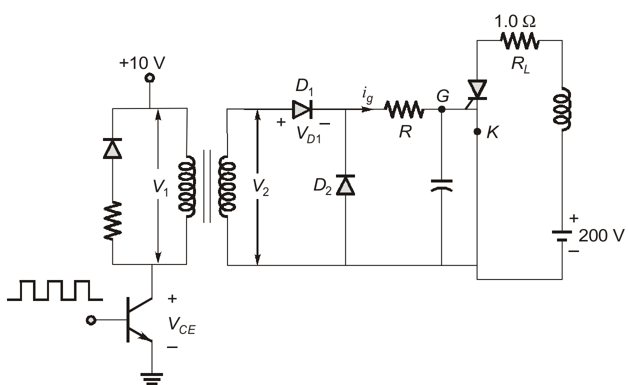
When MOSFET is in OFF state,

$$I_s = 0 \text{ and } V_{DS} > 0$$




**T6 : Solution**

(c)




When the pulses are applied to the base of the transistor. Transistor operates in ON state. So, the forward voltage drop in transistor $V_{CE}$ = 1 V.

$$V_1 = 10 - V_{CE} = 10 - 1 = 9 \text{ V}$$

$$V_2 = V_1\left(\frac{1}{1}\right) = V_1 = 9 \text{ V} \qquad \text{[turn ratio 1 : 1]}$$

$D_1$ is forward biased and voltage drop in diode $V_{D1}$ = 1 V.

$D_2$ is reversed biased and acts as open circuit.

Capacitor behaves as open circuit for DC voltage. Forward voltage drop of gate cathode junction

$$V_{gk} = 1 \text{ V}$$

Voltage drop across resistor $R$,

$$V_R = V_2 - V_{D1} - V_{gk} = 9 - 1 - 1 = 7 \text{ V}$$

To ensure turn –ON of SCR,

$$R = \frac{V_R}{I_{g(\max)}} = \frac{7}{150 \text{ mA}} \approx 47\ \Omega$$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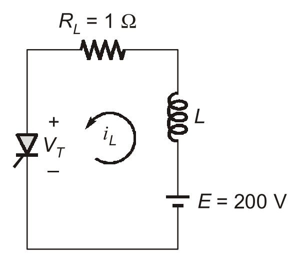
**T7 : Solution**

(a)




Forward voltage drop of SCR during ON-state

$$V_T = 1\text{ V}$$

$$E - \frac{Ldi_a}{dt} - Ri_a - V_T = 0$$

$$\Rightarrow \quad 200 - 0.15\frac{di_a}{dt} - i_a - 1 = 0$$

$$\Rightarrow \quad i_a = 199(1 - e^{-t/0.15})$$

Gate pulse width required = time taken by $i_a$ to rise upto $I_L = T$

$$I_L = i_a$$

$$\Rightarrow \quad 250 \times 10^{-3} = 199(1 - e^{-T/0.15})$$

$$T = 188.56\ \mu\text{s}$$

Width of the pulse, $T = 188.56\ \mu$s

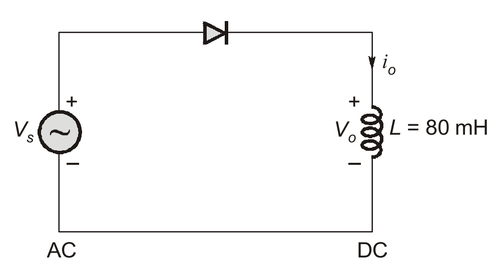
Magnitude of voltage, $V = 10$ V

Voltage second rating of $PT$

$$VT = T = 10 \times 188.56\ \mu\text{s} = 1885.6\text{ V-s} \approx 2000\ \mu\text{s}$$

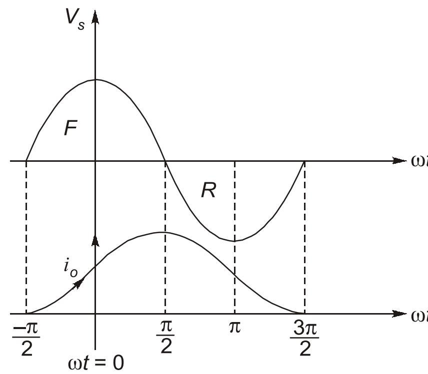
**T8 : Solution**

(d)




$$V_s = 230\cos\omega t$$

$$\omega = 314\text{ rad/sec}$$




Diode will turn on at $\omega t = \frac{-\pi}{2}$

Applying KVL

$$V_s = V_o$$

$$V_m \cos \omega t = L\frac{di}{dt}$$

$$\int di = \int \frac{V_m \cos \omega t}{L} dt$$

$$i_o = \frac{V_m}{\omega L} \sin \omega t + K$$

At $\omega t = -\frac{\pi}{2}$, $\quad i_o = 0$

$$0 = \frac{V_m}{\omega L} \sin\left(-\frac{\pi}{2}\right) + K$$

$$K = \frac{V_m}{\omega L}$$

$$i_o = \frac{V_m}{\omega L} \sin \omega t + \frac{V_m}{\omega L}$$

At $\omega t = \frac{\pi}{2}$

$$i_{peak} = \frac{V_m}{\omega L} \sin\frac{\pi}{2} + \frac{V_m}{\omega L}$$

$$= \frac{2V_m}{\omega L} = \frac{2 \times 230}{314 \times 80 \times 10^{-3}}$$

$$= 18.31 \text{ A}$$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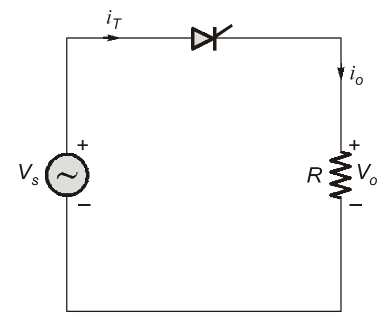
**T9 : Solution**

$$(I_T)_{\text{RMS rating}} = 35 \text{ A}$$




$$i_T = i_o$$

$$\text{Form factor} = \frac{(I_T)_{\text{RMS}}}{(I_T)_{\text{Avg}}}$$

$$= \frac{I_{or}}{I_o}$$

$$= \frac{V_{or}/R}{V_o/R}$$

$$= \frac{V_{or}}{V_o}$$

$$\text{Form factor} = \frac{\frac{V_m}{\sqrt{2\times 2\pi}}\left\{(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right\}^{\frac{1}{2}}}{\frac{V_m}{2\pi}[1+\cos\alpha]} = 3.98$$

Put $\alpha = \frac{\pi}{6}$

**Note :** At $\alpha = 0$, conduction angle of SCR is maximum.

$$(I_T)_{\text{Avg rating}} = \frac{(I_T)_{\text{RMS Rating}}}{\text{Form Factor}}$$

$$= \frac{35}{FF}$$

$$= \frac{35}{3.98} = 8.79$$

**T10 : Solution**

$$\text{Energy} = \int_0^{T_1} V\cdot i\,dt + \int_0^{T_2} v\cdot i\,dt$$

$$= V\left[\frac{1}{2}IT_1\right] + I\left[\frac{1}{2}VT_2\right]$$

$$= 600\left[\frac{150}{2}\times 1\times 10^{-6}\right] + 100\left[\frac{1}{2}\times 600\times 1\times 10^{-6}\right]$$

$$\text{Energy} = 75 \text{ mJ}$$

**T11 : Solution**

(c)

$$\text{Derating factor} = 1 - \text{String efficiency}$$

$$0.2 = 1 - \frac{6000}{n_s \times 1000} = 1 - \frac{1000}{n_p \times 200}$$

$$n_s = 7.5 \approx 8$$

$$n_p = 6.25 \approx 7$$

**T12 : Solution**

(b)

$$P_{avg} = I_{rms}^2 \cdot R_{ON}$$

$$R_{ON} = 0.15\ \Omega \text{ and } I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} 10t\, dt} = \frac{10}{\sqrt{6}}$$

$$P_{avg} = \frac{100}{6}\times 0.15 = 2.50 \text{ W}$$

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# 2 Controlled and Uncontrolled Rectifiers

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

(b)

Average output voltage

$$V_0 = \frac{2V_m}{\pi}\cos\alpha = \frac{2\sqrt{2}\times 230}{\pi}\cos 45° = 146.42 \text{ V}$$

$$I_0 = \frac{V_0}{R} = \frac{146.42}{10} = 14.642 \text{ A}$$

Reactive power input to the converter is

$$Q_i = \frac{2V_m}{\pi} I_0 \sin\alpha$$

$$= \frac{2\sqrt{2}\times 230}{\pi} \times 14.642 \times \sin 45°$$

$$Q_i = 2143.92 \text{ VAr}$$

**T2 : Solution**

$$V_0 = L\frac{di}{dt} = V_s$$

$$\int di = \int \frac{V_s}{L} dt = \int \frac{100\sin\omega t}{L} dt$$

$$i_0 = -\frac{100}{\omega L}\cos\omega t + K$$

$$\omega t = 100\pi \times 2.5 \times 10^{-3} = \frac{\pi}{4}$$

$$i_0(t = 2.5 \text{ ms}) = 0$$

$$\frac{-100\cos 45^\circ}{100\pi \times 31.83 \times 10^{-3}} + K = 0$$

$$K = 7.07$$

$$i_0 = -10\cos\omega t + 7.07$$

$$i_{0,\text{ peak}} = -10\cos\pi + 7.07$$

$$= 17.07 \text{ A}$$

## T3 : Solution

The half-wave diode rectifier uses a step-up transformer, therefore, ac voltage applied to rectifier

$$= 230 \times 460 \text{ V} = V_s$$

Average value of load voltage

$$V_0 = \frac{V_m}{\pi} = \frac{\sqrt{2} \times 460}{\pi} = 207.04 \text{ V}$$

Output dc power, $$P_{dc} = \frac{V_o^2}{R} = \frac{207.04^2}{60} = 714.43 \text{ W}$$

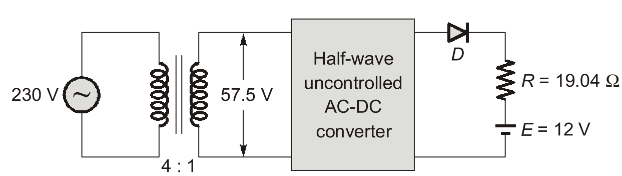
It is seen from the table that *TUF* for 1-phase half-wave diode rectifier is 0.2865.

$\therefore$ VA rating of transformer $= \dfrac{P_{dc}}{TUF} = \dfrac{714.43}{0.2865} = 2493.65$ VA

So, choose a transformer with 2.5 kVA (next round figure) rating.

## T4 : Solution

(1.05)




Input to the converter, $$V_s = \left(\frac{1}{4}\right)230 = 57.5 \text{ V}$$

Diode conducts when $V_s \geq E$

$$V_m \sin\theta_1 = E$$

$$57.5\sqrt{2}\sin\theta_1 = 12$$

$$\theta_1 = 8.486^\circ \text{ or } 0.148 \text{ rad}$$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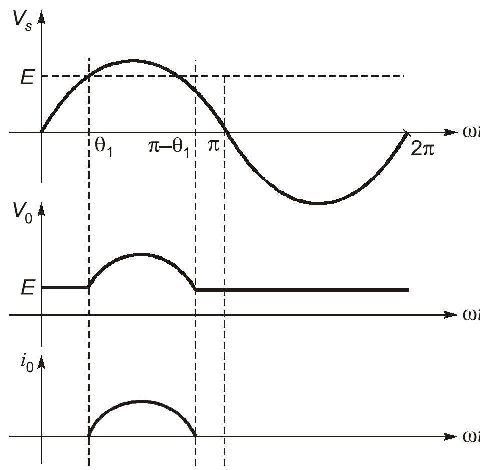



Charging current flows during $\theta_1 \le \omega t \le \pi - \theta_1$ and can be expressed as,

$$I_0 = \frac{1}{2\pi}\int_0^{2\pi} i_0 d\omega t = \frac{1}{2\pi}\int_{\theta_1}^{\pi-\theta_1}\left(\frac{V_m \sin\omega t - E}{R}\right)d\omega t$$

$$I_0 = \frac{1}{2\pi R}[2V_m \cos\theta_1 - E(\pi - 2\theta_1)]$$

$$= \frac{1}{2\pi \times 19.04}\left[2 \times 57.5\sqrt{2} \times \cos 8.486° - 12 \times (\pi - 2 \times 0.148)\right]$$

$$= 1.05 \text{ A}$$

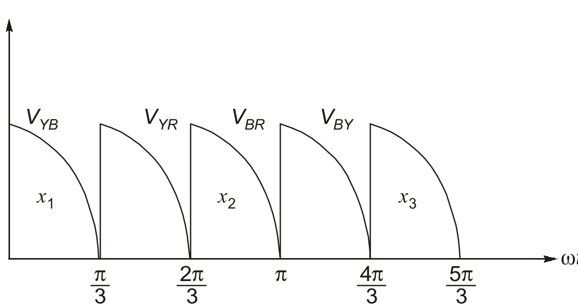
**T5 : Solution**

(d)

$\alpha = 60°,\ V_{YB} = V_{ML} \sin \omega t \text{ (Ref)}$

Lower limit, $L = 60 + \alpha = 120° = \frac{2\pi}{3}$ rad

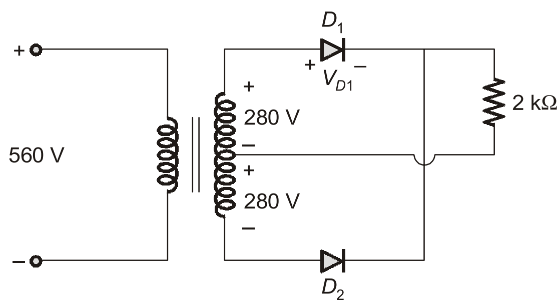
Upper limit, $U = 120 + \alpha = 180° = \pi$ rad



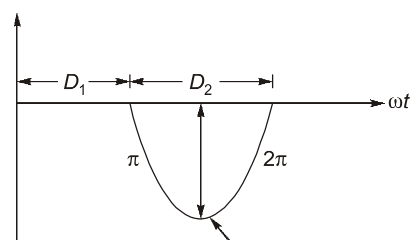

$x_1 \rightarrow V_{RY}$
$x_2 \rightarrow V_{YB}$
$x_3 \rightarrow V_{BR}$

**T6 : Solution**

(b)




$$V_s = 280\sqrt{2}\sin\omega t$$




$$\text{P.I.V.} = 2\times 280\sqrt{2}$$

The rms voltage across diode

$$= 280\sqrt{2} = 395.3 \text{ V}$$

**T7 : Solution**

(c)

Frequency of the voltage source, $f = 50$ Hz

Time period, $T = \frac{1}{f} = \frac{1}{50} = 20$ ms .

During positive half cycle of the source voltage, $0 < t < \frac{T}{2}$, energy is stored in the inductor and current increases.

During negative half cycle of the source voltage, $\frac{T}{2} \le t \le T$, current decreases and energy stored in the inductor is delivered to source.

**T8 : Solution**

(b)

$$V_s = 100\sqrt{2}\sin(100\pi t)$$

$$i = 10\sqrt{2}\sin\left(100\pi t - \frac{\pi}{3}\right) + 5\sqrt{2}\sin\left(300\pi t + \frac{\pi}{4}\right) + 2\sqrt{2}\sin\left(500\pi t - \frac{\pi}{6}\right) \text{ A}$$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$$\text{Active power} = V_{sr} \cdot I_{s1} \cos \phi_1 = 100 \times 10 \times \cos 60^\circ = 500\text{ W}$$

**T9 : Solution**

(b)

Rms value of input voltage,

$$V_{\text{rms}} = \frac{100\sqrt{2}}{\sqrt{2}} = 100\text{ V}$$

Rms value of current,

$$I_{\text{rms}} = \sqrt{\left(\frac{10\sqrt{2}}{\sqrt{2}}\right)^2 + \left(\frac{5\sqrt{2}}{\sqrt{2}}\right)^2 + \left(\frac{2\sqrt{2}}{\sqrt{2}}\right)^2} = 11.358\text{ A}$$

Let input power factor $\cos \phi$

$V_{\text{rms}} I_{\text{rms}} \cos \phi$ = active power drawn by the converter

$\Rightarrow$ $100 \times 11.358 \times \cos\phi = 500\text{ W}$

$\Rightarrow$ $\cos\phi = 0.44$

**T10 : Solution**

(c)

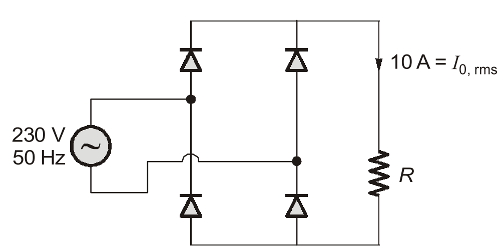
$$i_s \propto \frac{I_a}{n} \cdot \cos\frac{n\pi}{6} \qquad \text{where } n \in 1, 3, 5$$

For $n = 3$, $\quad i_s = 0$

For $n = 5$, $\quad i_s \propto -\frac{I_a}{5}$

Lowest harmonic present is fifth harmonic. Its frequency = 50 ×5 = 250 Hz.

**T11 : Solution**



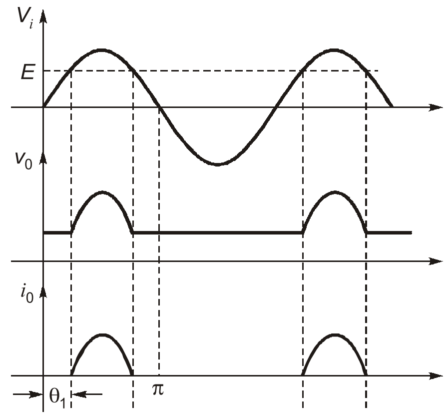

$$I_{0,\text{ rms}} = \frac{V_s}{R} \Rightarrow R = \frac{230}{10} = 23\ \Omega$$

**T12 : Solution**

(c)

$T_1$ and $T_4$ gets forward biased, when

$$V_m \sin \theta_1 \le E$$




$$I_{avg} = \text{(Average current)}$$

$$= \frac{1}{2\pi R}\int_{\theta_1}^{\pi-\theta_1}(V_m \sin \omega t - E)d\theta$$

∴ $$I_0\,(\text{avg}) = \frac{1}{2\pi R}[2V_m \cos\theta - E(\pi - 2\theta_1)]$$

$$= \frac{1}{2\pi \times 2}[2 \times (230 \times \sqrt{2})\cos \theta_1 - 200(\pi - 2\,\theta_1)]$$

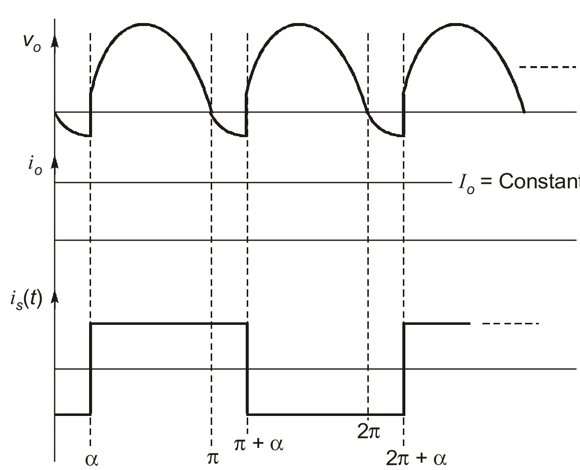
where, $$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$$

$$= \sin^{-1}\left(\frac{200}{230 \times \sqrt{2}}\right) = 38° = 0.66 \text{ rad}$$

∴ $$I_0\,(\text{avg}) = \frac{1}{2\pi \times 2}[2\sqrt{2} \times 230 \cos 38° - 200(\pi - 2 \times 0.66)] = 11.9 \text{ A}$$

**T13 : Solution**

Output waveforms of highly inductive load (without F.W. diode).





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Fourier series of supply current is given as

$$i_s(t) = \sum_{n=1,3,5}^{\infty} \frac{4I_o}{n\pi} \sin n\omega_o t$$

Frequency components present in supply current is
$1^{st}$, $3^{rd}$, $5^{th}$, $7^{th}$ : all odd frequencies.
Two most dominant harmonics are $3^{rd}$ and $5^{th}$, i.e., 150 Hz and 250 Hz.
Two most dominant frequencies are $1^{st}$ and $3^{rd}$, i.e., 50 Hz and 150 Hz.
Except fundamental, all other frequencies are harmonics in supply current.

**T14 : Solution**

1-$\phi$, SCR bridge rectifier

$$\alpha = 45°,\ R = 10\ \Omega$$

supply 230 V, 50 Hz

$$L_s = 2.28\text{ mH}, \quad \mu = ?$$

$$\Delta V_d = \frac{V_m}{\pi}[\cos\alpha - \cos(\alpha+\mu)] = 4f\,L_s I_0$$

$$V_0 = \frac{2V_m}{\pi}\cos\alpha - 4f\,L_s I_0 \text{ (with } L_s)$$

$$I_0 R = \frac{2V_m}{\pi}\cos\alpha - 4f\,L_s I_0$$

Find $I_0$

$$I_0 \times 10 = \frac{2\times 230\sqrt{2}}{\pi}\cdot\cos 45 - 4\times 50\times 2.28\times 10^{-3} I_0$$

$$I_0(10+0.456) = 146.42$$

$$I_0 = \frac{146.49}{10.456} = 14.0036\text{ A}$$

$$\Delta V_{d0} = \frac{230\sqrt{2}}{\pi}[\cos 45 - \cos(45+\mu)]$$

$$= 4\times 50\times 2.28\times 10^{-3}\times 14 = 6.384$$

$\cos 45° - \cos(45° + \mu) = 0.061659$

$$45 + \mu = 49.80 \Rightarrow \mu = 4.80°$$

**T15 : Solution**

$$V_o = 2\frac{V_m}{\pi}\cos\alpha = 2\frac{200\pi}{\pi}\cos 120°$$

$$V_o = -200\text{ V}$$

$$|V_o| = 200\text{ V}$$

Power balance equation,

$$EI_o = I_o^2 R + V_o I_o$$

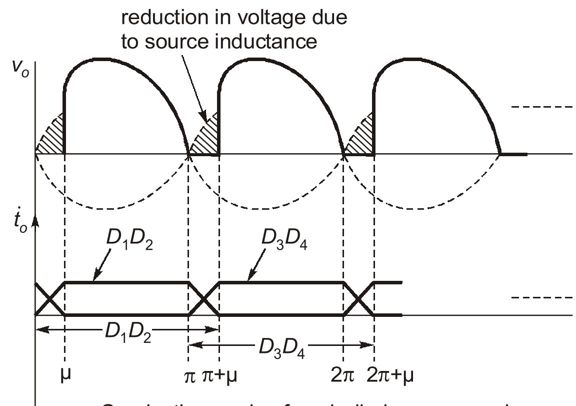
$$800\,I_o = I_o^2(20) + 200 I_o \Rightarrow I_o = 30\text{ A}$$

$$I_o = I_{or}$$

Power fed to source

$$= V_o I_o = 200\times 30 = 6\text{ kW}$$

## T16 : Solution




Conduction angle of each diode = π + μ rad

**Output Waveform**

$$V_{o(avg)} = \frac{2V_m}{\pi} \qquad (\because \text{ without } L_s)$$

$$V'_{o(avg)} = \frac{1}{\pi}\int_{\mu}^{\pi} V_m \sin\omega t \cdot d\omega t \qquad (\because \text{ with } L_s)$$

$$= \frac{V_m}{\pi}[1+\cos\mu]$$

$$\Delta V_{do} = V_{o(avg)} - V'_{o(avg)} = \frac{V_m}{\pi}[1-\cos\mu]$$

and $\Delta V_{do} = 4fL_sI_o$ [average reduction in voltage due to source inductance]

On equating,

$$\frac{V_m}{\pi}[1-\cos\mu] = 4fL_sI_o$$

$$\frac{220\sqrt{2}}{\pi}(1-\cos\mu) = 4 \times 50 \times 10 \times 10^{-3} \times 14$$

On solving, $\mu = 44.17°$

So, conduction angle of each diode

$$\gamma_D = 180° + \mu = 180° + 44.17° = 224.17°$$

## T17 : Solution

$$V_0 = \frac{V_m}{2\pi}(3+\cos\alpha)$$

$$E_bI_0 = 1600 \text{ W}$$

$$I_0 = \frac{1600}{80} = 20 \text{ A}$$

$$V_0 = E_b + I_0R_a$$

$$\frac{V_m}{2\pi}(3+\cos\alpha) = 80 + (20 \times 2)$$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$$\frac{80\pi}{2\pi}(3+\cos\alpha) = 80 + 40$$

$$\alpha = 90°$$

**T18 : Solution**

(0.78)

$$V_{sr} I_{sr} \cos\phi = V_0 I_0$$

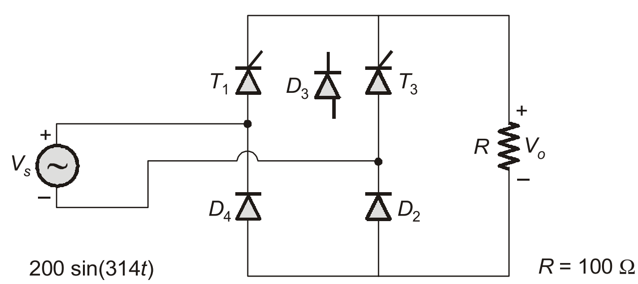
For single-phase fully controlled converter,

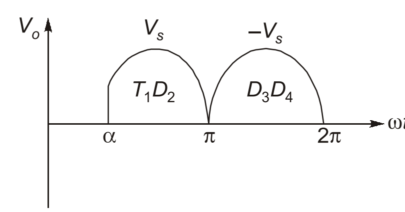
$$I_0 = I_{sr} = 10 \text{ A}$$

$$\cos\phi = \frac{V_0}{V_{sr}} = \frac{180}{230} = 0.78$$

**T19 : Solution**

(a, c, d)




$$V_o = \frac{1}{2\pi}\left[\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d\omega t + \int_{\pi}^{2\pi} -V_m \sin\omega t d\omega t\right]$$

$$V_o = \frac{V_m}{2\pi}[3+\cos\alpha]$$

$$= \frac{200}{2\pi}[3+\cos 60°] = 111.4 \text{ V}$$

$$I_o = \frac{V_o}{R} = \frac{111.4}{100} = 1.114 \text{ A}$$

$$I_{T1,avg} = \frac{1}{2\pi}\int_{\alpha}^{\pi} \frac{V_m \sin\omega t}{R} d\omega t$$

$$I_{T1} = \frac{V_m}{2\pi R}[1+\cos\alpha] = \frac{200}{2\pi \times 100}[1+\cos 60°]$$

$$= 0.4774 \text{ A}$$

Power drawn by load $P_o = V_{o,rms} I_{o,rms} = \dfrac{V_{o,rms}^2}{R}$

■■■■

# 3 Choppers

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

Circuit turnoff time,

$$t_c = \frac{CV_s}{I_0} = \frac{8 \times 10^{-6} \times 250}{20} = 1 \times 10^{-4}\ s$$

Maximum value of duty cycle,

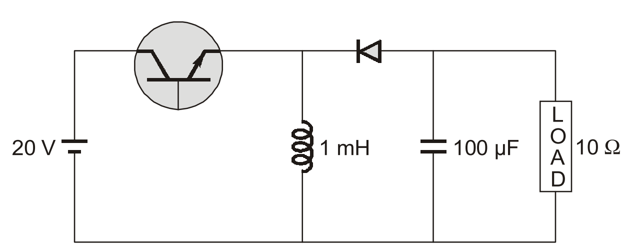
$$\alpha_{max} = (1 - 2ft_c)$$
$$= (1 - 2 \times 250 \times 1 \times 10^{-4})$$
$$\alpha_{max} = 0.95$$

maximum load or output voltage,

$$V_{0,\ max} = V_s[\alpha_{max} + 2ft_c]$$
$$= 250\left[0.95 + (2 \times 250 \times 1 \times 10^{-4})\right]$$
$$V_{0,\ max} = 250\ \text{V}$$

**T2 : Solution**

**(24)**




$\alpha = 0.75$, $f = 25$ kHz

Assume continous conduction:

$$V_0 = \frac{\alpha V_s}{1-\alpha} = \frac{0.75\times 20}{1-0.75}$$

$$V_0 = 60 \text{ V}$$

$$I_0 = \frac{V_0}{R} = \frac{60}{10} = 6 \text{ A}$$

$$I_L = \frac{I_0}{1-\alpha} = \frac{6}{1-0.75} = 24 \text{ A}$$

$$\Delta I_L = \frac{\alpha V_s}{f_L}$$

$$= \frac{0.75\times 60}{25\times 10^3\times(1\times 10^{-3})} = 1.8 \text{ A}$$

$$I_{L\,min} = I_L - \frac{\Delta I_L}{2} = 24 - \frac{1.8}{2} = 24 - 0.9$$

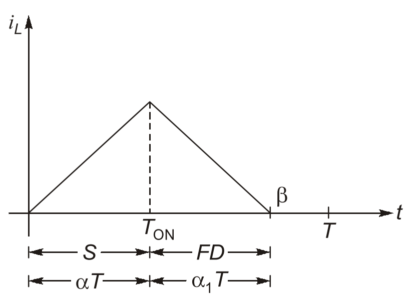
$(I_{L\,min} = 23.1 \text{ A}) > 0$

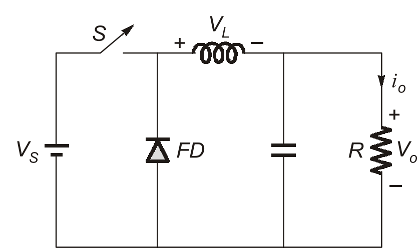
∴ Continous conduction assumption is correct.

$$I_L = 24 \text{ A}$$

**T3 : Solution**

**(c)**




$S \rightarrow$ ON :

KVL :

$$-V_S + V_L + V_o = 0$$
$$V_L = V_S - V_o$$
$$L\frac{di_L}{dt} = V_S - V_o$$
$$\frac{di_L}{dt} = \frac{V_S - V_o}{L}$$

$S \rightarrow$ OFF, $FD \rightarrow$ ON

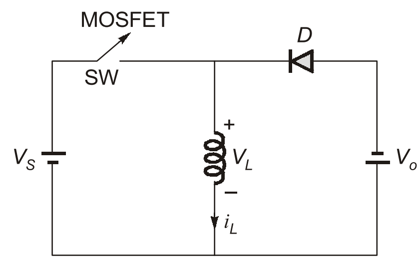
$$V_L + V_o = 0$$
$$V_L = -V_o$$
$$L\frac{di_L}{dt} = -V_o$$
$$\frac{di_L}{dt} = \frac{-V_o}{L}$$

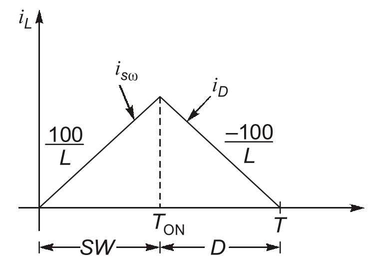
$R\uparrow, I_o\downarrow$

$\therefore I_L\downarrow \quad \therefore \text{Area}\downarrow \quad \therefore \beta\downarrow \quad \therefore V_o\uparrow$

$$\uparrow V_o = \frac{\alpha V_S}{\beta\downarrow}$$

**T4 : Solution**




$$f = 1000 \text{ kHz}$$
$$T = 10 \text{ μsec}$$
$$\alpha = 0.5$$
$$T_{ON} = \alpha . T = \alpha \times 10 \text{ μsec} = 0.5 \times 10 \text{ μsec} = 5 \text{ μsec}$$
$$V_s = R_{DS} i_{s\omega} + L\frac{di_L}{dt} \qquad (\text{Neglect } R_{DS} i_{s\omega})$$
$$V_s = L\frac{di_L}{dt}$$
$$\frac{di_L}{dt} = \frac{V_s}{L} = \frac{100}{L}$$
$$V_o = \frac{\alpha V_s}{1-\alpha} \quad (\text{at } \alpha = 0.5)$$
$$V_o = V_s = 100 \text{ V}$$

At the boundary, $0 \geq t \leq T_{ON}$

$\therefore$ $$i_{s\omega} = \frac{100}{L}t$$

$$I_{s\omega,\ rms} = \left\{\frac{1}{T}\int_0^{T_{ON}} i_{s\omega}^2 dt\right\}^{\frac{1}{2}}$$
$$= \frac{1}{T}\int_0^{T_{ON}} \left(\frac{100}{L}t\right)^2 dt$$
$$T = \frac{1}{f} = 10 \text{ μsec}$$
$$T_{ON} = \alpha T = 5 \text{ μsec}$$
$$L = 100 \text{ μH}$$
$$I^2_{s\omega,rms} = \frac{1}{T}\int_0^{T_{ON}} \left(\frac{100}{L}t\right)^2 dt = 4.1667 A^2$$

Condition power loss in MOSFET

$$= I^2_{s\omega,rms} . R_{DS} = 4.1667 \times 1 = 4.1667 \text{ W}$$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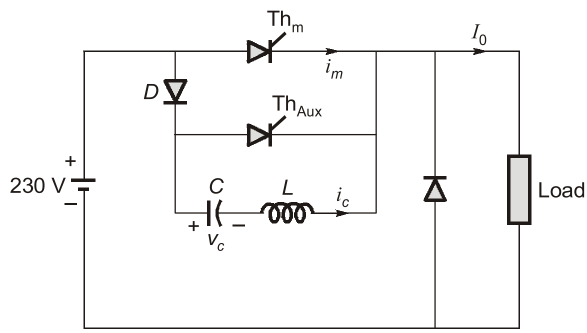
**T5 : Solution**

(c)




At $t = 0^-$, $v_c = V_s$, $i_c = 0$ and $i_{T1} = I_0$.

At $t = 0$, $Th_{aux}$ is triggered, a resonant current $i_c$ designs to flow from $C$ through $Th_{aux}$, $L$ and back to $C$. This resonant current is given by

$$i_c = -V_s\sqrt{\frac{C}{L}}\sin\omega_0 t$$
$$= -I_P \sin \omega_0 t$$

After half a cycle of $i_c \left\{t_1 = \frac{\pi}{\omega_0}\right\}$;

$i_c = 0$, $v_c = -V_s$ and $i_{T1} = I_0$. As $i_c$ tends to reverse, $Th_{aux}$ is turned off.

When $v_c = -V_s$, right hand plate has positive polarity, resonant current $i_c$ now builds up through $C$, $L$, $D$ and $Th_m$. As this current $i_c$ grows opposite to forward thyristor current of $Th_m$, net forward current $i_m = I_0 - i_c$ begins to decrease. Finally when $i_c$ in the reversed direction attains the value $I_0$, $i_m$ is reduced to zero and $Th_m$ is turned off.

$$i_m = I_0 - i_c$$
$$= I_0 - I_p \sin \omega_0 \Delta t = 0$$
$$\Delta t = \frac{1}{\omega_0}\sin^{-1}\left(\frac{I_o}{I_p}\right)$$

So, $Th_m$ is turned off between

$$t_1 < t < t_1 + \Delta t$$
$$t_1 = \frac{\pi}{\omega_0} = \pi\sqrt{LC}$$
$$= \pi \times \sqrt{10 \times 25.28}$$
$$= 50\ \mu\text{ sec}$$

Option (c) is correct.

Since, commutation of $Th_m$ starts from $t_1 = 50\ \mu$sec.

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**T6 : Solution**

(1.60)

Checking for continuous conduction mode

$$\Delta I_L = \frac{\alpha V_S}{fL} = \frac{0.6\times 15}{25\times 10^3\times 1\times 10^{-3}} = 0.36A$$

$$\frac{\Delta I_L}{2} = 0.18\text{A}$$

$$I_{L,\min} = I_L - \frac{\Delta I_L}{2} = I_S - \frac{\Delta I_L}{2}$$

$$= (9.375 - 0.18) = 9.195 > 0$$

As it is continuous conduction

$$V_0 = \frac{V_S}{1-\alpha} = \frac{15}{1-0.6} = 37.5V$$

$$I_0 = \frac{V_0}{R} = \frac{37.5}{10} = 3.75V$$

$$\frac{V_0}{V_S} = \frac{I_S}{I_o} = \frac{1}{1-\alpha}$$

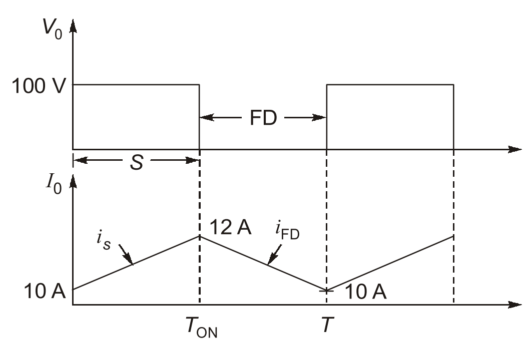
$$I_S = \frac{I_o}{1-\alpha} = \frac{3.75}{1-0.6} = 9.375A$$

$$R_{in} = \frac{V_S}{I_S} = \frac{15}{9.375} = 1.6\Omega$$

**T7 : Solution**

(b)

Stepdown chopper:




$$\tau = \frac{L}{R} = \frac{40.10^{-3}}{5} = 8.10^{-3}$$

$$V_0 = \alpha V_s$$

$S \to$ ON:

$$V_S = Ri_s + L\frac{di_s}{dt}$$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$$i_s = \frac{V_S}{R}\left(1 - e^{-t/8.10^{-3}}\right) + 10 \cdot e^{-t/8.10^{-3}}$$

$$= \frac{100}{5}\left(1 - e^{-t/8.10^{-3}}\right) + 10 \cdot e^{-t/8.10^{-3}}$$

$$= 20\left(1 - e^{-t/8.10^{-3}}\right) + 10 \cdot e^{-t/8.10^{-3}}$$

$$i_s = 20 - 10\, e^{-t/8.10^{-3}}$$

At $t = T_{ON}$, $\quad i_s = 12$ A

$\therefore \quad 12 \text{ A} = 20 - 10\, e^{-t/8.10^{-3}}$

$$10 e^{-T_{ON}/8.10^{-3}} = 8$$

$$e^{-T_{ON}/8.10^{-3}} = 0.8$$

$$\frac{-T_{ON}}{8.10^{-3}} = -0.223$$

$$T_{ON} = 1.785 \times 10^{-3} = 1.785 \text{ ms}$$

FD $\rightarrow$ ON:

$$i_{FD} = 12 \cdot e^{-t'/\tau}$$

$$= 12 \cdot e^{-t'/8.10^{-3}}$$

At $t' = T_{OFF}$, $\quad i_{FD} = 10$ A

$$10 = 12 \cdot e^{-T_{OFF}/8.10^{-3}}$$

$$e^{-T_{OFF}/8.10^{-3}} = \frac{10}{12}$$

$$\frac{-T_{OFF}}{8.10^{-3}} = -0.182$$

$$T_{OFF} = 1.458 \text{ ms}$$

$$\text{Time ratio} = \frac{T_{ON}}{T_{OFF}} = \frac{1.785}{1.458} = 1.22$$

**Alternate Solution :**

$$I_{o(avg)} = \frac{I_{o(max)} + I_{o(min)}}{2}$$

$$I_{o(avg)} = \frac{12 + 10}{2} = 11 \text{ A}$$

$$V_{o(avg)} = I_{o(avg)} \times R$$

$$= 11 \times 5 = 55 \text{ V}$$

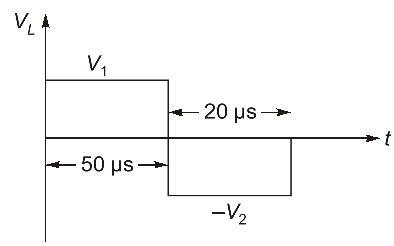
and $\quad V_{o(avg)} = \frac{T_{on}}{T} V_s$

$$\frac{55}{100} = \frac{T_{on}}{T}$$

$$\frac{T_{off}}{T} = \frac{T - T_{on}}{T} = \frac{45}{100}T$$

So, $$\frac{T_{on}}{T_{off}} = \frac{55}{45} = \frac{11}{9} = 1.222$$

**T8 : Solution**




$$V_1 \times 50\ \mu\text{sec} = V_2 .20\ \mu\text{sec} = 0$$

$$\frac{V_1}{V_2} = \frac{2}{5}$$

**T9 : Solution**

(2500)

On the verge of discontinuity

$$L = L_C \text{(critical inductance)}$$

$$I_{L,\min} = 0$$

$$I_{L(avg)} - \frac{\Delta I_L}{2} = 0 \Rightarrow I_{L(avg)} = \frac{\Delta I_L}{2}$$

$$I_{L(avg)} = \frac{D(1-D)\cdot V_s}{2fL} \qquad \{\because I_{L(avg)} = I_{o(avg)}\}$$

$$\frac{V_{o(avg)}}{R} = \frac{D(1-D)V_s}{2fL}$$

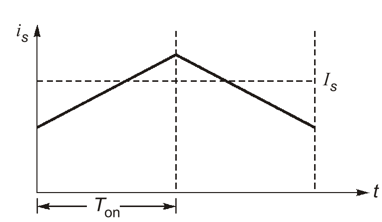
$$\frac{36}{R} = \frac{60\times 0.4\times 0.6}{2\times 100\times 10^3 \times 5\times 10^{-3}}$$

On solving, $R = 2500\ \Omega$

**T10 : Solution**

(Sol)

$$\frac{V_o}{V_s} = \frac{1}{1-\alpha}$$

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$$\frac{400}{360} = \frac{1}{1-\alpha}$$
$$\alpha = 0.1$$
$$V_s I_s = \text{Power}$$
$$360\, I_s = 4000 \Rightarrow I_s = 11.1 \text{ A}$$

Neglecting ripple in $i_s$,

$$I_{\text{switch (rms)}} = I_s \left(\frac{T_{on}}{T}\right)^{1/2}$$
$$= I_S \sqrt{\alpha} = 11.1\sqrt{0.1} = 3.5 \text{ A}$$

**T11 : Solution**

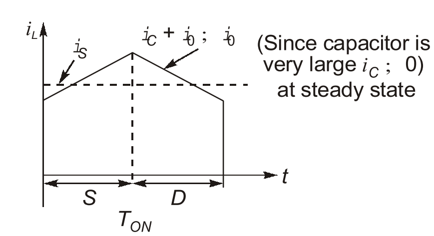
Buckboost converter,

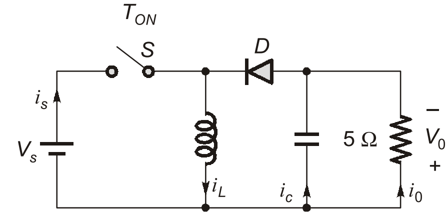
$$V_0 = \frac{\alpha V_S}{1-\alpha}$$
$$V_S = 50 \text{ V}$$
$$\alpha = 0.6$$
$$V_0 = 75 \text{ V}$$

$$\frac{V_0}{V_S} = \frac{I_S}{I_0} = \frac{\alpha}{1-\alpha} = \frac{0.6}{1-0.6} = \frac{0.6}{0.4} = \frac{3}{2}$$

$$I_0 = \frac{V_0}{R} = \frac{75}{5} = 15 \text{ A}$$

$$I_S = \frac{\alpha}{1-\alpha} \cdot I_0 = \frac{3}{2} \times 15 = 22.5 \text{ A}$$




Since capacitor is very large $i_C = 0$ at steady state

$$(i_L)_{avg} = (i_S)_{avg} + (i_0)_{avg}$$
$$I_L = I_S + I_0$$
$$I_L = 22.5 + 15 = 37.5 \text{ A}$$
$$\therefore \quad I_L = 37.5 \text{ A}$$

$$\Delta I_L = \frac{\alpha V_S}{fL} = \frac{0.6 \times 50}{10 \times 10^3 \times (0.6 \times 10^{-3})} = 5 \text{ A}$$

$$(i_L)_{peak} = I_L + \frac{\Delta I_L}{2} = 37.5 + \frac{5}{2} = 40 \text{ A}$$

∴ Peak value of current drawn from source

$$= (i_L)_{peak} = 40 \text{ A}$$

**T12 : Solution**

(a, c)

$$I_o = 10 \text{ A}$$
$$\alpha = 0.45$$
$$f = 80 \text{ kHz}$$
$$L = 10 \text{ mH}$$
$$C = 120 \text{ μF}$$

$$I_S = I_L = \frac{I_o}{1-\alpha} = \frac{10}{1-0.45} = 18.18 \text{ A}$$

$$\Delta V_C = AV_o = \frac{\alpha I_o}{fC} = \frac{0.45 \times 10}{80 \times 10^3 \times 120 \times 10^{-6}} = 0.468 \text{ V}$$

$$I_{s\omega} = \alpha I_s = 0.45 \times 18.18 = 8.18 \text{ A}$$

**T13 : Solution**

(a)

Apply boundary conditions,

$$I_L = \frac{\Delta I_L}{2}$$

Inductor current, $$I_L = \frac{I_o}{1-D}$$

∴ $$\frac{I_o}{1-D} = \frac{DV_s}{2fL}$$

$$\frac{V_s}{R(1-D)^2} = \frac{DV_s}{2fL}$$

$$f = \frac{D(1-D)^2 R}{2L} = \frac{0.6 \times (1-0.6)^2 \times 50}{2 \times 100 \times 10^{-6}}$$

$$f = 24 \text{ kHz}$$

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# 4 Inverters

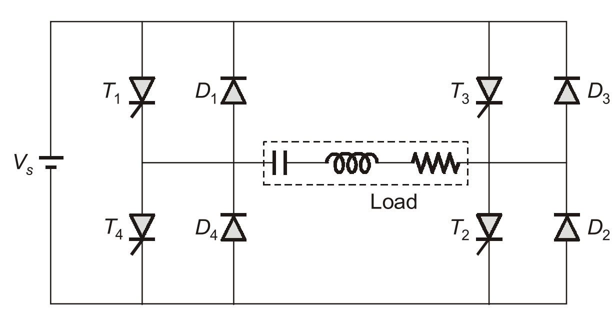
## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

$$R_\Delta = 30\ \Omega\text{/phase}$$
$$R_Y = 10\ \Omega\text{/phase}$$
$$V_{0,\text{ line}} = V_s\sqrt{\frac{2}{3}}$$
$$V_{0,\text{ phase}} = \frac{V_s\sqrt{2}}{3} = \frac{600\sqrt{2}}{3} = 200\sqrt{2}\text{ V}$$
$$P_0 = \frac{3V_{0,\text{phase}}^2}{R} = \frac{3\times(200\sqrt{2})^2}{10} = 24\text{ kW}$$

**T2 : Solution**

(a)




(a) Distortion factor, $$g = \frac{\text{Fundamental RMS Voltage}}{\text{Total RMS Voltage}}$$

$$g = \frac{V_{o1}}{V_{or}}$$

For 1-phase full bridge,

$$V_{o1} = \frac{2\sqrt{2}}{\pi}V_s$$

$$V_{or} = V_s$$

$$\therefore \quad g = \frac{2\sqrt{2}}{\pi} = 0.9$$

Total harmonic distortion,

$$\text{THD} = \sqrt{\frac{1}{g^2}-1}$$

$$\text{THD} = 48.34\%$$

(b) For 1-phase full bridge
Fourier series of output voltage

$$V_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi}\sin n\omega t$$

For RLC load

$$Z_n = R + j(X_{Cn} - X_{Cn})$$

$$|Z_n| = \sqrt{R^2 + (X_{Cn} - X_{Ln})^2}$$

$$\phi_n = \tan^{-1}\left(\frac{X_{Cn} - X_{Ln}}{R}\right)$$

Therefore, fourier series of load current

$$i_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi|Z_n|}\sin(n\omega t - \phi_n)$$

(c) Distortion factor, $g = \frac{I_{o1}}{I_{or}}$

$n^{th}$ harmonic current, $I_{on} = \frac{4V_s}{n\pi Z_n}\sin(n\omega t - \phi_n)$

$$\therefore \quad I_{o1} = \frac{4V_s}{\pi Z_n}\sin(\omega t - \phi_1)$$

Rms output current, $I_{or} = \sqrt{I_{o1}^2 + I_{o3}^2 + I_{o5}^2 + \ldots..}$

$$g = \frac{I_{o1}}{I_{or}} = 0.988$$

$$\text{THD\%} = \left(\sqrt{\frac{1}{g^2}-1}\right)\times 100 = 15.55\%$$

(d) Load power, $P = I_{or}^2.R$
Considering only fundamental component of load current,

$$I_{or} = (I_{o1})_{rms}$$

$$(I_{o1})_{rms} = \frac{4V_s}{\pi Z_1}\times\frac{1}{\sqrt{2}}$$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$$= \frac{4 \times 220}{\pi \times \sqrt{\frac{1}{\omega C} - \omega L}} \times \frac{1}{\sqrt{2}}$$

$$= 19.402$$

$$P = I_{o1}^2 . R = 2258.74 \text{ W}$$

Average DC source current,

$$I_s = \frac{1}{\pi}\int_0^{\pi} \sqrt{2} I_{o1} \sin(\omega t + 54°) d\omega t$$

$$= 10.52 \text{ A}$$

(e) Conduction angle of diode,

$$\phi = \tan^{-1} \frac{\left(\frac{1}{\omega C} - \omega L\right)}{R}$$

$$= 54° \text{ or } \frac{3}{10}\pi$$

Conduction time of diode,

$$\omega t_c = 54° \text{ or } \frac{3}{10}\pi$$

$$t_c = 3 \text{ mS}$$

Conduction angle of transistor,

$$\pi - \phi = 126° \text{ or } \frac{7}{10}\pi$$

Conduction time of transistor,

$$\omega t_c = 126° \text{ or } \frac{7}{10}\pi$$

$$t_c = 7 \text{ mS}$$

(f)

$$(V_{o1})_{\text{rms}} = \frac{4V_s}{\sqrt{2} \times \pi} = 198.07 \text{ V}$$

$$(I_{o1})_{\text{rms}} = \frac{(V_{o1})_{\text{rms}}}{Z} = \frac{198.07}{\sqrt{k^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}} = 19.402$$

$$\phi_1 = 54° \text{ or } \frac{3}{10}\pi$$

$$(I_{T1})_{\text{peak}} = 19.402 \times \sqrt{2} = 27.44 \text{ A}$$

$$(I_{T1})_{\text{rms}} = \left[\frac{1}{2\pi}\int_0^{\frac{7}{10}\pi} (I_m \sin\omega t)^2 d(\omega t)\right]^{1/2}$$

$$= 12.66 \text{ A}$$

**T3 : Solution**

For 120° mode

$$V_L = \frac{V_S}{\sqrt{2}}$$

For Δ load :

$$V_{Ph} = V_L = \frac{V_S}{\sqrt{2}}$$

$$I_{Phase} = \frac{V_{Ph}}{r} = \frac{V_S}{\sqrt{2}r} = \frac{200}{\sqrt{2}\times 15}$$

$$P = 3I^2_{Phase}r = 3\times\left(\frac{200}{\sqrt{2}\times 15}\right)^2\times 15$$

$$= 4 \text{ kW}$$

**T4 : Solution**

(d)

**T5 : Solution**

(d)

As $V_o < 0$, $(Q_3, D_3)$ and $(Q_4, D_4)$ should work.

Also $P = v_o\, i_o$

As $I_o > 0$

$P < 0$

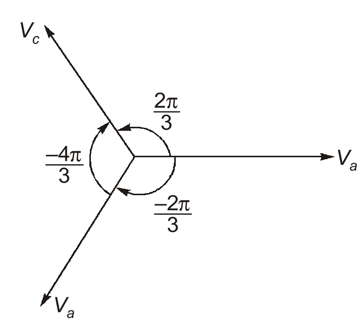
Power is being feedback.

So, $D_3$ and $D_4$ are working.

**T6 : Solution**

$$V_a = V_{1m}\sin\omega t + V_{5m}\sin(5\omega t) + V_{7m}\sin(7\omega t)$$

$$V_b = V_{1m}\sin\left(\omega t - \frac{2\pi}{3}\right) + V_{5m}\sin 5\left(\omega t - \frac{2\pi}{3}\right) + V_{7m}\sin 7\left(\omega t - \frac{2\pi}{3}\right)$$




$$V_b = V_{1m}\sin\left(\omega t - \frac{2\pi}{3}\right) + V_{5m}\sin\left(5\omega t + \frac{2\pi}{3}\right) + V_{7m}\sin\left(7\omega t - \frac{2\pi}{3}\right)$$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**T7 : Solution**

(b)

- The circuit shown in the figure is a single phase bridge auto sequential commutated inverter (1-phase ASCI).
- Thyristor pairs $T_1$, $T_2$ and $T_3$, $T_4$ are alternatively switches to obtain a nearly square wave load current. Two commutating capacitors, one $C_1$ in the upper half and the other $C_2$ in the lower half are connected as shown.
- Diodes $D_1$ to $D_4$ are connected in series with each SCR to prevent the commutation capacitors from discharging into the load.

The inverter output frequency is controlled by adjusting the period $T$ through the triggering circuits of thyristors.

The theoretical maximum output frequency obtainable

$$f_{max} = \frac{1}{4\,RC} = \frac{1}{4 \times 10 \times 0.1 \times 10^{-6}} = 250 \text{ kHz}$$

**T8 : Solution**

(a)

Device used in current source inverter (CSI) must have reverse voltage blocking capacity. Therefore, devices such as GTOs, power transistors and power MOSFETs cannot be used in a CSI. So, a diode is added in series with the devices for reverse blocking.

**T9 : Solution**

(c)

$$V_S = 600 \text{ V}$$

$$M_A = 1$$

$$\hat{V}_{L1} = \sqrt{3} M_A \cdot \frac{V_S}{2}$$

$$V_{L1,rms} = \left(\frac{\sqrt{3}}{2\sqrt{2}}\right) M_A V_S$$

$$= \frac{\sqrt{3}}{2\sqrt{2}} \times 600 = 367.4 \text{ V}$$

**T10 : Solution**

The output voltage $V_0$ can be represented by Fourier series as under:

$$V_0 = \sum_{n=1,3,5,...}^{\infty} a_n \cos n\omega t + b_n \sin n\omega t$$

where,

$$a_n = \frac{2}{T}\int_0^T f(t)\cos n\omega t \; d(\omega t)$$

$$b_n = \frac{2}{T}\int_0^T f(t)\sin n\omega t \; d(\omega t)$$

$$a_n = \frac{1}{\pi}\left[\int_0^{\alpha} 100\cos\omega t\, d(\omega t) + \int_{\alpha}^{180^\circ-\alpha} (-100)\cos\omega t\, d(\omega t)\right.$$
$$+ \int_{180^\circ-\alpha}^{180^\circ} 100\cos\omega t\, d(\omega t) + \int_{180^\circ}^{180^\circ+\alpha} -100\cos\omega t\, d(\omega t)$$
$$\left.+ \int_{180^\circ+\alpha}^{360^\circ-\alpha} 100\cos\omega t\, d(\omega t) + \int_{360^\circ-\alpha}^{360^\circ} -100\cos\omega t\, d(\omega t)\right]$$

$$a_n = \frac{100}{\pi}[\sin\alpha - \sin(180^\circ - \alpha) + \sin\alpha + \sin(180^\circ) - \sin(180^\circ - \alpha)$$
$$- \sin(180^\circ + \alpha) + \sin 180^\circ + \sin(360^\circ - \alpha) - \sin(180^\circ + \alpha)$$
$$- \sin 360^\circ + \sin(360^\circ - \alpha)]$$

$$a_n = 0$$

$$b_n = \frac{1}{\pi}\left[\int_0^{\alpha} 100\sin\omega t\, d(\omega t) + \int_{\alpha}^{180^\circ-\alpha} -100\sin\omega t d(\omega t)\right.$$
$$+ \int_{180^\circ-\alpha}^{180^\circ} 100\sin\omega t\, d(\omega t) + \int_{180^\circ}^{180^\circ+\alpha} -100\sin\omega t\, d(\omega t)$$
$$\left.+ \int_{180^\circ+\alpha}^{360^\circ-\alpha} 100\sin\omega t\, d(\omega t) + \int_{360^\circ-\alpha}^{360^\circ} -100\sin\omega t\, d(\omega t)\right]$$

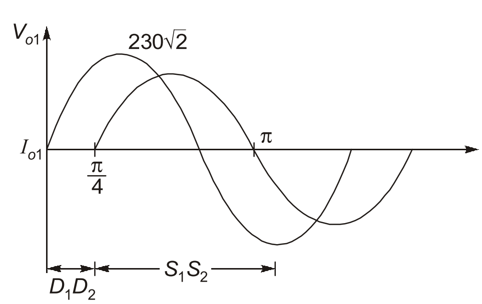
$$b_n = \frac{100}{\pi}[-\cos\alpha + 1 + \cos(180^\circ - \alpha) - \cos\alpha - \cos 180^\circ + \cos(180^\circ - \alpha)$$
$$+ \cos(180^\circ + \alpha) - \cos 180^\circ - \cos(360^\circ - \alpha) + \cos(180^\circ + \alpha)$$
$$+ \cos 360^\circ - \cos(360^\circ - \alpha)]$$

$$b_n = \frac{100}{\pi}[4 - 8\cos\alpha] = 50\sqrt{2}$$

$$\cos\alpha = 0.22231 = 77.15^\circ$$

**T11 : Solution**

$$V_{01} = 230\text{ V}$$
$$\hat{V}_{01} = 230\sqrt{2}$$




$$\hat{I}_{o1} = \frac{V_{o1}}{|Z_1|} = \frac{230\sqrt{2}}{\sqrt{R^2 + (X_L - X_C)^2}}$$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$$= \frac{230\sqrt{2}}{\sqrt{2^2+(8-6)^2}} = 115 \text{ A}$$

$$\phi_1 = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) = \tan^{-1}\left(\frac{8-6}{2}\right) = 45° = \frac{\pi}{4}$$

$$i_{o1} = 115\sin\left(\omega t - \frac{\pi}{4}\right)$$

$$I_{s1,\text{rms}} = \left\{\frac{1}{2\pi}\int_{\pi/4}^{\pi} 115^2 \sin^2\left(\omega t - \frac{\pi}{4}\right) d\omega t\right\}^{\frac{1}{2}}$$

$$Is_{1,\text{rms}} = \left\{\frac{1}{2\pi}\int_{0}^{3\pi/4} 115^2 \sin^2 \omega t d(\omega t)\right\}^{\frac{1}{2}} = 54.826 \text{ A}$$

**T12 : Solution**

Applying fourier series

$$a_n = 0$$

$$b_n = \frac{4V_s}{n\pi}[1 - \cos n\alpha_1 + \cos n\alpha_2]$$

To eliminate 3rd and 5th harmonic

$$b_3 = 1 - \cos 3\alpha_1 + \cos 3\alpha_2 = 0$$
$$b_5 = 1 - \cos 5\alpha_1 + \cos 5\alpha_2 = 0$$
$$\alpha_1 = 17.83°$$
$$\alpha_2 = 37.96°$$

**T13 : Solution**

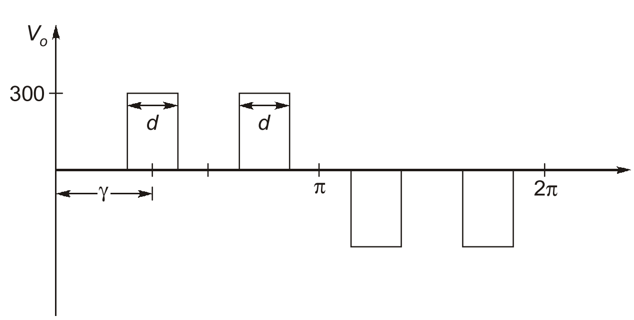
(a) Rms output voltage,

$$V_{or} = V_s\left[\frac{2d}{\pi}\right]^{1/2}$$

$$= 141.42 \text{ V}$$

(b) Fourier series of output voltage waveform

$$V_o = \sum_{n=1,3,5}^{\infty} \frac{8V_s}{n\pi} \sin n\gamma \sin\frac{nd}{2} \sin n\omega t$$



Peak value of 3rd harmonic,

$$\hat{V}_{o3} = \frac{8V_s}{3\pi}\sin(3\times 45°)\sin\frac{3\times 20}{2}$$

$$\hat{V}_{o3} = 90.03 \text{ V}$$

(c) Rms value of fundamental voltage,

$$(V_{o1})_{rms} = \frac{\frac{8V_s}{\pi}\sin\gamma\sin\frac{d}{2}}{\sqrt{2}}$$

$$(V_{o1})_{rms} = 66.328 \text{ V}$$

(d) 5th harmonic voltage,

$$V_{o5} = \frac{8V_s}{5\pi}\sin(5\times 45°)\sin\frac{5\times 20}{2}$$

$$= -82.76$$

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# 5 Resonant Converters and Power Electronics Applications (Drives & SMPS)

## Detailed Explanation of Try Yourself Questions

**T1 : Solution**

At $t = 0$, steady state exists and therefore, generated torque = load torque

$$T_e = T_L$$

In general, the dynamic equation for the motor load combination is
generated torque = inertia torque + friction torque + load torque

$$T_e = J\frac{d\omega_m}{dt} + D\omega_m + T_L$$

As friction torque is zero,

$$D\omega_m = 0$$

The differential equation, governing the speed of the drive at $t > 0$,

$$T_e = J\frac{d\omega_m}{dt} + T_L$$

$$100 = 0.01\frac{d\omega_m}{dt} + 40 \quad \text{...}(i)$$

$$\frac{d\omega_m}{dt} = 6000$$

$$dt = \frac{d\omega_m}{6000}$$

Its integration gives, $$t = \frac{\omega_m}{6000} + A \quad \text{...}(ii)$$

Initial speed at $t = 0^+$ remains 500 rpm. Therefore,

$$\omega_{m0} = \frac{2\pi \times 500}{60} = \frac{100\pi}{6} \text{ rad/sec}$$

Substituting this value in equation (*ii*),

$$0 = \frac{1}{6000} \times \frac{100\pi}{6} + A \quad \text{or} \quad A = \frac{-\pi}{360}$$

$$t = \frac{\omega_m}{6000} - \frac{\pi}{360}$$

Final speed, $\omega_m = \frac{2\pi \times 1000}{60} = \frac{200\pi}{6}$ rad/sec

$$t = \frac{200\pi}{6000 \times 6} - \frac{\pi}{360} = \frac{\pi}{360} \text{ sec } = 0.0873 \text{ sec}$$

$\therefore$ Time taken for the speed to reach 1000 rpm = 0.0873 sec $\simeq$ 87.3 msec

**T2 : Solution**

(a)

**T3 : Solution**

(c)

**T4 : Solution**

(a)

$$V_S = 400 \text{ V}$$
$$R_a = 0.2\ \Omega$$
$$K_m = 1.2 \text{ V-s/rad}$$
$$I_o = 300 \text{ A (constant)}$$
$$N_{min} = ?,\ N_{max} = ?$$
$$E_b = V_o + I_o R_a \qquad [V_o = (1-\alpha)V_s]$$
$$k_m \frac{2\pi}{60} N = V_o + I_o R_a \qquad \left[E_b = k_m \omega = k_m \frac{2\pi}{60} N\right]$$
$$k_m \frac{2\pi}{60} N_{min} = (V_o)_{min} + I_o R_a$$
$$k_m \frac{2\pi}{60} N_{min} = 0 + I_o R_a$$
$$\frac{1.2 \times 2\pi}{60} N_{min} = 300 \times 0.2$$
$$N_{min} = 477 \text{ rpm}$$

Similarly,

$$k_m \frac{2\pi}{60} N_{max} = V_o + I_o R_a$$
$$k_m \frac{2\pi}{60} N_{max} = V_s + I_o R_a$$
$$1.2 \times \frac{2\pi}{60} N_{max} = 400 + 300 \times 0.2$$
$$N_{max} = 3660 \text{ rpm}$$


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**T5 : Solution**

$$N_{S1} = 3000 \text{ rpm} \qquad \text{(synchronous speed at 50 Hz)}$$

$$N_1 = 2850 \text{ rpm} \qquad \text{(motor speed at 50 Hz)}$$

$$S_{FL} = \frac{3000 - 2850}{3000} = 0.05 \qquad \text{(rated slip at 50 Hz)}$$

where, by ($V/f$) control,

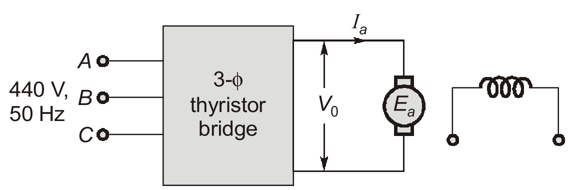
$$N_{S2} = 3000\left(\frac{40}{50}\right) = 2400 \text{ rpm} \qquad \text{(synchronous speed at 40 Hz)}$$

$\therefore$ $N_2$ = New running speed of motor

$$N_{s2}\left(1 - \frac{S_{FL}}{2}\right) = 2400\left(1 - \frac{0.05}{2}\right) = 2340 \text{ rpm}$$

**T6 : Solution**

(a)




For a separately excited DC motor

$$\text{Back emf} = E_a = V_0 - I_a R_a$$

Since, losses are neglected $R_a$ can be neglected

So,
$$E_a \approx V_0$$

$$V_0 = E_a = k_a \phi N \qquad \text{...(i)}$$

$$V_0 \propto N$$

At rated voltage $V_0 = 440$ V and $N = 1500$ rpm so, at half the rated speed. $\left(\frac{N}{2} = 750 \text{rpm}\right)$ output voltage of the bridge ($V_0$) is 220 V.

If $I_a$ is the average value of armature current rms value of supply current will be

$$I_s = I_a\sqrt{\frac{2}{3}}$$

Power delivered to the motor

$$P_0 = V_0 I_a$$

Input VA to the thyristor bridge

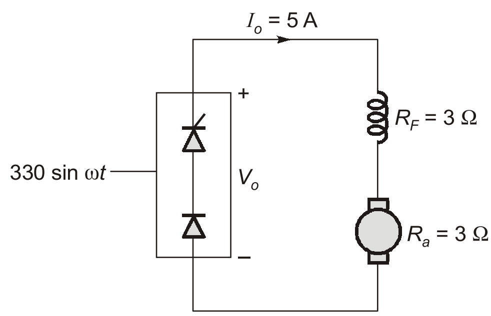
$$S_{in} = \sqrt{3} V_s I_s$$

Input power factor

$$= \frac{P_0}{S_{in}} = \frac{V_0 I_a}{\sqrt{3} V_s I_s} = \frac{220 \times I_a}{\sqrt{3} \times 440 \times I_a\sqrt{\frac{2}{3}}} = 0.354$$

**T7 : Solution**

(4.98)




$$\alpha = 45°$$
$$N = 1450 \text{ rpm}$$
$$T_a \propto \phi I_a$$
$$T_a = K_m I_o \quad \text{(If flux is constant)}$$
$$E_b = K_m \omega = K_m \frac{2\pi}{60} N$$
$$V_o = E_b + I_a(R_a + R_F)$$
$$\frac{V_m}{\pi}(1+\cos\alpha) = K_m \frac{2\pi}{60} N + 5(3+3)$$
$$\frac{330}{\pi}(1+\cos 45°) = K_m \frac{2\pi}{60} \times 1456 + 5 \times (3+3)$$
$$K_m = 0.98 \text{ V-s/rad}$$
$$T = 0.98 \times 5 = 4.9 \text{ Nm}$$

**T8 : Solution**

At rated torque,
$$I_o = 100 \text{ A}$$
$$V_o = E_b + I_o R_a$$
$$V_o = K_m \frac{2\pi}{60} \cdot N + I_o R_a$$
$$220 = K_m \frac{2\pi}{60} \times 2100 + 100 \times 0.1$$
$$K_m = 0.955$$
$$V_o = E_b + I_o R_a$$
$$\alpha V_S = k_m \cdot \frac{2\pi}{60} N + I_o R_a$$
$$0.4 \times 250 = 0.955 \times \frac{2\pi}{60} N + 100 \times 0.1$$
$$N = 900 \text{ rpm}$$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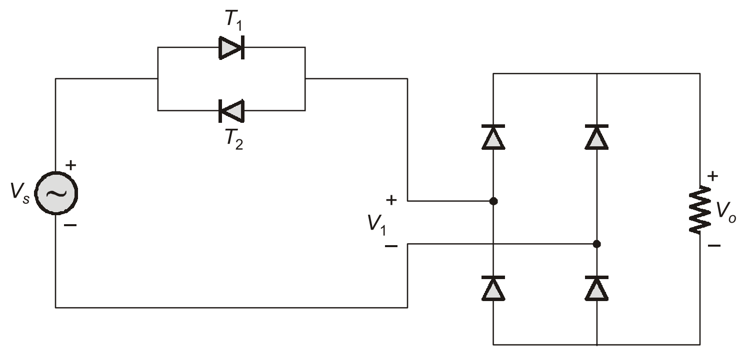
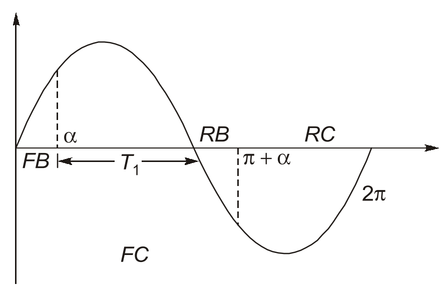
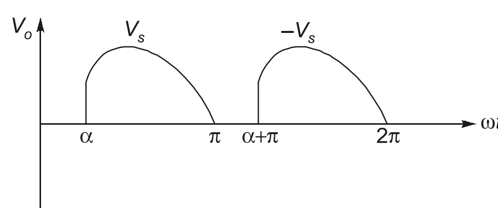
**T9 : Solution**




$$V_{or} = \frac{V_m}{\sqrt{2\pi}}\left\{(\pi - \alpha) + \frac{1}{2}\sin 2\alpha\right\}^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{2}$$

$$\therefore \quad I_{or} = \frac{V_{or}}{R} = \frac{V_m}{2R} = \frac{200\sqrt{2}}{2\times\frac{10}{\sqrt{2}}} = 20\text{ A}$$

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