ESE GATE PSUs

State Engg. Exams

MADE EASY Workbook 2024

Detailed Explanations of Try Yourself *Questions*

ELECTRICAL ENGINEERING

Power Electronics & Drives

MADE EASY Publications

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, $-V + L\frac{di}{dt} = 0$

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

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

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

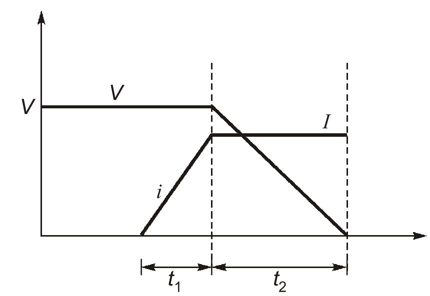
$$t_{min} = \frac{0.1}{100} \times 4 \times 10^{-3} = 4\ \mu s$$

∴ 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,

$$\text{power loss} = vi$$

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

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

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

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

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

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

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

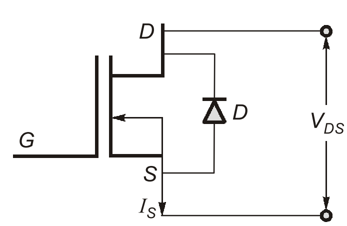
$$E_2 = I\int vdt = \frac{1}{2} VIt_2 \quad ...(ii)$$

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.

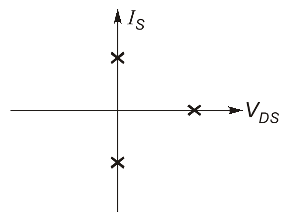
So, $I_S < 0$ and $V_{DS} = 0$

When MOSFET is in ON state,

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

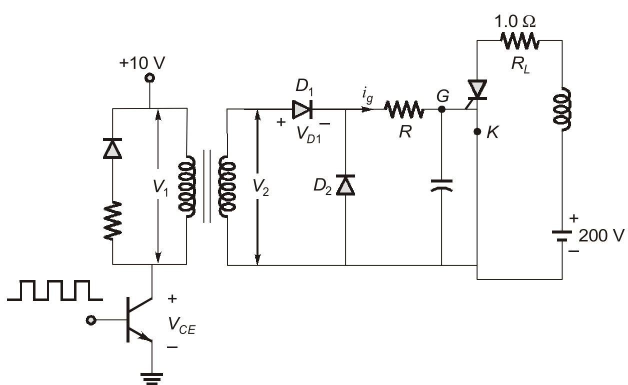
When MOSFET is in OFF state,

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



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,

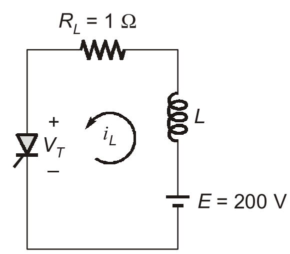
$$V_R = V_2 - V_{D1} - V_{gk} = 9 - 1 - 1 = 7 \text{ V}$$

To ensure turn –ON of SCR,

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

T7 : Solution

(a)



Forward voltage drop of SCR during ON-state

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

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

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

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

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

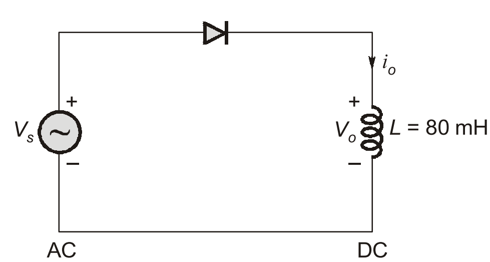
Magnitude of voltage, $V = 10 \text{ V}$

Voltage second rating of PT

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

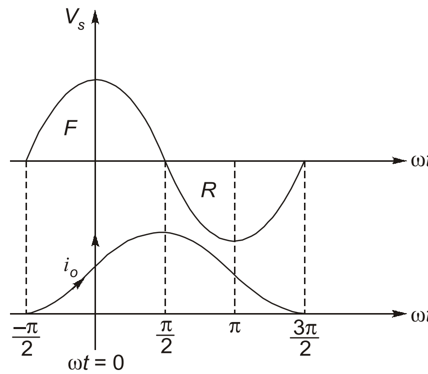
T8 : Solution

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

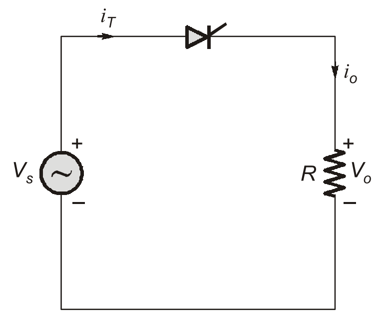
$$i_{peak} = \frac{V_m}{\omega L}\sin\frac{\pi}{2} + \frac{V_m}{\omega L}$$

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

$$= 18.31 \text{ A}$$

T9 : Solution

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



$$i_T = i_o$$

$$\text{Form factor} = \frac{(I_T)_{\text{RMS}}}{(I_T)_{\text{Avg}}} = \frac{I_{or}}{I_o} = \frac{V_{or}/R}{V_o/R} = \frac{V_{or}}{V_o}$$

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

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

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)

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

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

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

■■■■

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

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

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

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

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

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

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

$$K = 7.07$$

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

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

$$= 17.07 \text{ A}$$

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

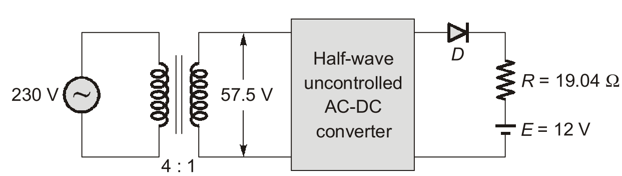
It is seen from the table that *TUF* for 1-phase half-wave diode rectifier is 0.2865.

$\therefore$ 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)



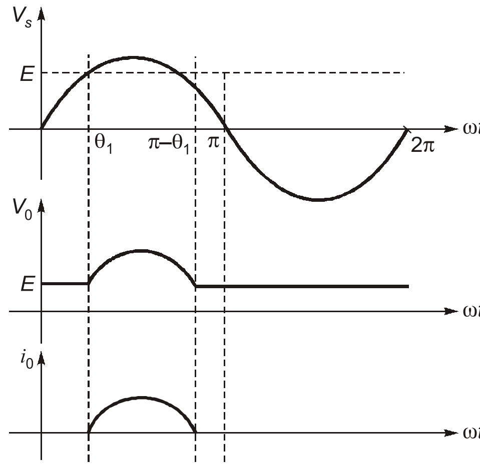
Input to the converter, $$V_s = \left(\frac{1}{4}\right)230 = 57.5 \text{ V}$$

Diode conducts when $V_s \geq E$

$$V_m \sin\theta_1 = E$$

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

$$\theta_1 = 8.486° \text{ or } 0.148 \text{ rad}$$



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

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

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

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

$$= 1.05 \text{ A}$$

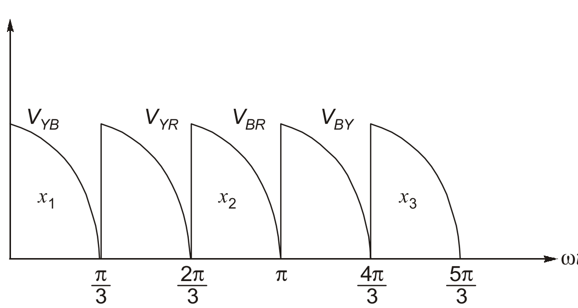
T5 : Solution

(d)

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

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

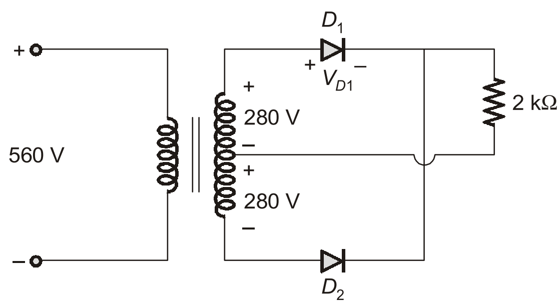
Upper limit, $U = 120 + \alpha = 180° = \pi$ rad



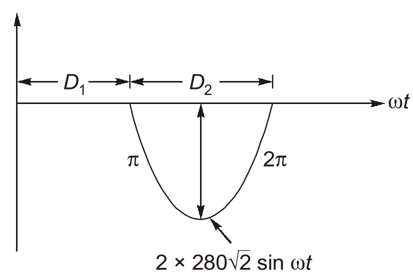
$x_1 \rightarrow V_{RY}$
$x_2 \rightarrow V_{YB}$
$x_3 \rightarrow V_{BR}$

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)

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

$$i = 10\sqrt{2}\sin\left(100\pi t - \frac{\pi}{3}\right) + 5\sqrt{2}\sin\left(300\pi t + \frac{\pi}{4}\right) + 2\sqrt{2}\sin\left(500\pi t - \frac{\pi}{6}\right) \text{ A}$$

$$\text{Active power} = V_{sr} \cdot I_{s1} \cos \phi_1$$
$$= 100 \times 10 \times \cos 60°$$
$$= 500 \text{ W}$$

T9 : Solution

(b)

Rms value of input voltage,

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

Rms value of current,

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

Let input power factor $\cos \phi$

$V_{rms} I_{rms} \cos \phi$ = 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)

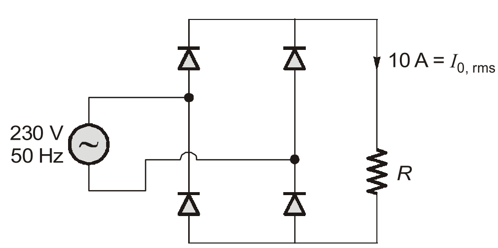
$$i_s \propto \frac{I_a}{n} \cdot \cos\frac{n\pi}{6} \qquad \text{where } n \in 1, 3, 5$$

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

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

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

T11 : Solution



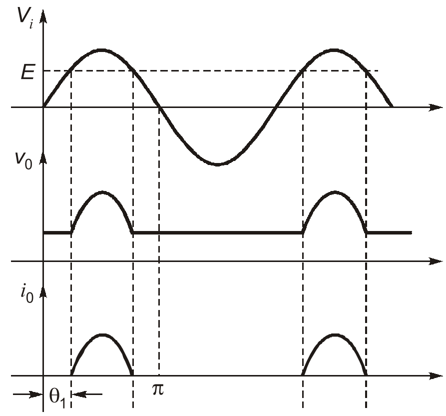
$$I_{0,\,rms} = \frac{V_s}{R} \Rightarrow R = \frac{230}{10} = 23\ \Omega$$

T12 : Solution

(c)

T_1 and T_4 gets forward biased, when

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



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

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

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

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

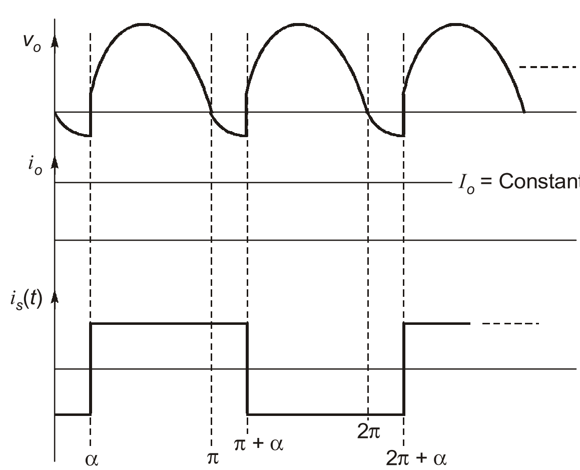
where, $$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$$

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

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

T13 : Solution

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



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
1st, 3rd, 5th, 7th : all odd frequencies.
Two most dominant harmonics are 3rd and 5th, i.e., 150 Hz and 250 Hz.
Two most dominant frequencies are 1st and 3rd, i.e., 50 Hz and 150 Hz.
Except fundamental, all other frequencies are harmonics in supply current.

T14 : Solution

1-ϕ, 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,

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

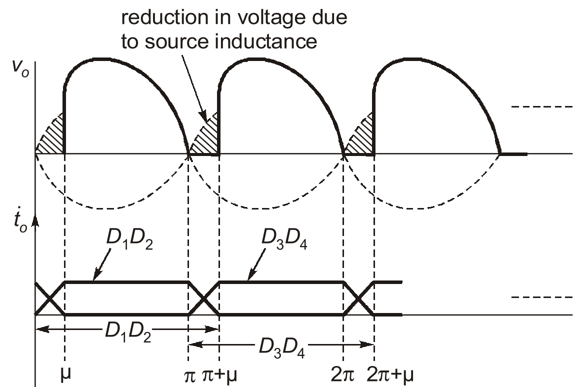
$$800\, I_o = I_o^2(20) + 200 I_o \Rightarrow I_o = 30 \text{ A}$$

$$I_o = I_{or}$$

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

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

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

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

$$V_0 = E_b + I_0R_a$$

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

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

$$\alpha = 90°$$

T18 : Solution

(0.78)

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

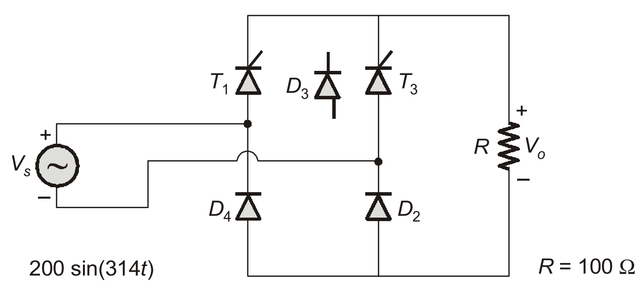
For single-phase fully controlled converter,

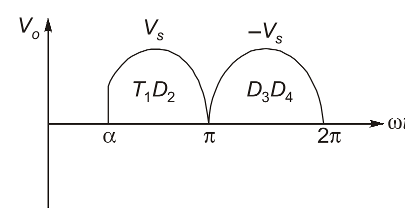
$$I_0 = I_{sr} = 10 \text{ A}$$

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

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,

$$t_c = \frac{CV_s}{I_0} = \frac{8\times10^{-6}\times250}{20} = 1\times10^{-4}\ s$$

Maximum value of duty cycle,

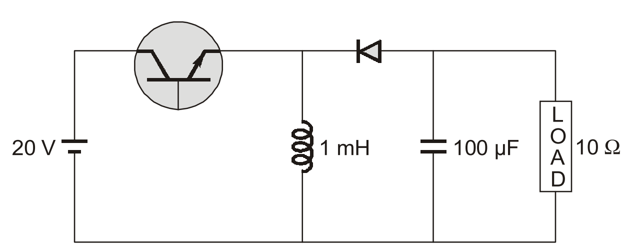
$$\alpha_{max} = (1-2ft_c)$$
$$= (1-2\times250\times1\times10^{-4})$$
$$\alpha_{max} = 0.95$$

maximum load or output voltage,

$$V_{0,\,max} = V_s[\alpha_{max}+2ft_c]$$
$$= 250\left[0.95+(2\times250\times1\times10^{-4})\right]$$
$$V_{0,\,max} = 250\text{ V}$$

T2 : Solution

(24)



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

Assume continous conduction:

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

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

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

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

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

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

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

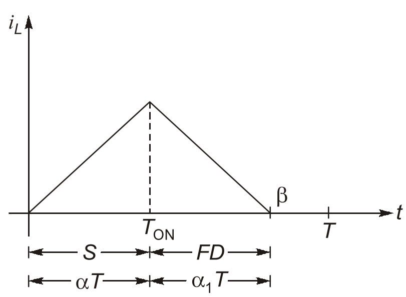
$(I_{L\,min} = 23.1 \text{ A}) > 0$

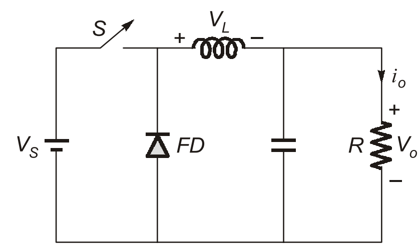
∴ Continous conduction assumption is correct.

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

T3 : Solution

(c)





$S \to$ ON :

KVL :

$$-V_S + V_L + V_o = 0$$

$$V_L = V_S - V_o$$

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

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

$S \to$ OFF, $FD \to$ ON

$$V_L + V_o = 0$$

$$V_L = -V_o$$

$$L\frac{di_L}{dt} = -V_o$$

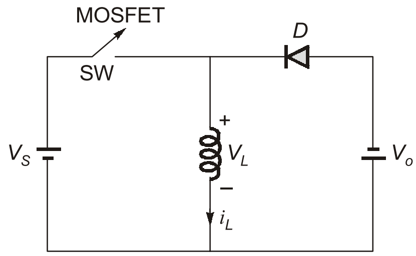
$$\frac{di_L}{dt} = \frac{-V_o}{L}$$

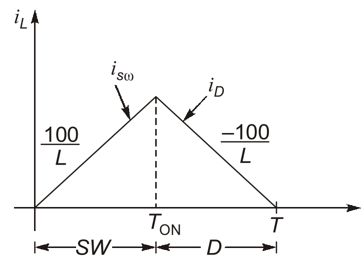
$R\uparrow, I_o\downarrow$

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

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

T4 : Solution





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

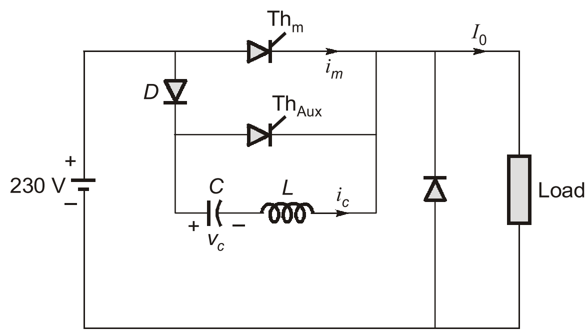
At the boundary, $0 \geq t \leq T_{ON}$

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

Condition power loss in MOSFET
$$= I^2{}_{s\omega,rms}.R_{DS} = 4.1667 \times 1 = 4.1667\text{ W}$$

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 $t_1 = 50$ μsec.

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

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

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

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

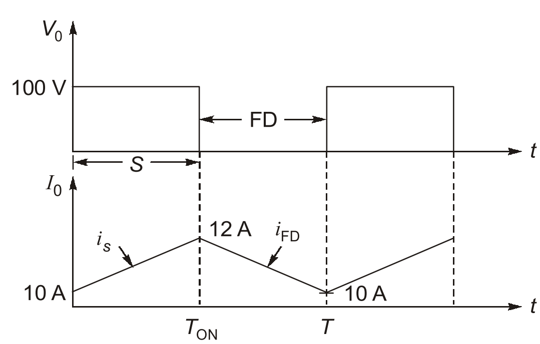
$$I_S = \frac{I_o}{1-\alpha} = \frac{3.75}{1-0.6} = 9.375A$$

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

T7 : Solution

(b)

Stepdown chopper:



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

$$V_0 = \alpha V_s$$

$S \rightarrow$ ON:

$$V_S = Ri_s + L\frac{di_s}{dt}$$

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

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

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

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

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

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

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

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

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

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

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 :

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

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

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

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

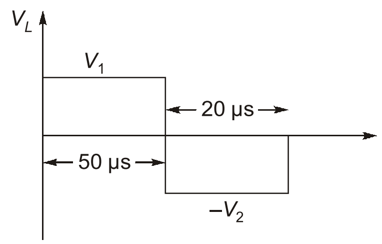
and $\quad V_{o(avg)} = \frac{T_{on}}{T} V_s$

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

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

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

T8 : Solution



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

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

T9 : Solution

(2500)

On the verge of discontinuity

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

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

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

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

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

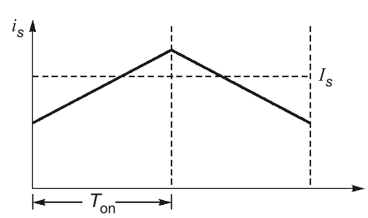
$$\frac{36}{R} = \frac{60 \times 0.4 \times 0.6}{2 \times 100 \times 10^3 \times 5 \times 10^{-3}}$$

On solving, $R = 2500\ \Omega$

T10 : Solution

(Sol)

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



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

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

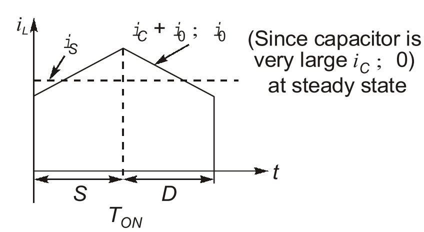
Buckboost converter,

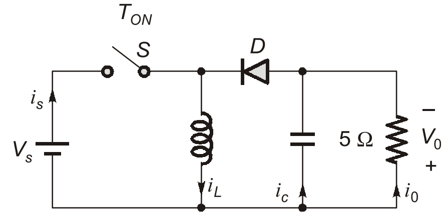
$$V_0 = \frac{\alpha V_S}{1-\alpha}$$
$$V_S = 50 \text{ V}$$
$$\alpha = 0.6$$
$$V_0 = 75 \text{ V}$$

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

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

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





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

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

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

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

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

■■■■

4 Inverters

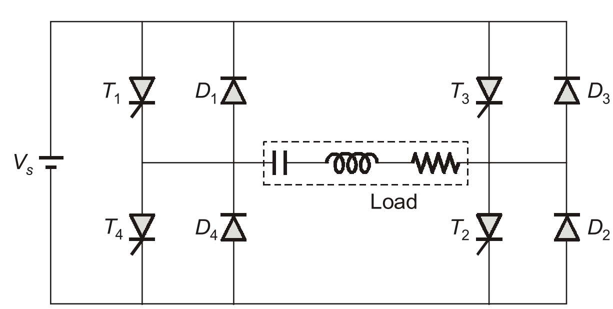
Detailed Explanation of Try Yourself Questions

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, $g = \dfrac{I_{o1}}{I_{or}}$

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

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

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,

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

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

$$= \frac{4\times 220}{\pi \times \sqrt{\frac{1}{\omega C} - \omega L}} \times \frac{1}{\sqrt{2}}$$

$$= 19.402$$

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

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 :

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

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

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

$$= 4 \text{ kW}$$

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 $I_o > 0$

$P < 0$

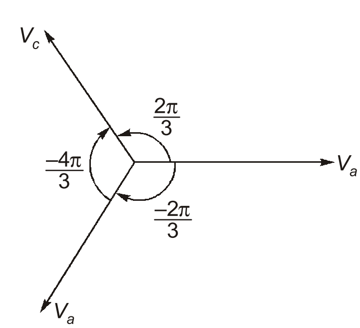
Power is being feedback.

So, D_3 and D_4 are working.

T6 : Solution

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

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



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

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,

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

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

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

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

$$a_n = 0$$

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

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

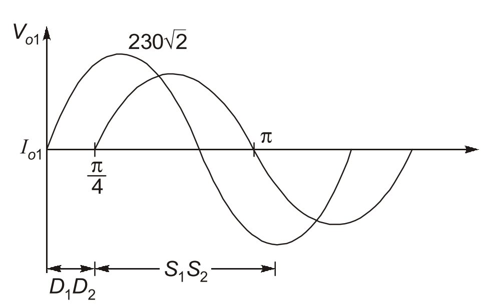
$$b_n = \frac{100}{\pi}[4 - 8\cos\alpha] = 50\sqrt{2}$$

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

T11 : Solution

$$V_{01} = 230\text{ V}$$

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



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

$$= \frac{230\sqrt{2}}{\sqrt{2^2+(8-6)^2}} = 115 \text{ A}$$

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

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

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

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

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

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

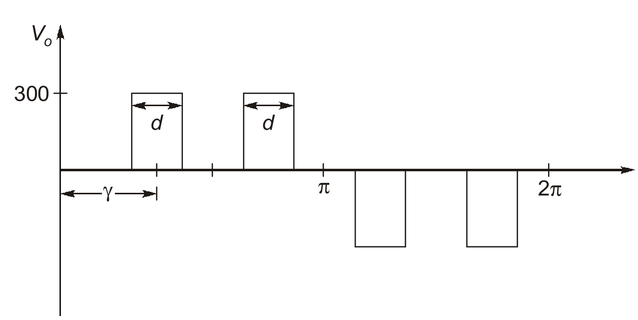
T13 : Solution

(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, $\omega_m = \dfrac{2\pi \times 1000}{60} = \dfrac{200\pi}{6}$ rad/sec

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

∴ Time taken for the speed to reach 1000 rpm = 0.0873 sec ≃ 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,

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

T5 : Solution

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

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

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

where, by (V/f) control,

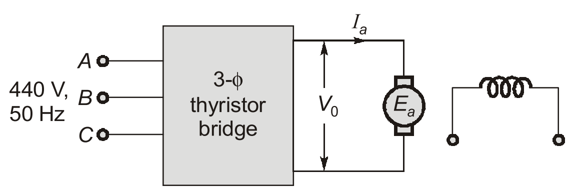
$$N_{S2} = 3000\left(\frac{40}{50}\right) = 2400 \text{ rpm} \quad \text{(synchronous speed at 40 Hz)}$$

∴ 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,

$$E_a \approx V_0$$

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

$$V_0 \propto N$$

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

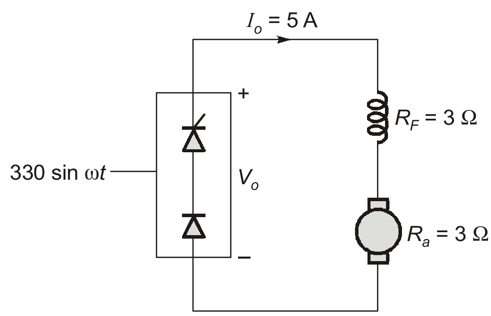
$$S_{in} = \sqrt{3} V_s I_s$$

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)

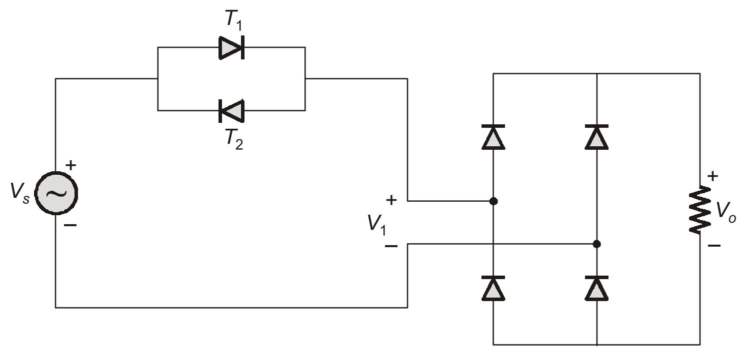


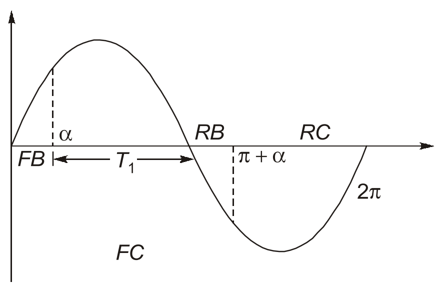
$$\alpha = 45°$$
$$N = 1450 \text{ rpm}$$
$$T_a \propto \phi I_a$$
$$T_a = K_m I_o \qquad \text{(If flux is constant)}$$
$$E_b = K_m \omega = K_m \frac{2\pi}{60} N$$
$$V_o = E_b + I_a(R_a + R_F)$$
$$\frac{V_m}{\pi}(1+\cos\alpha) = K_m \frac{2\pi}{60} N + 5(3+3)$$
$$\frac{330}{\pi}(1+\cos 45°) = K_m \frac{2\pi}{60}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

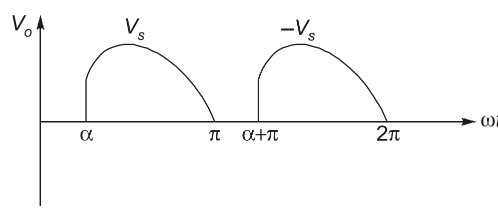
T8 : Solution

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

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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