2020

MADE EASY

WORKBOOK

Detailed Explanations of Try Yourself Questions

Electrical Engineering
Power Electronics

MADE EASY Publications

MADE EASY Publications

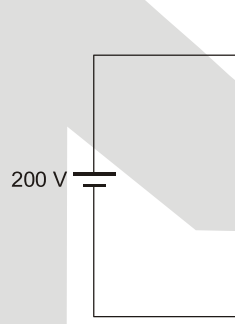
1 Power Semiconductor Devices

Detailed Explanation of Try Yourself Questions

T1 : Solution

The voltage equation for *RL* load is

$$E = Ri + L\frac{di}{dt}$$



$$i = \frac{E}{R}\left[1 - e^{-\frac{R}{L}t}\right]$$

$$0.1 = \frac{200}{20}\left[1 - e^{-100t}\right]$$

$$e^{-100t} = 0.99$$

$$t = 100.5\,\mu s$$

T2 : (c)

Option 2 and 4 allows current flow in both direction.

© Copyright

T3 : Solution

(d)

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

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

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

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

T4 : 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, $\int dt = \int \frac{L}{V}di$

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

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

T5 : 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

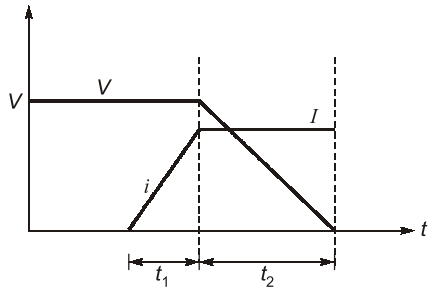
$$E_1 = \text{Energy loss} = \int vidt = V\int idt$$

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

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

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

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



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

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

MADE EASY Publications

2 Controlled and Uncontrolled Rectifiers

Detailed Explanation of Try Yourself Questions

T1 : Solution

(b)

Average current rating of SCR,

$$I_{TA} = \frac{I_0}{3} = \frac{36}{3} = 12 \text{ A}$$

Average power dissipated in each SCR

$$= I_{TA} \times V_T$$
$$= 12 \times 1.4 = 16.8 \text{ W}$$

T2 : 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

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

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

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

MADE EASY Publications

T3 : Solution

$$P = V_s I_s \cos\phi = V_0 I_0$$

$$\cos\phi = \frac{V_0 I_0}{V_s I_s}$$

$$V_0 = \frac{2V_m}{\pi}\cos\alpha$$

For ripple free load current,

$$I_0 = I_s$$

Input power factor, $$\cos\phi = \frac{\frac{2V_m}{\pi}\cos 30^\circ I_0}{\frac{V_m}{\sqrt{2}} I_0} = \frac{2\sqrt{2}}{\pi}\cos 30^\circ = 0.779$$

T4 : Solution

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

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

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

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

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

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

$$K = 7.07$$

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

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

$$= 17.07\text{ A}$$

T5 : Solution

(a)

The average output voltage for continuous ripple free output current is,

$$V_{0(av)} = \frac{3\sqrt{3}V_m}{2\pi}\cos\alpha$$

Here V_m is peak value of supply phase voltage. We have

$$V_{line(rms)} = 440\text{ V}$$

$$\therefore \quad V_{ph(rms)} = \frac{V_{line}}{\sqrt{3}} = \frac{440}{\sqrt{3}} = 254.03\text{ V}$$

 © Copyright

$$\therefore \quad V_m = \sqrt{2}\, V_{ph(\text{rms})}$$

$$= \sqrt{2} \times 254 = 359.21\,\text{V}$$

$$\therefore \quad V_{0(\text{av})} = \frac{3\sqrt{3} \times 359.21}{2\pi} \cos 30° = 257.26\ \text{V}$$

Average output current,

$$I_{0(\text{av})} = \frac{V_{0(\text{av})}}{\text{R}} = \frac{257.26}{20} = 12.86\ \text{A}$$

T6 : 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, $P_{dc} = \dfrac{V_o^2}{R} = \dfrac{207.04^2}{60} = 714.43\ \text{W}$

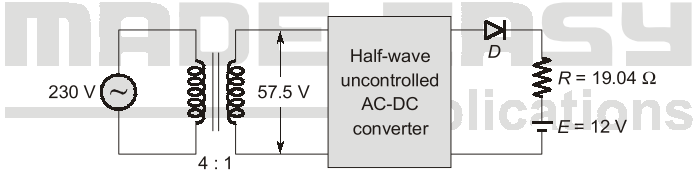
It is seen from the table that *TUF* for 1-phase half-wave diode rectifier is 0.2865.

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

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

T7 : Solution

(1.05)



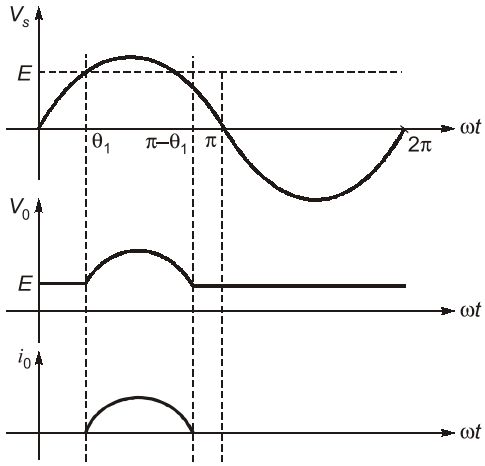
Input to the converter, $V_s = \left(\dfrac{1}{4}\right)230 = 57.5\,\text{V}$

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,

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

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

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

$$= 1.05 \text{ A}$$

■■■■

MADE EASY Publications

3 Choppers

Detailed Explanation of Try Yourself Questions

T1 : Solution

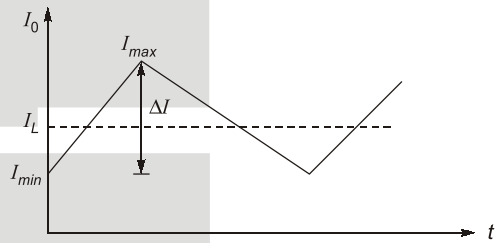
(a)

Given chopper is a buck chopper so, $V_0 = \alpha V_s$

$$\Delta I = \frac{V_0 T_{OFF}}{L}$$

$$\Delta I = 2I_L = 2I_0$$

This is applicable only at boundary of continuous and discontinuous condition



$$L_C = \frac{\alpha V_s (1-\alpha)}{2 I_0 f}$$

T2 : Solution

Average load current, $I_0 = \frac{I_1 + I_2}{2} = \frac{12+16}{2} = 14$ A

Average load voltage, $V_0 = I_0 R = 14 \times 10 = 140$ V

$V_0 = \alpha V_s$

$\therefore$ Duty cycle, $\alpha = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{V_0}{V_s} = \frac{140}{200} = 0.7$

$0.3\, T_{ON} = 0.7\, T_{OFF}$

$$\frac{T_{ON}}{T_{OFF}} = \frac{0.7}{0.3} = 2.33$$

MADE EASY Publications

T3 : 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,

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

maximum load or output voltage,

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

■■■■

MADE EASY Publications

4 Inverters

Detailed Explanation of Try Yourself Questions

T1 : Solution

$$V_{on} = \sum_{n=6k\pm1} \frac{4V_s}{n\pi} \sin\frac{n\pi}{3} \sin\left(n\omega t - \frac{n\pi}{3}\right)$$

$$V_{01,\,rms} = \frac{2\sqrt{2}\,V_s}{\pi} \sin\frac{\pi}{3} = \frac{2\sqrt{2}}{\pi} \times 300 \times \sin\frac{\pi}{3} = 233.83\ \text{V} \simeq 234\ \text{V}$$

T2 : Solution

[Ans. (a)]

T3 : Solution

$R_\Delta = 30\ \Omega$/phase

$R_Y = 10\ \Omega$/phase

$$V_{0,\,line} = V_s\sqrt{\frac{2}{3}}$$

$$V_{0,\,phase} = \frac{V_s\sqrt{2}}{3} = \frac{600\sqrt{2}}{3} = 200\sqrt{2}\ \text{V}$$

$$P_0 = \frac{3V_{0,phase}^2}{R} = \frac{3\times(200\sqrt{2})^2}{10} = 24\ \text{kW}$$

T4 : Solution

(a) The load voltage waveform V_0 and its fundamental component V_{01}.

Rms value of load voltage,

$$V_{01} = \frac{4V_s}{\pi\sqrt{2}} = \frac{4\times230}{\pi\sqrt{2}} = 207.1\text{V}$$

MADE EASY Publications

Rms value of current, $I_{01} = \dfrac{V_{01}}{Z_1}$

$$= \frac{V_{01}}{\left[R^2 + \left(\omega L - \frac{1}{\omega L}\right)^2\right]^{1/2}} = \frac{207.1}{\left[1^2 + (-1)^2\right]^{1/2}} = \frac{207.1}{\sqrt{2}} = 146.46 \text{ A}$$

$$\phi_1 = \tan^{-1}\frac{X_L - X_C}{R} = \tan^{-1}(-1) = -45°$$

The fundamental component of current i_{01} as a function of time is

$$i_{01} = \sqrt{2} I_{01} \sin(\omega t - \phi_1)$$

$$= \sqrt{2}\frac{207.1}{\sqrt{2}}\sin(\omega t - 45°) = 207.1\sin(\omega t + 45°)$$

Load current i_{01} and source current i_s and the conducting components are also indicated.

(b) Power delivered to load $= I_{01}^2 R = \left(\dfrac{207.1}{\sqrt{2}}\right)^2 \times 1 = 21.445$ kW

This must be equal to the power P_s delivered by the source

$\therefore \quad P_s = V_s I_s$ watts

where I_s = average value of the fundamental component of source current

$$= \frac{1}{\pi}\int_0^{\pi} \sqrt{2} I_{01} \sin(\omega t + 45°)\, d(\omega t)$$

$$= \frac{207.1}{\pi}\left[-\cos(\omega t + 45°)\right]_0^{\pi} = \frac{207.1}{\pi}[2\cos 45°] = 93.23 \text{ A}$$

$\therefore \quad P_s = 230 \times 93.23 = 21.443$ kW

(c) Figure reveals that v_{T1} is negative for some time before $T3$, $T4$ are triggered. Thus circuit turn-off time can be obtained from

or $\omega t_c = \dfrac{\pi}{4}$

$$t_c = \frac{1}{4}\cdot\frac{T}{2} = 0.125 \text{ ms} = 125 \text{ μs}$$

As voltage drop in diodes D1, D2 reverse biases T1, T2 for 125 μs, which is more than the thyristor turn-off time of 100 μs, no forced commutation is required.

T5 : Solution

(a) Here $V_s = 220$ V, $f = 50$ Hz; $R = 6\ \Omega$, $L = 30$ mH and $C = 180$ μF

$X_L = 2\pi \times 50 \times 30 \times 10^{-3} = 9.425\ \Omega$ and $X_C = \dfrac{10^6}{2\pi \times 50 \times 180} = 17.684\ \Omega$

 © Copyright

$$Z_n = \left[6^2 + \left(9.425n - \frac{17.684}{n}\right)^2\right]^{1/2} \text{ and } \phi_n = \tan^{-1}\left[\frac{9.425n - \frac{17.684}{n}}{6}\right]$$

(a) Rms value of output voltage, $V_{or} = V_s = 220$ V

Rms value of fundamental component of output voltage,

$$V_{01} = \frac{4 + 220}{\sqrt{2} \times \pi} = 198.07 \text{ V}$$

Rms value of all harmonic voltages, $V_{oh} = \sqrt{V_{or}^2 - V_{01}^2} = \sqrt{220^2 - 198.07^2} = 95.751$ V

$$\text{THD} = \frac{V_{oh}}{V_{01}} = \frac{95.751}{198.07} = 0.4834 \text{ or } 48.34\%$$

Distortion factor, $\mu = \frac{V_{01}}{V_{or}} = \frac{198.07}{220} = 0.9$

(b) Fundamental component of load current,

$$I_{01} = \frac{V_{01}}{Z_1}$$

$$\therefore \quad I_{01} = \frac{198.07}{[6^2 + (9.425 - 17.684)^2]^{1/2}} = 19.403 \text{ A}$$

and $$\phi_1 = \tan^{-1}\left[\frac{9.425 - 17.684}{6}\right] = -54°$$

$$I_{03} = \frac{V_{03}}{Z_3} = \frac{4 \times 220}{3\pi \times \sqrt{2}} \times \frac{1}{\left[6^2 + \left(9.425 \times 3 - \frac{17.684}{3}\right)^2\right]^{1/2}} = 2.849 \text{ A}$$

and $$\phi_3 = \tan^{-1}\left[\frac{9.425 \times 3 - \frac{17.684}{3}}{6}\right] = 75°$$

$$I_{05} = \frac{V_{05}}{Z_5} = \frac{4 \times 220}{5\pi \times \sqrt{2}} \times \frac{1}{\left[6^2 + \left(9.425 \times 5 - \frac{17.684}{5}\right)^2\right]^{1/2}} = 0.9 \text{ A}$$

and $$\phi_5 = \tan^{-1}\left[\frac{9.425 \times 5 - \frac{17.684}{5}}{6}\right] = 82.16°$$

Similarly, $I_{07} = 0.444$ A and $\phi_7 = 84.6°$

Therefore, load current expression in Fourier series is

$$i_0(t) = \sqrt{2}[19.403\sin(\omega t + 54°)] + 2.849\sin(3\omega t - 75°)$$
$$+ 0.9\sin(\omega t - 82.16° + 0.444\sin(7\omega t - 84.6°) + ...]$$
$$= 27.44\sin(\omega t + 54°) + 4.03\sin(3\omega t - 75°)$$
$$+ 1.273\sin(5\omega t - 82.16°) + 0.628\sin(7\omega t - 84.6°) + ...$$

$\therefore$ Fundamental rms load current, $I_{01} = 19.403$ A

(c) Peak load current, $I_m = [27.44^2 + 4.03^2 + 1.273^2 + 0.628^2]^{1/2}$
$= 27.77$ A

Rms value of harmonic load current,

$$I_{oh} = \left[\frac{I_m^2 + I_{m_1}^2}{2}\right]^{1/2} = \left[\frac{27.77^2 - 27.44^2}{2}\right]^{1/2} = 3.0182 \text{ A}$$

$$\text{THD} = \frac{I_{oh}}{I_{01}} = \frac{3.0182}{19.403} = 0.1555 \text{ or } 15.55\%$$

Rms load current, $I_{or} = \frac{I_m}{\sqrt{2}} = \frac{27.77}{\sqrt{2}} = 19.64$ A

Distortion factor, $\mu = \frac{I_{01}}{I_{or}} = \frac{19.403}{19.64} = 0.988$

(d) Load power, $P_0 = I_{or}^2 \times R = 19.64^2 \times 6 = 2314.4$ W

Average value of source current $= \frac{P_o}{V_s} = \frac{2314.4}{220} = 10.52$ A

(e) Expression for fundamental component of load current, $i_{01} = 27.44\sin(\omega t + 54°)$. It shows that current leads the voltage by 54°.

$\therefore$ Conduction time of each transistor $= (180 - 54) \times \frac{\pi}{180} \times \frac{1}{2\pi \times 50} = 7.0$ ms

Conduction time of each diode $= \frac{1}{2f} - 7.0 \times 10^{-3} = \frac{1}{100} - 7 \times 10^{-3} = 3$ ms

(f) Peak transistor current, $I_p = I_{01m} = 27.44$ A
Since each transistor conducts for 126° for every 360° or output cycle, rms value of transistor current,

$$I_{T1} = \frac{I_{01m}}{2\sqrt{\pi}}\left[126 \times \frac{\pi}{180} - \frac{\sin 252°}{2}\right] = 0.46135\, I_{01m}$$
$$= 0.46135 \times 27.44 = 12.66 \text{ A}$$

■■■■

 © Copyright

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

Detailed Explanation of Try Yourself Questions

T1 : Solution

$$E = V_0 - I_a R_a$$

$$V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$$

$$= \frac{330}{\pi}(1+\cos 30°) = 196 \text{ V}$$

$$E = V_0 - I_a \times R_a = 80$$

$$I_a = \frac{196-80}{4} = 9 \text{ A}$$

Motor torque, $$T = \frac{E_b \times I_a}{\omega} = \frac{80\times 9}{2\pi\times 1400}\times 60 = 4.91 \text{Nm}$$

T2 : 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 $t > 0$,

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

$$100 = 0.01\frac{d\omega_m}{dt} + 40 \qquad \ldots(i)$$

MADE EASY Publications

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

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

Its integration gives, $t = \frac{\omega_m}{6000} + A$ ...(*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, $\omega_m = \frac{2\pi \times 1000}{60} = \frac{200\pi}{6} \text{ rad/sec}$

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

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

T3 : Solution

under rated operating conditions of the separately excited dc motor,

$$V_t = E_a + I_a r_a = k_m \omega_m + I_a r_a$$

$$220 = k_m \frac{2\pi \times 1500}{60} + 10 \times 1 = 50\pi\, k_m + 10$$

∴ motor constant, $k_m = \frac{220 - 10}{50\pi} = 1.337 \text{ V-s/rad}$

for a torque of 5 Nm, motor armature current,

$$I_a = \frac{5}{1.337} = 3.74 \text{ A}$$

The equation giving the operation of converter motor is

$$V_0 = V_t = E_a + I_a r_a$$

$$\frac{2V_m}{\pi}\cos\alpha = k_m \omega_m + I_a r_a$$

$$\frac{2\sqrt{2} \times 230}{\pi}\cos 30° = 1.337\, \omega_m + 3.74 \times 1$$

$$\omega_m = 131.33 \text{ rad/sec}$$

$$\frac{2\pi N}{60} = 131.33 \text{ rad/sec}$$

$$N = 1254 \text{ rpm}$$

■■■■

 © Copyright