ELECTRICAL ENGINEERING

GATE | PSUs

POWER ELECTRONICS

Volume - I : Study Material with Classroom Practice Questions

Power Electronics

1. Basics & Power Semiconductor Devices

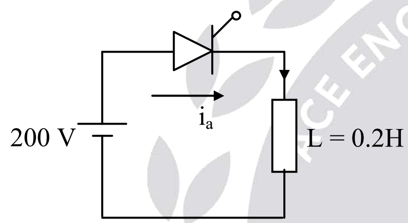
01. Ans: a) 100μs b) 100.5 μs c) 1005μs

Sol: (a) $I_L = 100$ mA

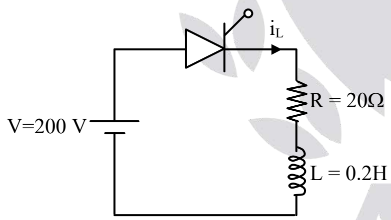
$$V = L\frac{di}{dt}$$

$$V\,t_p = L\,I_L$$

$$t_p = \frac{0.2\times 100\times 10^{-3}}{200} = 100\ \mu\text{sec}$$



(b) R = 20 Ω, L = 0.2 H



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

At $t = t_p$, $i_L = 100$ mA

$$100\times10^{-3} = \frac{200}{20}\left[1 - e^{-\frac{20}{0.2}t_p}\right]$$

$$10\times10^{-3} = [1 - e^{-100\,t_p}]$$

$$e^{-100\,t_p} = 0.99$$

$t_p = 100.5$ μsec

(c) R = 20 Ω, L = 2 H

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

$$100\times10^{-3} = \frac{200}{20}\left[1 - e^{-\frac{20}{2}t_p}\right]$$

$$10\times10^{-3} = [1 - e^{-10\,t_p}]$$

$$e^{-10\,t_p} = 0.99$$

$t_p = 1005$ μsec

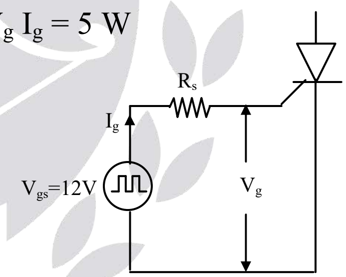
(d) If load inductance increases, SCR requires pulse width for longer duration.

02. Ans: (a) 7Ω (b) 1W

Sol: (a) Given

$V_g = 1.5 + 8\,I_g$

$V_g\,I_g = 5$ W



From KVL

$V_{gs} = I_g\,R_s + V_g$ …….…. (1)

$V_g\,I_g = 5$

$(1.5 + 8\,I_g)\,I_g = 5$

$I_g = 0.702$ A

$$\therefore V_g = \frac{5}{0.702} = 7.12\ \text{V}$$

From (1)

$12 = 0.702 \times R_s + 7.12$

$R_s = 6.95$ Ω

(b) $P_g = P_{gmax} \times D$

$= 5 \times 0.2 = 1$ W

03. Ans: (c)

Sol: $I_{g\,max}$ = 150 mA. Applied voltage V = 10 V. Voltage drop of transistor, diode and gate cathode junctions are 1 V.

Write KVL to the gate circuit

$-10 + I_{gmax} R + 1 + 1 + 1 = 0$

$150 \times 10^{-3} R = 7$

$R = 0.0467 \times 10^3 \Omega$

$= 46.7\ \Omega$

04. Ans: (a)

Sol: The time for which gate pulse should be applied along with SCR, at least anode current becomes more than latching current. Whenever SCR started conduction, the formula for anode current can be obtained as,

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

$$i = \frac{200}{1}\left[1 - e^{-\frac{1\times t}{0.15}}\right] = I_L$$

$$\Rightarrow 200\left[1 - e^{-\frac{1t}{0.15}}\right] = 0.25$$

$t = 187\,\mu\text{sec}$

Minimum volt second rating of transformer = voltage rating × Time for which signal should be applied

$= 10\times187 = 1870\ \mu$V-S

Hence next higher rating of transformer is to be selected

$\therefore$ volt-sec rating = 2000μ V-S

05. Ans: (88°C)

$T_c = 100°$

$T_j = 125°C$

$\theta_{CA} = 0.5$ °C/W

$T_s = ?$

$T_A = 40°C$

$$P = \frac{T_C - T_A}{\theta_{CA}} = \frac{100-40}{0.5} = 120W$$

$$120 = \frac{T_S - T_A}{0.4}$$

$T_S - T_A = 48 \Rightarrow T_S = 48+40 = 88°C$

06. Ans: (a) 229.17W, (b) 8.71%

Sol: $T_j = 125°C$; $\theta_{jc} = 0.16°C/W$

$\theta_{cs} = 0.08°C/W$; $T_S = 70°\,C$

(a) $P_{av} = \dfrac{T_j - T_S}{\theta_{js}}$

where $\theta_{js} = \theta_{jc} + \theta_{cs}$

$= 0.16 + 0.08 = 0.24°C/W$

$$= \frac{125-70}{0.24} = 229.16\ W$$

(b) Now $T_s = 60°C$

$$P_{av} = \frac{T_j - T_S}{\theta_{js}}$$

$$= \frac{125-60}{0.24} = 270.8\,W$$

Device rating means current rating and current rating is proportional to square root of power.

$$\%\ \text{increase} = \frac{\sqrt{270.8} - \sqrt{229.16}}{\sqrt{229.16}} \times 100$$

$= 8.71\%$

07. Ans: (b)

Sol: $T_{ON} = 5\ \mu$ sec, $I_L = 50$ mA, $I_H = 40$ mA

From circuit $i = \frac{V_S}{R}\left[1 - e^{-\frac{R}{L}t}\right] + \frac{V_s}{R}$

$$= \frac{100}{20}\left[1 - e^{-\frac{20}{0.5}t}\right] + \frac{100}{5000}$$

$$= 5\left[1 - e^{-40t}\right] + \frac{1}{50}$$

$$50\times10^{-3} = 5(1 - e^{-40t}) + \frac{1}{50}$$

$\Rightarrow t = 150\ \mu$ sec

08. Ans: (a) 7, 5, (b) 22.22 kΩ , (c) 0.094 μF

Sol: **(a)** V = 11 kV, I = 4 kA, $\eta = 90\%$

For series

$$\eta = \frac{\text{string voltage}}{n \times \text{voltage rating of SCR}}$$

$$n = \frac{11000}{0.9 \times 1800} \approx 7$$

For parallel

$$\eta = \frac{\text{string current rating}}{n \times \text{current rating of SCR}}$$

$$n = \frac{4000}{0.9 \times 1000} \approx 5$$

(b) $R = \frac{n\,V_{bm} - V_s}{(n-1)\Delta I_b}$

$\because\ \Delta I_b = I_{bmax} - I_{bmin}$

$$R = \frac{7(1800) - 11\times10^3}{(7-1)\times12\times10^{-3}}$$

= 12 mA – 0 = 12 mA

= 22.2 kΩ

(c). $C = \frac{(n-1)\ \Delta Q}{n\,V_{bm} - V_s}$

$$= \frac{(7-1)\times 25\times10^{-6}}{7\times1800 - 11\times10^3}$$

$= 0.0937\ \mu$F

09. Ans: 74 to 76

Sol: Energy loss during

$T_1 = \int_0^{T_1} v.i\,dt = 600\times\int_0^{T_1} i\,dt$

= 600 × area under current curve

$$= 600\times\frac{1}{2}\times150\times1\times10^{-6}$$

= 45 mJ

Energy loss during $T_2 = \int_0^{T_2} v.i\,dt$

$$= 100\times\int_0^{T_2} V\,dt$$

= 100 × area under voltage curve

$$= 100\times\frac{1}{2}\times600\times1\times10^{-6}$$

= 30 mJ

Total energy loss = 45 + 30 = 75 mJ

10.

Sol: Switching scheme – I

(i) Energy loss during ON condition:

$$(E_{loss})_{ON} = \int_0^{t_{on}} V\,i\,dt$$

$$= \int_0^{t_r}\left(400 - \frac{400}{t_r}t\right).\frac{20}{t_r}t\,dt$$

$$= \int_0^{t_r}\left[400(20)\frac{t}{t_r} - \frac{400(20)}{t_r^2}.t^2\right]dt$$

$$= (400)(20)\left[\frac{t_r^2}{2t_r} - \frac{t_r^3}{3t_r^2}\right]$$

$$= \frac{(400)(20)}{6}.t_r$$

$$(E_{loss})_{ON} = 133.33\mu J$$

$$(E_{loss})_{OFF} = \frac{VI}{6} t_{off}$$

$$= \frac{400.(20)}{6} \times 200ns$$

$$= 266.66\mu J$$

$E_{Total} = E_{ON} + E_{OFF}$

$= 133.33 + 266.66 \simeq 400\mu J$

(ii) $E = P \times t$

$P = E \times f$

$= (400\times10^{-6}) \times 100\times10^3$

$P = 40W$

Switching scheme-II

Energy loss during ON condition

(i) $(E_{loss})_{ON} = \int_0^{t_r} v\, i\, dt$

$$= \int_0^{t_r}\left(400 - \frac{400}{t_r}.t\right)20.dt$$

$$= 400(20)\int_0^{t_r}\left(1 - \frac{t}{t_r}\right)dt$$

$$= 8000\left(t_r - \frac{t_r^2}{2t_r}\right)$$

$$= \frac{8000}{2}.t_r$$

$$= \frac{8000}{2} \times 100\times10^{-9}$$

$$= 400\mu J$$

$$(E_{loss})_{OFF} = \frac{VI}{2} t_{OFF}$$

$$= \frac{400\times20}{2} \times 200\times10^{-6} J$$

$= 800\ \mu J$

$E_{Total} = E_{ON} + E_{OFF}$

$= 1200\ \mu J$

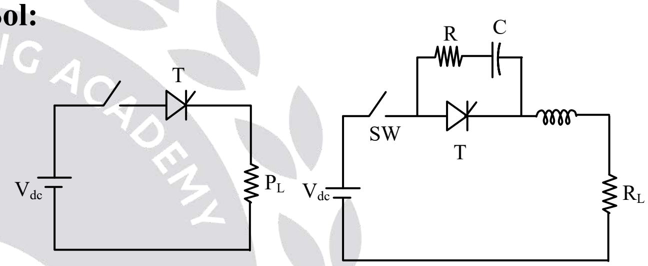
(ii) $P = E \times f$

$= (1200\times10^{-6}) \times 100\times10^3$

$P = 120W$

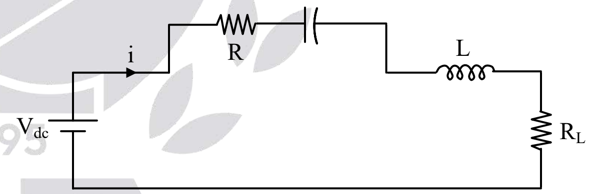
11. Ans: L = 4μH, C = 0.16 μF and R = 5 Ω

Sol:



At the time of switch closed:

SCR is forward blocking condition



KVL $\quad V_{dc} = (R + R_L)i + L\frac{di}{dt}$

$$i = \frac{V_{dc}}{R + R_L}\left[1 - e^{-t/\tau}\right]$$

Where $\tau = \dfrac{L}{R + R_2}$

$$\frac{di}{dt} = 0 - \frac{V_{dc}}{R + R_L}\left(-\frac{1}{\tau}e^{-t/\tau}\right)$$

$$\frac{di}{dt} = \frac{V_{dc}}{L}e^{-t/\tau}$$

$\frac{di}{dt}$ is maximum at t = 0

$$\left[\frac{di}{dt}\right]_{Max} = \frac{V_{dc}}{L}$$

$$L = \frac{V_{dc}}{(di/dt)_{Max}}$$

$$L = \frac{240\mu}{60} = 4\ \mu H$$

$$L = 4\ \mu H$$

Given damping ratio $\zeta = 0.5$

$$\zeta = \frac{R}{2}\sqrt{\frac{L}{C}}$$

$$0.5 = \frac{5}{2}\sqrt{\frac{4}{C}}$$

$\Rightarrow C = 0.16\ \mu F$

As SCR is in forward blocking mode voltage across SCR = I_aR

$$V_t = I_aR$$

$$\frac{dV_t}{dt} = R\frac{dI_a}{dt}$$

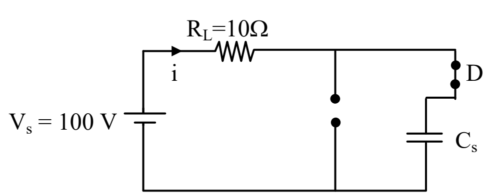
$$R = \frac{300}{60} = 5\ \Omega$$

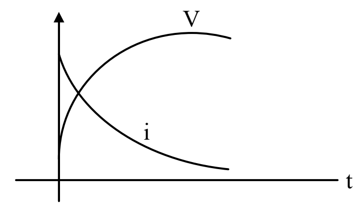
12. Ans: R = 50 Ω, C = 0.2μF

Sol: Given $\frac{dV}{dt} = 50\frac{V}{\mu s}$, $I_{discharge} = 2A$

When circuit is power up:

SCR is forward blocking condition





$$V_s = R_L i + \frac{1}{C}\int i\,dt$$

$$i = \frac{V_s}{R_L}e^{-t/\tau}$$

$$V_c = V_s\left[1 - e^{-t/\tau}\right]$$

$$\tau = R_LC$$

$$\frac{dV_C}{dt} = \frac{V_s e^{-t/\tau}}{R_LC}$$

$$\left(\frac{dV_C}{dt}\right)_{max} \text{ at } t = 0$$

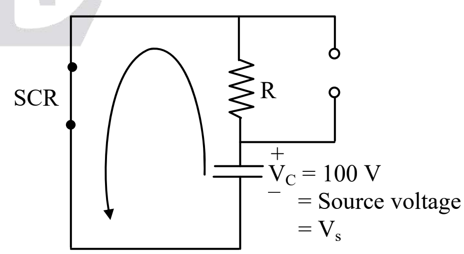
$$\frac{dV_C}{dt} = \frac{V_s}{R_LC}$$

$$\Rightarrow 50 \times 10^{-6} = \frac{100}{10 \times C}$$

C = 0.2 μF.

When SCR is ON:

By that time capacitor is already charged source voltage, so starts discharging



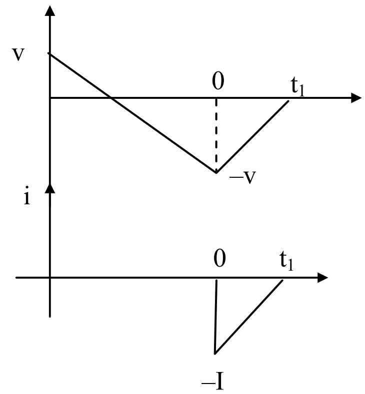
$$-100 + I_{disch}R = 0$$

$$R = \frac{100}{I_{disch}} = \frac{100}{2}$$

R = 50 Ω.

13. Ans: 1W, 900μC

Sol:



$$(E_{loss})_{OFF} = \int_0^t \nu i\, dt$$

$$= \int_0^t \left(-\nu + \frac{\nu}{t_1} t\right)\left(-i + \frac{i}{t_1} t\right) dt$$

$$= \int_0^{t_1} \left(-100 + \frac{100}{t_1}.t\right)\left(-300 + \frac{300}{t_1} t\right) dt$$

$$= 10^4 \int_0^{t_1} \left(-1 + \frac{t}{t_1}\right)\left(-3 + \frac{3}{t_1} t\right) dt$$

$$= 10^4 \int_0^{t_1} \left(3 - \frac{3(t)}{t_1} - \frac{3(t)}{t_1} + \frac{3t^2}{t_1^2}\right) dt$$

$$= 10^4 \left[3t_1 - \frac{6}{2t_1} t_1^2 + \frac{3}{t_1^2} . \frac{t_1^3}{3}\right]$$

$$= 10^4 [3t_1 - 3t_1 + t_1] = 10^4 t_1$$

$$= 10^4 \times 2 \times 10^{-6}$$

$$= 20 \text{ mW}$$

$P = E \times f$

$$= 20 \times 10^{-3} \times 50 = 1W$$

$$Q = \int i.dt$$

$$= \frac{1}{2} \times 300 \times 6 \times 10^{-6}$$

$Q = 900\mu C$

14. Ans: (c)

Sol: Electronic switch described in the statement should have forward blocking state, forward conduction state and reverse blocking state. SCR, NPN Transistor with series diode exhibits the above states.

15. Ans: (c)

Sol: $I_C = \dfrac{V_{CC} - V_{CE(sat)}}{R_L} = \dfrac{200-2}{10} = 19.8$ A

$$P_{on} = \frac{V_{CC} \times I_C}{6} \times t_{on} \times f_s$$

$$= \frac{200 \times 19.3}{6} \times 3\mu \times 1k = 1.98 \text{ W}$$

$$P_{off} = \frac{V_{CC} \times I_C}{6} \times t_{off} \times f_s = 0.792 \text{ W}$$

2. AC-DC Converters

01. Ans: $\dfrac{1}{4}$

Sol: In the absence of SCR $P_1 = \dfrac{V_{or}^2}{R} = \dfrac{V^2}{R}$

In the presence of SCR

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

For $\alpha = 90^0 \Rightarrow V_{or} = \dfrac{V}{2}$

$$\Rightarrow P_2 = \frac{V^2}{4R}$$

$$\frac{P_2}{P_1} = \frac{1}{4}$$

02. Ans: (a) 17.6V, (b) 329V,
(c) 445.3V, (d) 141.5V, 10.75A
(e) 8.98ms

Sol: (a) Voltage across thyristor

$V_T = V_m \sin\alpha - E$

$= 230\times\sqrt{2}\,\sin 25^\circ - 120$

$= 17.46$ V

(b) Now $V_T = V_m \sin\beta - E$

$= 230\times\sqrt{2}\,\sin 220^\circ - 120$

$= -329.07$ V

(c) Peak Inverse voltage $= V_m + E$

$= 230\times\sqrt{2} + 120$

$= 445.3$ V

(d) Average output voltage

$$V_0 = \frac{1}{2\pi}[V_m(\cos\alpha - \cos\beta) + E(2\pi + \alpha - \beta)]$$

$$= \frac{1}{2\pi}[230\times\sqrt{2}(\cos 25^\circ - \cos 220^\circ) + 120(2\pi + 25\times\frac{\pi}{180} - 220\times\frac{\pi}{180})]$$

$= 141.57$ V

Current $I_0 = \frac{V_0 - E}{R}$

$= \frac{141.57 - 120}{2}$

$= 10.78$ A

(e) $t_c = \frac{2\pi + \theta - \beta}{\omega} = \frac{2\pi + (21.64 - 220)}{\omega}\times\frac{\pi}{180}$

$= \frac{2.82}{100\pi} = 8.98\text{ms}$

03. Ans: 18A, 1A

Sol: $R = 5\ \Omega$, $L = 10$ mH,

$E = 80$ V and $V = 230$ V

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

$$= \frac{230\times\sqrt{2}}{\pi}(1 + \cos 50^\circ)$$

$= 170.08$ V

$$I_0 = \frac{V_0 - E}{R} = \frac{170.08 - 80}{5} = 18.01\text{A}$$

If SCR damaged, the circuit will work as half wave rectifier

$$V_0 = \frac{V_m}{2\pi}(1 + \cos\alpha)$$

$$= \frac{230\times\sqrt{2}}{2\pi}(1 + \cos 50^\circ) = 85\text{ V}$$

$$I_0 = \frac{V_0 - E}{R}$$

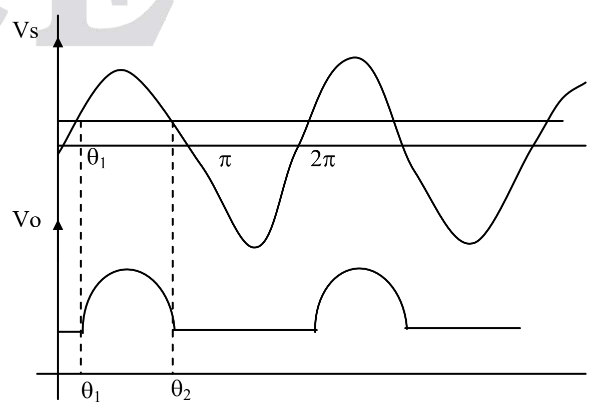
$$= \frac{85 - 80}{5} = 1\text{A}$$

04. Ans: (c)

Sol: $r = 2\ \Omega$

If SCR_2 gets open circuited then the circuit behaves like single phase half-wave rectifier. The SCR's are triggered by constant DC signal means

$\alpha = \theta_1$, $\beta = \theta_2 = \pi - \theta_1$



$V_m \sin \omega t = E \qquad \sin\theta_1 = \frac{E}{V_m}$

$$\theta_1 = \sin^{-1}\left(\frac{200}{230\times\sqrt{2}}\right) = 37.94^o$$

$$I_o = \frac{1}{2\pi R}\int_{\alpha}^{\theta_2=\pi-\alpha}(V_m \sin\omega t - E)\,d\omega t$$

$$= \frac{1}{2\pi R}\left[V_m(-\cos\omega t)_{\alpha}^{\pi-\alpha} - E(\pi-2\alpha)\right]$$

$$= \frac{1}{2\pi R}[2\times 230\times\sqrt{2}\ \cos(33.94^o)$$

$$-\ 200(\pi - 2\times 39.94^o \times \pi/180)]$$

$= 11.90\text{A}$

05. Ans: 120⁰, 0.54A, 1.016A

Sol: $V_0 = \frac{V_m}{\pi}(1+\cos\alpha)\ \&\ V_{0\max} = \frac{2V_m}{\pi}$

$V_0 = 0.25 \times V_{0max}$

$$\frac{V_m}{\pi}(1+\cos\alpha) = 0.25\times\frac{2\times V_m}{\pi}$$

$\alpha = 120°$

$$\therefore\ V_0 = \frac{240\times\sqrt{2}}{\pi}(1+\cos 120^\circ) = 54.01\text{ V}$$

$$I_0 = \frac{V_0}{R} = \frac{54.01}{100} = 0.54\text{ A}$$

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

$$= \frac{240\times\sqrt{2}}{\sqrt{2\pi}}\left[\left(\pi-\frac{2\pi}{3}\right)+\frac{1}{2}\left(\sin\left(\frac{4\pi}{3}\right)\right)\right]^{1/2}$$

$V_{rms} = 106.02$ V

$$I_{rms} = \frac{106.02}{100} = 1.061\text{ A}$$

06. Ans: 545.96 V

Sol: $\frac{3V_{ml}}{\pi}\cos(180° - \alpha)$

$$= -E + 2I_0r_s + 2\times V_t + \frac{3\omega L_s}{\pi}I_0$$

$$\frac{3\times 415\sqrt{2}}{\pi}\cos 150° = -E + (2\times 60\times 0.3)$$

$$+ (2\times 1.5) + \frac{3\times 100\pi\times 1.2\times 10^{-3}}{\pi}\times 60$$

E = 545.96 V

07. Ans: 467.82 V

Sol: $V_0 = \frac{3V_{ml}}{\pi}\cos\alpha$

$$= \frac{3\times\sqrt{2}\times 400}{\pi}\cos 30°$$

$= 467.8$ V

08. Ans: (a) 67.85⁰ , 0.36 lag (b) 92.36V

Sol: (a) $V_0 = RI_0 + E$

$$\frac{3V_{m\ell}}{\pi}\cos\alpha = RI_0 + E$$

$$\frac{3\times 220\sqrt{2}}{\pi}\cos\alpha = 0.2\times 10 + 110$$

$\alpha = 67.85°$

$P_0 = P_{in}$

$\sqrt{3}\,V_sI_s\cos\phi = V_0I_0$

$$\sqrt{3}\times 220\times 10\sqrt{\frac{2}{3}}\times\cos = (112).10$$

$\Rightarrow \cos\phi = 0.36$ lag

(b) $V_0 = RI_0 - E$

$$\frac{3V_{m\ell}}{\pi}\cos\alpha = 0.2\times 10 - 110 = -108$$

$V_{m\ell} = 130.59$ V

$$V_S = \frac{V_{m\ell}}{\sqrt{2}} = \frac{130.59}{\sqrt{2}} = 92.34\ V$$

09. Ans: (b)

Sol: The maximum current through battery will be evaluated based on extreme condition of operation

$$I_{0\ (max)} = \frac{400}{10} = 40\ \text{Amps}$$

10. Ans: (c)

Sol: kVA rating of input transformer $= \sqrt{3}\, V_l\ I_l$

Where I_l = Rms value of line current on ac side $= I_0\sqrt{\frac{2}{3}}$

$$\text{kVA rating} = \sqrt{3}\times 400\times 40\sqrt{\frac{2}{3}}$$

$$= 22.6\ \text{kVA}$$

11. Ans: (b)

Sol: Active power will be drawn by converter only due to fundamental component. Therefore,

$$\text{Active power} = V_S\ I_{S1}\ \text{Cos}\,\phi_1$$

$$= 100\times 10\ \text{Cos}\ 60$$

$$\text{Active power} = 500\,\text{watts}$$

12. Ans: (b)

Sol: Voltage applied $v = 100\sqrt{2}\sin(100\pi t)$

Current resulted

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

The current flowing through converter is a combination of fundamental, 3rd harmonic and 5th harmonic components.

The current flowing through the converter is non sinusoidal component then p.f will be written as

$$\text{Input power factor} = \frac{V_S\ I_{S_1}\ \cos\phi_1}{V_S\, I_S} = \frac{I_{S_1}}{I_S}\cos\phi_1$$

$$I_{S_1} = 10\ A$$

$$I_S = \sqrt{10^2+5^2+2^2} = 11.35\,A$$

$$\text{p.f} = \frac{10}{11.35}\cos 60 = 0.44$$

13. (i) 42.6° **(ii) 11.141A**

Sol: Maximum value occurs at $\alpha = 0$

$$V_0 = \frac{3V_{ml}}{2\pi}\cos\alpha = \frac{3V_{ml}}{2\pi}\cos(0)$$

$$\frac{3V_{ml}}{2\pi}\cos\alpha = 0.75\times\frac{3V_{ml}}{2\pi}$$

$\alpha = 41.409$

$\alpha > 30$, so we should not use above formula

$$\text{For } \alpha > \frac{\pi}{6},\quad V_0 = \frac{3V_{mp}}{2\pi}\left(1+\cos\left(\alpha+\frac{\pi}{6}\right)\right)$$

$$\frac{3V_{mp}}{2\pi}\left[1+\cos(\alpha+\pi/6)\right] = 0.75\times\frac{3V_{mp}\times\sqrt{3}}{2\pi}$$

$1 + \cos(\alpha+\pi/6) = 1.2990$

$\alpha + 30 = 72.600 \Rightarrow \alpha = 42.600°$

(ii) $I_0 = \frac{V_0}{R}\qquad \alpha > \frac{\pi}{6}$

$$V_0 = \frac{3V_{mp}}{2\pi}(1+\cos(\alpha+\pi/6))$$

$$= \frac{3\times\left(\frac{220}{\sqrt{3}}\right)\times\sqrt{2}}{2\pi}\left(1+\cos(42.600+30)\right)$$

$V_0 = 111.414$ and $I_0 = \frac{V_0}{R}$

$= 11.141$ A

14. Ans: 6 (Range: 5.9 to 6.1)

Sol: $\frac{2V_m}{\pi}\cos\alpha = E + RI_o$

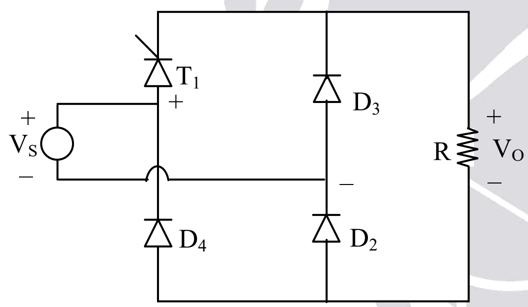
$\Rightarrow \frac{2\times 200\pi}{\pi}\cos 120^\circ = -800 + 20\times I_o A$

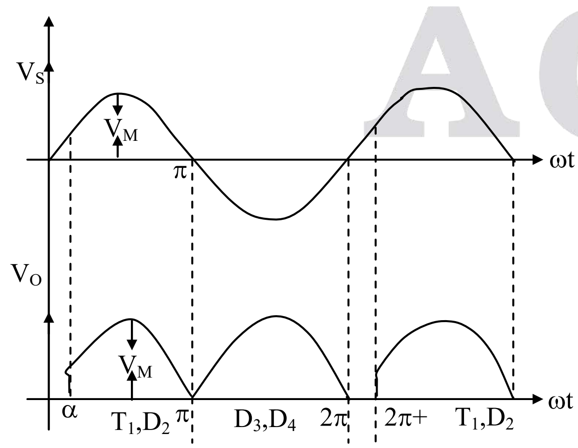
$\Rightarrow -200 = -800 + RI_o \Rightarrow I_o = 30$

As switches are lossless, power fed back to the source = 200 V × 30 A = 6 kW

15. Ans: 61.53 (61 to 62)

Sol:





During positive half cycle T_1 and D_2 are forward biases

$$V_0 = \frac{1}{2\pi}\left[\int_\alpha^\pi V_m \sin\omega t\, d\omega t + \int_\pi^{2\pi}(-V_m \sin\omega t)d\omega t\right]$$

$$= \frac{V_m}{2\pi}\int_\alpha^\pi \sin\omega t\ d\omega t - \frac{V_m}{2\pi}\int_\pi^{2\pi}\sin\omega t\, d\omega t$$

$$= \frac{V_m}{2\pi}(-\cos\omega t)_\alpha^\pi - \frac{V_m}{2\pi}(-\cos\omega t)_\pi^{2\pi}$$

$$= \frac{V_m}{2\pi}(1+\cos\alpha) + \frac{V_m}{2\pi}[1+1]$$

$$= \frac{V_m}{2\pi}[1+2+\cos\alpha]$$

$$V_0 = \frac{V_m}{2\pi}[3+\cos\alpha]$$

$$V_0 = \frac{100}{2\pi}\left[3+\cos 30^\circ\right] = 61.53 \text{ V}$$

16.

Ans: (a) 146.42 V,

(b) 732.11 W, 732.11 VAR and with FD: 176.74 V, 883.76 W, 366 VAR

Sol: Given data: $V_s = 230$, f = 50 Hz, $\alpha = 45°$,

$I_0 = 5$A

Without Free wheeling diode

It is a 1 - φ full converter

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

$V_0 = 146.4225$ V

$P_0 = V_0 I_0 = 146.4225 \times 5$

$P_0 = 732.1125$ W

$Q_0 = V_0 I_0 \tan\alpha$

$= 146.422\times 5 \times \tan 45°$

$= 732.1125$ VAR

If $\alpha = 60°$

$$V_0 = \frac{2V_m}{\pi}\cos\alpha = 103.536$$

$= 5$ A

$P_0 = V_0 I_0 = 517.68$W

$Q_0 = V_0 I_0 \tan\alpha$

$= 517.68 \times \tan 60$

$Q_0 = 896$ VAR

With free wheeling diode

Single phase full bridge converter with free wheeling diode will act as a single phase semi converter

$$V_0 = \frac{V_m}{\pi}(1+\cos\alpha)\ \frac{\sqrt{2}\times 230}{\pi}(1+\cos 45°)$$

$V_0 = 176.747$ V

$P_0 = V_0 I_0 = 176.747 \times 5$

$= 883.73$ W

$$Q_0 = V_0 I_0 \tan\frac{\alpha}{2}$$

$$= 883.73 \times \tan\frac{45}{2}$$

$Q_0 = 366.053$ VAR

(c) If $\alpha = 60°$

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

$V_0 = 155.304$ V

$I_0 = 5$ A

$P_0 = V_0 I_0$

$P_0 = 776.523$

$$Q_0 = V_0 I_0 \tan\frac{\alpha}{2}$$

$= 776.523 \tan 30°$

$Q_0 = 448.32$ VAR

In the two cases 1 - ϕ Full converter (without F.D) and 1 - ϕ Full converter (with F.D) if 'α' increases, active power decreases and reactive power increases.

17. Ans: (c)

Sol: $I_1 = I_{\text{load RMS}} = \sqrt{I_0^2 \times} = I_0$

$$I_2 = (I_{SCR})_{RMS} = \sqrt{\frac{I_0^2 \times 60}{360}} = \frac{I_0}{\sqrt{6}}$$

$$I_3 = (I_{FD})_{RMS} = \sqrt{\frac{I_0^2 \times 3 \times 60}{360}} = \frac{I_0}{\sqrt{2}}$$

$$I_1 : I_2 : I_3 = 1 : \frac{1}{\sqrt{6}} : \frac{1}{\sqrt{2}}$$

18. Ans: 224.17

Sol: When source inductance is not taken into account, each diode will conduct for 180°

When source inductance is taken into account, each diode will conduct for $(180+\mu)°$

Where μ is overlap angle and can be determined as follows:

$$\cos\mu = 1 - \frac{2\omega L_s}{V_m} I_o$$

$$\Rightarrow \cos\mu = 1 - \frac{2\times 100\pi \times 10 \times 10^{-3}}{220\sqrt{2}} \times 14$$

$= 0.71727$

$\Rightarrow \mu = 44.17°$

$\therefore$ Conduction angle for D_1 is 180+44.17

$= 224.17°$

3. DC-DC Converters

01. Ans: 5A, 5.104A, 4.896A

Sol: f = 2 kHz, V_{dc} = 100V, $\frac{L}{R} = 6\,\text{m sec}$

$R_L = 10\Omega$

$$I_0 = \frac{V_0}{R} = \frac{50}{10} \Rightarrow 5A$$

$$\Delta I_L = \frac{V_{dc}}{L} D(1-D)T$$

$$= \frac{100}{60\times10^{-3}} \times 0.5(0.5) \times \frac{1}{2\times10^3}$$

$$= \frac{50\times0.5\times0.5}{60} = 0.208\text{ A}$$

$$I_{L\max} = I_L + \frac{\Delta I_L}{2} = 5 + \frac{0.208}{2} = 5.104\text{ A}$$

$$I_{L\min} = I_L - \frac{\Delta I_L}{2} = 4.896\text{ A}$$

02. (a) Ans: (c) (b) 2.5 A, 37.5 μH

Sol: (a) D = 0.5, f = 100 kHz,

$\Delta i_c = 1.6A$, $I_0 = 5A$

$\Delta I_C = \Delta I_L$

$$I_{L\max} = I_L + \frac{\Delta I_L}{2}$$

$$= 5 + \frac{1.6}{2} = 5.8\text{ A}$$

(b) Average switch current

$$= \frac{1}{T_s}\left[4.2\times\frac{T_s}{2} + \frac{1}{2}\times(5.8-4.2)\times\frac{T_s}{2}\right]$$

= 2.5A

$$\Delta I_L = \frac{V_{dc}}{L} D(1-D)T$$

$$= \frac{24}{L}\times0.5(1-0.5)\times\frac{1}{100} = 1.6$$

$L = 37.5\mu H$

03. (a) $\frac{1}{3}$

(b) 333.333 μH

(c) 312.5 μH

(d) 8.33mH, 12.5 nF

Sol: ΔV_0 = 10 mV

ΔI_L = 0.5 A, T = 50 μs

(a) Duty cycle ratio

$V_o = DV_{dc}$

$$D = \frac{V_o}{V_{dc}} = \frac{5V}{15} = \frac{1}{3}$$

(b) filter Inductance

$$\Delta I_2 = \frac{V_{dc}}{L} D(1-D)T$$

$$\Rightarrow 0.5 = \frac{5\times\frac{1}{3}\times\frac{2}{3}\times50\mu}{L}$$

$L = 333.33\ \mu H$

(c) $$\Delta V_0 = \frac{V_{dc}}{8LCf^2} D(1-D)$$

$$10\times10^{-3} = \frac{15}{8\times333.33\times10^{-6}\times C\times20\times10^3}.\frac{1}{3}\left(1-\frac{1}{3}\right)$$

C = 312.5 μF

(d) $$L_{cr} = \frac{(1-D)R}{2f}$$

$$= \frac{(1-0.33)500}{2\times20\times10^3} = 8.33\text{ mH}$$

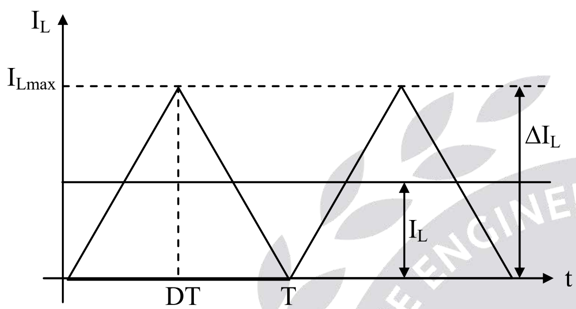
$$C = \frac{1}{16L}(1-D)T^2$$

$$C = \frac{1}{16\times 8.33\times 10^{-3}}\times\frac{2}{3}\times\left(\frac{1}{400\times 10^{6}}\right)$$

$$= 12.5\text{nF}$$

04. Ans: 2480 to 2520

Sol: Given I_c is just continuous



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

Given D = 0.6, f = 100 kHz, L = 5mH

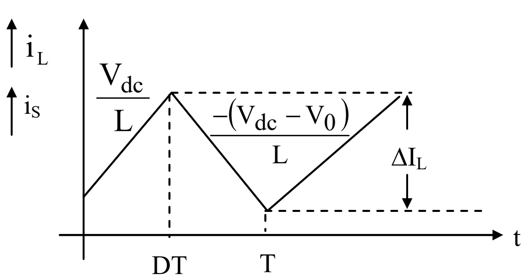
$$R_{cr} = \frac{2L}{(1-D)T} = \frac{2L}{(1-D)}\times f$$

$$R_{cr} = \frac{2\times 5\times 10^{-3}\times 100\times 10^{3}}{(1-0.6)}$$

$$R_{cr} = 2500\,\Omega$$

05.(i) Ans: (b)

Sol: Given circuit is Boost converter circuit. In this circuit source current and inductor current are same.



Average output voltage

$$V_0 = \frac{V_{dc}}{1-D} = \frac{12}{1-0.4} = 20\text{V}$$

Average output current

$$I_0 = \frac{V_0}{R} = \frac{20}{20} = 1\text{A}$$

Source current

$$I_s = \frac{I_0}{1-0} = \frac{1}{1-0.4} = \frac{1}{0.6} = \frac{10}{6} = \frac{5}{3}\text{A}$$

05.(ii) Ans: (c)

Sol: Peak to peak source current ripple.

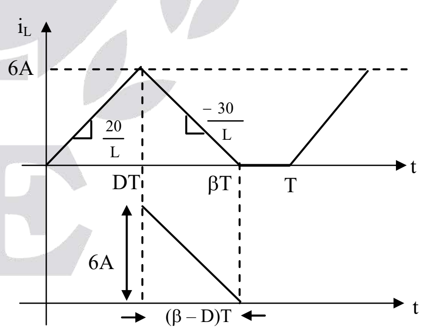
$$\Delta I_L = \Delta I_s = \frac{V_{dc}}{L}DT$$

$$= \frac{12}{100\times 10^{-6}}\times 0.4\times\frac{1}{250\times 10^{3}}$$

$$= 0.192\text{A}$$

06. Ans: 2 (Range 2 to 2)

Solution:



In continuous conduction mode,

$$V_0 = \frac{V_{dc}}{1-D} = \frac{20}{1-0.5} = 40\text{V}$$

But given $V_0 > 40$ V, so it is discontinuous mode of operation.

Power balance equation $P_0 = P_{in}$

$$\Rightarrow V_{dc}.I_s = 50\times\left(\frac{50}{50}\right)$$

$$I_s = \frac{50}{20} = 2.5\,\text{A}$$

$$\frac{V_0}{V_{dc}} = \frac{\beta}{\beta - D} = \frac{50}{20} = 2.5$$

$\Rightarrow \beta = 2.5 \times \beta - (2.5 \times 0.5)$

$\beta = 0.833$

$$I_L = \frac{\frac{1}{2}\times I_{L\,Max}\times \beta T}{T} = 2.5$$

$I_{L\,Max} = 6$ A

$$I_{D,rms} = \left[\frac{6^2}{3}\times\left(\frac{5}{6}-\frac{1}{2}\right)\times\frac{T}{T}\right]^{\frac{1}{2}}$$

$$= \left[\frac{6^2}{3}\times\frac{2}{6}\right]^{\frac{1}{2}}$$

$I_{D,rms} = 2$ A

07. Ans: (a) 0.6

(b) 0.72 A

(c) 1.61 A

(d) 34.09 mA

(e) 72μH, 500nF

Sol: Given

$I_0 = 0.5$ A, $V_0 = 15$ V, $V_{DC} = 6$ V

(a) $V_0 = \dfrac{V_{dc}}{1-D}$

$\Rightarrow$ Duty cycle D = 0.6

(b) $\Delta I_L = \dfrac{V_{dc}}{L}DT$

$$= \frac{6}{250\times10^{-6}}0.6\times\frac{1}{20K}$$

$= 0.72$ A

(c) $I_{L\max} = I_L + \dfrac{\Delta I_L}{2} = \dfrac{20}{1-D} + \dfrac{\Delta I_L}{2}$

$$= 0.5 + \frac{0.72}{2} = 1.61A$$

(d) $\Delta V_c = \dfrac{I_D.DT}{C} = \dfrac{0.5\times0.6\times\frac{1}{20\times K}}{440\times10^{-6}}$

$= 34.1$ mV

(e) $L_{cr} = \dfrac{D(1-D)^2RT}{2}$

$$= \frac{0.6(1-0.6)^2}{2}\times30\times\frac{1}{20k}$$

$$R = \frac{V_o}{I_0} = \frac{15}{0.5} = 30$$

$L_{cr} = 72\mu$H

$$C_{cr} = \frac{(1-D)I_0DT}{2V_{DC}}$$

$$= \frac{(1-0.6)0.5\times0.6\times\frac{1}{20k}}{2\times6} = 0.5\ \mu\text{F}$$

08. Ans: 3.51 A (Range: 3.0 to 4.0)

Sol: For continuous inductor current,

$$V_o = \frac{V_{dc}}{1-D} \Rightarrow 1-D = \frac{360}{400} \Rightarrow D = 0.1$$

As output power is 4 kW at 400 V, $I_o = 10$ A

From power balance, $P_{in} = P_{out}$ or $V_{dc}\times I_i = V_o\times I_o$, it will give $I_i = \dfrac{4000}{360} = 11.11\,\text{A}$

As the switching frequency is not given in the question, we cannot proceed further

But by assuming one condition i.e the current through supply line is constant of 11.11 A then r.m.s value of switch current

$$=11.11\times\sqrt{\frac{DT}{T}}=11.11\sqrt{D}$$

$$=11.11\sqrt{0.1}=3.51\text{ A}$$

09. Ans: (a) 83.3μs (b) 83.3A

Sol: (a) Buck-boost converter, f = 10 kHz

$$I_{L\max}=\frac{100}{L}DT \;\ldots\ldots\ldots\ldots\text{ (1)}$$

$$=\frac{500}{L}(T-DT)\;\ldots\ldots\ldots\ldots\text{ (2)}$$

From (1) & (2)

$$\frac{100}{L}DT=\frac{500}{L}(T-DT)$$

$$DT=\frac{500}{600}T=\frac{5}{6}\times\frac{1}{10\times10^3}\Rightarrow 83.3\mu\sec$$

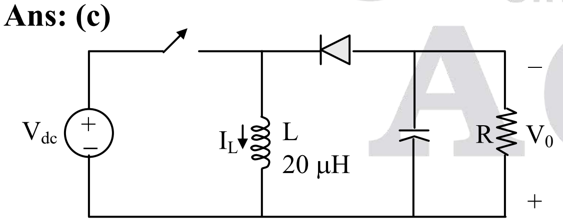
(b) Peak current through switch

$$I_{L\max}=\frac{V_{dc}}{L}DT$$

$$=\frac{100}{100\times10^{-6}}\times83.3\times10^{-6}=83.3\text{A}$$

10. Ans: (c)

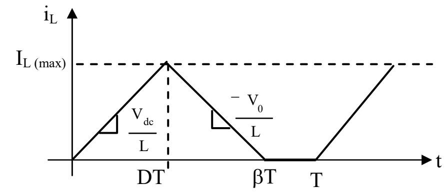
Sol:



In CCM Buck Boost,

$$V_0=V_{dc}\left[\frac{D}{1-D}\right]=20\times\frac{0.6}{0.4}=30\text{ V}$$

But given V_0 > 30 V, so it is discontinuous mode of operation.



From i_L waveform

$$\frac{20}{L}DT=\frac{60}{L}(\beta T-DT)$$

$$\Rightarrow 4DT=3\beta T\Rightarrow \beta=\frac{4}{3}\times D=0.8$$

$$\therefore I_{L\max}=\frac{V_{dc}}{L}\times DT=\frac{20}{20\mu}\times0.6\times20\mu=12\text{ A}$$

$$I_{L\ (avg)}=\frac{\frac{1}{2}\times12\times0.8\times20\mu}{20\mu}=4.8\text{ A}$$

11. Ans: (a) 18V
(b) 0.163V
(c) 1.152A
(d) 4.326A
(e)38.4 μH and 1μF

Sol: (a) $V_0=\frac{D}{1-D}V_{dc}$

$$=\frac{0.6}{1-0.6}\times12$$

= 18V

(b) $\Delta V_c=\frac{I_0}{L}DT$

$$=\frac{1.5}{250\times10^{-6}}\times0.6\times\frac{1}{25K}=0.144\text{ V}$$

(c) $\Delta I_L=\frac{V_{dc}}{L}DT$

$$=\frac{12}{250\times10^{-6}}\times0.6\times\frac{1}{25k}$$

$= 1.152$ A

(d) $I_{L\,max} = I_L + \frac{\Delta I_L}{2} = \frac{1.5}{1-0.6} + \frac{1.152}{2}$

$= 4.326$

(e) $L_{cr} = \frac{(1-D)^2 RT}{2} = 38.4\,\mu H$

$$C_{cr} = \frac{I_0 T(1-D)}{2V_{dc}} = \frac{1.5 \times \frac{1}{25\times 10^3}(1-0.6)}{2\times 12}$$

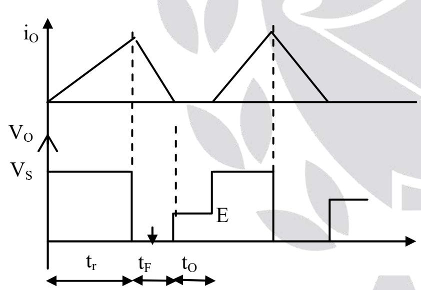
$= 1\ \mu F$

12. Ans: (c)

Sol: For step down chopper for R_L

Load $V(t) = V_0 = DV_s = \frac{T_{ON}}{T} V_s$

For RLE load, the output waveform is



From above diagram $t = t_r + t_f + t_o$

The terminal voltage exits only for the periods t_r and t_o, remaining time zero

$\therefore$ The average voltage $= \frac{V_S t_r + E_b t_o}{t}$

13. Ans: (a)

Sol: In Buck boost converter, $V_o = \frac{D}{1-D} V_{dc}$

When $V_{dc} = 32$ V,

$$\frac{D}{1-D} = \frac{48}{32} \Rightarrow D = \frac{3}{5} = 0.6$$

When $V_{dc} = 72$ V,

$$\frac{D}{1-D} = \frac{48}{72} \Rightarrow D = \frac{2}{5} = 0.4$$

$\therefore$ The range of D will be $\frac{2}{5} < D < \frac{3}{5}$

or $0.4 < D < 0.6$

14. Ans: 40

Sol: Given circuit is buck boost converter.

Source current is same switch current.

Peak value of switch current means,

$$i_{sw,peak} = I_{L,\max} = I_L + \frac{\Delta I_L}{2}$$

$$\Delta I_L = \frac{V_{dc}}{L} DT$$

$$= \frac{50}{0.6\times 10^{-3}} \times 0.6 \times 0.1 \times 10^{-3} = 5\text{ A}$$

$$I_L = \frac{I_o}{1-D} = \frac{\left(\frac{75}{5}\right)}{1-0.6} = 37.5\text{ A}$$

$$\therefore I_{L,\max} = 37.5 + \frac{5}{2} = 40\text{ A}$$

15. Ans: (d)

Sol: $i = V_0 \sqrt{\frac{C}{L}} \sin \omega_0 t$

$$= V_0 \sqrt{\frac{C}{L}} \sin \frac{1}{\sqrt{LC}} t$$

$$= 100 \sqrt{\frac{10\times 10^{-6}}{1\times 10^{-3}}} \sin \frac{1}{\sqrt{10\times 10^{-6} \times 10^{-3}}} t$$

$i = 10 \sin(10^4 t)$ A

16. Ans: (a)

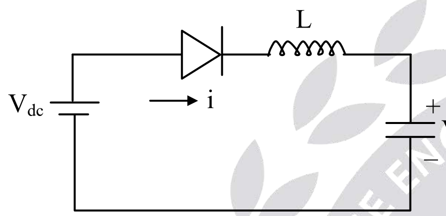
Sol: Given circuit is a current commutation circuit. When ever both the currents are equal and opposite then the thyristor will be turned off.

$10\sin 10^4 t = 5$ (Refer previous solution)

$t = 52\mu sec$

17. Ans: 35.1 μs, 189.4 V

Sol:



$i_L(0) = I_0$

$$\frac{Ldi}{dt} + \frac{1}{C}\int idt = V_{dc}$$

$$L[SI(s) - I_0] + \frac{1}{C}\int\frac{I(s)}{S} + \frac{CV_{co}}{S} = \frac{Vdc}{S}$$

$$I(s)\left[SL + \frac{1}{Cs}\right] - LI_0 + \frac{V_{co}}{S} = \frac{Vdc}{S}$$

$$I(s) = \frac{Vdc - V_{co}}{S} \times \frac{1}{SL + \frac{1}{Cs}} + LI_0 \times \frac{1}{SL + \frac{1}{Cs}}$$

$$= \frac{V_{dc} - V_{co}}{S} \times \frac{CS}{S^2 + LC + 1} + LI_0 \times \frac{CS}{S^2LC + 1}$$

$$= \frac{V_{dc} - V_{co}}{LC} \times \frac{C}{S^2 + \omega^2} + \frac{LI_0}{LC} \times \frac{CS}{S^2 + \omega^2}$$

$$i(t) = \frac{V_{dc} - V_{co}}{\omega L}\sin\omega t + I_0\cos\omega t$$

$$V_c(t) = V_{dc} - \frac{Ldi}{dt}$$

$$= V_{dc} - L\left[\frac{V_{dc} - v_{co}}{L}\right]\cos\omega t - I_0\sin\omega t(\omega)$$

$$v_c(t) = V_{dc} - (V_{dc} - V_{co})\cos\omega t + I_0\sqrt{\frac{L}{C}}\sin\omega t$$

If $V_{co} - V_{dc} = i(t) = I_0 \cos\omega t$

$$t_{on} = \frac{\pi}{2\omega} = \frac{\pi}{2}\sqrt{LC}$$

$$t_{on} = \frac{\pi}{2}\sqrt{10\times10^{-6}\times50\times10^{-6}}$$

$= 35.1$ μs

If $V_{co} = V_{dc} = V_c = V_{dc} + I_0\sqrt{\frac{L}{C}}\sin\omega t$

at turn OFF $\omega t = \frac{\pi}{2}$

$$\therefore V_c = V_{dc} + I_0\sqrt{\frac{L}{C}}$$

$$= 100 + 200\sqrt{\frac{10\mu}{50\mu}}$$

$= 189.4$V

18. Ans: (a) 1075μs, (b) 427.85A, (c) 137.5μs, (d) 20V

Sol: Given data

$V_s = 220V$, $R = 0.5\Omega$, $L = 2mH$, $E = 40V$

Commutation parameters: $L = 20\mu H$,

$C = 50\mu F$. $T_{ON} = 800\mu sec$

$T = 2000\mu sec$ & $I_0 = 80A$

(a) Effective on period

$$T_{ON}^1 = T_{ON} + 2.\frac{CVs}{I_0}$$

$$= (800\times10^{-6}) + 2\left(\frac{50\times10^{-6}\times220}{80}\right)$$

$= 1075$ μsec

(b) Peak currents through T_1 and T_A

$$I_{T_1P} = I_0 + V_s\sqrt{\frac{C}{L}}$$

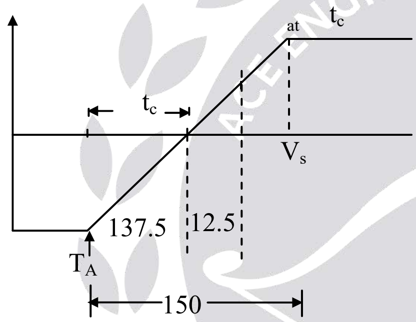
$$= 80 + 220\sqrt{\frac{50}{20}} = 427.85A$$

$$I_{T_AP} = I_0 = 80A$$

(c) turn off time for T_1

$$t_c = \frac{CVs}{I_0} = \frac{50\times10^{-6}\times220}{80} = 137.5\mu\sec$$

(d) Capacitor voltage 150µsec after T_A, is triggered



V_s at t_c = 220 V

137.5 → 220 V

12.5 → ?

$$V_c = \frac{220}{137.5}\times12.5 = 20\text{ V}$$

19.(i) Ans: (b)

Sol: The minimum time is required for change the polarity of capacitor form V_s to $-V_s$

$$\text{i.e. } t_1 = \frac{\pi}{\omega_o}$$

$$= \pi\times\sqrt{LC}$$

$$= \pi\times\sqrt{2\times10^{-3}\times1\times10^{-6}}$$

$$= 140\ \mu\text{ sec.}$$

This time is turn ON time of thyristor i.e. T_{ON} = 140 µ sec

(ii) Ans: (b)

Sol: In a voltage commutated chopper, average value of output voltage is given by

$$V_o = \frac{V_s}{T}(T_{ON} + 2t_c) = \frac{V_s}{T}\left(T_{ON} + 2.\frac{CV_s}{I_o}\right)$$

$$= \frac{250}{1\times10^{-3}}\left[140\times10^{-6} + 2\times\frac{1\times10^{-6}\times250}{10}\right]$$

= 47.5 V

4. DC-AC Converters

01. (a) 26.1V (b) 240W
(c) 48.43% (d) 5A
(e) 48V

Sol: a) $V_{01} = \frac{\sqrt{2}}{\pi}V_{dc} = 0.45\times48 = 21.6V$

b) $P_0 = \frac{\left(\frac{V_{dc}}{2}\right)^2}{R} = \frac{24^2}{2.4} = 240W$

c) THD = 48.43%

d) Peak current through switch

$$I_P(sw) = \frac{V_{dc}}{2R} = 10A$$

Average current of diode $= \frac{10}{2} = 5A$

e) PIV = 48V

With full bridge

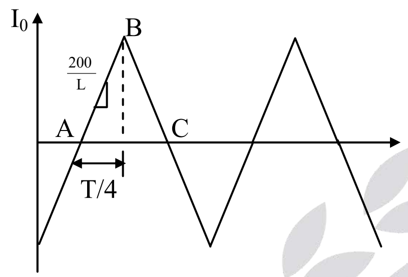
$$V_{01} = \frac{2\sqrt{2}}{\pi}V_{dc}, \qquad P_0 = \frac{V_{dc}^2}{R}$$

$$I_P(sw) = \frac{V_{dc}}{R}$$

$$I_{avg}(diode) = \frac{I_P}{2}, \qquad PIV = 48V$$

02. Ans: (i). (b) & (ii). (a)

Sol:



$y = mx$, $I_P = \frac{200}{L} \times \frac{T}{4}$ **[T = 20 msec]**

(i) $I_P = \frac{200}{0.1} \times 5 \times 10^{-3} = 10A$

(ii) Each diode will conduct for $\frac{T}{4}$ sec

= 5 msec

03. Ans: (c)

Sol: $V_1 = \frac{4V_{dc}}{\pi\sqrt{2}} = \frac{4\times 12}{\pi\sqrt{2}}$

$V_1 = \frac{48}{\pi\sqrt{2}}$

Given $V_2 = 240$ and $N_1 = 10$

$\frac{N_2}{N_1} = \frac{V_2}{V_1}$

$N_2 = \frac{240\times\sqrt{2}\times 3}{4\times 12} \times 10$

$= 150\sqrt{2}$

04. Ans: (c)

Sol: Given $2d = 150^0$

Fundamental component peak value

$= \frac{4V_s}{\pi}\sin d \,.\, \text{Sin}\frac{\pi}{2}$

fundamental component r.m.s value

$(V_1) = \frac{4V_s}{\sqrt{2}\pi}\sin d \,.\, \text{Sin}\frac{\pi}{2}$

$= \frac{4\times V_s \sin(75^0)}{\sqrt{2}\pi}$

$= \frac{1.22}{\sqrt{2}}V_s = 0.862\,V_s$

and r.ms. value of output voltage

$V_{r.m.s} = V_s\left(\frac{2d}{\pi}\right)^{1/2}$

$= V_s\left(\frac{150}{\pi}\times\frac{\pi}{180}\right)^{1/2}$

$= 0.912\,V_s$

Given

$THD = \sqrt{\frac{V^2_{r.m.s} - V_1^2}{V_1}} \times 100$

$= \frac{\sqrt{\left[(0.912)^2 - (0.862)^2\right]V_s^2}}{V_s\,0.862} \times 100$

$= \frac{0.2978}{0.862} = 34.55\%$

05. Ans: (a) 200.8V, (b) 24.75^0, (c) 203.64V

Sol: Given data:

$V_{dc} = 220V$, $P = 5$, $2d = 150$

(a) $V_0 = V_{dc}\sqrt{\frac{2d}{\pi}}$

$= 220\sqrt{\frac{150}{180}} \Rightarrow 200.83V$

(b) Now $V_{dc} = V_{dc} + 10\%$ of V_{dc} = 242 V

$$V_{dc}\sqrt{\frac{5\times 2d}{\pi}} = 200.8$$

$$(242)^2 \times \frac{5\times 2d}{180} = (200.8)^2$$

$$2d = 24.78$$

(c) $200.8 = V_{dc} \times \sqrt{\frac{5\times 35}{180}}$ (pulse width 35)

$$V_{dc} = 203.64V$$

06. Ans: (a) (i) 13.2A, (ii) 9.33A, (iii) 7.84 kW, (iv) 18.67A
(b) (i) 11.43A, (ii) 8.08A, (iii) 5.88 kW (iv) 14A

Sol: Given data R = 15Ω

In 180^0 mode

(i) rms value of load current

$$I_{or} = \frac{V_{pn}}{R} = \frac{\frac{\sqrt{2}}{3}V_{dc}}{R}$$

$$= \frac{\sqrt{2}}{3}\times\frac{420}{15} = 13.2A$$

(ii) $I_T = I_0\sqrt{\frac{\pi}{2\pi}} \Rightarrow \frac{I_0}{\sqrt{2}} = 9.33A$

(iii) Load Power $= 3\times I_0^2 R$

$$= 3\times(13.2)^2\times 15$$

$$= 7.84 \text{ kW}$$

(iv) $420 \times I_s = 7.84\times 10^3$

$$I_s = 18.67A$$

120^0 Operation:

i) $I_0 = \frac{V_{ph}}{R} = \frac{\frac{V_{dc}}{\sqrt{6}}}{R} = \frac{\frac{420}{\sqrt{6}}}{15} = 11.43A$

ii) $I_T = \frac{I_0}{\sqrt{3}} = \frac{11.43}{\sqrt{3}} = 6.6A$

iii) $P_0 = 3\times I_0^2 R$

$$= 3\times 11.43^2\times 15 = 5.88kW$$

(iv) $I_s = \frac{5880}{420} = 14A$

07. Ans: 2.15 μF

Sol: $t_c = F.S \times t_2 = 24$ μs

$\omega t_c = (2\pi)\times 24\mu = 0.75$ rad

$\omega t_c = \phi_1 = 0.754$

$$\tan^{-1}\left(\frac{X_c - X_L}{R}\right) = 0.754$$

$$\frac{X_C - X_L}{3} = 0.013$$

$X_C - 12 = 0.039 \Rightarrow X_C = 12.039$

$$\frac{1}{\omega_C} = 12.039$$

C = 12.15 μF

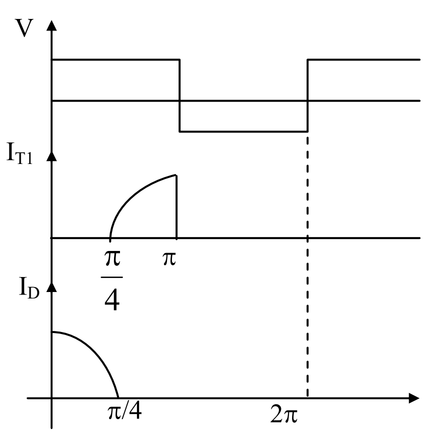
08. Ans: (a) 115A, 81.3 A

Sol: (a) $I_{01} = \frac{230}{2} = 115$ A

$I_{sw,\,r} = \frac{115}{\sqrt{2}} = 81.3$ A

(b) R = 2 Ω, X_L = 8 Ω, X_c = 6 Ω

$$Z_1 = \sqrt{R^2 + (X_L - X_C)^2} = 2\sqrt{2}\ \Omega$$



$$(i_T)^2_{RMS} = \frac{1}{2\pi}\int_{\frac{\pi}{4}}^{\pi} I_m^2 \sin^2\omega t\, d(\omega t)$$

$$= \frac{I_m^2}{2\pi}\int_{\frac{\pi}{4}}^{\pi} \frac{1-\cos 2\omega t}{2}\, d(\omega t)$$

$$= \frac{I_m^2}{4\pi}\left[\frac{3\pi}{4`} + \frac{1}{2}\right]$$

$$(i_T)_{RMS} = I_m(0.476)$$

$$I_m = \frac{230\sqrt{2}}{\sqrt{4+4}} = 81.317\times\sqrt{2}\ \text{A}$$

$$(i_T)_{RMS} = 0.476\times\sqrt{2}\times 81.317$$

$$= 54.73\text{A}$$

$$(i_0)_{RMS} = \frac{1}{2\pi}\int_0^{\frac{\pi}{4}} I_m^2 \sin^2\omega t\ \ d\omega t$$

$$= 0.15\ I_m$$

$$= 0.15\times\sqrt{2}\times 81.317 = 17.328\text{A}$$

09. Ans: (a) 500 μs (b) 750 V

Sol: **(a)** Circuit turn off time $t_c = \frac{T}{4} = 500\ \mu s$

(b) $V = \frac{I}{C}\times T$

$$= \frac{30}{20\mu}\times 500\mu = 750\ \text{V}$$

10. Ans: 77.15°

Sol: The given output voltage waveform is having quarter wave symmetry

$\therefore a_n = 0$

And $b_n = \frac{1}{\pi}\int_0^{2\pi} f(t)\sin(n\,\omega t)d\omega t$

$$= \frac{2}{\pi}\int_0^{\pi} f(t)\sin(n\,\omega t)d\omega t$$

For fundamental n = 1

$$\therefore b_1 = \frac{2V_{dc}}{\pi}\left[\int_0^{\alpha}\sin\omega t\, d\omega t - \int_{\alpha}^{\pi-\alpha}\sin\omega t\, d\omega t + \int_{\pi-\alpha}^{\pi}\sin\omega t\, d\omega t\right]$$

$$= \frac{2V_{dc}}{\pi}\left[\left|-\cos\omega t\right|_0^{\alpha} + \left|\cos\omega t\right|_{\alpha}^{\pi-\alpha} - \left|\cos\omega t\right|_{\pi-\alpha}^{\pi}\right]$$

$$= \frac{2V_{dc}}{\pi}[2 - 4\cos\alpha]$$

RMS value of fundamental output voltage can be

$$\Rightarrow \frac{2V_{dc}}{\pi\sqrt{2}}[2-4\cos\alpha] = 50\,\text{V}$$

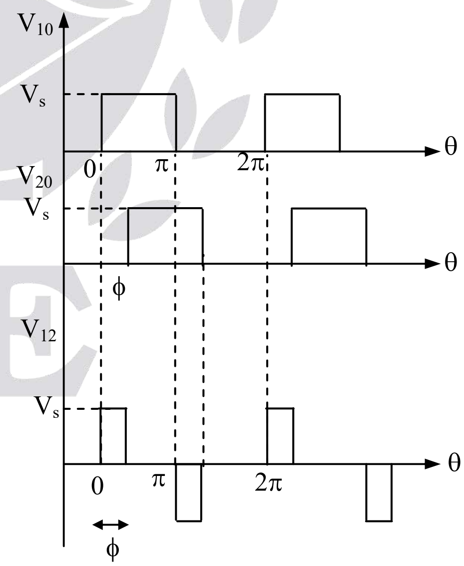
$\Rightarrow \cos\alpha = 0.2223$

$\Rightarrow \alpha = 77.15^o$

11. Ans: $V_s\sqrt{\frac{\phi}{\pi}}$

Sol: $V_{12} = V_{10} - V_{20}$

From Fig. (b)



Explanation: At instant 0, $V_{10} = V_s$ and $V_{20} = 0$

$\Rightarrow V_{12} = V_{10} - V_{20} = V_s - 0 = V_s$

After period of ϕ, $V_{10} = V_s$ and $V_{20} = V_s$

$\Rightarrow V_{12} = 0$

At instant of π, $V_{10} = 0$ and $V_{20} = V_s$

$\Rightarrow V_{12} = V_{10} - V_{20} = 0 - V_s = -V_s$

R.M.S value of V_{12}.

$$(V_{12})_{r.m.s} = \left[\frac{1}{\pi}\int_0^{\phi} V_s^{\,2}\, d\theta\right]^{1/2}$$

$$= \left[\frac{V_s^{\,2}}{\pi}(\theta)_0^{\phi}\right]^{1/2}$$

$$= V_s\sqrt{\frac{\phi}{\pi}}$$

12. Ans: 9.9 to 10.1

Sol: Modulation index, $m_a = \frac{\hat{v}_m}{\hat{v}_{tri}}$

$$= \frac{0.8}{1} = 0.8$$

Amplitude of the fundamental output voltage, $\left(\hat{V}_{AO}\right)_1 = m_a \times \frac{V_{dc}}{2}$

$$= 0.8 \times 250 = 200\,V$$

From the given modulating voltage equation, it can be understood that $\omega_1 = 200\pi$ means, fundamental component frequency = 100 Hz

Load impedance at 100 Hz frequency,

$$Z_1 = \sqrt{R^2 + X^2}$$

$$= \sqrt{12^2 + 16^2} = 20\,\Omega$$

$$\therefore \hat{I}_{L1} = \frac{\hat{V}_{AO1}}{Z_1} = \frac{200}{20} = 10\,A$$

13. Ans: 24 (Range: 23 to 25)

Sol: By converting the load into equivalent star,

$$R_{ph} = \frac{30}{3} = 10\,\Omega$$

In 180° conduction mode, rms value of each phase voltage,

$$V_{ph} = \frac{\sqrt{2}}{3}V_{dc}$$

$$= \frac{\sqrt{2}}{3} \times 600 = 200\sqrt{2}\,V$$

Power consumed by the load,

$$P_o = 3 \times \frac{V_{ph}^2}{R}$$

$$= 3 \times \frac{\left(200\sqrt{2}\right)^2}{10} = 24\,kW$$

14. Ans: 60 to 64

15. Ans: (d)

Sol: For 180°mode, $P = 3\frac{V_{ph\,RMS}^2}{R}$

$$10kW = \frac{3}{R}\left(\frac{V_{dc}\sqrt{2}}{3}\right)^2$$

$$\frac{V_{dc}^2}{R} = 15kW$$

For 120° mode, $P = \frac{3V_{ph\,RMS}^2}{R}$

$$= \frac{3}{R}\left(\frac{V_{dc}}{\sqrt{6}}\right)^2$$

$$= 3\frac{V_{dc}^2}{R}.\frac{1}{6}$$

$$= 3 \times 15 \times \frac{1}{6}$$

P = 7.5kW

16. Ans: (c)

Sol: Modulation index M = $\frac{\text{referance voltage}}{\text{carrier voltage}}$

$$= \frac{1}{5} = 0.2$$

Number of cycles (N)

$$= \frac{f_c}{2f_r} - 1$$

$$= \frac{1000}{2\times 50} - 1 = 10 - 1 = 9$$

Order of harmonics = 2N ± 1

= 18 ± 1

=17, 19

17. Ans: (c)

Sol: R = 40 Ω and $X_L = 100\pi \times \left(\frac{0.3}{\pi}\right) = 30\,\Omega$

Load impedance, $Z = \sqrt{R^2 + X_L^2}$

$$= \sqrt{40^2 + 30^2} = 50\,\Omega$$

$P_o = 1440$

$\Rightarrow I_{o1}^2 \times 40 = 1440$

$\Rightarrow I_{o1} = 6\text{ A}$

RMS value of fundamental output voltage,

$$V_{o1} = \frac{M \times V_{DC}}{\sqrt{2}}$$

$$= \frac{0.6 \times V_{DC}}{\sqrt{2}}$$

But, $I_{o1} = \frac{V_{o1}}{Z_1}$

$$= \frac{0.6 \times V_{DC}}{\sqrt{2} \times 50} = 6$$

$$\Rightarrow V_{DC} = \frac{50 \times 6 \times \sqrt{2}}{0.6}$$

$$= 500\sqrt{2}\text{ V}$$