



ELECTRICAL ENGINEERING

POWER ELECTRONICS

Volume-1 : Study Material with Classroom Practice Questions

Power Electronics

Solutions for Volume-1 Class Room Practice Questions

1. Basics & Power Semiconductor Devices

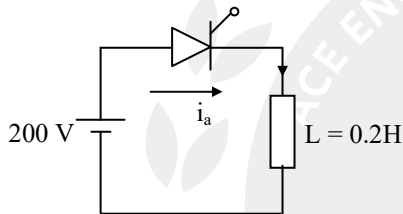
01. Ans: a) 100μs b) 100.5 μs c) 1005μs

Sol: (a) $I_L = 100 \text{ mA}$

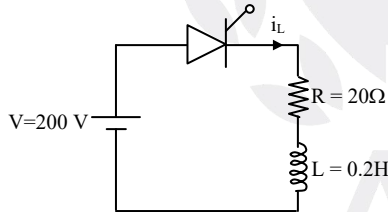
$$V = L \frac{di}{dt}$$

$$V t_p = L I_L$$

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



(b) $R = 20 \Omega$, $L = 0.2 \text{ H}$



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

At $t = t_p$, $i_L = 100 \text{ mA}$

$$100 \times 10^{-3} = \frac{200}{20} \left[1 - e^{-\frac{20}{0.2}t_p} \right]$$

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

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

$$t_p = 100.5 \mu \text{sec}$$

(c) $R = 20 \Omega$, $L = 2 \text{ H}$

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

$$100 \times 10^{-3} = \frac{200}{20} \left[1 - e^{-\frac{20}{2}t_p} \right]$$

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

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

$$t_p = 1005 \mu \text{sec}$$

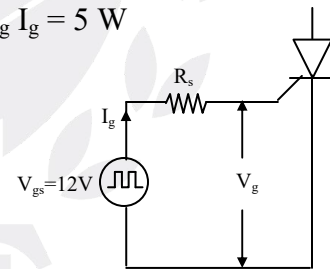
(d) If load inductance increases, SCR requires pulse width for longer duration.

02. Ans: (a) 7Ω (b) 1W

Sol: (a) Given

$$V_g = 1.5 + 8 I_g$$

$$V_g I_g = 5 \text{ W}$$



From KVL

$$V_{gs} = I_g R_s + V_g \dots\dots\dots (1)$$

$$V_g I_g = 5$$

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

$$I_g = 0.702 \text{ A}$$

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

From (1)

$$12 = 0.702 \times R_s + 7.12$$



$$R_s = 6.95 \Omega$$

$$\begin{aligned} \text{(b) } P_g &= P_{g\max} \times D \\ &= 5 \times 0.2 = 1 \text{ W} \end{aligned}$$

03. (i) Ans: (c) (ii) (a)

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

Write KVL to the gate circuit

$$-10 + I_{g\max} R + 1 + 1 + 1 = 0$$

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

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

$$= 46.7 \Omega$$

(ii) 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 $\times$ Time for which signal should be applied

$$= 10 \times 187 = 1870 \mu \text{ V-s}$$

Hence next higher rating of transformer is to be selected

$$\therefore \text{volt-sec rating} = 2000 \mu \text{ V-s}$$

04. Ans: 10 to 11

Sol: The rectifier diode can be represented as voltage drop = $IR + V$

$$\text{For } 0.8 \text{ V at } 2 \text{ A, } 0.8 = 2R + V \dots\dots\dots (1)$$

$$\text{For } 1.2 \text{ V at } 30 \text{ A, } 1.2 = 30R + V \dots\dots\dots (2)$$

By solving (1) & (2) $R = 14.2 \text{ m}\Omega$, $V = 0.7716$

$$I_{\text{avg}} = \frac{I_m}{\pi} = \frac{30}{\pi} = 9.55 \text{ A}$$

$$I_{\text{rms}} = \frac{I_m}{2} = 15 \text{ A}$$

$$\begin{aligned} \therefore \text{Conduction loss} &= I_{\text{rms}}^2 R + V I_{\text{avg}} \\ &= (15^2 \times 14.2 \times 10^{-3}) + (9.55 \times 0.7716) \\ &= 10.564 \text{ W} \end{aligned}$$

05. Ans: (88°C)

$$\text{Sol: } T_c = 100^\circ; \quad T_j = 125^\circ \text{C}$$

$$\theta_{CA} = 0.5^\circ \text{C/W} \quad T_s = ?$$

$$T_A = 40^\circ \text{C}$$

$$P = \frac{T_c - T_A}{\theta_{CA}}$$

$$= \frac{100 - 40}{0.5} = 120 \text{ W}$$

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

$$T_s - T_A = 48$$

$$\Rightarrow T_s = 48 + 40 = 88^\circ \text{C}$$

06. Ans: (i) 229.17W, (ii) 8.71%

$$\text{Sol: } T_j = 125^\circ \text{C} \quad ; \quad \theta_{jc} = 0.16^\circ \text{C/W}$$

$$\theta_{cs} = 0.08^\circ \text{C/W} \quad ; \quad T_s = 70^\circ \text{C}$$



$$(i) P_{av} = \frac{T_j - T_s}{\theta_{js}}$$

$$\begin{aligned} \text{where } \theta_{js} &= \theta_{jc} + \theta_{cs} \\ &= 0.16 + 0.08 = 0.24^\circ\text{C/W} \\ &= \frac{125 - 70}{0.24} = 229.16 \text{ W} \end{aligned}$$

(ii) Now $T_s = 60^\circ\text{C}$

$$\begin{aligned} P_{av} &= \frac{T_j - T_s}{\theta_{js}} \\ &= \frac{125 - 60}{0.24} = 270.8 \text{ W} \end{aligned}$$

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

$$\begin{aligned} \% \text{ increase} &= \frac{\sqrt{270.8} - \sqrt{229.16}}{\sqrt{229.16}} \times 100 \\ &= 8.71\% \end{aligned}$$

07. Ans: (b)

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

$$\begin{aligned} \text{From circuit } i &= \frac{V_s}{R} \left[1 - e^{-\frac{R}{L}t} \right] + \frac{V_s}{R} \\ &= \frac{100}{20} \left[1 - e^{-\frac{20}{0.5}t} \right] + \frac{100}{5000} \\ &= 5 \left[1 - e^{-40t} \right] + \frac{1}{50} \end{aligned}$$

$$50 \times 10^{-3} = 5(1 - e^{-40t}) + \frac{1}{50}$$

$$\Rightarrow t = 150 \mu \text{ sec}$$

08. Ans: (i) 7, 5, (ii) 22.22 k Ω , (iii) 0.094 μF

Sol: (i) $V = 11 \text{ kV}$, $I = 4 \text{ kA}$, $\eta = 90\%$

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

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

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

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

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

$$\begin{aligned} R &= \frac{7(1800) - 11 \times 10^3}{(7-1) \times 12 \times 10^{-3}} \\ &= 12 \text{ mA} - 0 = 12 \text{ mA} \\ &= 22.2 \text{ k}\Omega \end{aligned}$$

$$\begin{aligned} (iii) C &= \frac{(n-1) \Delta Q}{n V_{bm} - V_s} \\ &= \frac{(7-1) \times 25 \times 10^{-6}}{7 \times 1800 - 11 \times 10^3} = 0.0937 \mu\text{F} \end{aligned}$$

09. Ans: 74 to 76

Sol: Energy loss during

$$\begin{aligned} T_1 &= \int_0^{T_1} v \cdot i \, dt = 600 \times \int_0^{T_1} i \, dt \\ &= 600 \times \text{area under current curve} \\ &= 600 \times \frac{1}{2} \times 150 \times 1 \times 10^{-6} \\ &= 45 \text{ mJ} \end{aligned}$$

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

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

$$= 100 \times \text{area under voltage curve}$$



$$= 100 \times \frac{1}{2} \times 600 \times 1 \times 10^{-6} = 30 \text{ mJ}$$

$$\text{Total energy loss} = 45 + 30 = 75 \text{ mJ}$$

10.

Sol: Switching scheme – I

(i) Energy loss during ON condition:

$$\begin{aligned} (E_{\text{loss}})_{\text{ON}} &= \int_0^{t_{\text{on}}} V i \, dt \\ &= \int_0^{t_r} \left(400 - \frac{400}{t_r} t \right) \cdot \frac{20}{t_r} t \, dt \\ &= \int_0^{t_r} \left[400(20) \frac{t}{t_r} - \frac{400(20)}{t_r^2} t^2 \right] dt \\ &= (400)(20) \left[\frac{t_r^2}{2t_r} - \frac{t_r^3}{3t_r^2} \right] \\ &= \frac{(400)(20)}{6} \cdot t_r \end{aligned}$$

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

$$\begin{aligned} (E_{\text{loss}})_{\text{OFF}} &= \frac{VI}{6} t_{\text{off}} \\ &= \frac{400 \cdot (20)}{6} \times 200 \text{ ns} = 266.66 \mu\text{J} \end{aligned}$$

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

$$= 133.33 + 266.66 \approx 400 \mu\text{J}$$

(ii) $E = P \times t$

$$P = E \times f$$

$$= (400 \times 10^{-6}) \times 100 \times 10^3$$

$$P = 40 \text{ W}$$

Switching scheme-II

Energy loss during ON condition

$$\begin{aligned} \text{(i)} \quad (E_{\text{loss}})_{\text{ON}} &= \int_0^{t_r} v i \, dt \\ &= \int_0^{t_r} \left(400 - \frac{400}{t_r} t \right) 20 \, dt \end{aligned}$$

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

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

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

$$= \frac{8000}{2} \times 100 \times 10^{-9} = 400 \mu\text{J}$$

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

$$= \frac{400 \times 20}{2} \times 200 \times 10^{-6} \text{ J}$$

$$= 800 \mu\text{J}$$

$$E_{\text{Total}} = E_{\text{ON}} + E_{\text{OFF}} = 1200 \mu\text{J}$$

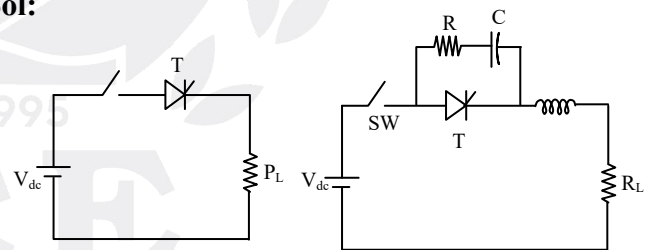
(ii) $P = E \times f$

$$= (1200 \times 10^{-6}) \times 100 \times 10^3$$

$$P = 120 \text{ W}$$

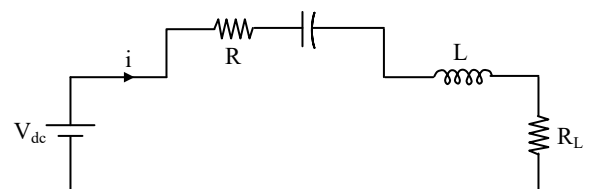
11. Ans: $L = 4 \mu\text{H}$, $C = 0.16 \mu\text{F}$ and $R = 5 \Omega$

Sol:



At the time of switch closed:

SCR is forward blocking condition





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

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

$$\text{Where } \tau = \frac{L}{R + R_L}$$

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

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

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

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

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

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

$$L = 4 \mu\text{H}$$

Given damping ratio $\zeta = 0.5$

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

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

$$\Rightarrow C = 0.16 \mu\text{F}$$

As SCR is in forward blocking mode

voltage across SCR = $I_a R$

$$V_t = I_a R$$

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

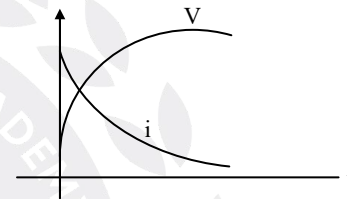
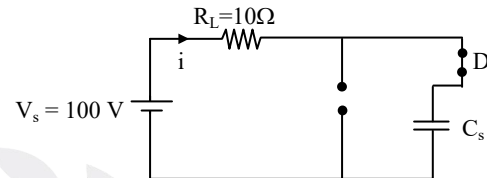
$$R = \frac{300}{60} = 5 \Omega$$

12. Ans: $R = 50 \Omega$, $C = 0.2 \mu\text{F}$

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

When circuit is power up:

SCR is forward blocking condition



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

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

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

$$\tau = R_L C$$

$$\frac{dV_c}{dt} = \frac{V_s}{R_L C} e^{-t/\tau}$$

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

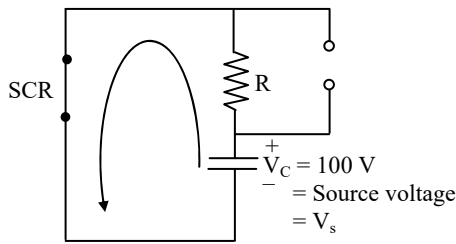
$$\frac{dV_c}{dt} = \frac{V_s}{R_L C}$$

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

$$C = 0.2 \mu\text{F}$$

When SCR is ON:

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



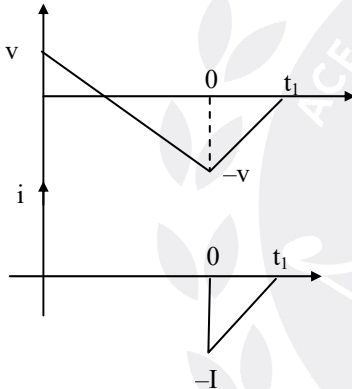
$$-100 + I_{\text{disch}} R = 0$$

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

$$R = 50 \Omega.$$

13. Ans: 1W, 900μC

Sol:



$$(E_{\text{loss}})_{\text{OFF}} = \int_0^{t_1} v i \, dt$$

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

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

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

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

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

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

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

$$= 20 \text{ mW}$$

$$P = E \times f$$

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

$$Q = \int i \, dt$$

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

$$Q = 900 \mu\text{C}$$

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)

$$\text{Sol: } I_C = \frac{V_{CC} - V_{CE(\text{sat})}}{R_L}$$

$$= \frac{200 - 2}{10} = 19.8 \text{ A}$$

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

$$= \frac{200 \times 19.8}{6} \times 3 \mu \times 1 \text{ K}$$

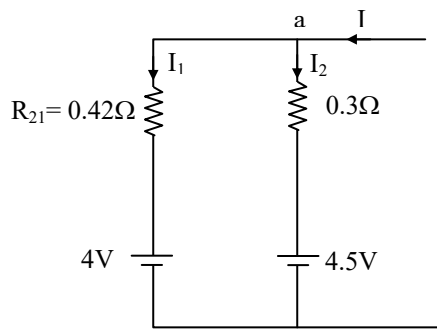
$$= 1.98 \text{ W}$$

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

$$= 0.792 \text{ W}$$

16. Ans: 9.54%

Sol: From the given data



The voltage at node a is

$$I = \left(\frac{V_a - 4.5}{0.3} \right) + \left(\frac{V_a - 4}{0.4} \right)$$

$$30 = V_a (5.833) - (15 + 10)$$

$$55 = V_a (5.833)$$

$$V_a = 9.43 \text{ V}$$

$$\Delta I = I_2 - I_1 = -13.575 + 16.43 = 2.858 \text{ A}$$

$$\frac{\Delta I}{I} \times 100 = \frac{2.858}{30} \times 100 = 9.52\%$$

2. AC-DC Converters

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

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

In the presence of SCR

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

$$\text{For } \alpha = 90^\circ \Rightarrow V_{or} = \frac{V}{2}$$

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

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

02. Ans: (i) 17.6V, (ii) 329V,
(iii) 445.3V, (iv) 141.5V, 10.75A
(v) 8.98ms

Sol: (i) Voltage across thyristor

$$\begin{aligned} V_T &= V_m \sin \alpha - E \\ &= 230 \times \sqrt{2} \sin 25^\circ - 120 \\ &= 17.46 \text{ V} \end{aligned}$$

$$\begin{aligned} \text{(ii) Now } V_T &= V_m \sin \beta - E \\ &= 230 \times \sqrt{2} \sin 220^\circ - 120 \\ &= -329.07 \text{ V} \end{aligned}$$

$$\begin{aligned} \text{(iii) Peak Inverse voltage} &= V_m + E \\ &= 230 \times \sqrt{2} + 120 \\ &= 445.3 \text{ V} \end{aligned}$$

(iv) Average output voltage

$$\begin{aligned} V_0 &= \frac{1}{2\pi} [V_m (\cos \alpha - \cos \beta) + E(2\pi + \alpha - \beta)] \\ &= \frac{1}{2\pi} [230 \times \sqrt{2} (\cos 25^\circ - \cos 220^\circ) \\ &\quad + 120(2\pi + 25 \times \frac{\pi}{180} - 220 \times \frac{\pi}{180})] \\ &= 141.57 \text{ V} \end{aligned}$$

$$\begin{aligned} \text{Current } I_0 &= \frac{V_0 - E}{R} \\ &= \frac{141.57 - 120}{2} \\ &= 10.78 \text{ A} \end{aligned}$$

$$\begin{aligned} \text{(v) } t_c &= \frac{2\pi + \theta - \beta}{\omega} = \frac{2\pi + (21.64 - 220)}{\omega} \times \frac{\pi}{180} \\ &= \frac{2.82}{100\pi} = 8.98 \text{ ms} \end{aligned}$$

03. Ans: 18A, 1A

Sol: $R = 5 \Omega$, $L = 10 \text{ mH}$,
 $E = 80 \text{ V}$ and $V = 230 \text{ V}$



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

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

$$= 170.08 \text{ V}$$

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

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

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

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

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

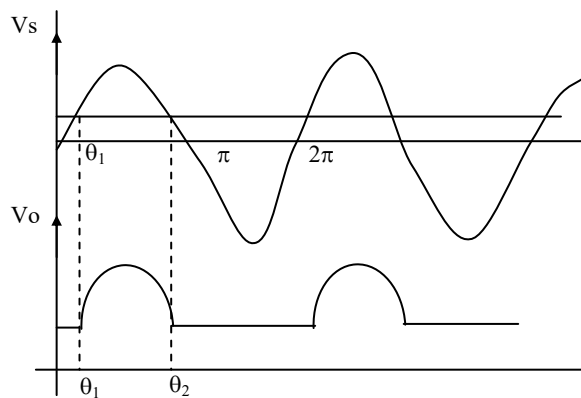
$$= \frac{85 - 80}{5} = 1 \text{ A}$$

04. Ans: (c)

Sol: $R = 2 \Omega$

If SCR₂ gets open circuited then the circuit behaves like single phase half-wave rectifier. The SCR's are triggered by constant DC signal means

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



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

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

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

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

$$= \frac{1}{2\pi R} [2 \times 230 \times \sqrt{2} \cos(37.94^\circ)]$$

$$- 200 \left(\pi - 2 \times 37.94^\circ \times \frac{\pi}{180} \right)$$

$$= 11.90 \text{ A}$$

05. Ans: 120° , 0.54A, 1.016A

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

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

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

$$\alpha = 120^\circ$$

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

$$= 54.01 \text{ V}$$

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

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

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

$$V_{\text{rms}} = 106.02 \text{ V}$$

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



06. Ans: 545.96 V

$$\begin{aligned}\text{Sol: } \frac{3V_{m\ell}}{\pi} \cos(180^\circ - \alpha) \\ = -E + 2I_0 r_s + 2 \times V_t + \frac{3\omega L_s}{\pi} I_0 \\ \frac{3 \times 415\sqrt{2}}{\pi} \cos 150^\circ = -E + (2 \times 60 \times 0.3) \\ + (2 \times 1.5) + \frac{3 \times 100\pi \times 1.2 \times 10^{-3}}{\pi} \times 60 \\ E = 545.96 \text{ V}\end{aligned}$$

07. Ans: 467.82 V

$$\begin{aligned}\text{Sol: } V_0 &= \frac{3V_{m\ell}}{\pi} \cos \alpha \\ &= \frac{3 \times \sqrt{2} \times 400}{\pi} \cos 30^\circ \\ &= 467.8 \text{ V}\end{aligned}$$

$$\text{Output power} = \frac{V_{\text{rms}}^2}{R}$$

$$\begin{aligned}V_{\text{rms}} &= V_{m\ell} \left(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} \cos 2\alpha \right)^{\frac{1}{2}} \\ &= 400\sqrt{2} \left[\frac{1}{2} + \frac{3\sqrt{3}}{8\pi} \right]^{\frac{1}{2}} \\ &= 475.562\end{aligned}$$

$$\text{Output power} = 22.61 \text{ kW}$$

08. Ans: (i) 67.85°, 0.36 lag (ii) 92.36V

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

$$\begin{aligned}\frac{3V_{m\ell}}{\pi} \cos \alpha &= RI_0 + E \\ \frac{3 \times 220\sqrt{2}}{\pi} \cos \alpha &= 0.2 \times 10 + 110 \\ \alpha &= 67.85^\circ\end{aligned}$$

$$P_0 = P_{\text{in}}$$

$$\sqrt{3} V_s I_s \cos \phi = V_0 I_0$$

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

$$\Rightarrow \cos \phi = 0.36 \text{ lag}$$

$$\text{(ii) } V_0 = RI_0 - E$$

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

$$V_{m\ell} = 130.59 \text{ V}$$

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

09. (i) Ans: (b) (ii) Ans: (c)

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

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

$$\begin{aligned}\text{(ii) kVA rating of input transformer} \\ = \sqrt{3} V_l I_l\end{aligned}$$

Where I_l = Rms value of line current on

$$\text{ac side} = I_0 \sqrt{\frac{2}{3}}$$

$$\begin{aligned}\text{kVA rating} &= \sqrt{3} \times 400 \times 40 \sqrt{\frac{2}{3}} \\ &= 22.6 \text{ kVA}\end{aligned}$$

10. Ans: (d)

Sol: Power supplied to load = $V_0 I_0$

$$= \frac{2V_m}{\pi} I_0 = \frac{2\sqrt{2}V_s}{\pi(n)} I_0$$



VA rating of secondary winding = 2
[voltage rating of each secondary winding ×
current rating of each secondary winding]

$$= 2 \left[\frac{V_m}{n} \times \frac{I_0}{2} \right]$$

$$= \frac{\sqrt{2} V_s I_0}{n}$$

Primary VA rating = $V_s \cdot \frac{I_0}{n}$

Average VA rating of transformed

$$= \frac{V_s I_0 + \sqrt{2} V_s I_0}{2n}$$

$$= 1.207 \frac{V_s I_0}{n}$$

$$\therefore \frac{\text{Average VA rating of transformer}}{\text{Power supplied to load}} = \frac{1.207}{0.9}$$

$$= 1.341$$

11. (i) Ans: (b) (ii) Ans: (b)

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

$$\text{Active power} = V_s I_{s1} \cos \phi_1$$

$$= 100 \times 10 \cos 60$$

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

(ii) 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

Input power factor

$$= \frac{V_s I_{s1} \cos \phi_1}{V_s I_s} = \frac{I_{s1}}{I_s} \cos \phi_1$$

$$I_{s1} = 10 \text{ A}$$

$$I_s = \sqrt{10^2 + 5^2 + 2^2}$$

$$= 11.35 \text{ A}$$

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

12. Ans: 15.47 (Range: 14.5 to 16.5)

Sol: $P_0 = V_0 \cdot I_0 = 3000 \text{ W}$

$$\Rightarrow \left[\frac{2V_m}{\pi} \cos \alpha - \frac{2\omega L_s}{\pi} I_0 \right] I_0 = 3000$$

$$\left[\frac{2 \times 230\sqrt{2}}{\pi} \times \frac{\sqrt{3}}{2} - \frac{2 \times 100\pi \times 1.4 \times 10^{-3}}{\pi} \times I_0 \right] I_0 = 3000$$

$$\Rightarrow 179.33 I_0 - 0.28 I_0^2 - 3000 = 0$$

$$\Rightarrow I_0 = 17.19 \text{ A}$$

$$\cos(\alpha + \mu) = \cos \alpha - \frac{2\omega L_s}{V_m} I_0$$

$$= \frac{\sqrt{3}}{2} - \frac{2 \times 100\pi}{230\sqrt{2}} \times \frac{1.4}{1000} \times 17.19$$

$$\Rightarrow \alpha + \mu = 34.96^\circ \Rightarrow \mu = 4.96^\circ$$

$$\text{DPF} = \cos \left[\alpha + \left(\frac{\mu}{2} \right) \right] = 0.843 \text{ lag}$$



Power balance equation

$$\Rightarrow V_{S1} \times I_{S1} \cos \phi_1 = P_o$$

$$\Rightarrow 230 \times I_{S1} \times 0.843 = 3000$$

$$\Rightarrow I_{S1} = \frac{3000}{230 \times 0.843} = 15.47 \text{ A}$$

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

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

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

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

$$\alpha + 30 = 72.600$$

$$\Rightarrow \alpha = 42.600^\circ$$

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

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

=

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

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

$$= 11.141 \text{ A}$$

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

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

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

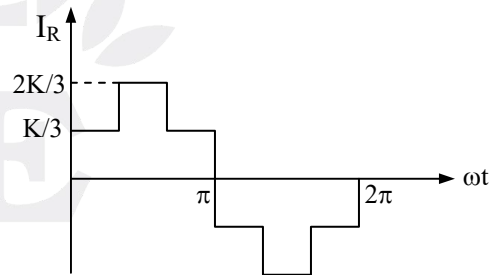
$$\Rightarrow -200 = -800 + RI_o \Rightarrow I_o = 30$$

As switches are lossless, power fed back to the source = $200 \text{ V} \times 30 \text{ A} = 6 \text{ kW}$

15. Ans: (b)

Sol: The line current in the Δ side of transformer is nothing but source current of 3- ϕ full converter and it is quasi square wave form of Pulse width $\frac{2\pi}{3}$

The phase currents in Δ side of transformer is 6 step square wave form and its equivalent Y side wave form will have magnitude of steps $\frac{K}{3}$ and $\frac{2K}{3}$. Hence I_R wave form will be as follows



16. Ans: (i) 146.42 V,

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

Sol: Given data:

$$V_s = 230, f = 50 \text{ Hz}, \alpha = 45^\circ, I_o = 5 \text{ A}$$

Without Free wheeling diode

It is a 1- ϕ full converter



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

$$= \frac{2 \times 230 \times \sqrt{2}}{\pi} \cos 45^\circ$$

$$V_0 = 146.4225 \text{ V}$$

$$P_0 = V_0 I_0 = 146.4225 \times 5$$

$$P_0 = 732.1125 \text{ W}$$

$$Q_0 = V_0 I_0 \tan \alpha$$

$$= 146.4225 \times 5 \times \tan 45^\circ$$

$$= 732.1125 \text{ VAR}$$

$$\text{If } \alpha = 60^\circ$$

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

$$= 5 \text{ A}$$

$$P_0 = V_0 I_0 = 517.68 \text{ W}$$

$$Q_0 = V_0 I_0 \tan \alpha$$

$$= 517.68 \times \tan 60$$

$$Q_0 = 896 \text{ VAR}$$

With free wheeling diode

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

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

$$V_0 = 176.747 \text{ V}$$

$$P_0 = V_0 I_0 = 176.747 \times 5$$

$$= 883.73 \text{ W}$$

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

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

$$Q_0 = 366.053 \text{ VAR}$$

(iii) If $\alpha = 60^\circ$

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

$$V_0 = 155.304 \text{ V}$$

$$I_0 = 5 \text{ A}$$

$$P_0 = V_0 I_0$$

$$P_0 = 776.523$$

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

$$= 776.523 \tan 30^\circ$$

$$Q_0 = 448.32 \text{ VAR}$$

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)

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

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

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

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

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 $(180 + \mu)^\circ$

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

$$\cos \mu = 1 - \frac{2\omega L_s}{V_m} I_0$$



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

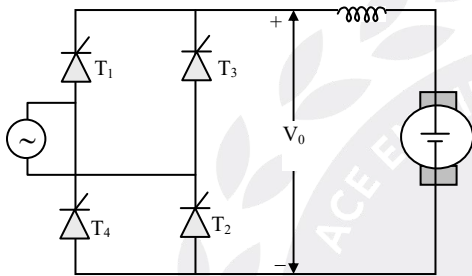
$$= 0.71727$$

$$\Rightarrow \mu = 44.17^\circ$$

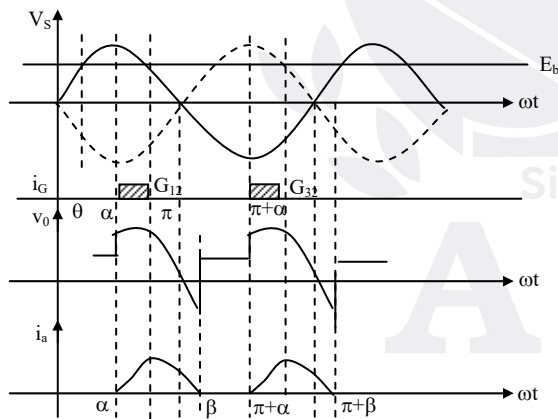
$$\therefore \text{Conduction angle for } D_1 = 180 + 44.17 \\ = 224.17^\circ$$

19. Ans: 5.225 A

Sol: $L_a = 50 \text{ mH}$; $\alpha = 90^\circ$; $E_b = 180 \text{ V}$



$$\theta = \sin^{-1} \left(\frac{E}{V_m} \right) = \sin^{-1} \left(\frac{180}{220\sqrt{2}} \right) = 35.35^\circ$$



When $T_1 T_2$ pair is ON at $\omega t = \alpha$

$$L_a \frac{di_0}{dt} + E_b = V_m \sin \omega t$$

$$\frac{di_0}{dt} = \frac{V_m \sin \omega t - E_b}{L_a}$$

$$\frac{di_0}{dt} = 0 \text{ at } \omega t = (\pi - \theta) \text{ hence } i_0 \text{ is maximum}$$

$$\int di_0 = \int \frac{V_m}{L_a} \sin \omega t dt - \int \frac{E_b}{L_a} dt$$

$$i_0 = \frac{V_m}{\omega L_a} (-\cos \omega t) - \frac{E_b}{L_a} t + K$$

initial condition is $i_0 = 0$ at $\omega t = \alpha = \pi/2$

$$\therefore 0 = \frac{V_m}{\omega L_a} \left(-\cos \frac{\pi}{2} \right) - \frac{E_b}{L_a} \times \frac{\pi}{2\omega} + K$$

$$\therefore K = \frac{E_b}{L_a} \times \frac{\pi}{2\omega}$$

$\therefore$ equation for

$$i_0 = \frac{V_m}{\omega L_a} (-\cos \omega t) - \frac{E_b}{L_a} t + \frac{E_b}{L_a} \frac{\pi}{2\omega}$$

Maximum value of i_0 is at $\omega t = (\pi - \theta)$

$$\therefore i_{0 \max} = \frac{220\sqrt{2}}{100\pi \times 50 \times 10^{-3}} \left[-\cos(180 - 35.35^\circ) \right] \\ - \frac{180}{50 \times 10^{-3}} \times \frac{(180 - 35.35)}{100\pi} \times \frac{\pi}{180} + \frac{180}{50 \times 10^{-3}} \times \frac{\pi}{2 \times 100\pi} \\ = 5.225 \text{ A}$$

3. DC-DC Converters

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

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

$$R_L = 10 \Omega$$

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

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

$$= \frac{100}{60 \times 10^{-3}} \times 0.5(0.5) \times \frac{1}{2 \times 10^3}$$

$$= \frac{50 \times 0.5 \times 0.5}{60} = 0.208 \text{ A}$$

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



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

02. (i) Ans: (c) (ii) 2.5 A, 37.5 μH

Sol: (i) $D = 0.5$, $f = 100 \text{ kHz}$,

$$\Delta i_c = 1.6 \text{ A}, I_0 = 5 \text{ A}$$

$$\Delta I_C = \Delta I_L$$

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

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

(ii) Average switch current

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

$$= 2.5 \text{ A}$$

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

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

$$L = 37.5 \mu\text{H}$$

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

(ii) 333.333 μH

(iii) 312.5 μH

(iv) 8.33mH, 12.5 nF

Sol: $\Delta V_0 = 10 \text{ mV}$

$$\Delta I_L = 0.5 \text{ A}, T = 50 \mu\text{s}$$

(i) Duty cycle ratio

$$V_o = DV_{dc}$$

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

(ii) filter Inductance

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

$$\Rightarrow 0.5 = \frac{5 \times \frac{1}{3} \times \frac{2}{3} \times 50 \mu}{L}$$

$$L = 333.33 \mu\text{H}$$

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

$$10 \times 10^{-3} = \frac{15}{8 \times 333.33 \times 10^{-6} \times C \times 20 \times 10^3} \cdot \frac{1}{3} \left(1 - \frac{1}{3} \right)$$

$$C = 312.5 \mu\text{F}$$

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

$$= \frac{(1-0.33)500}{2 \times 20 \times 10^3} = 8.33 \text{ mH}$$

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

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

$$= 12.5 \text{ nF}$$

04. (i) Ans: 937.5 W (ii) 1041.7 W

Sol: $f = 20 \text{ kHz}$, $T = 50 \mu\text{s}$

$D = 0.5$, Given circuit is boost converter

(i) When switch is ON [$0 < t < DT$]

$$L \frac{di_L}{dt} = 100 \Rightarrow \frac{di_L}{dt} = \frac{100}{L}$$

When switch is OFF

$$L \frac{di_L}{dt} = 100 - 300 = -200$$

$$\frac{di_L}{dt} = -\frac{200}{L}$$

From the given slopes, given condition is discontinuous conduction mode.

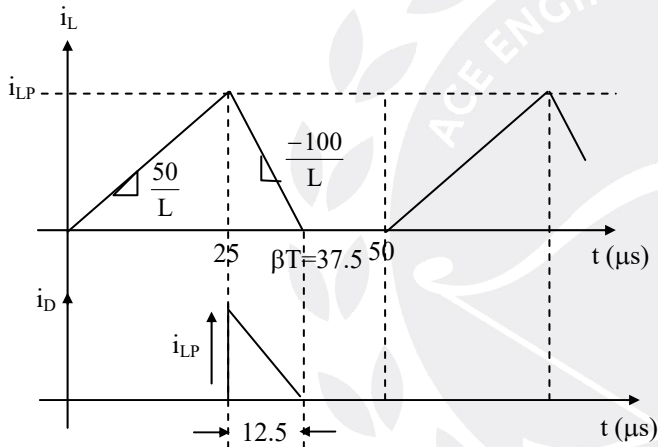
$$\therefore \frac{V_0}{V_{dc}} = \frac{\beta}{\beta - D}$$

$$\Rightarrow \frac{300}{100} = \frac{\beta}{\beta - D} \Rightarrow \beta = 0.75$$

From i_L waveform, $i_{LP} = \frac{100}{L} \times DT$

$$= \frac{100}{100 \times 10^{-6}} \times 25 \times 10^{-6}$$

$$= 25 \text{ A}$$



$$\therefore I_{Dav} = \frac{\frac{1}{2} \times i_{LP} \times (\beta - D)T}{T}$$

$$= \frac{\frac{1}{2} \times 25 \times 12.5 \times 10^{-6}}{50 \times 10^{-6}} = 3.125 \text{ A}$$

$$P_{out} = V_2 \times I_{Dav} = 300 \times 3.125$$

$$= 937.5 \text{ W}$$

∴ Power transferred from B₁ to B₂ = 937.5 W

(ii) When switch is ON [0 < t < DT]

$$L \frac{di_L}{dt} = 100 \Rightarrow \frac{di_L}{dt} = \frac{100}{L}$$

When switch is OFF

$$L \frac{di_L}{dt} = 100 - 250 = -150$$

$$\frac{di_L}{dt} = -\frac{150}{L}$$

From the given slopes, given condition is discontinuous conduction mode.

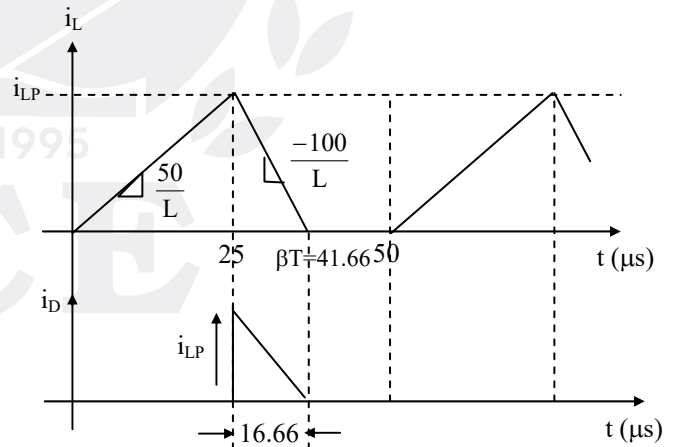
$$\therefore \frac{V_0}{V_{dc}} = \frac{\beta}{\beta - D}$$

$$\Rightarrow \frac{250}{100} = \frac{\beta}{\beta - D} \Rightarrow \beta = \frac{5}{6}$$

From i_L waveform, $i_{LP} = \frac{100}{L} \times DT$

$$= \frac{100}{100 \times 10^{-6}} \times 25 \times 10^{-6}$$

$$= 25 \text{ A}$$



$$\therefore I_{Dav} = \frac{\frac{1}{2} \times i_{LP} \times (\beta - D)T}{T}$$



$$= \frac{\frac{1}{2} \times 25 \times 16.66 \times 10^{-6}}{50 \times 10^{-6}} = 4.166 \text{ A}$$

$$P_{out} = V_2 \times I_{Dav} = 250 \times 4.166$$

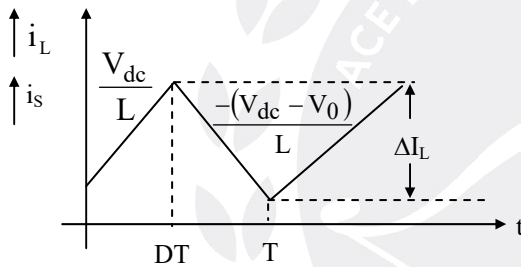
$$= 1041.667 \text{ W}$$

$\therefore$ Power transferred from B₁ to B₂ =

1041.667 W

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

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

05. (ii) Ans: (c)

Sol: Peak to peak source current ripple.

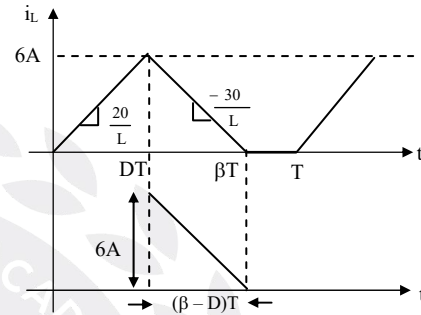
$$\Delta I_L = \Delta I_s = \frac{V_{dc}}{L} DT$$

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

$$= 0.192 \text{ A}$$

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 $V_0 > 40 \text{ V}$, so it is discontinuous mode of operation.

Power balance equation $P_0 = P_{in}$

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

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

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

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

$$\beta = 0.833$$

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

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

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



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

$$I_{D,rms} = 2 \text{ A}$$

07. Ans: (i) 0.6

(ii) 0.72 A

(iii) 1.61 A

(iv) 34.09 mA

(v) 72μH, 500nF

Sol: Given

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

$$(i) V_0 = \frac{V_{dc}}{1-D}$$

$$\Rightarrow \text{Duty cycle } D = 0.6$$

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

$$= \frac{6}{250 \times 10^{-6}} \times 0.6 \times \frac{1}{20K}$$

$$= 0.72 \text{ A}$$

$$(iii) I_{L,max} = I_L + \frac{\Delta I_L}{2} = \frac{20}{1-D} + \frac{\Delta I_L}{2}$$

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

$$(iv) \Delta V_c = \frac{I_D \cdot DT}{C} = \frac{0.5 \times 0.6 \times \frac{1}{20 \times K}}{440 \times 10^{-6}}$$

$$= 34.1 \text{ mV}$$

$$(v) L_{cr} = \frac{D(1-D)^2 RT}{2}$$

$$= \frac{0.6(1-0.6)^2 \times 30 \times \frac{1}{20k}}{2}$$

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

$$L_{cr} = 72 \mu H$$

$$C_{cr} = \frac{(1-D)I_0 DT}{2V_{DC}}$$

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

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, $I_o = 10 \text{ A}$

From power balance, $P_{in} = P_{out}$ or $V_{dc} \times I_i =$

$$V_o \times I_o, \text{ it will give } I_i = \frac{4000}{360} = 11.11 \text{ A}$$

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: (i) 83.3μs (ii) 83.3A

Sol: (i) Buck-boost converter, $f = 10 \text{ kHz}$

$$I_{L,max} = \frac{100}{L} DT \quad \dots\dots\dots (1)$$

$$= \frac{500}{L} (T - DT) \quad \dots\dots\dots (2)$$

From (1) & (2)

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

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



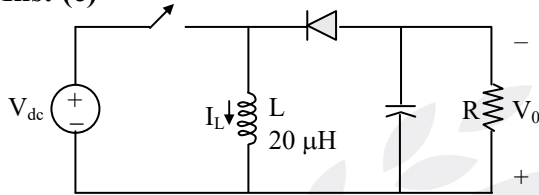
(ii) Peak current through switch

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

$$= \frac{100}{100 \times 10^{-6}} \times 83.3 \times 10^{-6} = 83.3 \text{ A}$$

10. Ans: (c)

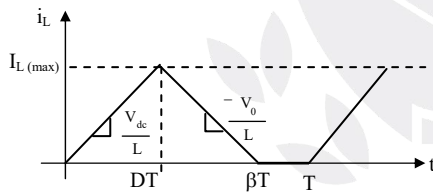
Sol:



In CCM Buck Boost,

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

But given $V_o > 30 \text{ V}$, so it is discontinuous mode of operation.



From i_L waveform

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

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

$$\therefore I_{L \max} = \frac{V_{dc}}{L} \times DT = \frac{20}{20\mu} \times 0.6 \times 20\mu = 12 \text{ A}$$

$$I_{L \text{ (avg)}} = \frac{\frac{1}{2} \times 12 \times 0.8 \times 20\mu}{20\mu} = 4.8 \text{ A}$$

11. Ans: (i) 18V

(ii) 0.163V

(iii) 1.152A

(iv) 4.326A

(v) 38.4 μH and 1μF

Sol: (i) $V_o = \frac{D}{1-D} V_{dc}$

$$= \frac{0.6}{1-0.6} \times 12$$

$$= 18 \text{ V}$$

(ii) $\Delta V_c = \frac{I_o}{L} DT$

$$= \frac{1.5}{250 \times 10^{-6}} \times 0.6 \times \frac{1}{25 \text{ K}} = 0.144 \text{ V}$$

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

$$= \frac{12}{250 \times 10^{-6}} \times 0.6 \times \frac{1}{25 \text{ k}}$$

$$= 1.152 \text{ A}$$

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

$$= 4.326$$

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

$$C_{cr} = \frac{I_o T(1-D)}{2V_{dc}}$$

$$= \frac{1.5 \times \frac{1}{25 \times 10^3} (1-0.6)}{2 \times 12} = 1 \mu\text{F}$$

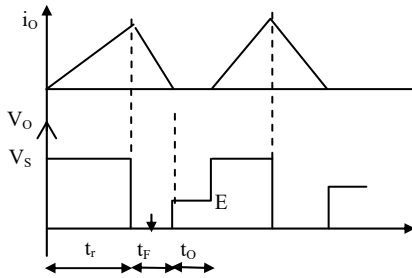
12. Ans: (c)

Sol: For step down chopper for R_L

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



For RLE load, the output waveform is



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

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

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

13. Ans: (a)

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

When $V_{dc} = 32 \text{ V}$,

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

When $V_{dc} = 72 \text{ V}$,

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

$\therefore$ 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)

$$\begin{aligned} \text{Sol: } i &= V_0 \sqrt{\frac{C}{L}} \sin \omega_0 t \\ &= V_0 \sqrt{\frac{C}{L}} \sin \frac{1}{\sqrt{LC}} t \\ &= 100 \sqrt{\frac{10 \times 10^{-6}}{1 \times 10^{-3}}} \sin \frac{1}{\sqrt{10 \times 10^{-6} \times 10^{-3}}} t \\ i &= 10 \sin(10^4 t) \text{ A} \end{aligned}$$

16. Ans: (a)

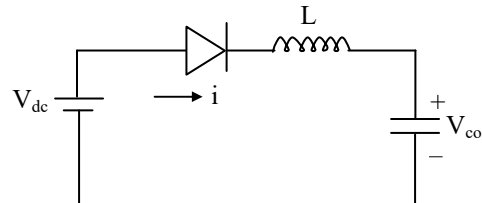
Sol: Given circuit is a current commutation circuit. When ever both the currents are equal and opposite then the thyristor will be turned off.

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

$$t = 52 \mu\text{sec}$$

17. Ans: 35.1 μs , 189.4 V

Sol:





$$i_L(0) = I_0$$

$$\frac{L di}{dt} + \frac{1}{C} \int i dt = V_{dc}$$

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

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

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

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

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

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

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

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

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

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

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

$$t_{on} = \frac{\pi}{2} \sqrt{10 \times 10^{-6} \times 50 \times 10^{-6}} \\ = 35.1 \mu s$$

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

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

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

$$= 100 + 200 \sqrt{\frac{10 \mu}{50 \mu}} = 189.4 V$$

- 18. Ans: (i) 1075 μs, (ii) 427.85A, (iii) 137.5 μs, (iv) 20V**

Sol: Given data

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

$$\text{Commutation parameters: } L = 20\mu H,$$

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

$$T = 2000\mu sec \text{ \& } I_0 = 80A$$

(i) Effective on period

$$T_{ON}^1 = T_{ON} + 2 \cdot \frac{CV_s}{I_0}$$

$$= (800 \times 10^{-6}) + 2 \left(\frac{50 \times 10^{-6} \times 220}{80} \right)$$

$$= 1075 \mu sec$$

(ii) Peak currents through T_1 and T_A

$$I_{T_1 p} = I_0 + V_s \sqrt{\frac{C}{L}}$$

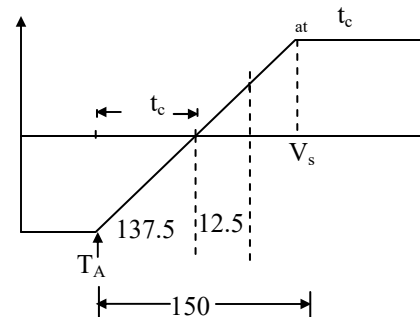
$$= 80 + 220 \sqrt{\frac{50}{20}} = 427.85A$$

$$I_{T_A p} = I_0 = 80A$$

(iii) turn off time for T_1

$$t_c = \frac{CV_s}{I_0} = \frac{50 \times 10^{-6} \times 220}{80} = 137.5 \mu sec$$

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





$$V_s \text{ at } t_c = 220 \text{ V}$$

$$137.5 \rightarrow 220 \text{ V}$$

$$12.5 \rightarrow ?$$

$$V_c = \frac{220}{137.5} \times 12.5 = 20 \text{ V}$$

19. (i) Ans: (b) (ii) Ans: (b)

Sol: (i) The minimum time is required for change the polarity of capacitor from V_s to $-V_s$

$$\begin{aligned} \text{i.e. } t_1 &= \frac{\pi}{\omega_o} \\ &= \pi \times \sqrt{LC} \\ &= \pi \times \sqrt{2 \times 10^{-3} \times 1 \times 10^{-6}} \\ &= 140 \mu \text{ sec.} \end{aligned}$$

This time is turn ON time of thyristor i.e.

$$T_{ON} = 140 \mu \text{ sec}$$

(ii) In a voltage commutated chopper, average value of output voltage is given by

$$\begin{aligned} V_o &= \frac{V_s}{T} (T_{ON} + 2t_c) \\ &= \frac{V_s}{T} \left(T_{ON} + 2 \cdot \frac{CV_s}{I_o} \right) \\ &= \frac{250}{1 \times 10^{-3}} \left[140 \times 10^{-6} + 2 \times \frac{1 \times 10^{-6} \times 250}{10} \right] \\ &= 47.5 \text{ V} \end{aligned}$$

4. DC-AC Converters

- 01. (i) 26.1V (ii) 240W**
(iii) 48.43% (iv) 5A
(v) 48V

Sol: i) $V_{o1} = \frac{\sqrt{2}}{\pi} V_{dc} = 0.45 \times 48 = 21.6 \text{ V}$

ii) $P_o = \frac{\left(\frac{V_{dc}}{2} \right)^2}{R} = \frac{24^2}{2.4} = 240 \text{ W}$

iii) THD = 48.43%

iv) Peak current through switch

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

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

v) PIV = 48V

With full bridge

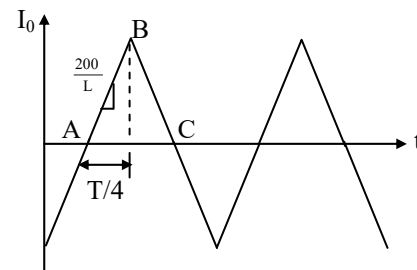
$$V_{o1} = \frac{2\sqrt{2}}{\pi} V_{dc}, \quad P_o = \frac{V_{dc}^2}{R}$$

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

$$I_{avg}(\text{diode}) = \frac{I_p}{2}, \quad \text{PIV} = 48 \text{ V}$$

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

Sol:





$$y = mx, I_p = \frac{200}{L} \times \frac{T}{4} \quad [T = 20 \text{ msec}]$$

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

$$(ii) \text{ Each diode will conduct for } \frac{T}{4} \text{ sec} \\ = 5 \text{ msec}$$

03. Ans: (c)

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

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

$$\text{Given } V_2 = 240 \text{ and } N_1 = 10$$

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

$$N_2 = \frac{240 \times \sqrt{2} \times 3}{4 \times 12} \times 10 \\ = 150\sqrt{2}$$

04. Ans: (c)

$$\text{Sol: Given } 2d = 150^\circ$$

Fundamental component peak value

$$= \frac{4V_s}{\pi} \sin d \cdot \sin \frac{\pi}{2}$$

fundamental component r.m.s value

$$(V_1) = \frac{4V_s}{\sqrt{2}\pi} \sin d \cdot \sin \frac{\pi}{2}$$

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

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

and r.m.s. 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

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

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

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

05. Ans: (i) 200.8V, (ii) 24.75°, (iii) 203.64V

Sol: Given data:

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

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

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

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

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

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

$$2d = 24.78$$

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

$$V_{dc} = 203.64V$$

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 $R = 15\Omega$

In 180° 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° Operation:

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

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

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

$$= 3 \times 11.43^2 \times 15 = 5.88 \text{ kW}$$

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

07. Ans: 2.15 μF

Sol: $t_c = F.S \times t_2 = 24 \mu s$

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

$$\omega t_c = \phi_1 = 0.754$$

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

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

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

$$\frac{1}{\omega C} = 12.039$$

$$C = 2.15 \mu F$$

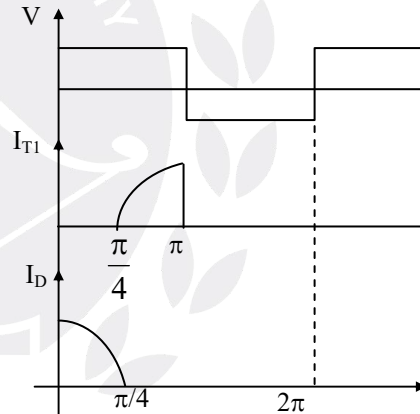
08. Ans: (a) 115A, 81.3 A

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

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

(b) $R = 2 \Omega, X_L = 8 \Omega, X_c = 6 \Omega$

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



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

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

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

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

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

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

$$= 54.73A$$



$$\begin{aligned}(i_0)_{\text{RMS}} &= \frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2 \omega t \, d\omega t \\ &= 0.15 I_m \\ &= 0.15 \times \sqrt{2} \times 81.317 = 17.328 \text{ A}\end{aligned}$$

09. Ans: (i) 500 μ s (ii) 750 V

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

$$\begin{aligned}\text{(ii) } V &= \frac{I}{C} \times T \\ &= \frac{30}{20\mu} \times 500\mu = 750 \text{ V}\end{aligned}$$

10. Ans: 77.15°

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

$$\therefore a_n = 0$$

$$\begin{aligned}\text{And } b_n &= \frac{1}{\pi} \int_0^{2\pi} f(t) \sin(n\omega t) d\omega t \\ &= \frac{2}{\pi} \int_0^{\pi} f(t) \sin(n\omega t) d\omega t\end{aligned}$$

For fundamental $n = 1$

$$\begin{aligned}\therefore b_1 &= \frac{2V_{dc}}{\pi} \left[\int_0^{\alpha} \sin \omega t \, d\omega t - \int_{\alpha}^{\pi-\alpha} \sin \omega t \, d\omega t + \int_{\pi-\alpha}^{\pi} \sin \omega t \, d\omega t \right] \\ &= \frac{2V_{dc}}{\pi} \left[-\cos \omega t \Big|_0^{\alpha} + \left| \cos \omega t \right|_{\alpha}^{\pi-\alpha} - \left| \cos \omega t \right|_{\pi-\alpha}^{\pi} \right] \\ &= \frac{2V_{dc}}{\pi} [2 - 4 \cos \alpha]\end{aligned}$$

RMS value of fundamental output voltage can be

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

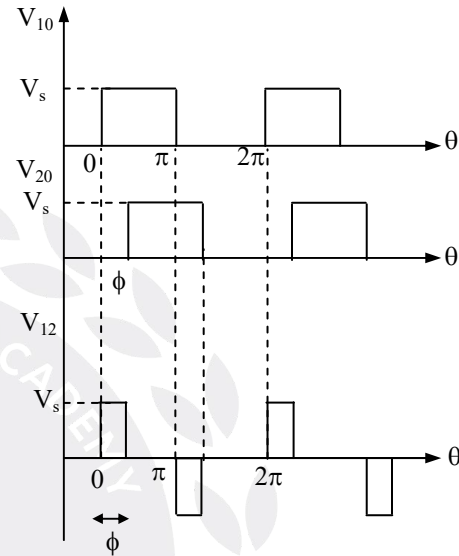
$$\Rightarrow \cos \alpha = 0.2223$$

$$\Rightarrow \alpha = 77.15^\circ$$

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} .

$$\begin{aligned}(V_{12})_{\text{r.m.s}} &= \left[\frac{1}{\pi} \int_0^{\phi} V_s^2 d\theta \right]^{1/2} \\ &= \left[\frac{V_s^2}{\pi} (\theta)_0^{\phi} \right]^{1/2} \\ &= V_s \sqrt{\frac{\phi}{\pi}}\end{aligned}$$



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, $(\hat{V}_{AO})_1 = m_a \times \frac{V_{dc}}{2}$

$$= 0.8 \times 250 = 200 \text{ V}$$

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,

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

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

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

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,

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

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

Power consumed by the load,

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

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

14. Ans: 60 to 64

Sol: $m_a = 0.7$

$$V_{in} = 100 \text{ V}$$

$$L = 9.55 \text{ mH}$$

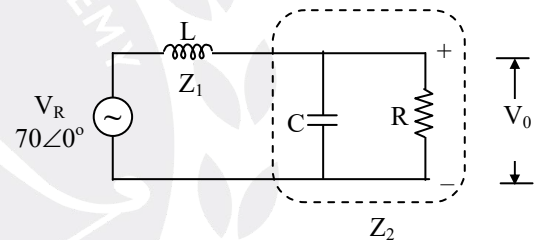
$$C = 63.66 \mu\text{F}$$

$$R = 5 \Omega, f = 50 \text{ Hz}$$

$$V_R = \hat{V}_R \sin(2\pi ft)$$

$$= (m_a \times V_{in}) \sin(100\pi t)$$

$$= (0.7 \times 100) \sin(100\pi t) = 70 \sin(100\pi t)$$



$$V_0 = 70\angle 0^\circ \times \frac{Z_2}{Z_1 + Z_2}$$

$$= 70\angle 0^\circ \times \frac{5 \times (-j50)}{5 - j50}$$

$$= 70\angle 0^\circ \times \frac{j3 + \frac{5 \times (-j50)}{5 - j50}}{5 - j50}$$

$$= 70\angle 0^\circ \times \left[\frac{-j250}{15j + 150 - j250} \right]$$

$$= 70\angle 0^\circ \left[\frac{-j250}{150 - j235} \right]$$

$$V_0 = 62.77 \text{ V}$$



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, $P = \frac{3V_{ph\ RMS}^2}{R}$

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

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

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

$$P = 7.5kW$$

16. Ans: (c)

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

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

Number of cycles (N)

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

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

Order of harmonics = $2N \pm 1$

$$= 18 \pm 1$$

$$= 17, 19$$

17. Ans: (c)

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

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

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

$$P_o = 1440$$

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

$$\Rightarrow I_{ol} = 6\ A$$

RMS value of fundamental output voltage,

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

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

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

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

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

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

18. Ans: 244.8 (Range 244 to 246)

Sol: The line to line voltage at fundamental

frequency can be written as, $\hat{v}_{ph1} \propto m_a$

$$\hat{v}_{ph1} = m_a \times \frac{V_{dc}}{2}$$

$$V_{LL1(rms)} = \frac{\sqrt{3}}{\sqrt{2}} \times m_a \times \frac{V_{ds}}{2}$$

$$= 0.612 \times m_a \times V_{dc}$$

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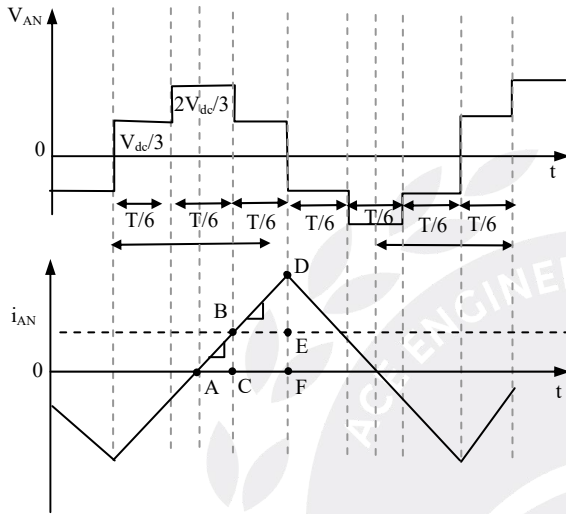


$$= 0.612 \times 0.8 \times 500$$

$$= 244.8 \text{ V}$$

19. Ans: 30 A

Sol:



$$\Delta ABC, \frac{2V_{dc}}{3L} = \frac{BC}{AC}$$

$$\Rightarrow BC = \frac{2V_{dc}}{3L} \times \frac{T}{12} = \frac{V_{dc}}{18Lf}$$

$$\text{In } \Delta BDE, \frac{V_{dc}}{3L} = \frac{DE}{BE}$$

$$\Rightarrow DE = \frac{V_{dc}}{3L} \times \frac{T}{6} = \frac{V_{dc}}{18Lf}$$

$$i_0(\text{ph}) = BC + DE = \frac{V_{dc}}{18Lf} + \frac{V_{dc}}{18Lf} = \frac{V_{dc}}{9Lf}$$

$$i_0 = \frac{270}{9 \times 20 \times 10^{-3} \times 50} = 30 \text{ A}$$

20. Ans: 47.325 V, 78.03V, 58 V

Sol: The Fourier series of function given in above figure is

$$V_{on} = \frac{4V_s}{n\pi} (1 - 2\cos n\alpha_1 + 2\cos n\alpha_2)$$

$$\text{Given } V_s = 150 \text{ V}, \alpha_1 = 23.62^\circ, \alpha_2 = 33.3^\circ$$

$$V_{o7,m} = \frac{4V_s}{7\pi} [1 - 2\cos(7 \times 23.62) + 2\cos(7 \times 33.3)]$$

$$= 0.3155 V_s = 47.325 \text{ V}$$

$$V_{o9,m} = \frac{4V_s}{9\pi} [1 - 2\cos(9 \times 23.62) + 2\cos(9 \times 33.3)]$$

$$= 0.5202 V_s = 78.03 \text{ V}$$

$$V_{o11,m} = \frac{4V_s}{11\pi} [1 - 2\cos(11 \times 23.62) + 2\cos(11 \times 33.3)]$$

$$= 0.3867 V_s = 57.85 \text{ V}$$

21. Ans: 9.1 to 9.3

Sol: Input power = Output power

$$\Rightarrow V_{rms} I_{rms} = 5 \text{ kW}$$

$$(220) I_{rms} = 5000$$

$$I_{rms} = \frac{5000}{220} = 22.72 \text{ A}$$

$$\tan \delta = \frac{I_s X_s}{V_s} = \frac{\left(\frac{500}{22}\right) \times (2\pi f L)}{V_{rms}}$$

$$= \frac{\frac{500}{22} \times 100\pi \times 5 \times 10^{-3}}{220}$$

$$= 0.1621$$

$$\Rightarrow \delta = \tan^{-1}(0.1621) = 9.2^\circ$$