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ELECTRICAL ENGINEERING

POWER ELECTRONICS & DRIVES

Volume - 1 : Study Material with Classroom Practice Questions

Power Electronics & Drives

Solutions for Volume-1 Class Room Practice Questions

1. Basics & Power Semiconductor Devices

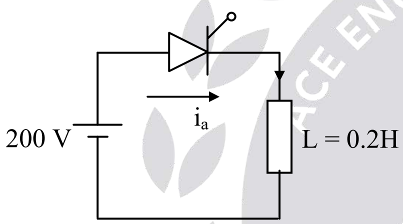
01. Ans: a) 100μs b) 100.5 μs c) 1005μs

Sol: (a) $I_L = 100$ mA

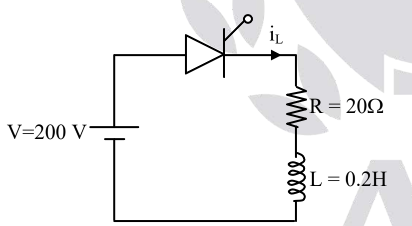
$$V = L\frac{di}{dt}$$

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

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



(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

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

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

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

$t_p = 100.5$ μsec

(c) R = 20 Ω, L = 2 H

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

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

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

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

$t_p = 1005$ μsec

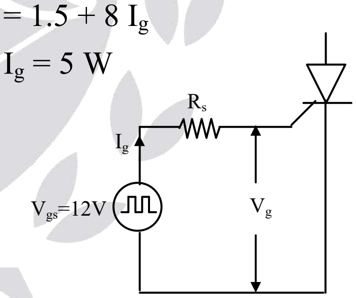
(d) If load inductance increases, SCR requires pulse width for longer duration.

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)

$12 = 0.702 \times R_s + 7.12$

$R_s = 6.95\ \Omega$

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

$= 5 \times 0.2 = 1$ W

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

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

Write KVL to the gate circuit

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

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

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

$= 46.7\ \Omega$

(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 × Time for which signal should be applied

$= 10 \times 187 = 1870\ \mu$V-s

Hence next higher rating of transformer is to be selected

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

04. Ans: 10 to 11

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

For 0.8 V at 2A, 0.8 = 2R+V ……….. (1)

For 1.2 V at 30A, 1.2 = 30 R+V …….. (2)

By solving (1) & (2) R= 14.2mΩ, V=0.7716

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

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

$\therefore$ Conduction loss = $I_{rms}^2 R + VI_{avg}$

$= (15^2 \times 14.2 \times 10^{-3}) + (9.55 \times 0.7716)$

$= 10.564$ W

05. Ans: (88°C)

Sol: $T_c = 100°$; $T_j = 125°$C

$\theta_{CA} = 0.5$ °C/W $T_s = ?$

$T_A = 40°$C

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

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

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

$T_S - T_A = 48$

$\Rightarrow T_S = 48 + 40 = 88°$C

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

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

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

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

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

$= 0.16 + 0.08 = 0.24°$C/W

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

(ii) Now $T_s = 60°C$

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

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

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: (i) 7, 5, (ii) 22.22 kΩ , (iii) 0.094 μF

Sol: **(i)** 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

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

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

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

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

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

= 12 mA – 0 = 12 mA

= 22.2 kΩ

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

$$= \frac{(7-1)\times 25\times10^{-6}}{7\times1800 - 11\times10^3} = 0.0937\ \mu\text{F}$$

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

$$= 100\times\frac{1}{2}\times600\times1\times10^{-6} = 30\text{ mJ}$$

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) $E = P\times t$

$P = E\times f$

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

$P = 40W$

Switching scheme-II

Energy loss during ON condition

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

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

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

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

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

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

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

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

$= 800\ \mu J$

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

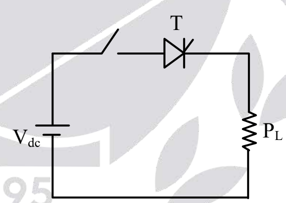
(ii) $P = E\times f$

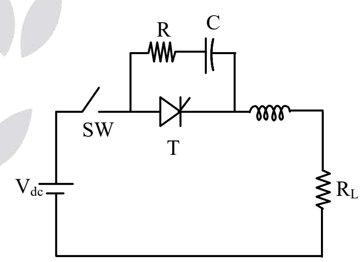
$= (1200\times 10^{-6})\times 100\times 10^3$

$P = 120W$

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

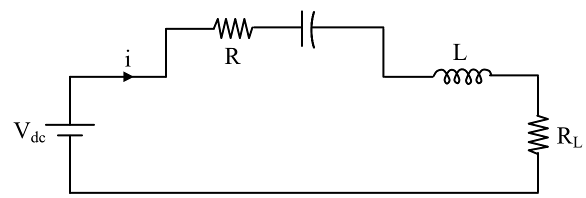
Sol:





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 $\tau = \frac{L}{R + R_2}$

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

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

$\frac{di}{dt}$ 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 μH

Given damping ratio ζ = 0.5

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

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

⇒ C = 0.16 μF

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

$V_t = I_aR$

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

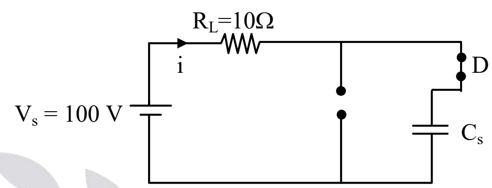
$$R = \frac{300}{60} = 5\ \Omega$$

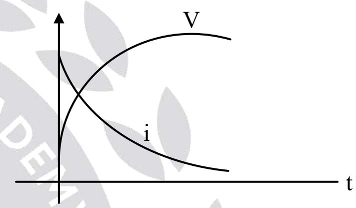
12. Ans: R = 50 Ω, C = 0.2μF

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

When circuit is power up:

SCR is forward blocking condition





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

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

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

$$\tau = R_L C$$

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

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

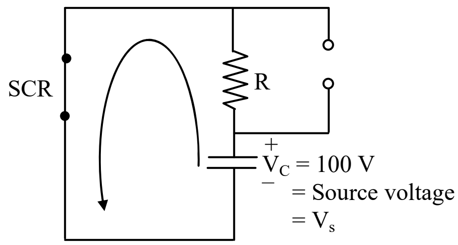
$$\frac{dV_C}{dt} = \frac{V_s}{R_L C}$$

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

C = 0.2 μF.

When SCR is ON:

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



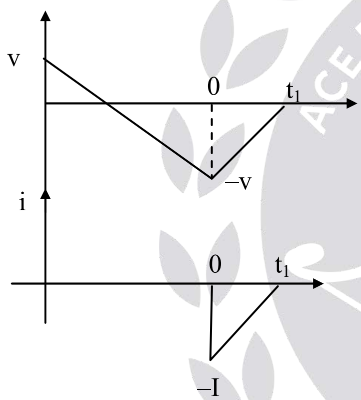
$$-100 + I_{disch} R = 0$$

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

$$R = 50\ \Omega.$$

13. Ans: 1W, 900μC

Sol:



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

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

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

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

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

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

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

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

$$= 20 \text{ mW}$$

$$P = E \times f$$

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

$$Q = \int i.dt$$

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

$$Q = 900\mu C$$

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: $I_C = \dfrac{V_{CC} - V_{CE(sat)}}{R_L}$

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

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

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

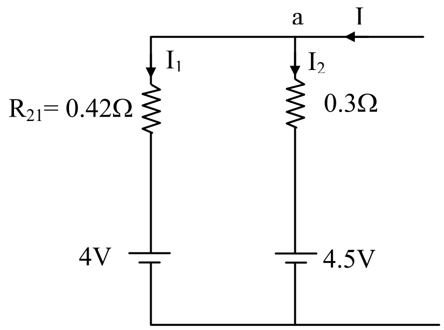
$$= 1.98 \text{ W}$$

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

$$= 0.792 \text{ W}$$

16. Ans: 9.54%

Sol: From the given data



The voltage at node a is

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

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

$55 = V_a(5.833)$

$V_a = 9.43V$

$\Delta I = I_2 - I_1 = -13.575 + 16.43 = 2.858$ 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

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

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

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

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

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

Sol: (i) Voltage across thyristor

$V_T = V_m \sin \alpha - E$

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

$= 17.46$ V

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

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

$= -329.07$ V

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

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

$= 445.3$ V

(iv) 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 $I_0 = \frac{V_0 - E}{R}$

$$= \frac{141.57 - 120}{2} = 10.78 \text{ A}$$

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

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

03. Ans: 18A, 1A

Sol: R = 5 Ω, L = 10 mH,

E = 80 V and V = 230 V

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

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

$$= 170.08 \text{ V}$$

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

$$= \frac{170.08 - 80}{5} = 18.01\text{A}$$

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

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

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

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

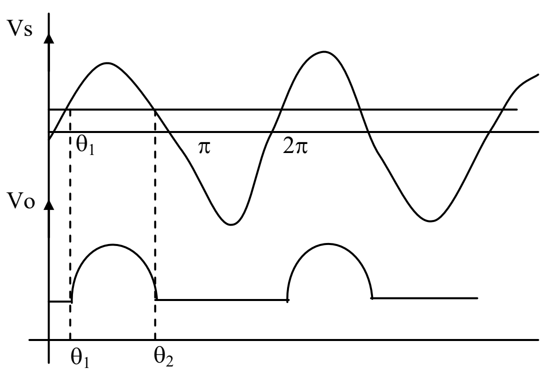
$$= \frac{85 - 80}{5} = 1\text{A}$$

04. Ans: (c)

Sol: $R = 2\ \Omega$

If 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

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



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

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

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

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

$$= \frac{1}{2\pi R}\left[2\times 230\times\sqrt{2}\cos(33.94^\circ)\right]$$

$$- 200\left(\pi - 2\times 39.94^o \times \frac{\pi}{180}\right)$$

$$= 11.90\text{A}$$

05. Ans: 120^0, 0.54A, 1.016A

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

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

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

$$\alpha = 120^\circ$$

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

$$= 54.01 \text{ V}$$

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

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

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

$V_{rms} = 106.02$ 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

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

$$V_{rms} = V_{m\ell}\left(\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}\cos 2\alpha\right)^{\frac{1}{2}}$$

$$= 400\sqrt{2}\left[\frac{1}{2}+\frac{3\sqrt{3}}{8\pi}\right]^{\frac{1}{2}}$$

= 475.562

Output power = 22.61 kW

08. Ans: (i) 67.85^0 , 0.36 lag (ii) 92.36V

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

$$\frac{3V_{m\ell}}{\pi}\cos\alpha = R\,I_0 + E$$

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

$$\alpha = 67.85°$$

$$P_0 = P_{in}$$

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

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

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

(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

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

(ii) kVA rating of input transformer

$$= \sqrt{3}\,V_l\,I_l$$

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

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

$$= 22.6 \text{ kVA}$$

10. Ans: (d)

Sol: Power supplied to load = V_0I_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 = $V_s.\frac{I_0}{n}$

Average VA rating of transformer

$$= \frac{V_sI_0 + \sqrt{2}V_sI_0}{2n}$$

$$= 1.207\frac{V_sI_0}{n}$$

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

$$= 1.341$$

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

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

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

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

Active power $= 500$ 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

$$= \frac{V_S\ I_{S_1}\ \cos\phi_1}{V_S\,I_S} = \frac{I_{S_1}}{I_S}\cos\phi_1$$

$I_{S_1} = 10$ A

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

$$= 11.35\,\text{A}$$

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

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

Sol: $P_0 = V_0\ .\ I_0 = 3000$W

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

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

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

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

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

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

$$\Rightarrow \alpha + \mu = 34.96° \Rightarrow \mu = 4.96°$$

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

Power balance equation

$$\Rightarrow V_{S1} \times I_{S1}\cos\phi_1 = P_0$$

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

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

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

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

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

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

$\alpha + 30 = 72.600$

$\Rightarrow \alpha = 42.600°$

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

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

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

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

$= 11.141$ A

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

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

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

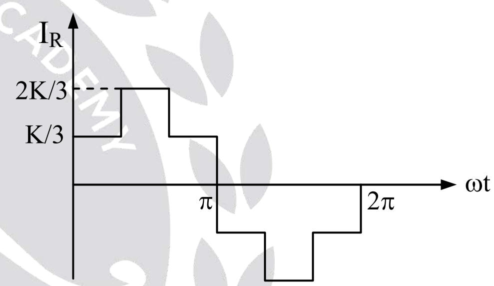
$$\Rightarrow -200 = -800 + RI_o \Rightarrow I_o = 30$$

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

15. Ans: (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 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

$P_0 = V_0\, I_0 = 517.68W$

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

= 517.68 × 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

(iii) 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 tan30°

$Q_0 = 448.32$ 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:

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

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

$= 0.71727$

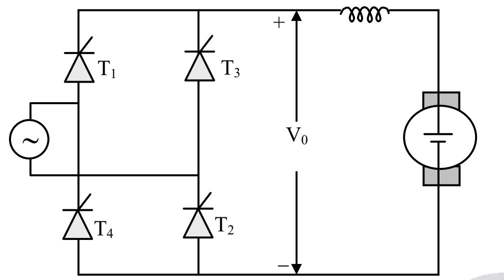
$\Rightarrow \mu = 44.17°$

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

= 224.17°

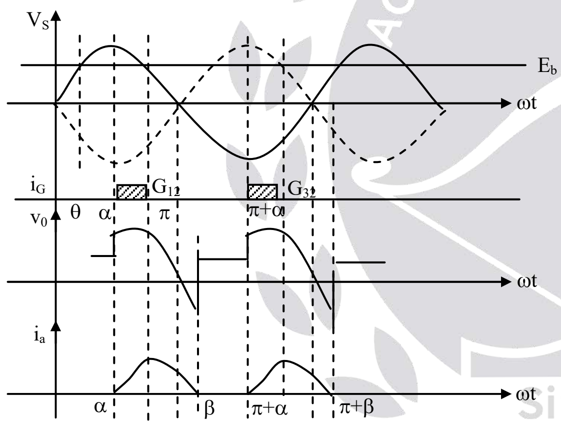
19. Ans: 5.225 A

Sol: $L_a = 50$ mH ; $\alpha = 90°$; $E_b = 180$ V



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

$$= \sin^{-1}\left(\frac{180}{220\sqrt{2}}\right) = 35.35°$$



When T_1T_2 pair is ON at $\omega t = \alpha$

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

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

$\frac{di_0}{dt} = 0$ at $\omega t = (\pi - \theta)$ hence i_0 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 $\omega t = \alpha = \pi/2$

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

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

∴ 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 $\omega t = (\pi - \theta)$

$\therefore i_{0\,max} =$

$$\frac{220\sqrt{2}}{100\pi\times 50\times 10^{-3}}\left[-\cos(180-35.35°)\right]$$

$$-\frac{180}{50\times10^{-3}}\times\frac{(180-35.35)}{100\pi}\times\frac{\pi}{180} + \frac{180}{50\times10^{-3}}\times\frac{\pi}{2\times100\pi}$$

$$= 5.225 \text{ A}$$

3. DC-DC Converters

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

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

$R_L = 10\Omega$

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

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

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

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

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

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

02. (i) Ans: (c) (ii) 2.5 A, 37.5 μH

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

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

$\Delta I_C = \Delta I_L$

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

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

(ii) Average switch current

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

= 2.5A

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

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

L = 37.5μH

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

(ii) 333.333 μH

(iii) 312.5 μH

(iv) 8.33mH, 12.5 nF

Sol: $\Delta V_0 = 10$ mV

$\Delta I_L = 0.5$ A, T = 50 μs

(i) Duty cycle ratio

$V_o = DV_{dc}$

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

(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 μH

(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 μF

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

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

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

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

= 12.5nF

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

Sol: $f = 20$ kHz, $T = 50$ μs

$D = 0.5$, 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.

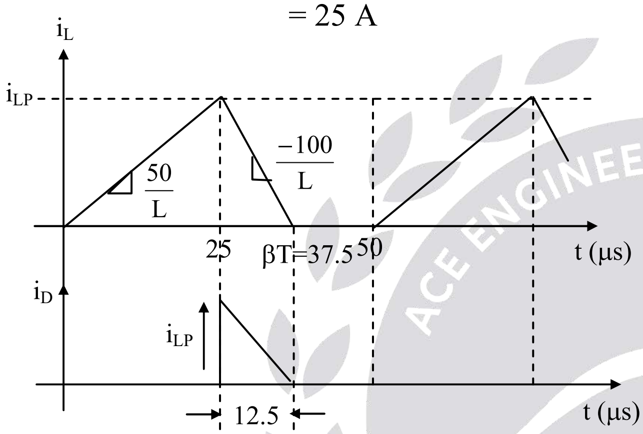
$$\therefore \frac{V_0}{V_{dc}} = \frac{\beta}{\beta - D}$$

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

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

$$= \frac{100}{100\times10^{-6}} \times 25\times10^{-6}$$

$$= 25 \text{ A}$$



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

$$= \frac{\frac{1}{2}\times 25\times 12.5\times10^{-6}}{50\times10^{-6}} = 3.125 \text{ A}$$

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

$= 937.5$ W

$\therefore$ Power transferred from B_1 to B_2 = 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.

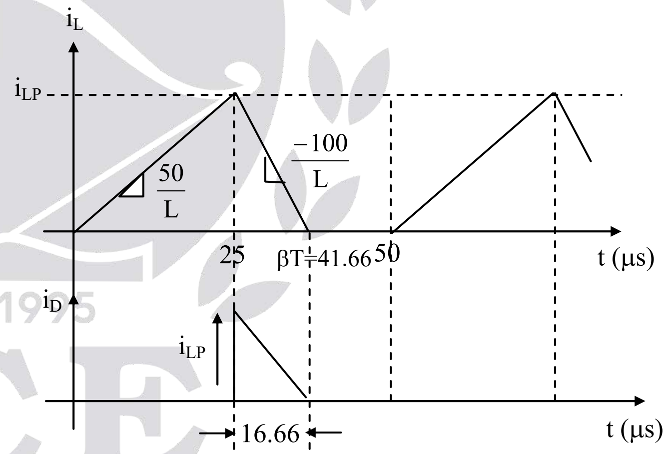
$$\therefore \frac{V_0}{V_{dc}} = \frac{\beta}{\beta - D}$$

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

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

$$= \frac{100}{100\times10^{-6}} \times 25\times10^{-6}$$

$$= 25 \text{ A}$$



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

$$= \frac{\frac{1}{2}\times 25\times 16.66\times10^{-6}}{50\times10^{-6}} = 4.166 \text{ A}$$

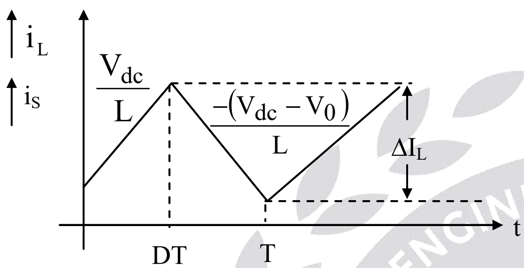
$P_{out} = V_2 \times I_{Dav} = 250 \times 4.166$

$= 1041.667$ W

∴ Power transferred from B_1 to B_2 = 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

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

$$= \frac{12}{1-0.4} = 20V$$

Average output current

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

Source current

$$I_s = \frac{I_0}{1-D} = \frac{1}{1-0.4}$$

$$= \frac{1}{0.6} = \frac{10}{6} = \frac{5}{3}A$$

05. (ii) Ans: (c)

Sol: Peak to peak source current ripple.

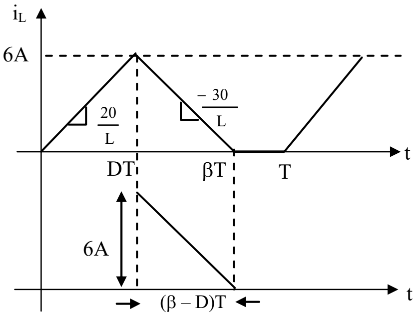
$$\Delta I_L = \Delta I_s = \frac{V_{dc}}{L}DT$$

$$= \frac{12}{100\times10^{-6}}\times0.4\times\frac{1}{250\times10^3}$$

$$= 0.192A$$

06. Ans: 2 (Range 2 to 2)

Sol:



In continuous conduction mode,

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

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

Power balance equation $P_0 = P_{in}$

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

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

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

$\Rightarrow \beta = 2.5\times\beta - (2.5\times0.5)$

$\beta = 0.833$

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

$I_{L\,Max} = 6$ 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: (i) 0.6
(ii) 0.72 A
(iii) 1.61 A
(iv) 34.09 mA
(v) 72μH, 500nF

Sol: Given

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

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

$\Rightarrow$ Duty cycle D = 0.6

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

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

$= 0.72$ A

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

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

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

$= 34.1$ mV

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

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

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

$L_{cr} = 72\mu H$

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

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

$= 0.5\ \mu F$

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, $I_o = 10$ A

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

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

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

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

09. Ans: (i) 83.3μs (ii) 83.3A

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

$I_{L\max} = \frac{100}{L} DT$ ……….. (1)

$= \frac{500}{L}(T - DT)$ ..……… (2)

From (1) & (2)

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

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

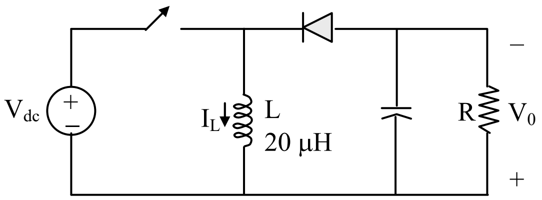
(ii) Peak current through switch

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

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

10. Ans: (c)

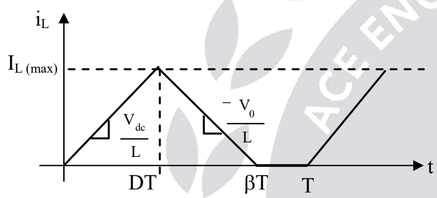
Sol:



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

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

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

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

$$= \frac{20}{20\mu}\times 0.6\times 20\mu = 12\,\text{A}$$

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

11. Ans: (i) 18V (ii) 0.163V
(iii) 1.152A (iv) 4.326A
(v) 38.4 μH and 1μF

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

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

$$= 18\text{V}$$

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

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

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

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

$$= 1.152\text{ A}$$

(iv) $I_{L\,max} = I_L + \frac{\Delta I_L}{2}$

$$= \frac{1.5}{1-0.6} + \frac{1.152}{2}$$

$$= 4.326$$

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

$$C_{cr} = \frac{I_0T(1-D)}{2V_{dc}}$$

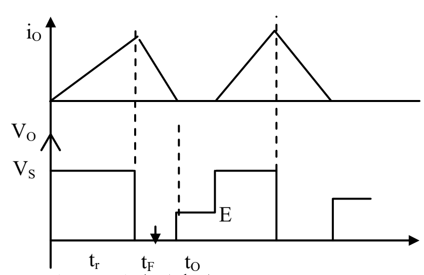
$$= \frac{1.5\times\frac{1}{25\times 10^3}(1-0.6)}{2\times 12} = 1\,\mu\text{F}$$

12. Ans: (c)

Sol: For step down chopper for R_L

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 $= \dfrac{V_S t_r + E_b t_o}{t}$

13. Ans: (a)

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

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 $\dfrac{2}{5} < D < \dfrac{3}{5}$

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,

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

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

$$= \frac{50}{0.6\times10^{-3}} \times 0.6 \times 0.1\times10^{-3} = 5\text{ A}$$

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

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

15. Ans: (d)

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

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

$$= 100\sqrt{\frac{10\times10^{-6}}{1\times10^{-3}}} \sin \frac{1}{\sqrt{10\times10^{-6}\times10^{-3}}} t$$

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

16. Ans: (a)

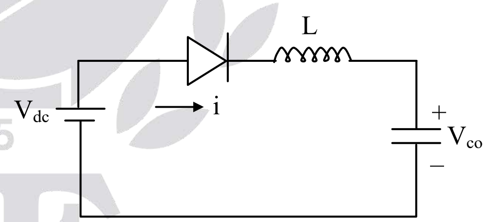
Sol: Given circuit is a current commutation circuit. When ever both the currents are equal and opposite then the thyristor will be turned off.

$10\sin10^4 t = 5$ (Refer previous solution)

$t = 52\mu$sec

17. Ans: 35.1 μs, 189.4 V

Sol:



$i_L(0) = I_0$

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

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

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

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

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

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

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

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

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

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

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

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

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

$= 35.1\ \mu s$

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

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

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

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

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

Sol: Given data

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

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

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

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

(i) Effective on period

$$T^1_{ON} = T_{ON} + 2.\frac{CV_s}{I_0}$$

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

$= 1075\ \mu sec$

(ii) Peak currents through T_1 and T_A

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

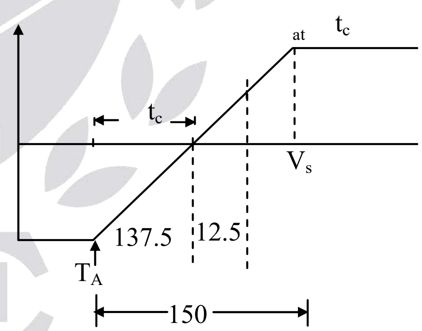
$$= 80 + 220\sqrt{\frac{50}{20}} = 427.85A$$

$I_{T_AP} = I_0 = 80A$

(iii) turn off time for T_1

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

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



V_s at t_c = 220 V

137.5 → 220 V

12.5 → ?

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

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

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

$$V_o = \frac{V_s}{T}(T_{ON} + 2t_c)$$
$$= \frac{V_s}{T}\left(T_{ON} + 2.\frac{CV_s}{I_o}\right)$$
$$= \frac{250}{1\times10^{-3}}\left[140\times10^{-6} + 2\times\frac{1\times10^{-6}\times250}{10}\right]$$
$$= 47.5\text{ V}$$

4. DC-AC Converters

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

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

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

iii) THD = 48.43%

iv) Peak current through switch

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

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

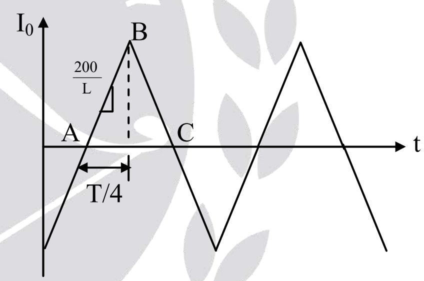
v) PIV = 48V

With full bridge

$$V_{01} = \frac{2\sqrt{2}}{\pi}V_{dc}, \qquad P_0 = \frac{V_{dc}^2}{R}$$
$$I_P(sw) = \frac{V_{dc}}{R}$$
$$I_{avg}(diode) = \frac{I_P}{2}, \qquad \text{PIV} = 48\text{V}$$

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

Sol:



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

(i) $I_P = \frac{200}{0.1}\times5\times10^{-3} = 10\text{A}$

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

= 5 msec

03. Ans: (c)

Sol: $V_1 = \frac{4V_{dc}}{\pi\sqrt{2}} = \frac{4\times12}{\pi\sqrt{2}}$

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

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

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

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

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

05. Ans: (i) 200.8V, (ii) 24.75^0, (iii) 203.64V

Sol: Given data:

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

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

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

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

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

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

$$2d = 24.78$$

(iii) $200.8 = V_{dc}\times\sqrt{\frac{5\times 35}{180}}$ (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 $= 3\times I_0^2 R$

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

$= 7.84$ kW

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

$I_s = 18.67$A

120^0 Operation:

i) $I_0 = \dfrac{V_{ph}}{R} = \dfrac{\frac{V_{dc}}{\sqrt{6}}}{R}$

$= \dfrac{\frac{420}{\sqrt{6}}}{15} = 11.43\text{A}$

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

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

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

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

07. Ans: 2.15 μF

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

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

$\omega t_c = \phi_1 = 0.754$

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

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

$X_C - 12 = 0.039$

$\Rightarrow X_C = 12.039$

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

$C = 2.15\ \mu F$

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

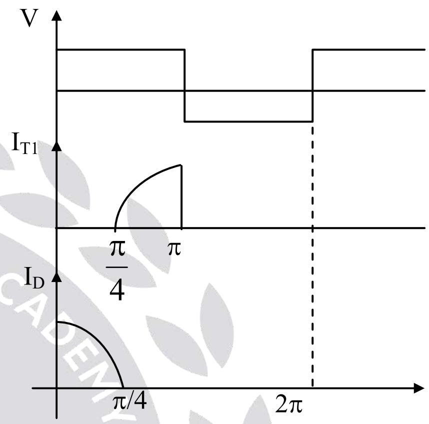
Sol: (a) $I_{01} = \dfrac{230}{2} = 115$ A

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

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

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

$= 2\sqrt{2}\ \Omega$



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

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

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

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

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

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

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

$$= 54.73\text{A}$$

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

$= 0.15\ I_m$

$= 0.15 \times \sqrt{2} \times 81.317$

$= 17.328$A

09. Ans: (i) 500 μs (ii) 750 V

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

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

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

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

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

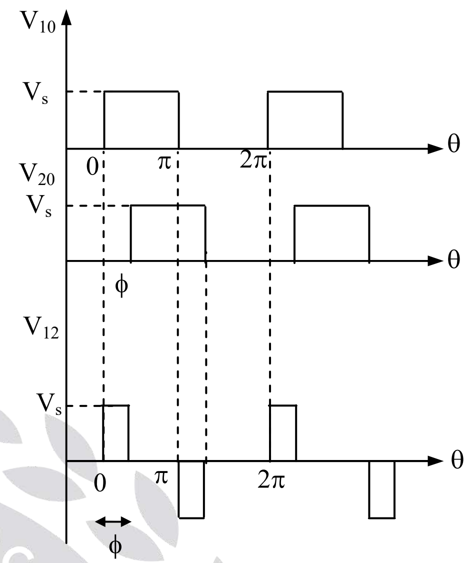
$\Rightarrow \cos\alpha = 0.2223$

$\Rightarrow \alpha = 77.15^o$

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

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

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,

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

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

14. Ans: 60 to 64

Sol: $m_a = 0.7$

$V_{in} = 100$ V

L = 9.55 mH

C = 63.66 μF

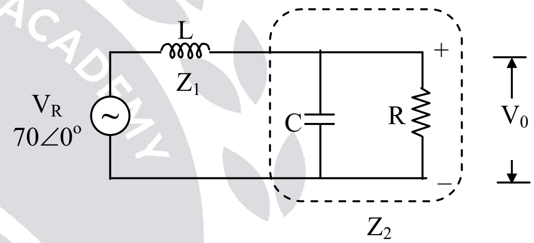
R = 5 Ω, f = 50 Hz

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

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

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

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



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

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

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

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

$V_0 = 62.77$ V

15. Ans: (d)

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

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

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

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

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

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

$P_o = 1440$

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

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

RMS value of fundamental output voltage,

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

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

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

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

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

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

18. Ans: 244.8 (Range 244 to 246)

Sol: The line to line voltage at fundamental frequency can be written as, $\hat{v}_{ph1} \propto m_a$

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

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

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

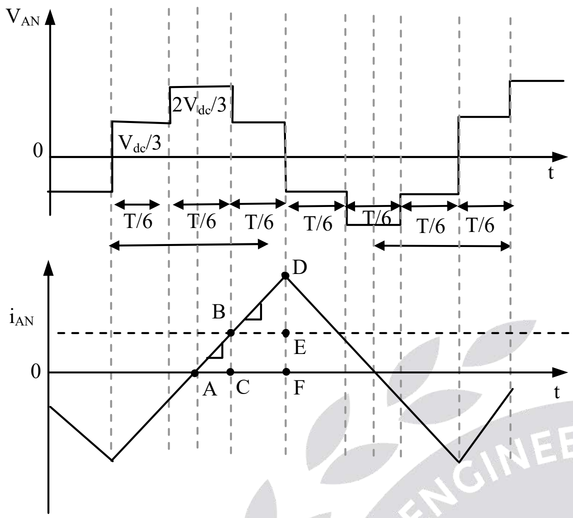
$V_{LL\ 1(rms)} = 0.612 \times m_a \times V_{dc}$

$= 0.612 \times 0.8 \times 500$

= 244.8V

19. Ans: 30 A

Sol:



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

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

Is ΔBDE, $\frac{V_{dc}}{3L} = \frac{DE}{BE}$

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

$$i_{0\,(ph)} = BC + DE = \frac{V_{dc}}{18Lf} + \frac{V_{dc}}{18Lf} = \frac{V_{dc}}{9Lf}$$

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

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

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

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

Given $V_S = 150$ V, $\alpha_1 = 23.62^o$, $\alpha_2 = 33.3^o$

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

$= 0.3155\ V_S = 47.325$ V

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

$= 0.5202\ V_S = 78.03$ V

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

$= 0.3867 V_S = 57.85$ V

21. Ans: 9.1 to 9.3

Sol: Input power = Output power

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

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

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

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

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

$= 0.1621$

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

Conventional Solutions

01.

Sol: $V_{dc} = 230$ V; $R = 6\ \Omega$, $L = 20$ mH; $C = 100\ \mu F$;
$f = 100$ Hz; $\omega = 200\pi = 628$

$$V_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n\pi} \sin n\omega t$$

(i) THD $= \sqrt{\frac{V_{rms}^2 - V_{o1}^2}{V_{o1}^2}}$

$$= \sqrt{\frac{V_{dc}^2}{\left(\frac{2\sqrt{2}}{\pi}\right)^2 V_{dc}^2} - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$\therefore$ THD = 48.43%

(ii) $i_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n\pi Z_n}\sin(n\omega t - \phi_n)$

$$Z_n = \sqrt{R^2 + \left(n\omega L - \frac{1}{n\omega C}\right)^2} \;;$$

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

$Z_1 = 6.8714\ \Omega$; $\phi_1 = -29.1696°$

$Z_3 = 32.9449\ \Omega$; $\phi_3 = 79.50°$

$Z_5 = 59.9498\ \Omega$; $\phi_5 = 84.256°$

$Z_7 = 85.90\ \Omega$; $\phi_7 = 85.994°$

$$\therefore\ I_{m1} = \frac{4V_{dc}}{(\pi)Z_1} = \frac{292.845}{6.8714} = 42.617\text{ A}$$

$$I_{m3} = \frac{4V_{dc}}{3\pi Z_3} = 2.9629\text{ A}$$

$$I_{m5} = \frac{4V_{dc}}{5\pi Z_5} = 0.9769\text{ A}$$

$$I_{m7} = \frac{4V_{dc}}{7\pi Z_7} = 0.487\text{ A}$$

$i(t) = 42.617\ \sin(\omega t + 29.169°) + 2.9629\ \sin(3\omega t - 79.5°) + 0.9769\ \sin(5\omega t - 84.256°) + 0.487\ \sin(7\omega t - 85.994°)$

(iii) THD of load current $= \sqrt{\frac{I_{rms}^2}{I_{01}^2} - 1}$

$$I_{rms}^2 = I_{01}^2 + I_{03}^2 + I_{05}^2 + I_{07}^2$$

$$= \frac{I_{m1}^2 + I_{m3}^2 + I_{m5}^2 + I_{m7}^2}{2}$$

$\Rightarrow I_{rms} = 30.21737$; $I_{01} = 30.1347$;

$I_m = 42.734$

$$\therefore\ \text{THD} = \sqrt{\left(\frac{30.217}{30.1347}\right)^2 - 1}$$

$= 7.409\%$

(iv) Load power $= V_{dc1}\ I_{01}\ \cos\phi_1$

$$= \left(\frac{2\sqrt{2}}{\pi}\right)V_{dc} \times \left(\frac{2\sqrt{2}V_{dc}}{\pi Z_1}\right)\cos\phi_1$$

$= 207.07 \times 30.134 \times \cos(-29.169)$

$= 5448.72$ W

Input power = output power

$\Rightarrow V_s\ I_s$ = load power = 5448.72 W

$\Rightarrow$ Source current $(I_s) = \frac{5448.72}{V_s}$

$= \frac{5448.72}{230}$

$= 23.69$ A

(V) The current leads the fundamental voltage component by 29.169°. This means diode conducts for 29.169° and thyristor conducts for 150.831°.

Conduction time of diode $= 29.169° \times \frac{5}{180°}$

$= 0.9025$ ms

Conduction time of thyristor = 4.18975 ms

(Vi) Peak thyristor current $I_m = I_{rms} \times \sqrt{2}$

$= 42.734$ A

RMS value of thyristor $= \frac{42.734}{2}$

$= 21.367$ A

5. AC-AC Converters

01.

Sol: $R_L = 5\ \Omega$, V = 230 V, 50 Hz; P_0 = 5 kW

$$V_{rms}^2 = P_0 \times R = 25000$$

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

$$\Rightarrow 25000 = \left(\frac{1}{2\pi}\right)\left(230\sqrt{2}\right)^2\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

$$\Rightarrow 1.4846 = \pi - \alpha + \frac{\sin 2\alpha}{2}$$

$$\Rightarrow \alpha - \frac{\sin 2\alpha}{2} = 1.6569$$

$$\Rightarrow \alpha = 92.45°$$

$$\therefore \text{Duty cycle} = \left(\frac{\pi - \alpha}{\pi}\right)$$

$$= \frac{180 - 92.45}{180} = 0.486$$

(ii) $$\text{Power factor} = \frac{1}{\sqrt{\pi}}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]^{1/2}$$

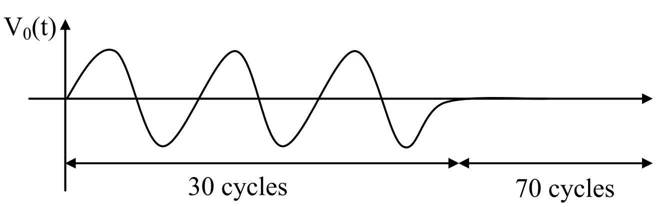
$$= 0.687 \text{ lag}$$

02.

Sol: $R_L = 20\ \Omega$; V = 220 V, 50 Hz,

T_{on} = 30cycles = 600 ms

T_{off} = 70cycles = 1400 ms



(i) $$V_{rms}^2 = \frac{1}{T}\int_0^{T_{on}} V_m^2 \sin^2 \omega t\, dt$$

$$= \frac{1}{2000\text{ms}}\int_0^{600} V_m^2 \sin^2 \omega t\, dt$$

$$= \left(\frac{1}{2}\right)\left(V_m^2\right)(60)\int_0^{10}\sin^2 \omega t\, dt$$

$$= 30V_m^2\left(\frac{1}{2}\right)\left[\int_0^{10}(1 - \cos 2\omega t)dt\right]$$

$$= 15V_m^2\left[t - \left(\frac{\sin 2\omega t}{\omega}\right)_0^{10}\right]$$

$$= 15V_m^2\left[\left(10\times10^{-3}\right) - \left[\frac{\sin 2\times100\pi\times10\times10^{-3} - 0}{\omega}\right]\right]$$

$$V_{rms}^2 = 0.15\,V_m^2$$

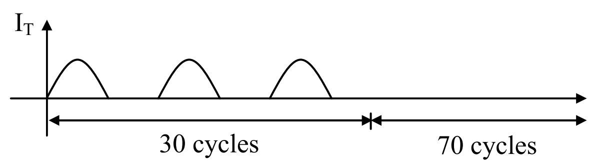
$$\Rightarrow V_{rms} = 120.5 \text{ V}$$

(ii) $$\text{Input power factor} = \frac{P_0}{V_s I_s} = \frac{V_{rms,\,output}}{V_{rms,\,input}}$$

$$= \frac{120.5}{220} = 0.5477 \text{ lag}$$

(iii) $$I_{s,rms} = \frac{V_{rms}}{R} = \frac{120.5}{20} = 6.024 \text{ A}$$

$$I_{T,\,rms} = \frac{I_{rms}}{\sqrt{2}} = 4.26 \text{ A}$$



$$I_{T,avg} = \frac{1}{T}\int_0^{T_{on}} I_m \sin \omega t\, dt\ ;\ I_m = \frac{V_m}{R} = 11\sqrt{2}$$

$$= \frac{1}{2000\text{ms}}\int_0^{600\text{ms}} I_m \sin \omega t\, dt$$

$$= \left(\frac{1}{2}\right)(I_m)(30)\int_0^{10} \sin\omega t\, dt$$

$$= 15I_m\left(\frac{-\cos\omega t}{\omega}\right)_0^{10}$$

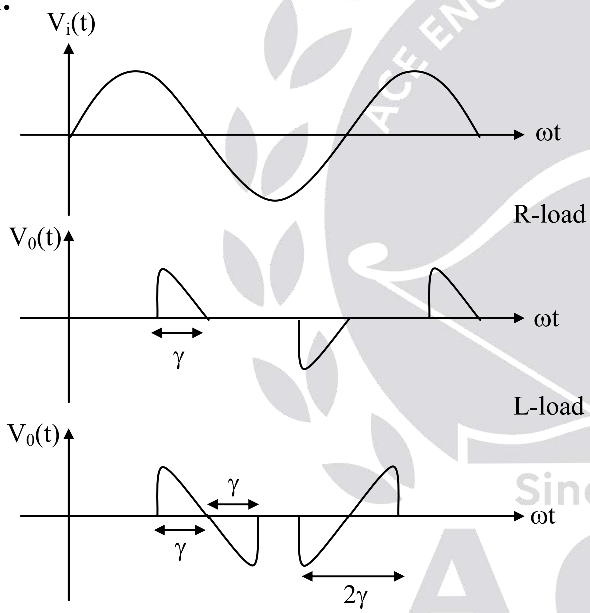
$$= 15I_m\left[\frac{1-\cos(100\pi\times 10\times 10^{-3})}{\omega}\right]$$

$$= 15I_m\,(2/\omega)$$

$$I_{T,avg} = \frac{30}{100\pi}\times I_m = \frac{0.3I_m}{\pi} = 1.48552\text{ A}$$

03.

Sol:



So, the conduction angle of each SCR from above figure is 2γ.

04.

Sol: (i) $V_{rms}^2 = \frac{V_m^2}{2\pi}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$

$$= \frac{(230\sqrt{2})^2}{2\pi}\left[\pi - \pi/3 + \frac{\sin 120^o}{2}\right]$$

$$= 42557.99$$

$$P = \frac{V_{rms}^2}{R} = 4255.8\text{ W}$$

(ii) As D_1 gets open circuited, the positive half of waveform becomes zero. So, the new rms voltage is reduced by $\sqrt{2}$ times and power is reduced to half of original value.

$$\therefore\ P = \frac{4255.8}{2} = 2127.9\text{ W}$$

6. Fundamentals of Drives

01. Ans: (i) 62.84A, (ii) 118.46Nm

Sol: Given Data, 15 Hp, 220V, 1000rpm

$$R_a + R_f = 0.2\Omega$$

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

$$= \frac{250\times\sqrt{2}}{\pi}(1+\cos 30^0) = 210\text{V}$$

$$E_b = K_b I_a \omega_m$$

$$= 0.03\times I_a \times \frac{2\pi N}{60} = 3.14I_a$$

$$V_f = (R_a + R_f)I_a + E_b$$

$$210 = 0.2I_a + 3.14I_a$$

$$\Rightarrow I_a = 62.87\text{A}$$

Torque $T = K_b I_a^2$

$$= 0.03 \times (62.87)^2 = 118.5\text{Nm}$$

02. Ans: (i) 1254 rpm, (ii) 8.54Nm

Sol: Given 220 V, 1500 r.p.m, 10 A motor.

(i) Motor constant K_m can be evaluated from the rating of motor as follows:

$V_t = E_a + I_aR_a$

$220 = K_m\omega_m + I_aR_a$

$K_m\omega_m = -10(1) + 220 \Rightarrow 210$

$$K_m = \frac{210\times 60}{2\pi\times 1500} = 1.337\ \text{V}-\text{s/rad}$$

$\alpha_1 = 30°$, $T_e = 5$ Nm

For the torque of 5 Nm, armature current

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

The equation for the operation of converter motor is

$V_0 = V_t = E_a + I_ar_a$

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

$$\frac{2\,\text{x}\,\sqrt{2}\times 230}{\pi}\cos 30^0 = 1.337\times\omega_m + (3.74)1$$

$\omega_m = 131.31$ rad/sec

N = 1253.92 r.p.m

(ii) $\alpha = 45^0$, N = 1000 r.p.m, T_e = ?

$$\frac{2\sqrt{2}\times 230}{\pi}\cos 45^0 = 1.337\times\frac{2\pi\,\text{x}\,1000}{60} + I_a\times 1$$

$146.4 = 140.01 + I_a \times 1$

$I_a = 6.39$ A

$T_e = K_m I_a$

$= 1.337 \times 6.39$

$= 8.543$ N – m

03. Ans: (i) 45.12A, 45.12Nm, (ii) 0.92lag

Sol: Given Data,

$I_f = 2\text{A}$, $R_a = 0.8\Omega$, $K_2 = 0.5$ Vs/rad

$V_s = 230$, N = 1500 rpm, $\alpha = 30^0$

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

$$= \frac{230\times\sqrt{2}}{\pi}\left(1+\cos 30^0\right) \Rightarrow 193.2\text{V}$$

$$V_0 = V_t = E_b + I_aR_a$$

$$193.2 = K_2\,I_f\omega_m + I_aR_a$$

$$193.2 = 0.5(2)\left(\frac{2\pi\times 1500}{60}\right) + I_a(0.8)$$

$I_a = 45.12\text{A}$

Torque: $T_e = K_2I_fI_a$

$= 0.5\times 2\times 45.12$

$= 45.12\text{N}-\text{m}$

Power factor: $P_f = \dfrac{V_tI_a}{V_sI_{sr}}$

$$= \frac{193.2\times 45.12}{230\times 45.12\sqrt{\dfrac{180-30}{180}}}$$

$= 0.92$ lag

04. Ans: 0.608

Sol: Given data: $R_a = 2.5\Omega, I_a = 20\text{A}$

Chopper frequency = 1 kHz, $V_{dc} = 250$ V

Duty cycle (D) =?

At rated conditions (i.e, at 1000 rpm), back emf, $E_{b1} = 220 - 20 \times 2.5 = 170$ V

At 600 rpm, the back emf (E_{b2}) can be determined as,

$$E_{b2} = \frac{N_2}{N_1} \times E_{b1}$$

$$= \frac{600}{1000} \times 170 = 102 \text{ V}$$

$$DV_{dc} = 102 + (20)(2.5)$$

$$D = \frac{152}{250} = 0.608$$

05. Ans: α = 39.2° and μ=8.3°

Sol: $V_t = E_b + I_aR_a$

$$\frac{3V_{m\ell}}{\pi}\cos\alpha - \frac{3\omega L_S}{\pi} I_a = E_b + I_a R_a$$

$$\frac{3\times 400\sqrt{2}}{\pi}\cos\alpha - \frac{3\times 100\pi}{\pi}\times\frac{0.5}{1000}\times 175$$

$= (0.25 \times 1500) + 175 \times 0.1$

$540.18\cos\alpha - 26.25 = 375+17.5$

$\alpha = 39.17°$

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

$\cos(39.17°+\mu) =$

$$\cos(39.15°) - 2\times\frac{2\pi\times 50\times 0.5\times 10^{-3}}{400\sqrt{2}}\times 175$$

$\mu = 8.14°$

06. Ans: (i) 69.7° (ii) 0.82 (iii) 70.5%

Sol: Given

$V = 200$ V

$N = 1450$ rpm

$I_0 = 100$ A

$R_a = 0.04\ \Omega$

$3-\phi$ half controlled converter

$3-\phi$ 220 V , 50 Hz

$V_0 = E + I_aR_a$

$$200 = \frac{K\times 2\times\pi\times 1450}{60} + (100\times 0.04)$$

$$K = 1.29\frac{\text{V}-\text{sec}}{\text{rad}}$$

(a) $\frac{3\times V_{ml}}{2\pi}(1+\cos\alpha) = 200\text{V}$

$$\frac{3\times\sqrt{2}\times 220}{2\pi}(1+\cos\alpha) = 200\text{V}$$

$\alpha = 69.79°$

(b) Fundamental power factor = DPF

$$= \cos\frac{\alpha}{2}$$

$$= \cos\frac{69.72}{2}$$

$= 0.82055$

(c) $\text{THD} = \sqrt{\left(\frac{I_S}{I_{S_1}}\right)^2 - 1}$

I_S = rms value of source current

= rms value of fundamental source current

$$I_S = I_0\sqrt{\frac{\pi-\alpha}{\pi}} \quad \alpha \geq \frac{\pi}{3}$$

$$I_{S_1} = \frac{\sqrt{6}}{\pi} I_0 \cos\frac{\alpha}{2}$$

$$I_S = 100\text{A}\sqrt{\frac{180-69.79°}{180}}$$

$= 78.25$ A

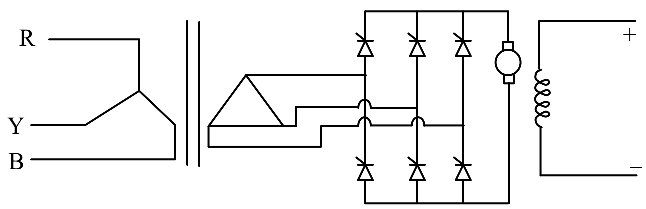
$$I_{S_1} = \frac{\sqrt{6}}{\pi}\times 100\times\cos\left(\frac{69.79}{2}\right)$$

$$\text{THD} = \sqrt{\left[\frac{78.25}{63.935}\right]^2 - 1}$$

$= 70.56\ \%$

07. Ans: (a) 1.559: 1 (b) (i) 34.65° (ii) 104.2°

Sol:



(a) Given data motor rated terminal voltage equals the rated voltage when converter firing angle is zero.

$$\frac{3V_{m\ell}}{\pi}\cos\alpha = 220\text{ V } (\alpha = 0)$$

$$\frac{3V_{m\ell}}{\pi}\cos 0° = 220\text{ V}$$

$$V_{m\ell} = \frac{220\times\pi}{3}$$

$$V_{m\ell} = 230.383$$

$$V_{L.L} = \frac{230.383}{\sqrt{2}} = 162.905\text{ V}$$

In Δ connection

$V_{ph} = V_{L-L} = 162.905$ V

Given

$V_{LL} = 440$ V

In Star connection

$$V_{ph} = \frac{440}{\sqrt{3}} = 254.0341\text{ V}$$

Transformer phase turns ratio from primary to secondary $= \dfrac{254.0341}{162.905\text{V}} = 1.559: 1$

(b) At rated conditions

(i) $V_0 = E + I_aR_a$

$\mathbf{V_0 = K\omega + I_aR_a}$

$$220 = K\times\frac{2\times\pi\times1500}{60} + 50\times0.5$$

$$K = 1.2414\,\frac{\text{V}-\text{sec}}{\text{rad}}$$

'E' at 120 rpm

$$E = 1.2414\times\frac{2\times\pi\times1200}{60}$$

E = 156 V

$$\frac{3V_{m\ell}}{\pi}\cos\alpha = 156 + 50\times0.5$$

$V_{m\ell} = 230.383$ [from (a)]

Cos α = 0.8277

α = 34.64°

(ii) Find E at rated condition

$V_0 = E + I_aR_a$

220 = E + 50 × 0.5

E = 195 V

ϕ = constant

$E \propto N$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

$$E_2 = E_1\frac{N_2}{N_1} = 195\,\frac{(-800)}{1500}$$

$E_2 = -104$ V

$$\frac{3\times V_{m\ell}}{\pi} = E + I_aR_a$$

Given torque is twice the rated torque

$$\frac{I_{a2}}{I_{a1}} = \frac{T_2}{T_1} \Rightarrow I_{a2} = 50\times2$$

$I_{a2} = 100$ A

$$\frac{3\times230.383}{\pi}\cos\alpha = -104 + (100\times0.5)$$

cosα = – 0.245 ⇒ α = 104.21°.

08. (i) 120.05 A, 0.5145 lag, 81.862 A, 0.8112 lag
At normal: 134.1 A, 0.28573lag, 90.486A, 0.763lag
(ii) 220.2 Nm, 404.702 Nm
At normal: 137.38 Nm, 475.662 Nm

Sol: 3–ϕ, 15 kW, 4 pole, 50 Hz, 420 V
r_1= 0.5 Ω, , r_2=0.4Ω, X_1=X_2=1.5Ω

At rated conditions:

Understarting:

$$I_2 = \frac{V_1}{\left(r_1 + \frac{r_2}{s}\right) + j(x_1 + x_2)}$$

$$= \frac{420}{\left(0.5 + \frac{0.4}{1}\right) + j(1.5 + 1.5)}$$

$= 134.1 \angle -73.3°A$

Pf = 0.287lag

$$T_e = \frac{3}{\omega_s}.I_2^2 \frac{r_2}{S}$$

$$= \frac{3}{50\pi} \times (134.1)^2 \times \frac{0.4}{1}$$

= 137.38N-m

Under maximum Torque condition:

$$s_{mT} = \frac{r_2}{\sqrt{r_1^2 + (x_1 + x_2)^2}}$$

$$s_{mT} = \frac{0.4}{\sqrt{(0.50^2 + (1.5 + 1.5)}}$$

= 0.1315

$$I_2 = \frac{420}{\left(0.5 + \frac{0.4}{0.1315}\right) + j(1.5 + 1.5)}$$

$= 90.478 \angle -40.265^\circ A$

P.f = 0.763 lag

$$T_e = \frac{3}{50\pi}(90.478)^2 \times \frac{0.4}{0.1315}$$

= 475.6 Nm

At reduced voltage condition

Under starting:

$$I_2 = \frac{210}{(0.5 + \frac{0.4}{1} + j(1.5 + 1.5) \times \frac{1}{2}}$$

$= 120 \angle -59^\circ A$

Pf = 0.515 lag

$$T_e = \frac{3}{25\pi} \times (120)^2 \times \left(\frac{0.4}{1}\right)$$

= 220 Nm

Under max torque conditions:

$$s_{mT} = \frac{R_2}{\sqrt{r_1^2 + (x_1 + x_2)^2}}$$

$$= \frac{0.4}{\sqrt{(0.5)^2 + \left(\frac{3}{2}\right)^2}}$$

= 0.253

$$I_2 = \frac{210}{\left(0.5 + \frac{0.4}{0.253}\right) + j(1.5)}$$

p.f = 0.81 lag

T_e = 404.78 Nm

Due to the reduced voltage and reduced frequency

(i) current gets reduced where as power factor get improved under maximum torque conditions.
(ii) the maximum torque gets reduced
(iii) maximum torque occurs at higher value of slip.