



GATE | PSUs



Electrical Engineering

POWER ELECTRONICS

Text Book: Theory with worked out Examples and Practice Questions

Power Electronics

(Solutions for Text Book Practice Questions)

1. Basics & Semiconductor Devices

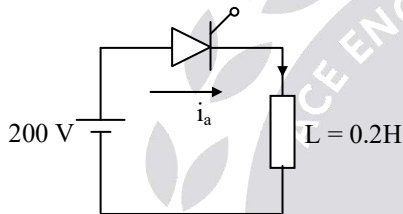
01. Ans: (i) 100 μ s (ii) 100.5 μ s (iii) 1005 μ s

Sol: (i) $I_L = 100$ mA

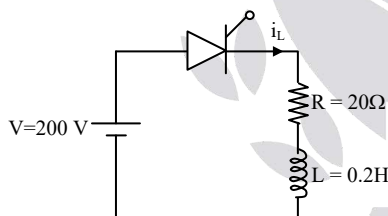
$$V = L \frac{di}{dt}$$

$$V t_p = L I_L$$

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



(ii) $R = 20 \Omega$, $L = 0.2$ H



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

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

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

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

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

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

(iii) $R = 20 \Omega$, $L = 2$ H

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

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

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

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

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

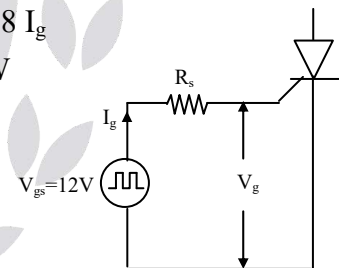
(iv) If load inductance increases, SCR requires pulse width for longer duration.

02. Ans: (i) 7 Ω (ii) 1W

Sol: (i) 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)

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

$$R_s = 6.95 \Omega$$

(ii) $P_g = P_{g\text{max}} \times D$

$$= 5 \times 0.2 = 1 \text{ W}$$

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) $R = 14.2 \text{ m}\Omega$, $V = 0.7716$

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

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

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

05. Ans: (88°C)

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

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

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

$$\begin{aligned} P &= \frac{T_c - T_A}{\theta_{CA}} \\ &= \frac{100 - 40}{0.5} = 120 \text{ W} \end{aligned}$$

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

$$T_s - T_A = 48$$

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

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

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

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

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

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

$$= 0.16 + 0.08 = 0.24^\circ \text{C/W}$$

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

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

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

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

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

$$\therefore \Delta I_b = I_{b\max} - I_{b\min}$$

$$R = \frac{7(1800) - 11 \times 10^3}{(7-1) \times 12 \times 10^{-3}}$$

$$= 12 \text{ mA} - 0 = 12 \text{ mA}$$

$$= 22.2 \text{ k}\Omega$$

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

$$= \frac{(7-1) \times 25 \times 10^{-6}}{7 \times 1800 - 11 \times 10^3} = 0.0937 \mu\text{F}$$

08. Ans: 74 to 76

Sol: Energy loss during

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

$$= 600 \times \text{area under current curve}$$

$$= 600 \times \frac{1}{2} \times 150 \times 1 \times 10^{-6}$$

$$= 45 \text{ mJ}$$

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

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

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

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

Total energy loss = 45 + 30

$$= 75 \text{ mJ}$$

09. (i) scheme-I $E_{ON} = 133.3 \mu\text{J}$, $E_{OFF} = 266.6 \mu\text{J}$

scheme-II $E_{ON} = 400 \mu\text{J}$, $E_{OFF} = 800 \mu\text{J}$

(ii) scheme-I : 40W

scheme-II : 120W

Sol: Switching scheme – I

(i) Energy loss during ON condition:

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

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

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

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

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

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

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

$$= \frac{400 \cdot (20)}{6} \times 200 \text{ ns} = 266.66 \mu\text{J}$$

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

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

$$(ii) E = P \times t$$

$$P = E \times f$$

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

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

Switching scheme-II

(i) Energy loss during ON condition

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

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

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

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

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

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

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

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

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

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

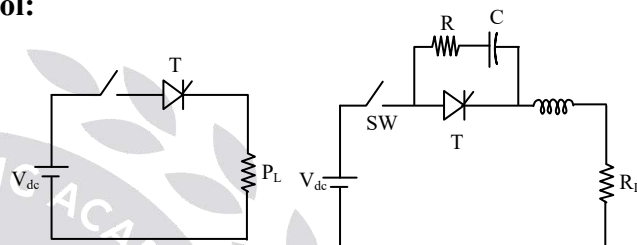
$$(ii) P = E \times f$$

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

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

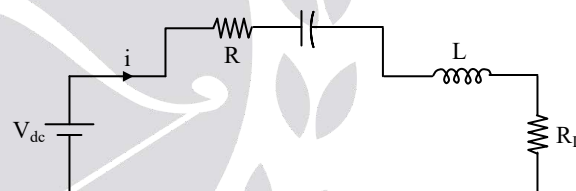
10. Ans: L = 4 μH, C = 0.16 μF and R = 5 Ω

Sol:



At the time of switch closed:

SCR is forward blocking condition



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

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

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

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

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

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

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

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

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

$$L = 4 \mu H$$

Given damping ratio $\zeta = 0.5$

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

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

$$\Rightarrow C = 0.16 \mu F$$

As SCR is in forward blocking mode

voltage across SCR = $I_a R$

$$V_t = I_a R$$

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

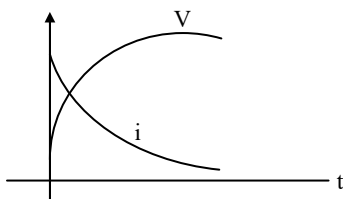
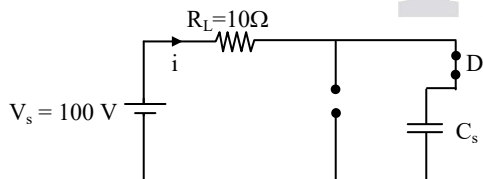
$$R = \frac{300}{60} = 5 \Omega$$

11. Ans: $R = 50 \Omega$, $C = 0.2 \mu F$

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

When circuit is power up:

SCR is forward blocking condition



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

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

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

$$\tau = R_L C$$

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

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

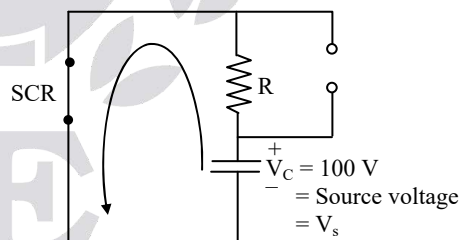
$$\frac{dV_c}{dt} = \frac{V_s}{R_L C}$$

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

$$C = 0.2 \mu F.$$

When SCR is ON:

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



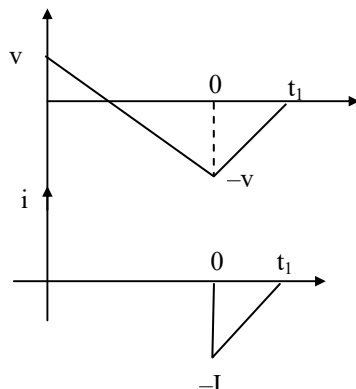
$$-100 + I_{disch} R = 0$$

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

$$R = 50 \Omega.$$

12. Ans: 1W, 900 μ C

Sol:



$$\begin{aligned}
 (E_{\text{loss}})_{\text{OFF}} &= \int_0^{t_1} v i \, dt \\
 &= \int_0^{t_1} \left(-v + \frac{v}{t_1} t \right) \left(-i + \frac{i}{t_1} t \right) dt \\
 &= \int_0^{t_1} \left(-100 + \frac{100}{t_1} t \right) \left(-300 + \frac{300}{t_1} t \right) dt \\
 &= 10^4 \int_0^{t_1} \left(-1 + \frac{t}{t_1} \right) \left(-3 + \frac{3t}{t_1} \right) dt \\
 &= 10^4 \int_0^{t_1} \left(3 - \frac{3(t)}{t_1} - \frac{3(t)}{t_1} + \frac{3t^2}{t_1^2} \right) dt \\
 &= 10^4 \left[3t_1 - \frac{6}{2t_1} t_1^2 + \frac{3}{t_1^2} \cdot \frac{t_1^3}{3} \right] \\
 &= 10^4 [3t_1 - 3t_1 + t_1] = 10^4 t_1 \\
 &= 10^4 \times 2 \times 10^{-6} \\
 &= 20 \text{ mW}
 \end{aligned}$$

$$\begin{aligned}
 P &= E \times f \\
 &= 20 \times 10^{-3} \times 50 = 1 \text{ W}
 \end{aligned}$$

$$\begin{aligned}
 Q &= \int i \cdot dt \\
 &= \frac{1}{2} \times 300 \times 6 \times 10^{-6}
 \end{aligned}$$

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

13. Ans: (c)

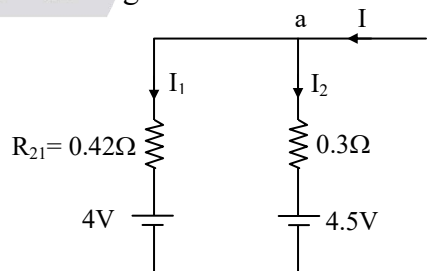
Sol: Electronic switch described in the statement should have forward blocking state, forward conduction state and reverse blocking state. SCR, NPN Transistor with series diode exhibits the above states.

14. Ans: (c)

$$\begin{aligned}
 \text{Sol: } I_C &= \frac{V_{CC} - V_{CE(\text{sat})}}{R_L} \\
 &= \frac{200 - 2}{10} = 19.8 \text{ A} \\
 P_{\text{on}} &= \frac{V_{CC} \times I_C}{6} \times t_{\text{on}} \times f_s \\
 &= \frac{200 \times 19.8}{6} \times 3 \mu \times 1 \text{ K} \\
 &= 1.98 \text{ W} \\
 P_{\text{off}} &= \frac{V_{CC} \times I_C}{6} \times t_{\text{off}} \times f_s \\
 &= 0.792 \text{ W}
 \end{aligned}$$

15. Ans: 9.52% (Range 9% to 10%)

Sol: From the given data



The voltage at node a is

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

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

$$55 = V_a(5.833)$$

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

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

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

16. Ans: (a, d)

Sol: In option a and d reverse conduction is possible due to anti-parallel diode. Hence option a & d are correct.

17. Ans: 40 A

$$\begin{aligned} \text{Sol: (i) } Q_{rr} &= \frac{1}{2} \left(\frac{di}{dt} \right) \frac{t_{rr}^2}{1+s} \\ &= \frac{1}{2} \times 10 \times \frac{36}{1+0.5} \\ &= 120 \text{ } \mu\text{C} \end{aligned}$$

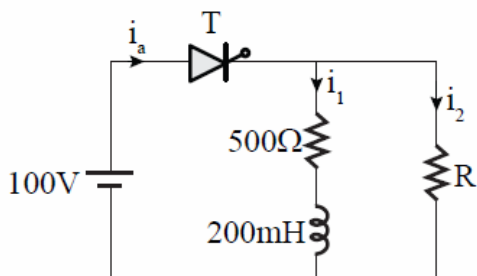
$$\text{(ii) } Q_{rr} = \frac{1}{2} I_{RM} \cdot t_{rr}$$

$$I_{RM} = \frac{Q_{rr} \times 2}{t_{rr}}$$

$$I_{RM} = \frac{120 \times 2}{6} = 40 \text{ A}$$

18. Ans:

Sol:



$$I_L = I_0 \left(1 - e^{-\frac{t}{\tau}} \right)$$

$$\frac{500}{500} (1 - e^{-150t}) = \frac{1}{5} (1 - e^{-0.125}) = 23.5 \text{ mA}$$

$$\begin{aligned} I_R &= I - I_L = 40 \text{ mA} - 22.5 \text{ mA} = 16.5 \text{ mA} \\ \Rightarrow R &= 6060.6 \Omega \end{aligned}$$

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

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

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

$$= 141.57 \text{ V}$$

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

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

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

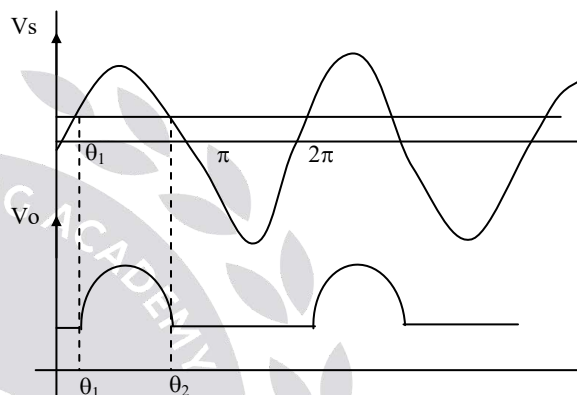
$$I_0 = \frac{V_0 - E}{R} = \frac{85 - 80}{5} = 1 \text{ A}$$

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

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



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

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

$$I_0 = \frac{1}{2\pi R} \int_{\alpha}^{\theta_2 = \pi - \alpha} (V_m \sin \omega t - E) d\omega t$$

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

$$= \frac{1}{2\pi R} [2 \times 230 \times \sqrt{2} \cos(33.94^\circ) - 200 \left(\pi - 2 \times 39.94^\circ \times \frac{\pi}{180} \right)]$$

$$= 11.90 \text{ A}$$

05. Ans: 120⁰, 0.54A, 1.016A

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

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

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

$$\alpha = 120^\circ$$

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

$$= 54.01 \text{ V}$$

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

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

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

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

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

06. Ans: 545.96 V

Sol: $\frac{3V_{m\ell}}{\pi} \cos(180^\circ - \alpha)$

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

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

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

$$E = 545.96 \text{ V}$$

07. Ans: 467.82 V, 22.616 kW

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

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

$$= 467.8 \text{ V}$$

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

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

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

$$= 475.562$$

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

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

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

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

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

$$\alpha = 67.85^\circ$$

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

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

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

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

(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. Ans: (b)

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

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

10. Ans: (c)

Sol: kVA rating of input transformer

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

Where I_l = Rms value of line current on ac

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

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

11. 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]

$$\begin{aligned} &= 2 \left[\frac{V_m}{n} \times \frac{I_0}{2} \right] \\ &= \frac{\sqrt{2}V_s I_0}{n} \end{aligned}$$

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

Average VA rating of transformer

$$\begin{aligned} &= \frac{V_s I_0 + \sqrt{2} V_s I_0}{2n} \\ &= 1.207 \frac{V_s I_0}{n} \end{aligned}$$

$$\begin{aligned} \therefore \frac{\text{Average VA rating of transformer}}{\text{Power supplied to load}} &= \frac{1.207}{0.9} \\ &= 1.341 \end{aligned}$$

12. Ans: (b)

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

$$\begin{aligned} \text{Active power} &= V_s I_{s1} \cos \phi_1 \\ &= 100 \times 10 \cos 60 \end{aligned}$$

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

13. Ans: (b)

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

Current resulted

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

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

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

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

$$\begin{aligned} I_s &= \sqrt{10^2 + 5^2 + 2^2} \\ &= 11.35 \text{ A} \end{aligned}$$

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

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

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

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

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

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

$$\Rightarrow I_0 = 17.19A$$

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

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

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

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

Power balance equation

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

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

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

15. (i) 42.6° (ii) 11.141A

Sol: (i) 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

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

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

$$= 0.75 \times \frac{3V_{mp} \times \sqrt{3}}{2\pi}$$

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

$$\alpha + 30 = 72.600$$

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

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

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

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

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

$$= 11.141 A$$

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

Sol: $\frac{2V_m}{\pi} \cos \alpha = E + RI_0$

$$\Rightarrow \frac{2 \times 200\pi}{\pi} \cos 120^\circ = -800 + 20 \times I_0 A$$

$$\Rightarrow -200 = -800 + RI_0 \Rightarrow I_0 = 30$$

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

- 17. Ans: Without FD: (i) 146.42 V,**
(ii) 732.11 W, 732.11 VAR and
With FD: (i) 176.74 V,
(ii) 883.76 W, 366 VAR

Sol: Given data:

$$V_s = 230, f = 50 \text{ Hz}, \alpha = 45^\circ, I_0 = 5 \text{ A}$$

Without Free wheeling diode

(i) It is a 1 - ϕ full converter

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

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

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

(ii) $P_0 = V_0 I_0 = 146.4225 \times 5$

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

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

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

$$= 732.1125 \text{ VAR}$$

If $\alpha = 60^\circ$

$$V_0 = \frac{2V_m}{\pi} \cos \alpha = 103.536 = 5 \text{ A}$$

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

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

$$= 517.68 \times \tan 60^\circ$$

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

With free wheeling diode

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

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

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

(ii) $P_0 = V_0 I_0 = 176.747 \times 5$

$$= 883.73 \text{ W}$$

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

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

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

(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.

18. Ans: (c)

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

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

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

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

19. 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:

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

$$\cos\mu = 1 - \frac{2 \times 100\pi \times 10 \times 10^{-3}}{20\sqrt{2}} \times 14 = 0.71727$$

20. Ans: 13.3 msec

$$\text{Sol: } V_{0(\text{avg})} = \frac{1}{2\pi} \int_{\alpha}^{\beta} V_m \sin \omega t d\omega t$$

$$= \frac{V_{\text{on}}}{2\pi} \int_{40^\circ}^{120^\circ} \sin \omega t d\omega t$$

$$= \frac{230 \times \sqrt{2}}{2\pi} (-\cos \omega t) \Big|_{40}^{120}$$

$$= \frac{230 \times \sqrt{2}}{2\pi} [\cos 40 - \cos 120]$$

$$= 65.54 \text{ V}$$

$$t_c = \frac{2\pi - \beta}{\omega} = \frac{2\pi - \frac{2\pi}{3}}{2\pi f}$$

$$= \frac{4\pi}{2\pi \times 50} = 13.3 \text{ msec}$$

$$\therefore I_0 = \frac{I_0}{R} = \frac{65.54}{5} = 13.11 \text{ A}$$

21. Ans: 90

Sol: Power delivered to loss less battery

$$EI_0 = 1600 \text{ W}$$

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

From the given circuit, $V_0 = RI_0 + E$

$$\frac{V_m}{2\pi} (3 + \cos \alpha) = 120$$

$$3 + \cos \alpha = 3$$

$$\alpha = 90^\circ$$

3. DC-AC Converters

01. (i) 26.1V (ii) 240W

(iii) 48.43% (iv) 5A

(v) 48V

$$\text{Sol: i) } V_{01} = \frac{\sqrt{2}}{\pi} V_{dc} = 0.45 \times 48 = 21.6 \text{ V}$$

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

iii) THD = 48.43%

iv) Peak current through switch

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

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

v) PIV = 48V

With full bridge

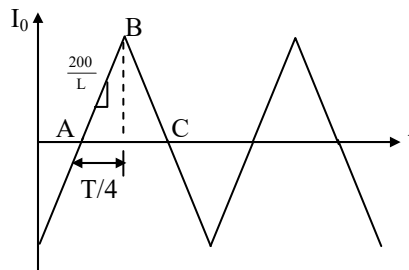
$$V_{01} = \frac{2\sqrt{2}}{\pi} V_{dc}, \quad P_0 = \frac{V_{dc}^2}{R}$$

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

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

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

Sol:



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

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

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

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

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

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

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

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

Sol: Given data:

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

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

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

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

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

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

$$2d = 24.78$$

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

$$V_{dc} = 203.64V$$

06. Ans: (a) (i) 13.2A, (ii) 9.33A,
(iii) 7.84 kW, (iv) 18.67A
(b) (i) 11.43A, (ii) 6.6A,
(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) $I_0 = \frac{V_{ph}}{R} = \frac{\frac{V_{dc}}{\sqrt{6}}}{R} = \frac{\frac{420}{\sqrt{6}}}{15} = 11.43A$

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

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

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

(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: (i) 500 μs (ii) 750 V

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

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

09. Ans: 77.16°

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

$$\therefore a_n = 0$$

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

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

For fundamental $n = 1$

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

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

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

RMS value of fundamental output voltage can be

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

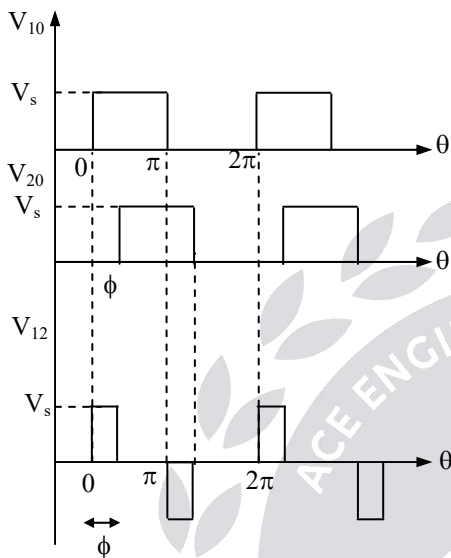
$$\Rightarrow \cos \alpha = 0.2223$$

$$\Rightarrow \alpha = 77.16^\circ$$

10. 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} .

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

11. Ans: 9.9 to 10.1

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

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

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,

$$\begin{aligned} Z_1 &= \sqrt{R^2 + X^2} \\ &= \sqrt{12^2 + 16^2} = 20 \Omega \end{aligned}$$

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

12. 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,

$$\begin{aligned} V_{ph} &= \frac{\sqrt{2}}{3} V_{dc} \\ &= \frac{\sqrt{2}}{3} \times 600 = 200\sqrt{2} \text{ V} \end{aligned}$$

Power consumed by the load,

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

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

13. Ans: 60 to 64

Sol: $m_a = 0.7$

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

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

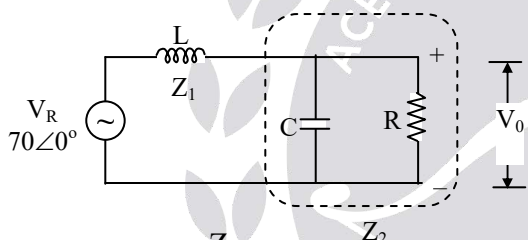
$$C = 63.66 \text{ } \mu\text{F}$$

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

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

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

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



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

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

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

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

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

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

14. Ans: (d)

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

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

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

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

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

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

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

$$P = 7.5 \text{ kW}$$

15. 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 $= 2N \pm 1$

$$= 18 \pm 1$$

$$= 17, 19$$

16. Ans: (c)

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

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

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

$$P_o = 1440$$

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

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

RMS value of fundamental output voltage,

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

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

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

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

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

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

17. Ans: 244.8 (Range 244 to 246)

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

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

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

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

$$V_{LL1(rms)} = 0.612 \times m_a \times V_{dc}$$

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

$$= 244.8 \text{ V}$$

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

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

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

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

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

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

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

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

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

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

19. Ans: 51.07

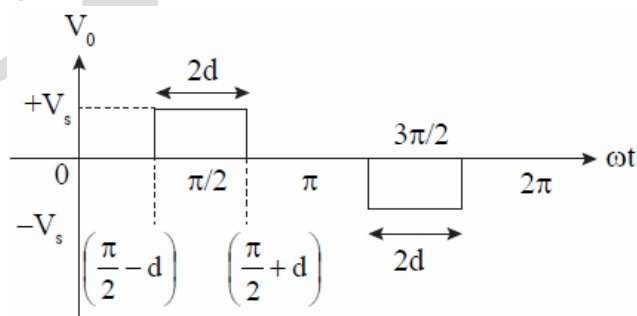
Sol: $V_s = 325 \text{ volt (DC)}$

$$\text{M.I.} = 0.8$$

$$\text{M.I.} = \frac{(V_{ab1})_{\text{peak}}}{V_s}$$

$$(V_{ab1})_{\text{peak}} = \text{M.I.} \times V_s = 0.8 \times 325 = 260 \text{ volts}$$

Now according to FSA



$$V_o = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos n\omega t + b_n \sin n\omega t]$$

Here, $\frac{a_0}{2} = 0, a_n = 0$

$$b_n = \frac{2}{\pi} \int_{\frac{\pi-d}{2}}^{\frac{\pi+d}{2}} V_s \sin(n\omega t) = \frac{4V_s}{n\pi} \sin\left(\frac{n\pi}{2}\right) \cdot \sin(nd)$$

$$V_0 = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_s}{n\pi} \sin\left(\frac{n\pi}{2}\right) \cdot \sin(nd) \sin(n\omega t)$$

$$(V_{ab1})_{\text{peak}} = (V_{01})_{\text{peak}} = \frac{4V_s}{2} \sin(d)$$

Now, as $(V_{01})_{\text{peak}} = 260$

$$\frac{4V_s}{\pi} \sin(d) = 260$$

$$\frac{4 \times 325}{\pi} \sin(d) = 260$$

$$d = 38.93^\circ$$

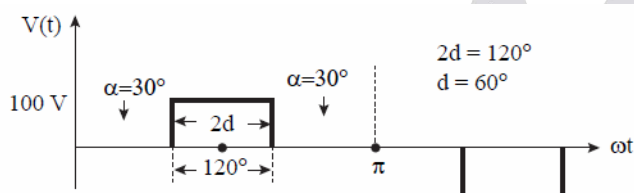
According to given waveform, $2\theta = \pi - 2d$

$$\theta = \frac{\pi - 2d}{2} \quad \text{or} \quad \frac{180 - 2d}{2}$$

$$\theta = 51.07^\circ$$

20. Ans: 20

Sol: The wave for m is produced in 1- ϕ inverter using single pulse modulation the value of σ is so selected that it is free from 3rd harmonic. It is only for a pulse width of 120° i.e., $\sigma = 30^\circ$



∴ Fourier analysis expression of output voltage wave form is

$$V(t) = \sum_{n=1,3}^{\infty} \left(\frac{4V_s}{n\pi} \sin \frac{n\pi}{2} \sin nd \right) \sin n\omega t$$

$$\begin{aligned} \frac{V_s}{V_i} &= \frac{\left[\frac{4V_s}{5\pi} \cdot \sin \frac{5\pi}{2} \sin(5 \times 60) \right] \frac{1}{\sqrt{2}}}{\left[\frac{4V_s}{\pi} \cdot \sin \frac{\pi}{2} \sin(60) \right] \frac{1}{\sqrt{2}}} \\ &= \frac{1}{5} \times \frac{\sin \frac{5\pi}{2}}{\sin \frac{\pi}{2}} \times \frac{\sin 300}{\sin 60} \times 100\% \end{aligned}$$

$$\frac{|V_s|}{|V_i|} = 20\%$$

4. DC-DC Converters

01. Ans: 5A, 0.208A, 5.104A, 4.896A

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

$$R_L = 10\Omega$$

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

$$\begin{aligned} \Delta I_L &= \frac{V_{dc}}{L} D(1-D)T \\ &= \frac{100}{60 \times 10^{-3}} \times 0.5(0.5) \times \frac{1}{2 \times 10^3} \\ &= \frac{50 \times 0.5 \times 0.5}{60} = 0.208 \text{ A} \end{aligned}$$

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

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

02. (i) Ans: (c) (ii) 2.5 A, 37.5 μ H

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

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

$$\Delta I_C = \Delta I_L$$

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

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

(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) 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.

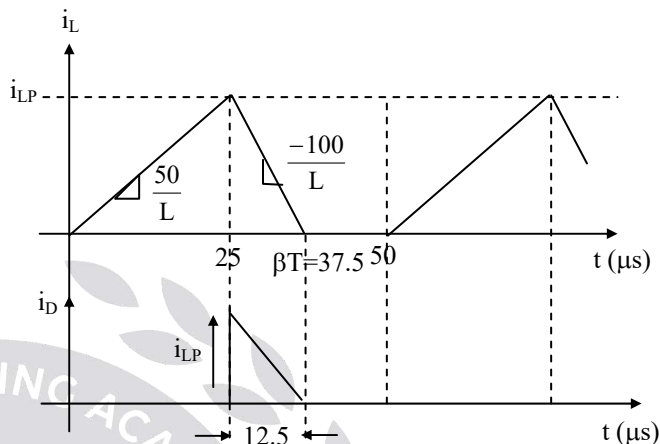
$$\therefore \frac{V_o}{V_{dc}} = \frac{\beta}{\beta - D}$$

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

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

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

$$= 25 \text{ A}$$



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

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

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

$$= 937.5 \text{ W}$$

$$\therefore \text{Power transferred from } B_1 \text{ to } B_2 = 937.5 \text{ W}$$

(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.

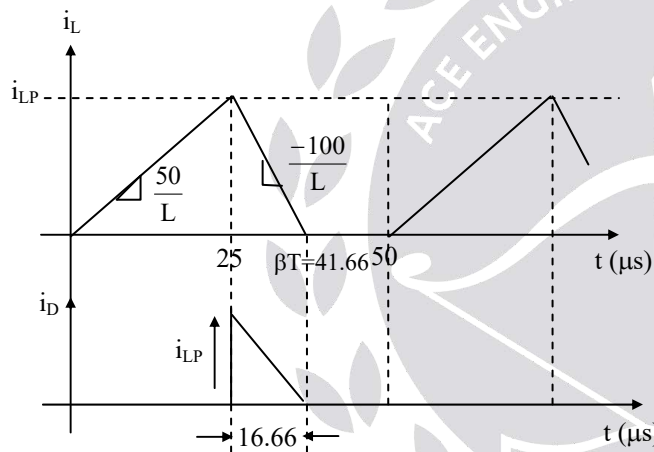
$$\therefore \frac{V_0}{V_{dc}} = \frac{\beta}{\beta - D}$$

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

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

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

$$= 25 \text{ A}$$



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

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

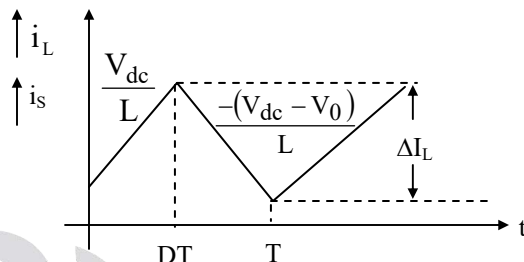
$$P_{out} = V_2 \times I_{Dav} = 250 \times 4.166$$

$$= 1041.667 \text{ W}$$

$\therefore$ Power transferred from B_1 to $B_2 =$
1041.667 W

04. (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

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

04. (ii) Ans: (c)

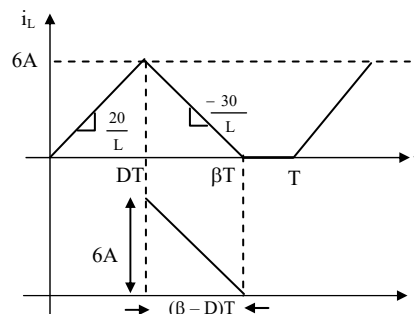
Sol: Peak to peak source current ripple.

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

$$= \frac{12}{100 \times 10^{-6}} \times 0.4 \times \frac{1}{250 \times 10^3} = 0.192 \text{ A}$$

05. Ans: 2 (Range 2 to 2)

Sol:



In continuous conduction mode,

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

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

Power balance equation $P_o = P_{in}$

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

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

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

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

$$\beta = 0.833$$

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

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

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

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

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

06. 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, $I_o = 10A$

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

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

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

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

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

07. Ans: (i) 83.33μs (ii) 83.33A

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

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

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

From (1) & (2)

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

$$DT = \frac{500}{600} T = \frac{5}{6} \times \frac{1}{10 \times 10^3} \Rightarrow 83.33 \mu\text{sec}$$

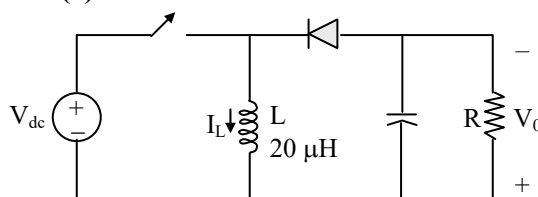
(ii) Peak current through switch

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

$$= \frac{100}{100 \times 10^{-6}} \times 83.3 \times 10^{-6} = 83.33A$$

08. Ans: (c)

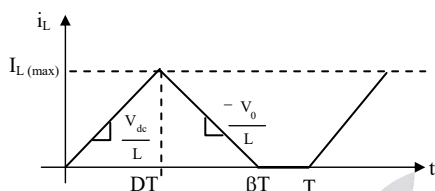
Sol:



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

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

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

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

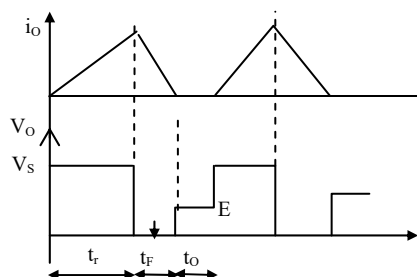
$$I_{L \text{ (avg)}} = \frac{\frac{1}{2} \times 12 \times 0.8 \times 20\mu}{20\mu} = 4.8 \text{ A}$$

09. 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

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

10. 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 $0.4 < D < 0.6$

11. Ans: 40

Sol: Given circuit is buck boost converter.

Source current is same switch current.

Peak value of switch current means,

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

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

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

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

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

12. Ans: (d)

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

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

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

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

13. Ans: (a)

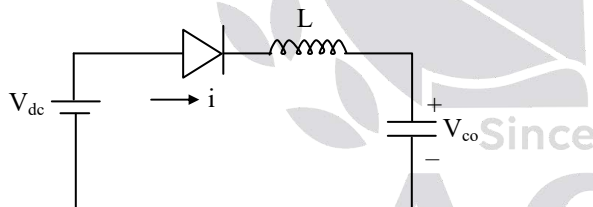
Sol: Given circuit is a current commutation circuit. When ever both the currents are equal and opposite then the thyristor will be turned off.

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

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

14. Ans: 35.12 μs , 189.4 V

Sol:



$$i_L(0) = I_0$$

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

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

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

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

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

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

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

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

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

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

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

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

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

$$= 35.12 \mu\text{s}$$

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

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

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

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

15. Ans: (i) 1075 μs , (ii) 427.85A, 80A
(iii) 137.5 μs , (iv) 20V

Sol: Given data

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

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

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

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

(i) Effective on period

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

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

$$= 1075 \mu\text{sec}$$

(ii) Peak currents through T_1 and T_A

$$I_{T1P} = I_0 + V_s \sqrt{\frac{C}{L}}$$

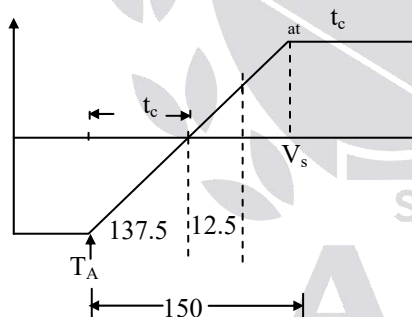
$$= 80 + 220 \sqrt{\frac{50}{20}} = 427.85 \text{ A}$$

$$I_{TA,P} = I_0 = 80 \text{ A}$$

(iii) turn off time for T_1

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

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



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

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

$$12.5 \rightarrow ?$$

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

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

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

$$V_s \text{ to } -V_s$$

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

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

$$= \pi \times \sqrt{2 \times 10^{-3} \times 1 \times 10^{-6}}$$

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

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

$$V_o = \frac{V_s}{T} (T_{ON} + 2t_c)$$

$$= \frac{V_s}{T} \left(T_{ON} + 2 \cdot \frac{CV_s}{I_0} \right)$$

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

$$= 47.5 \text{ V}$$

17. Ans: 1.6 [1.55 to 1.65]

Sol: $f = 25 \text{ kHz}$; $D = 0.6$

Find $R_{in} = ?$ (in W)

To check continuous conduction or discontinuous conduction

$$K = \frac{2fL}{R} \text{ and } k_{cr} = D(1 - D)^2$$

$$\text{Now } k = \frac{2fL}{R} = \frac{2 \times 25 \text{ k} \times 0.001}{10} = 5$$

$$k_{cr} = D(1 - D)^2 = 0.6 \times (1 - 0.6)^2 = 0.096$$

As $[k > k_{cr}]$ means continuous conduction case

$$\text{In C.C.C. } V_o = \frac{V_s}{(1 - D)}$$

According to Power balance equation

$$\frac{P_i}{P} = \frac{P_o}{P}$$

$$V_s i_{savg} = V_o I_o$$

$$V_s i_{savg} = \frac{V_{o1}^2}{R} = \frac{V_s^2}{R(1-D)^2}$$

$$i_{savg} = \frac{15}{10(1-0.6)^2}$$

$$i_{savg} = 9.375 \text{ amp}$$

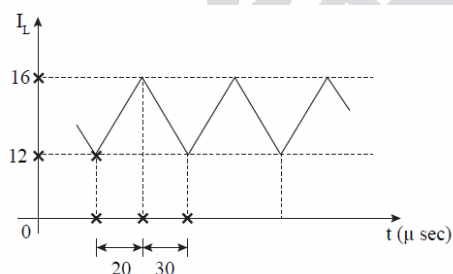
Now average resistance (R_{in})

$$R_{in} = \frac{V_s}{i_{savg}} = \frac{15}{9.375}$$

$$\Rightarrow R_{in} = 1.6 \Omega$$

18. Ans: 168 [Range: 165 to 171]

Sol: Buck boost converter



$$\Delta V_o = \Delta V_c = 1V; C = ?$$

$$i_{Lavg} = \frac{12+16}{2} = 14A$$

$$T_{ON} = 20 \times 10^{-6} \text{ sec};$$

$$T_{off} = 30 \times 10^{-6} \text{ sec}$$

$$T = 50 \times 10^{-6} \text{ sec}$$

$$C = \frac{\Delta Q}{\Delta V_o}$$

$$C = \frac{I_o \times T_{ON}}{\Delta V_o} \dots\dots\dots (1)$$

$$i_{oavg} = I_o = i_{Lavg} \times (1-D)$$

$$\therefore I_o = 14 \times \left(1 - \frac{20}{50}\right) = 8.4 \text{ A}$$

From (1)

$$C = \frac{8.4 \times 20 \times 10^{-6}}{1} = 168 \text{ F}$$

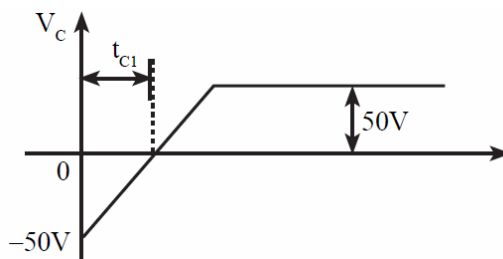
19. Ans: 50

Sol: Given circuit is voltage commutated chopper circuit

At $t = 0$

Th_A is triggered.

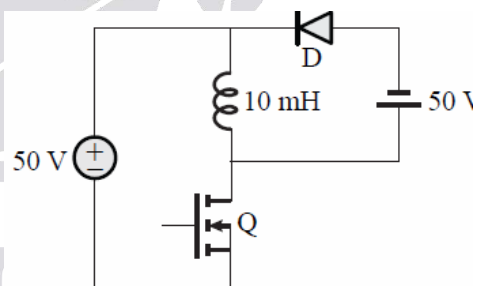
Capacitor discharges through load linearly



$$t_c = \frac{CV_s}{I_o} = \frac{10 \times 10^{-6} \times 50}{10} = 50 \text{ sec}$$

20.

Sol: The given DC-DC converter is match with buck boost converter.



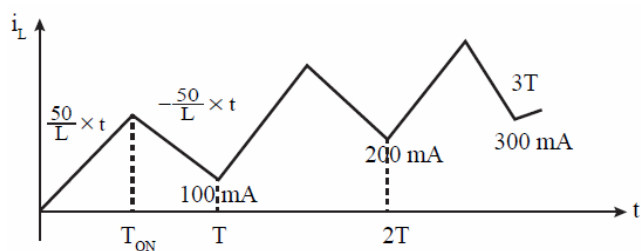
In DC-DC buck boost converter, for continuous conduction.

$$V_o = \frac{D}{1-D} V_s = \frac{0.6}{1-0.6} \times 50 = 75 \text{ W}$$

But given output voltage is 50V, so it is not continuous conduction mode. At the same time, it is not discontinuous conduction mode. (DCM) because, in D.C.M output voltage will be more than 50V.

So in every cycle inductor getting emerges in 0.6 T and deliver during 0.4 T duration. The slope of

current during ON time (T_{ON}) and OFF time (T_{OFF}) are as follows.



$$\frac{V_s}{L} \times t \dots \dots \dots T_{ON}$$

$$\frac{V_0}{L} \times t \dots \dots \dots T_{OFF}$$

$$L = 10 \text{ mH}$$

$$T = \frac{1}{10 \times 10^3} = 100 \therefore s$$

$$D = 0.6$$

During 1st cycle, at the end of T_{ON} ,

$$I_{L1} = \frac{50}{10 \times 10^{-3}} \times 100 \times 10^{-6} \times 0.6 = 300 \text{ mA}$$

$$\text{At the end of } T: I_{L2} = 300 - \frac{50}{L} \times T_{OFF}$$

$$I_{L2} = 300 \times 10^{-3} - \frac{50}{10 \times 10^{-3}} \times 0.4 \times 100 \times 10^{-6} = 100 \text{ mA}$$

At the end of 1st cycle it gets a current of 100 mA. It is continuous so at the end of 10th cycle, current through inductor is 1000 mA. 1 A

$$\therefore \text{Stored energy in inductor} = \frac{1}{2} LI^2 = \frac{1}{2} \times 10 \times 10^{-3} \times (1)^2 = 5 \text{ mJ}$$

21. Ans: 13 [13 to 13]

Sol: Boost converter

$$f = 50 \text{ Hz}, i_{\max} = ?$$

$$V_0 = \frac{V_s}{(1-D)}$$

$$40 = \frac{V_s}{(1-D)}$$

$$\therefore D = 0.5$$

$$i_{0\text{avg}} = \frac{V_0}{R} = \frac{40}{10} = 4 \text{ A}$$

$$i_{L\text{avg}} = \frac{i_{0\text{avg}}}{(1-D)} = \frac{4}{2 \times 500 \times 2 \times 10^{-3}} = 10 \text{ A}$$

$$i_{\max} = i_{L\text{avg}} + \frac{\Delta i_L}{2} = 8 + \frac{10}{2} = 13 \text{ A}$$

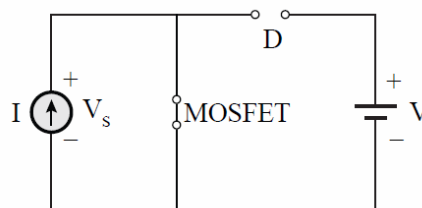
22. Ans: 90 to 90

Sol: $D = 0.4, I = i_s = 10 \text{ A}, V = V_0 = 15 \text{ V}$

Power delivered by current source = ?

During $t = 0$ to DT :

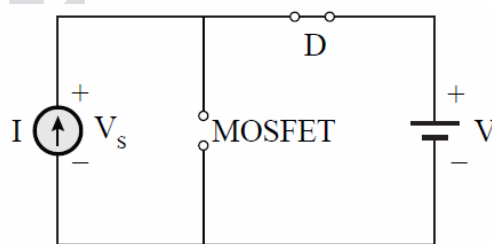
MOSFET-ON, D-OFF



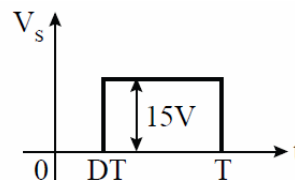
$$\therefore V_s = 0 \text{ V}$$

During $t = DT$ to T :

MOSFET-OFF, D-ON



$$V_s = V = 15 \text{ V}$$



$$V_{\text{avg}} = \frac{(T - DT) \times 15}{T} = (1 - D) \times 15$$

$$= (1 - 0.4) \times 15$$

$$V_{\text{avg}} = 9 \text{ V}$$

∴ Power delivered by current source

$$= V_{\text{avg}} I_{\text{avg}}$$

$$= 9 \times 10$$

$$= 90 \text{ W}$$

5. AC-AC Converters

01.

Sol: $P_{\text{Load}} = 5 \text{ kW}$

$$V_{\text{rms}} = 200 \text{ V}$$

$$R = 5 \Omega$$

$$S = \frac{V^2}{R} = \frac{230^2}{5} = 10580 \text{ W}$$

$$\therefore \delta = \frac{P_{\text{load}}}{S} = \frac{5000}{10510} = 0.472$$

$$\therefore \text{pf} = \sqrt{\delta} = \sqrt{0.472} = 0.687 \text{ lag}$$

02.

Sol: $V_{\text{in(rms)}} = \frac{V_{\text{on}}}{\sqrt{2}}$

$$= \frac{282.6}{\sqrt{2}} = 200 \text{ V}$$

$$P = V_{\text{rms}} \times Z_{\text{rms}} \times \text{pf}$$

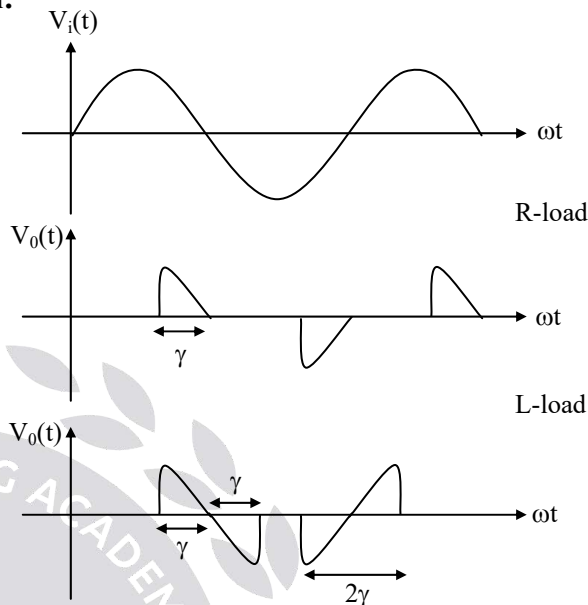
$$= V_{\text{out(rms)}} \times Z_{\text{out(rms)}}$$

$$\therefore V_{\text{in(rms)}} \times \text{pf}_{\text{in}} = V_{\text{0(rms)}}$$

$$P = \frac{V_{\text{0(rms)}}}{V_{\text{in(rms)}}} = \frac{162}{200} = 0.81$$

03.

Sol:



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

04.

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

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

$$= 42557.99$$

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

(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.

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

05.

Sol: $T_{\text{total}} = n_{\text{on}} + n_{\text{off}}$

$$T_{\text{total}} = 9 + 7 - 16 \text{ cycles}$$

$$\delta = \frac{n_{\text{ON}}}{T_{\text{total}}} = \frac{9}{16} = 0.5625$$

$$V_{0r} = V_{sr} \times \sqrt{\delta} = 220 \times \sqrt{0.5625}$$

$$= 165 \text{ V}$$

$$\text{pf} = \sqrt{\delta}$$

$$= \sqrt{0.5625}$$

$$= 0.75$$

 06. **Ans: (a)**
Sol: For controlling the load the minimum value of firing angle $\alpha >$ load phase angle

$$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

$$= \tan^{-1}\left(\frac{50}{50}\right) = 45^\circ$$

 Firing angle for which output voltage is uncontrollable = $0 < \alpha \leq \phi$
 $= 0 < \alpha < 45^\circ$

6. Fundamentals of Drives

 01. **Ans: (i) 62.84A, (ii) 118.46Nm**
Sol: Given Data, 15 Hp, 220V, 1000rpm

$$R_a + R_f = 0.2\Omega$$

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

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

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

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

$$210 = 0.2I_a + 3.14I_a \Rightarrow I_a = 62.87\text{A}$$

$$\text{Torque } T = K_b I_a^2$$

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

 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:

$$V_t = E_a + I_a R_a$$

$$220 = K_m \omega_m + I_a R_a$$

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

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

$$\alpha_1 = 30^\circ, T_e = 5 \text{ Nm}$$

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

$$V_0 = V_t = E_a + I_a R_a$$

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

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

$$\omega_m = 131.31 \text{ rad/sec}$$

$$N = 1253.92 \text{ r.p.m}$$

 (ii) $\alpha = 45^\circ$, $N = 1000 \text{ r.p.m}$, $T_e = ?$

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

$$146.4 = 140.01 + I_a \times 1$$

$$I_a = 6.39 \text{ A}$$

$$T_e = K_m I_a$$

$$= 1.337 \times 6.39 = 8.543 \text{ N-m}$$

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

Sol: Given Data,

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

$$V_s = 230, N = 1500 \text{ rpm}, \alpha = 30^\circ$$

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

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

$$V_0 = V_t = E_b + I_a R_a$$

$$193.2 = K_2 I_f \omega_m + I_a R_a$$

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

$$I_a = 45.12A$$

Torque: $T_e = K_2 I_f I_a$

$$= 0.5 \times 2 \times 45.12 \Rightarrow 45.12N-m$$

Power factor: $P_f = \frac{V_t I_a}{V_s I_{sr}}$

$$= \frac{193.2 \times 45.12}{230 \times 45.12 \sqrt{\frac{180-30}{180}}} = 0.92 \text{ lag}$$

04. Ans: 0.608

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

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

Duty cycle (D) = ?

At rated conditions (i.e., at 1000 rpm), back

$$\text{emf}, E_{b1} = 220 - 20 \times 2.5 = 170 \text{ V}$$

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: $\alpha = 39.2^\circ$ and $\mu = 8.3^\circ$

Sol: $V_t = E_b + I_a R_a$

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

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

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

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

$$\alpha = 39.17^\circ$$

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

$$\cos(39.17^\circ + \mu) =$$

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

$$\mu = 8.14^\circ$$

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

Sol: Given

$$V = 200 \text{ V}$$

$$N = 1450 \text{ rpm}$$

$$I_0 = 100 \text{ A}$$

$$R_a = 0.04 \Omega$$

3- ϕ half controlled converter

3- ϕ 220 V, 50 Hz

$$V_0 = E + I_a R_a$$

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

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

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

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

$$\alpha = 69.79^\circ$$

(b) Fundamental power factor = DPF

$$\begin{aligned} &= \cos \frac{\alpha}{2} \\ &= \cos \frac{69.72}{2} \\ &= 0.82055 \end{aligned}$$

(c) $THD = \sqrt{\left(\frac{I_s}{I_{s1}}\right)^2} - 1$

I_s = rms value of source current
= rms value of fundamental source current

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

$$I_{s1} = \frac{\sqrt{6}}{\pi} I_0 \cos \frac{\alpha}{2}$$

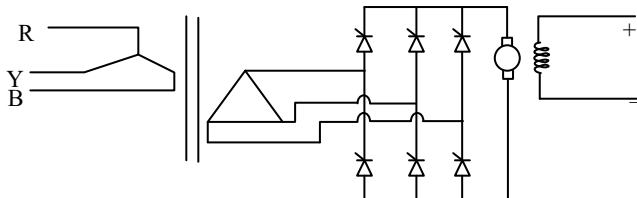
$$\begin{aligned} I_s &= 100A \sqrt{\frac{180 - 69.79^\circ}{180}} \\ &= 78.25 \text{ A} \end{aligned}$$

$$I_{s1} = \frac{\sqrt{6}}{\pi} \times 100 \times \cos\left(\frac{69.79}{2}\right)$$

$$\begin{aligned} THD &= \sqrt{\left[\frac{78.25}{63.935}\right]^2} - 1 \\ &= 70.56 \% \end{aligned}$$

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.

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

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

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

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

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

In Δ connection

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

Given

$$V_{LL} = 440 \text{ V}$$

In Star connection

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

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

(b) At rated conditions

$$(i) V_0 = E + I_a R_a$$

$$V_0 = K\omega + I_a R_a$$

$$220 = K \times \frac{2 \times \pi \times 1500}{60} + 50 \times 0.5$$

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

'E' at 120 rpm

$$E = 1.2414 \times \frac{2 \times \pi \times 1200}{60}$$

$$E = 156 \text{ V}$$

$$\frac{3V_{m\ell}}{\pi} \cos \alpha = 156 + 50 \times 0.5$$

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

$$\cos \alpha = 0.8277$$

$$\alpha = 34.64^\circ$$

(ii) Find E at rated condition

$$V_0 = E + I_a R_a$$

$$220 = E + 50 \times 0.5$$

$$E = 195 \text{ V}$$

$$\phi = \text{constant}$$

$$E \propto N$$

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

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

$$E_2 = -104 \text{ V}$$

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

Given torque is twice the rated torque

$$\frac{I_{a2}}{I_{a1}} = \frac{T_2}{T_1} \Rightarrow I_{a2} = 50 \times 2$$

$$I_{a2} = 100 \text{ A}$$

$$\frac{3 \times 230.383}{\pi} \cos \alpha = -104 + (100 \times 0.5)$$

$$\cos \alpha = -0.245$$

$$\alpha = 104.21^\circ$$

08. Ans: 114.62 [113 to 116]

Sol: 1- ϕ full converter $V_{S \text{ RMS}} = 240 \text{ V}$

$$f = 50 \text{ Hz}; \alpha = ?$$

Separately excited DC motor

$$V_{a \text{ rated}} = 210 \text{ V}; i_{a \text{ rated}} = 10 \text{ A}$$

$$N_{\text{rated}} = 1200 \text{ rpm}; R_a = 1 \Omega$$

$$\phi = \text{constant}; N = 600 \text{ rpm}$$

$$i_a = i_{a \text{ rated}}$$

$$E_{b \text{ rated}} = V_{a \text{ rated}} - i_{a \text{ rated}} \times R_a \\ = 210 - 10 \times 1$$

$$E_b \propto N$$

$$\frac{E_b}{E_{b \text{ rated}}} = \frac{N}{N_{\text{rated}}}$$

$$\therefore E_b = \frac{600}{1200} \times 200 = 100 \text{ V}$$

For regenerative braking [inverter mode operation]

$$V_a = i_a R_a - E_b \\ = 10 \times 1 - 100 = -90 \text{ V}$$

$$\text{Now; } V_a = \frac{2V_m}{\pi} \cos \pi$$

$$-90 = \frac{2 \times 240 \sqrt{2}}{\pi} \times \cos \alpha$$

$$\alpha = 114.62^\circ$$

09. Ans: (c)

Sol: Given that

$$N_1 = 1400 \text{ rpm}, N_2 = 1000 \text{ rpm}$$

$$I_1 = 40 \text{ A}, I_2 = 20 \text{ A (50\% of rated torque)}$$

$$R_a = 0.4 \Omega$$

$$V_{\text{rms}} = 220 \text{ V}$$

$$\alpha_1, \alpha_2 = ?$$

$$\text{We know that, } V_t = E_{b2} + I_{a2} R_a$$

$$V_t = \frac{2V_m}{\pi} \cos \alpha_1$$

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

$$E_{b1} = V - I_a R_1$$

$$= 220 - 40 \times 0.4 = 204$$

$$E_{b2} = \frac{1000}{1400} \times 204 = 145.71$$

$$\frac{2V_m}{\pi} \cos \alpha_1 = 145.71 + (20)(0.4) = 135.71$$

$$\cos \alpha_1 = 0.776$$

$$\alpha_1 = 39^\circ$$

In dual converter

$$\alpha_1 + \alpha_2 = 180^\circ$$

$$\alpha_2 = 180^\circ - 39^\circ$$

$$\alpha_2 = 141^\circ$$

