CLASS TEST

S.No.: 01SK_ABCDEFG_06052024

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# POWER ELECTRONICS

## ELECTRICAL ENGINEERING

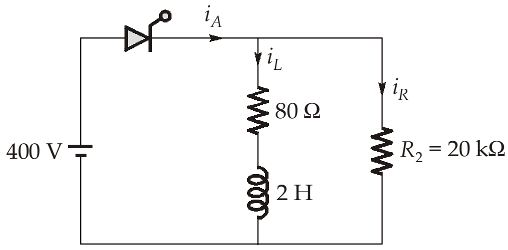
Date of Test : 06/05/2024

## ANSWER KEY

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | (b) | 7. | (a) | 13. | (a) | 19. | (c) | 25. | (d) |
| 2. | (c) | 8. | (a) | 14. | (a) | 20. | (d) | 26. | (b) |
| 3. | (a) | 9. | (a) | 15. | (b) | 21. | (c) | 27. | (a) |
| 4. | (c) | 10. | (d) | 16. | (a) | 22. | (b) | 28. | (d) |
| 5. | (a) | 11. | (a) | 17. | (b) | 23. | (b) | 29. | (b) |
| 6. | (d) | 12. | (b) | 18. | (a) | 24. | (d) | 30. | (d) |

## DETAILED EXPLANATIONS

**1. (b)**




Current through 20 kΩ resistor,

$$i_R = \frac{400}{20 \times 10^3} = 0.02 \text{ A}$$

Current through inductor,

$$i_L = \frac{V}{R_1}\left(1 - e^{-R_1/Lt}\right) = \frac{200}{40}\left(1 - e^{-40t}\right)$$

$$= 5(1 - e^{-40t})$$

$$i_A = i_R + i_L$$

$$= 0.02 + 5(1 - e^{-40t})$$

To turn on $i_A \geq$ latching current,

$$0.02 + 5(1 - e^{-40t}) = 60 \text{ mA}$$

$$T = 200 \text{ μsec}$$

**2. (c)**

Using relation,

$$\cos\alpha - \cos(\alpha + \mu) = \text{constant} \quad ...(1)$$

$$\alpha = 35°, \quad \mu = 4°$$

$$K = \cos 35° - \cos(35 + 4°) = 0.042$$

At $\alpha = 0°$

Let,

$$\mu = \mu_0$$

$$K = \cos 0° - \cos(0 + \mu_0)$$

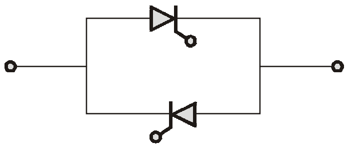
$$0.042 = 1 - \cos\mu_0$$

$$\cos\mu_0 = 0.958$$

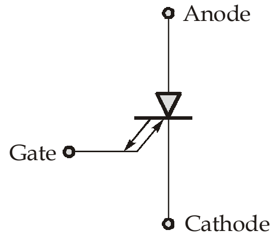
$$\mu_0 = 16.66°$$

$$\text{Inductive voltage regulation} = \frac{1 - \cos\mu_0}{2} = 0.0209$$

**3.** **(a)**




Bidirectional and Bipolar




It is also unidirectional and bipolar

**4.** **(c)**

Due to absence of minority carrier reverse recover time of schottky diode is in nanosecond. It is used in SMPS.

**5.** **(a)**

The source is a 'cosine' function. So capacitor charges to its maximum value instantaneously as switch is closed at $t$ = 0. So diode conducts for 0°.

**6.** **(d)**

$$\text{Average load current} = \frac{12+16}{2} = 14 \text{ A}$$

$$\text{Average load voltage} = V_0 = I_0 R = 14 \times 10 = 140 \text{ V}$$

$$V_0 = \alpha\, V_s$$

Since the chopper is step down or type-A,

$$140 = \alpha\, 200$$

$$\alpha = \frac{140}{200} = 0.7$$

$$\frac{T_{on}}{T_{on}+T_{off}} = 0.7$$

$$0.3\, T_{on} = 0.7\, T_{off}$$

$$\frac{T_{on}}{T_{off}} = 2.33$$

**7.** **(a)**

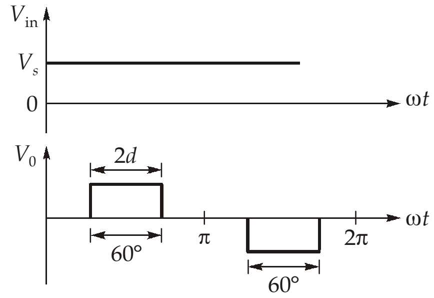
In 6 pulse thyristor, frequency components available on supply side current are

$f_s$ , $(6K \pm 1)\, f_s$ where $K$ = 1, 2, 3, 4, ....

**60**, 300, 420, 660

Lowest frequency component is 60.

**8. (a)**

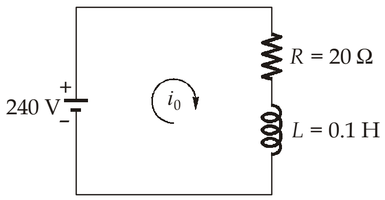


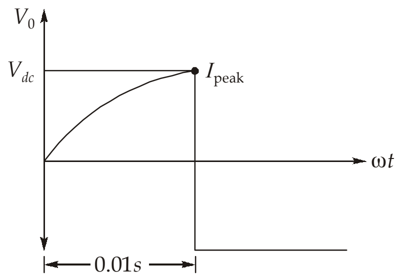

$$V_{or} = V_s\sqrt{\frac{2d}{\pi}}$$

$$V_{0\ rms} = 600\sqrt{\frac{60°}{180°}} = 346.4 \text{ V}$$

**9. (a)**

During the positive half cycle the circuit is,




$$i(t) = \frac{V_s}{R}\left(1-e^{-t/\tau}\right) = \frac{240}{20}\left(1-e^{\frac{-0.01\times 20}{0.1}}\right)$$

$$i_{(0.01)} = 10.37 \text{ A}$$

**10. (d)**

In the output phase voltage the even, third and multiples of 3rd harmonics are absent. So, lowest order harmonics are 5th harmonics,

$$\text{Fourier series, } V_R = \sum_{n=6k\pm1} \frac{2V_s}{n\pi}\sin n\omega t$$

So, frequency of 5th harmonis = 5 × fundamental frequency = 5 × 50 = 250 Hz

**11. (a)**

The main thyristor is turned off when $i_c$ is,

$$i_c = I_p \sin \omega t = I_0$$

$$\omega t = \sin^{-1}\left(\frac{I_0}{I_p}\right)$$

Peak value of current through capacitor,

$$I_p = V_s\sqrt{\frac{C}{L}} = 230 \times \sqrt{\frac{20\times10^{-6}}{5\times10^{-6}}} = 460 \text{ A}$$

$$\omega t = \sin^{-1}\left(\frac{300}{460}\right) = 40.70°$$

Voltage across main thyristor $= V_s \cos \omega t$

$= 230 \times \cos 40.70°$

$= 174.37$ V

**12. (b)**

The power loss, $$P = \frac{1}{T}\int_0^3 V_s(t)\, i_s(t)\, dt$$

$$= \frac{1}{T}\int_0^3\left(\frac{200}{3}t\right)\left(\frac{600}{3}t\right)dt = \frac{40000}{3T}\int_0^3 t^2\, dt$$

$$P = \frac{40000}{3T}\left[\frac{t^3}{3}\right]_0^3$$

Where $T$ is in μsec

$\Rightarrow$ $$T = \frac{1}{50}\times10^6 = 20000$$

So, $$P = \frac{40000}{3\times20000}\left[\frac{3^3}{3}\right]$$

$P = 6$ Watt average power loss

**13. (a)**

Given, $$\frac{V_{dc}}{2} = 96$$

$$V_{dc} = 192 \text{ V}$$

Rms value of the fundamental voltage in the output,

$$V_{01} = \frac{2V_s}{\sqrt{2}\pi} = \frac{2\times192}{\sqrt{2}\pi} = 86.43 \text{ V}$$

Fundamental power in the output,

$$= \frac{(V_{01})^2}{R} = \frac{(86.43)^2}{5} = 1494 \text{ W}$$

**14. (a)**

Fourier expression of output voltage is,

$$V_{0,\,n} = \sum_{n=1,3,5}^{\infty}\frac{2V_{dc}}{n\pi}\sin n\omega t \text{ V}$$

Harmonic factor for 3rd harmonic

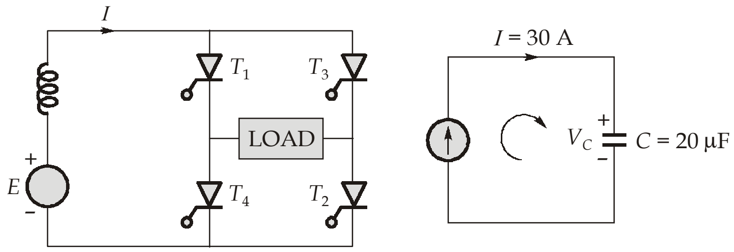
$$\text{H.F.} = \frac{V_{3,\,rms}}{V_{1,\,rms}}$$

$$\text{H.F.} = \frac{V_{3,\,rms}}{V_{1,\,rms}} = \frac{\dfrac{2\times 48}{\sqrt{2}\times 3\pi}}{\dfrac{2\times 48}{\sqrt{2}\,\pi}}\times 100$$

$$= \frac{1}{3}\times 100 = 33.33\%$$

**15.** **(b)**

During the on period of $T_1$ and $T_2$ the circuit behaves as

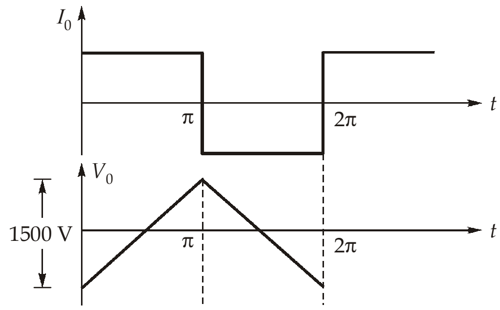



$$V_C = \frac{1}{C}\int_0^{t_{on}} i\,dt$$

$$V_C = \frac{30}{20\times 10^{-6}}T_{on}$$

Where, $$T_{on} = \frac{1}{2f} = \frac{1}{2\times 500} = 1\times 10^{-3}\text{ s}$$

$$V_C = \frac{30}{20\times 10^{-6}}\times 1\times 10^{-3} = 1500\text{ V}$$




Peak to peak of output voltage is 1500 V.

The reverse voltage that appears across thyristor is 750 V.

**16.** **(a)**

To eliminante the $5^{th}$ harmonic content,

$$2d = \frac{2\pi}{5}$$

$$d = \frac{\pi}{5} = 36°$$

The 7th harmonic rms value is,

$$V_{07\,(\text{rms})} = \frac{4V_S}{7\pi\sqrt{2}}\sin\frac{7\pi}{2}\sin(7\times 36°)$$

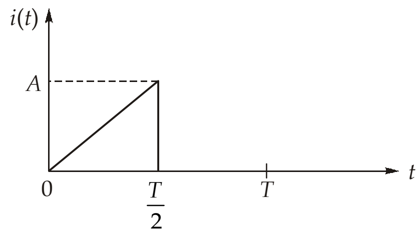
$$= 0.122\ V_S$$

**17. (b)**

$$\text{Average ON state loss} = I_{\text{rms}}^2 R_{ON}$$

Where, $I_{\text{rms}} \rightarrow$ rms value current,

$R_{\text{ON}} \rightarrow$ On state resistance of MOSFET




$$i(t) = \frac{A}{T/2}t = \frac{2A}{T}t$$

$$i_{\text{rms}} = \sqrt{\frac{1}{T}\int_0^{T/2}[i(t)]^2\,dt} = \sqrt{\frac{1}{T}\int_0^{T/2}\frac{4A^2}{T^2}t^2dt}$$

$$= \sqrt{\frac{1}{T}\times\frac{4A^2}{T^2}\left(\frac{t^3}{3}\right)_0^{T/2}} = \sqrt{\frac{1}{T}\times\frac{4A^2}{T^2}\times\frac{T^3}{8\times 3}} = \frac{A}{\sqrt{6}}$$

$$\text{Average ON state loss} = \left(\frac{15}{\sqrt{6}}\right)^2\times 0.25 = 9.375\text{ W}$$

**18. (a)**

$$\text{Gate-cathode characteristic slope} = \frac{V_g}{I_g}$$

Where, $V_g$ = Allowable voltage across SCR

$I_g$ = Allowable current across SCR

$$\frac{V_g}{I_g} = 120$$

$$V_g = 120\ I_g \quad \text{...(i)}$$

Allowable gate power dissipation = 0.4 watt

$$V_g I_g = 0.4\text{ Watt}$$

Put value of '$V_g$' from equation (i)

$$(120 I_g) I_g = 0.4$$

$$I_g = \sqrt{\frac{0.4}{120}} A = 0.0577 \text{ A}$$

$$V_g = 120 \times 0.0577 = 6.92 \text{ V}$$

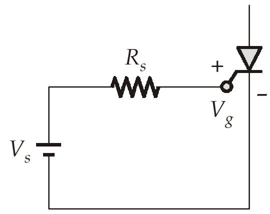
We know,

$$V_s = V_g + R_s I_g$$

$$20 = 6.928 + 0.0577 R_s$$

$$0.0577 R_s = 13.071$$

$$R_s = 226.54 \ \Omega$$




**19. (c)**

The diode will start conducting at an angle $\theta_1$ , where

$$\theta_1 = \sin^{-1}\frac{E}{(V_s)_{max}} = \sin^{-1}\frac{120}{230\times\sqrt{2}} = 21.64°$$

Average value of charging current,

$$I_{0\text{ avg}} = \frac{1}{2\pi R}[2V_m\cos\theta_1 - E(\pi - 2\theta_1)]$$

$$= \frac{1}{2\pi\times 10}\left[2\times 230\times\sqrt{2}\times\cos 21.64° - 120\left(\pi - \frac{2\times 21.64°\times\pi}{180}\right)\right]$$

$$= 5.071 \text{ A}$$

Power delivered to battery

$$= EI_{0\text{ avg}} = 120 \times 5.071 = 608.82 \text{ W}$$

(Power delivered to battery) × (Charging time in hours) = Battery capacity

$$(608.52) \times \text{charging time} = 8850 \text{ Wh}$$

$$\text{Charging time} = \frac{8850}{608.52}\text{hours} = 14.54 \text{ hours}$$

**20. (d)**

For 1-$\phi$ semiconverter,

$$\text{Supply rms current, } I_{rms} = I_{dc}\left[\frac{\pi-\alpha}{\pi}\right]^{1/2} = I_{dc}\left[\frac{\pi-\pi/4}{\pi}\right]^{1/2} = 0.866 \, I_{dc}$$

The rms value of the supply fundamental component of input current

$$I_{rms,\,1} = \frac{2\sqrt{2}}{\pi}I_{dc}\cos\left(\frac{\alpha}{2}\right)$$

$$= \frac{2\sqrt{2}}{\pi}I_{dc}\cos\left(\frac{\pi}{4\times 2}\right) = 0.83178 \, I_{dc}$$

$$\text{Harmonic factor } (Hf) = \left[\left(\frac{I_{rms}}{I_{rms,1}}\right)^2 - 1\right]^{1/2} = \left[\left(\frac{0.866 I_{dc}}{0.83178 I_{dc}}\right)^2 - 1\right]^{1/2} = 28.98\%$$

**21. (c)**

Case-I,

$$T_j = 110° \text{ C}, \qquad T_s = 80° \text{ C}$$

$$P_{av\,1} = \frac{110-80}{0.16+0.05} = 142.85 \text{ W}$$

Case-II,

$$T_j = 110° \text{ C}, \qquad T_s = 50° \text{ C}$$

$$P_{av\,2} = \frac{110-50}{0.16+0.05} = 285.71 \text{ W}$$

Thyristor rating is proportional to the square root of average power loss

$$\% \text{ increase in rating} = \frac{\sqrt{285.71}-\sqrt{142.85}}{\sqrt{142.85}} \times 100 = 41.42\%$$

**22. (b)**

For Buck-converter

$$\text{Average output voltage} = DV_s$$

Where, $D$ = Duty ratio, $V_s$ = input voltage

$$V_s = 40 \text{ V}, \qquad V_0 = 16 \text{ V}$$

$$f = 20 \text{ kHz}$$

$$16 = D \times 40$$

$$D = \frac{16}{40} = 0.4$$

Peak to peak ripple current,

$$\Delta I_L = \frac{V_s D(1-D)}{L f}$$

$$0.8 = \frac{40 \times 0.4 \times 0.6}{L \times 20 \times 10^3}$$

$$L = 600 \text{ μH}$$

**23. (b)**

$$V_s = 250 \text{ V}, \qquad V_0 = 625 \text{ V}$$

For boost converter,

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

$$625 = \frac{250}{1-D}$$

$\Rightarrow$ $D = 0.6$

$$I_{L\,\min} = I_L - \frac{\Delta I_L}{2} = \frac{3125}{250} - \frac{250 \times 0.6}{2 \times 10 \times 10^{-3} \times 25 \times 10^3}$$

$$= 12.2 \text{ A} > 0$$

It is operating in continuous conduction, Now $$I_0 = \frac{3125}{625} = 5\text{ A}$$

$$\frac{V_0}{V_s} = \frac{I_s}{I_0} = \frac{1}{1-D}$$

$$\Rightarrow \quad I_s = \frac{I_0}{1-D} = \frac{5}{1-0.6} = 12.5\text{ A}$$

$$R_{in} = \frac{V_s}{I_s} = \frac{250}{12.5} = 20\ \Omega$$

**24. (d)**

Output voltage $(V_0)$ = 36 V

Input voltage $(V_s)$ = 24 V

For Buck-boost converter

$$V_0 = \frac{DV_s}{1-D}$$

$$36 = \frac{24D}{1-D}$$

$$\Rightarrow \quad 36 - 36D = 24D$$

$$60D = 36$$

$$\Rightarrow \quad D = 0.6$$

$$\Delta I_L = \frac{DV_s}{Lf}$$

At the boundary,

$$I_{Lavg} - \frac{\Delta I_L}{2} = 0$$

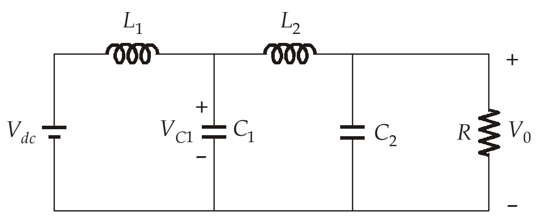
$$\frac{I_0}{1-D} = \frac{\Delta I_L}{2} \qquad \left[I_{Lavg} = \frac{I_0}{1-D}\right]$$

$$\frac{144/36}{1-0.6} = \frac{0.6\times 24}{2\times 20\times 10^3\times L}$$

$$L = \frac{0.4}{4}\times\frac{0.6\times 24}{2\times 20\times 10^3} = 36\ \mu\text{H}$$

**25. (d)**

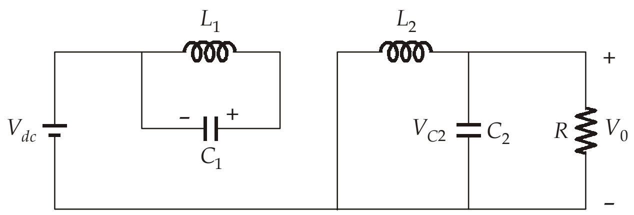
For ON period:




$$V_{L1} = (V_{dc} - V_{c1})$$

$$V_{L2} = (V_0 - V_{c1})$$

For OFF-period




$$V_{L1} = -V_{C1}\,, \qquad V_{L2} = -V_{C2} = -V_0$$

Now, for inductor '$L_1$'

$$(V_L)_{avg} = 0$$

$$(V_{dc} - V_{C1})DT - V_{C1}(1 - D)T = 0$$

$$V_{C1} = DV_{dc}$$

Similarly for inductor '$L_2$'

$$(V_{C1} - V_0)DT - V_0(1 - D)T = 0$$

$$V_0 = DV_{c1} = D^2V_{dc}$$

So, $$V_0 = D^2V_{dc} = (0.75)^2 \times 80 \text{ V} = 45 \text{ V}$$

**26. (b)**

$$P_{avg} = I_{rms}^2 \cdot R_{ON}$$

$$R_{ON} = 0.15\ \Omega \text{ and } I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} 10t\,dt} = \frac{10}{\sqrt{6}}$$

$$P_{avg} = \frac{100}{6} \times 0.15 = 2.50 \text{ W}$$

**27. (a)**

For 1-$\phi$ full bridge inverter

$$V_{dc} = 60 \text{ V}, \qquad R = 12\ \Omega$$

$$V_{01\ rms} = \frac{2\sqrt{2}\,V_{dc}}{\pi} = \frac{2\sqrt{2}}{\pi} \times 60 = 54.046 \text{ V}$$

$$\text{Power} = \frac{V_{01\,rms}^2}{R} = \frac{(54.046)^2}{12} = 243.41 \text{ W}$$

**28. (d)**

Pole voltage, phase voltage,

$$V_{pole} = V_R \rightarrow \text{quasi square wave } 2d = \frac{2\pi}{3} \text{ rad}$$

$$n = 6K \pm 1 = 1, 5, 7, 11, 13 \ldots..$$

Line voltage $\rightarrow$ 6 step :

$$n = 6K \pm 1 = 1, 5, 7, 11, 13 \ldots..$$

**29. (b)**

Average output voltage of the converter,

$$V_0 = \frac{3V_{mL}}{\pi}\cos\alpha$$

Load current, $I_0 = 20$ A

Back emf, $E_b = 180$ V

$R_a = 1\ \Omega$

Applying KVL,

$$V_0 - 1 \times I_0 - 180 = 0$$

$$V_0 = 180 + 1 \times 20 = 200 \text{ V}$$

Now, $$\frac{3V_{mL}}{\pi}\cos\alpha = 200$$

$$\frac{3 \times 400 \times \sqrt{2}}{3.14} \times \cos\alpha = 200$$

$$\cos\alpha = 0.37$$

$$\alpha = 68.28°$$

**30. (d)**

$$V_i = 200\sqrt{2}\sin(120\pi t)\text{V}$$

$$i_i = \left(20\sqrt{2}\sin\left(120\pi t - \frac{\pi}{3}\right) + 10\sqrt{2}\sin\left(360\pi t + \frac{\pi}{4}\right)\right) + 4\sqrt{2}\sin\left(840\pi t - \frac{\pi}{6}\right)\text{A}$$

Fundamental component of input voltage,

$$(V_i)_1 = 200\sqrt{2}\sin(120\pi t)\text{V}$$

$$(V_i)_{rms} = 200 \text{ V}$$

Fundamental component of current,

$$(i_L)_{1,\ rms} = \frac{20\sqrt{2}}{\sqrt{2}} = 20$$

Phase difference between the two components

$$\phi_1 = \frac{\pi}{3}$$

Active power due to fundamental component

$$P_1 = (V_i)_{1\ rms} \times (i_i)_{1\ rms} \cos\phi_1$$

$$P_1 = 200 \times 20 \times \cos\left(\frac{\pi}{3}\right) = 2000 \text{ W}$$

rms value of input voltage = 200 V

$$\text{rms value of current} = \sqrt{\left(\frac{20\sqrt{2}}{\sqrt{2}}\right)^2 + \left(\frac{10\sqrt{2}}{\sqrt{2}}\right)^2 + \left(\frac{4\sqrt{2}}{\sqrt{2}}\right)^2} = \sqrt{400 + 100 + 16} = \sqrt{516}$$

$$= 22.71 \text{ A}$$

Let input power factor $\cos\phi$

$$200 \times 22.71 \times \cos\phi = 2000$$

$$\cos\phi = \frac{10}{22.71} = 0.44$$

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