POSTAL
Book Package
2023

Electrical Engineering

Conventional Practice Sets

Power Electronics

Contents

Sl. Topic **Page No.**

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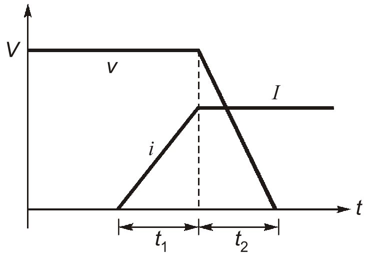
1

CHAPTER

Power Semi-conductor Diode and Transistor

Q.1 The voltage across and current through a power semiconductor device switching transients are shown in the figure. Deduce the expression for the energy lost in the ON/OFF transition in terms of V, I, t and t_2.



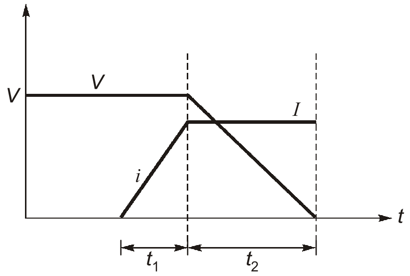
Solution:

During t_1 interval voltage is constant (V), while current starts increasing. Thereafter, in t_2 interval voltage starts decreasing and becomes zero and current becomes constant (I), so the transition is turn on.

During t_1 interval:

$$\text{Power loss} = vi$$

$$\text{Energy loss, } E_1 = \int vi\,dt \; [= E_1(\text{Say})]$$



$\because$ v is constant in this interval,

$$\therefore \quad E_1 = V \cdot \int i\,dt$$

$$= V(\text{Area under } i\text{-}t \text{ curve in } t_1)$$

or

$$E_1 = V\left[\frac{1}{2}It_1\right] = \frac{1}{2}VIt_1$$

During t_2 interval:

$$\text{Power loss} = vi$$

$$\text{Energy loss, } E_2 = \int vi\,dt$$

$\because$ i is constant in the interval ($=I$)

$$\therefore \quad E_2 = I \cdot \int v\,dt$$

$$= I(\text{Area under } v\text{-}t \text{ curve in } t_2)$$

or

$$E_2 = I\left(\frac{1}{2}Vt\right) = \frac{1}{2}VIt_2$$

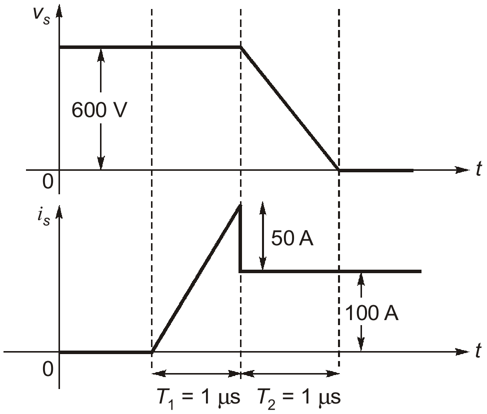
Therefore, total energy lost during ON transition,

$$E_{\text{lost}} = E_1 + E_2 = \frac{1}{2}VIt_1 + \frac{1}{2}VIt_2$$

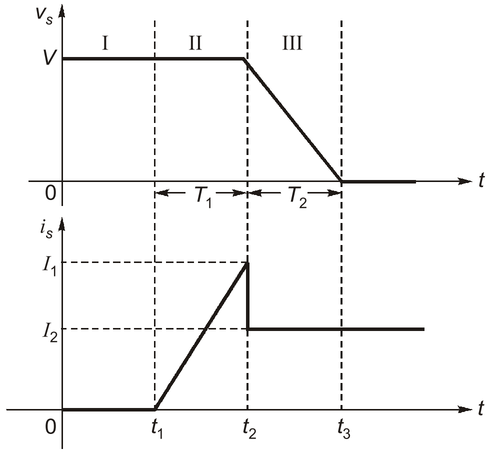
or,

$$E_{\text{lost}} = \frac{1}{2}VI(t_1 + t_2)$$

Q.2 If the voltage (V_s) across and current (i_s) through a power semiconductor switch during turn-on process are shown in the figure below, then calculate the energy dissipated during the turn-on process.



Solution:



We know that, Energy $= \displaystyle\int_0^t vi\,dt$

Here, Energy $= E_{\text{I}} + E_{\text{II}} + E_{\text{III}}$

$$= V \cdot 0 + \int_{t_1}^{t_2} V \cdot i_s\,dt + \int_{t_2}^{t_3} v_s \cdot I_2\,dt$$

$$= 0 + V\int_0^{T_1} i_s\,dt + I_2\int_0^{T_2} v_s\,dt$$

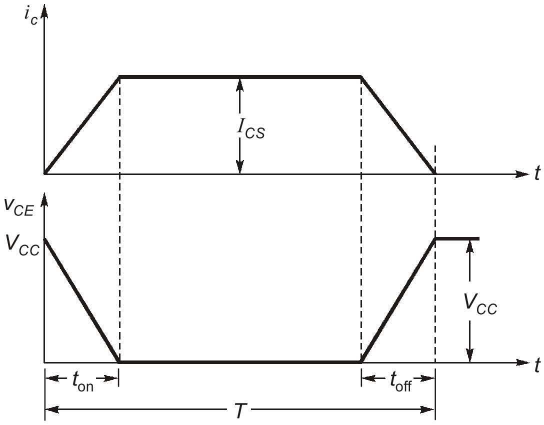
$$= V\left[\frac{1}{2}I_1T_1\right] + I_2\left[\frac{1}{2}VT_2\right]$$

$$= 600\left[\frac{150}{2}\times 1\times 10^{-6}\right] + 100\left[\frac{600}{2}\times 1\times 10^{-6}\right]$$

$$= 75000 \times 10^{-6}\text{ J}$$

∴ Energy = 75 mJ

Q.3 Find the energy loss during switch-on and off intervals of a power transistor with switching characteristics as shown in the figure. Where I_{CS} = 80 A, V_{CC} = 220 V, t_{on} = 1.5 ms and t_{off} = 4 ms. Also determine the average power loss in the transistor if switching frequency is 2 kHz.



Solution:

From the switching characteristics given in the figure above.

$$\text{Energy loss during trun-on } (E_{\text{loss (on)}}) = \int_0^{t_{on}} i_c \cdot v_{CE}\, dt$$

$$= \int_0^{t_{on}} \left[\frac{I_{CS}}{t_{on}}\right] t \cdot \left(V_{CC} - \frac{V_{CC}}{t_{on}} t\right) dt$$

$$= \int_0^{t_{on}} \frac{I_{CS} V_{CC}}{t_{on}} \cdot t\, dt - \int_0^{t_{on}} \frac{I_{CS} V_{CC}}{t_{on}^2} \cdot t^2\, dt$$

$$= \frac{I_{CS} V_{CC}}{t_{on}} \cdot \frac{t_{on}^2}{2} - \frac{I_{CS} V_{CC}}{t_{on}^2} \cdot \frac{t_{on}^3}{3} = \frac{I_{CS} V_{CC}}{6} \cdot t_{on}$$

$$\therefore \quad E_{\text{loss(on)}} = \frac{80 \times 220}{6} \times 0.15 \times 10^{-3} \text{ Watt-sec.}$$

$$E_{\text{loss(on)}} = 0.44 \text{ Watt-sec.}$$

Similarly, $$E_{\text{loss(off)}} = \frac{I_{CS} V_{CC}}{6} \cdot t_{\text{off}}$$

or $$E_{\text{loss(off)}} = \frac{80 \times 220}{6} \times 0.4 \times 10^{-3} \text{ Watt-sec.}$$

$$\therefore \quad E_{\text{loss(off)}} = 1.17 \text{ Watt-sec.}$$

Average power loss in the power transistor for switching frequency of 2 kHz

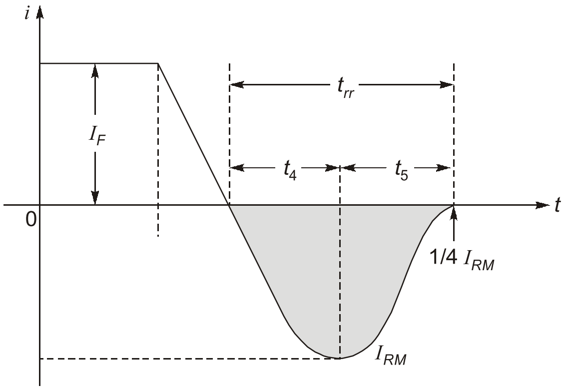
= (Energy loss in ON and OFF switching) × Switching frequency

$$= \frac{I_{CS} V_{CC}}{6} (t_{on} + t_{\text{off}}) \times f$$

$$= (0.44 + 1.17) \times 2 \times 10^3 = 3.22 \text{ kW}$$

Q4 **For a power diode, the reverse recovery time is 3.9 µs and the rate of diode-current decay is 50 A/µs. For a softness factor of 0.3, calculate the peak inverse current and storage charge.**

Solution:



Given, Reverse recovery time $(t_{rr}) = 3.9\ \mu\text{s}$

$$\text{Softness factor } \left(\frac{t_5}{t_4}\right) = 0.3$$

$$\therefore \quad t_5 = 0.3\, t_4$$

$$t_{rr} = t_4 + t_5 = 3.9\ \mu\text{s}$$

or, $$1.3\, t_4 = 3.9\ \mu\text{s}$$

or, $$t_4 = 3\ \mu\text{s}$$

Given, $$\frac{di}{dt} = 50\ \text{A}/\mu\text{s}$$

The peak inverse current I_{RM} can be expressed as:

$$I_{RM} = t_4 \frac{di}{dt} = 3 \times 50 \text{ Amp.}$$

or, $$I_{RM} = 150 \text{ Amp.}$$

Assuming reverse recovery characteristic to be triangular,

$$\text{Storage charge } (Q_R) = \frac{1}{2} I_{RM} \cdot t_{rr} = \frac{1}{2} \times 150 \times 3.9\ \mu C$$

$$Q_R = 292.5\ \mu\text{C}$$

$$\therefore \quad I_{RM} = 150\ \text{A and } Q_R = 292.5\ \mu\text{C}$$

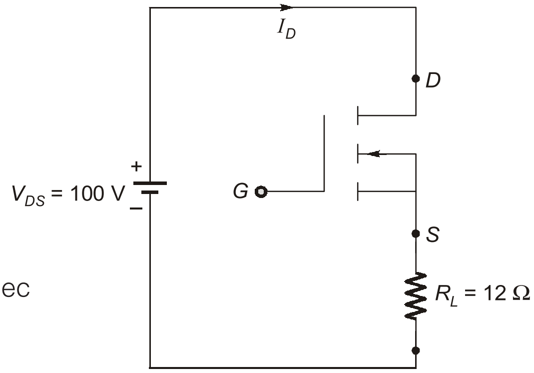
Q.5 For the circuit shown in figure below, determine:

(a) Power loss in the on-state

(b) Power loss during the turn-on interval.

MOSFET parameters are: t_r = 2 ms, $R_{DS(on)}$ = 0.2 Ω, duty cycle (D) = 0.7 and f = 30 kHz.

Solution:



When MOSFET is on:

Drain current,

$$I_D = \frac{V_{DS}}{R_L + R_{DS(\text{on})}}$$

$$= \frac{100}{12 + 0.2} = 8.197\ \text{A}$$

Switching period,

$$T = \frac{1}{f} = \frac{1}{30 \times 10^3} = 33.333\ \mu\text{sec}$$

$$\text{Duty cycle } (D) = \frac{t_{\text{on}}}{T}$$

∴ on time is given by,

$$t_{\text{on}} = D \cdot T = 0.7 \times 33.333 \times 10^{-6}$$

$$= 23.3331\ \mu\text{s}$$

(a) Energy loss during on state,

$$E_{\text{on}} = I_D^2 R_{DS(\text{on})} \cdot t_{\text{on}}$$

$$= (8.197)^2 \times 0.2 \times (23.3331 \times 10^{-6})$$

$$= 313.554\ \mu\text{J}$$

Now, power loss during on state,

$$P_{\text{on}} = E_{\text{on}} \cdot f$$

$$= 313.554 \times 10^{-6} \times 30 \times 10^3$$

$$= 9.4066\ \text{W}$$

(b) Energy loss during the turn-on [assuming triangular switching on characteristic]

$$E_{\text{turn-on}} = \frac{V_{DS} \cdot I_D \cdot t_r}{6} = \frac{100 \times 8.197}{6} \times 2 \times 10^{-6}$$

$$= 273.233\ \mu\text{J}$$

Power loss during turn-on,

$$P_{\text{turn-on}} = E_{\text{turn-on}} \cdot f = 273.233 \times 10^{-6} \times 30 \times 10^3$$

$$= 8.197\ \text{W}$$

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