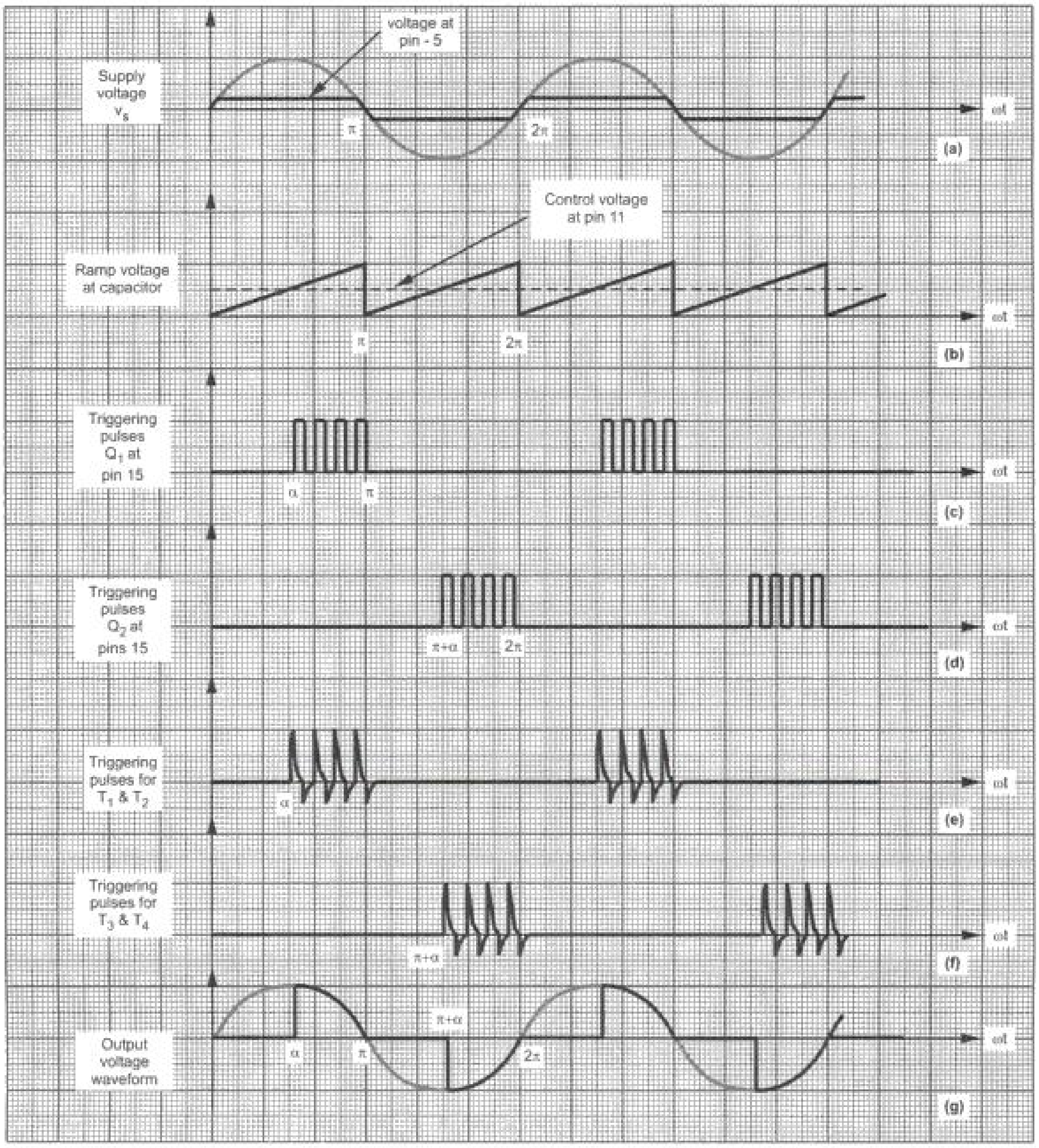


Fig. 2.8.5 Waveforms of AC phase control using TCA 785

2.9 Protection Circuits

Due to unpredicted changes in the load and supply voltages, fault conditions are arised. Under these conditions, the voltage or current ratings of the power devices are exceeded. Hence there is a possibility of damage to the power device. Such damage can be avoided by using protection circuits. Following are the possible faults and required protection circuits :

i) High rate of change of voltage across the power device is called dv/dt. This normally turns-on the thyristor and damages BJTs. The value of dv/dt can be effectively reduced with the help of snubbers (RC circuit) and Metal Oxide Varistors (MOV).

ii) High rate of change of current in the device is called $^{di}/_{dt}$. The spread of current inside the device requires some time. If sufficient time is not given for current spread, then localized hot spot is created in side the device. The device is damaged due to this fault. The $^{di}/_{dt}$ problem normally occurs in thyristors. This problem can be avoided by putting the current limiting inductor in series with the device. The inductor limits rapid changes in the current.

iii) Overcurrent normally occurs due to variations in the load. Overcurrent causes excessive heating of the device and it leads to damage. Fuses are normally used to limit overcurrents.

2.10 Protection against $^{dv}/_{dt}$ and Overvoltages

2.10.1 Snubber Circuits (Turn-off Snubber)

Answer following questions after reading this topic.

1. *Why snubber circuits are required ? Explain snubber circuits.*
Marks[4], May-2000; Marks[16], Dec.-2002; Marks[6], Dec.-2003, 2004
2. *Explain the protection of power devices by snubber circuit.*

Most likely and **asked in** previous University Exam

The transient overvoltages can switch on the thyristor. In some cases the thyristor can be damaged due to these transient voltages. These transient voltages are very common when the converter is having inductive loads. The thyristors can be protected against transient voltages by a RC network as shown in Fig. 2.10.1. This RC network is connected in parallel across the thyristor. It is called *snubber circuit*. The resistance has the value of few hundred ohms. Whenever there is a large spike or voltage transient across the thyristor, it is absorbed by the RC circuit. The RC circuit (snubber) acts as a lowpass filter for this voltage transient. The resistance has normally low value so that the transient is absorbed by the capacitor quickly. Thus the

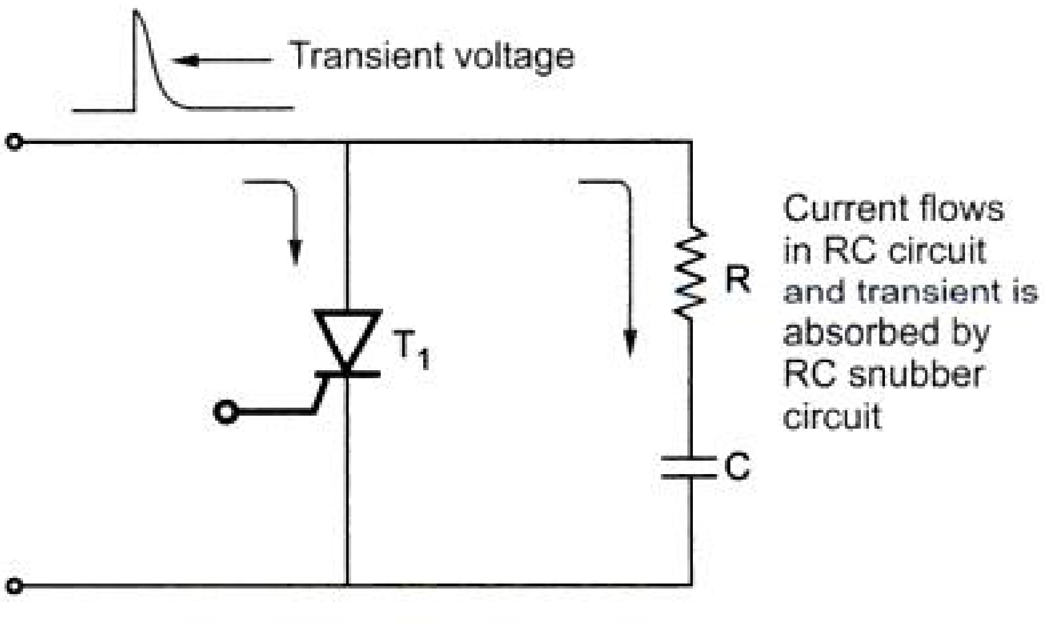


Fig. 2.10.1 A snubber (RC) network is used for transient voltage protection

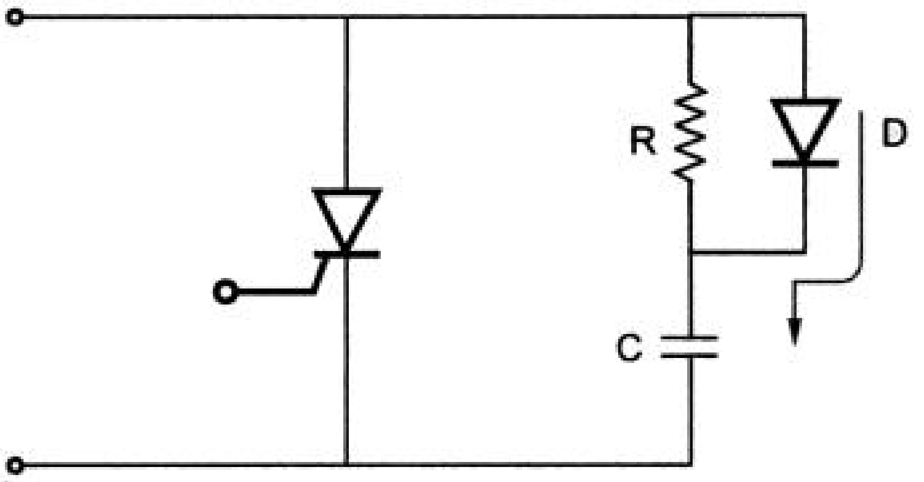


Fig. 2.10.2 Snubber is used for $\frac{dv}{dt}$ protection

thyristor is protected against voltage transients. The RC snubber circuit is very commonly used for protection of thyristors against transient voltages (high frequency voltage spikes).

$\frac{dv}{dt}$ also generates large voltage transients. These rapid voltage variations can also be suppressed by snubber circuit. The capacitor acts as a short for these $\frac{dv}{dt}$ variations. The snubber can be made more effective by connecting a diode across the resistance as shown in Fig. 2.10.2.

In case of voltage transient, the current flows through diode and capacitor. The capacitor acts as a short for the voltage transient. Thus it is suppressed. When thyristor turns-on, the capacitor discharges through resistance R. The R, C and diode snubber is more commonly used because it is very effective for $\frac{dv}{dt}$ and other voltage transients.

Design of snubber

The value of capacitor is given as,

$$C = \frac{1}{2L}\left(\frac{0.564\, V_m}{\frac{dv}{dt}}\right)^2 \qquad \text{... (2.10.1)}$$

Here V_m is the peak value of supply voltage

$\frac{dv}{dt}$ is the permissible $\frac{dv}{dt}$.

L is the source inductance.

And resistance is given as,

$$R = 2\sigma\sqrt{\frac{L}{C}} \qquad \text{... (2.10.2)}$$

Here σ is the damping factor. It's value is normally taken as 0.65.

Example 2.10.1 : *Calculate the required parameters for snubber circuit to provide $\frac{dv}{dt}$ protection to a SCR used in single phase bridge converter. The SCR has a maximum $\frac{dv}{dt}$ capability of 60 V / μsec. The input line to line voltage has a peak value of 425 volts and the source inductance is 0.2 mH.*

Solution : Given :

$$\frac{dv}{dt} = 60\ V\,/\,\mu sec$$

$$L = 0.2\ \text{mH}$$

$$V_m = 425\ \text{V}$$

From equation (2.10.1),

$$C = \frac{1}{2L}\left(\frac{0.564\ V_m}{\frac{dv}{dt}}\right)^2 = \frac{1}{2\times 0.2\times 10^{-3}}\left(\frac{0.564\times 425}{60}\times 10^{-6}\right)^2$$

$$= 0.04\ \mu F$$

In the above equation observe that we have multiplied numerator by 10^{-6} inside the brackets. It comes from 60 $V\,/\,\mu s$, i.e. $\frac{60}{1\times 10^{-6}}$ to be substituted in equation for C.

Let the damping factor be $\sigma = 0.65$. From equation 2.10.2,

$$R = 2\,\sigma\sqrt{\frac{L}{C}} = 2\times 0.65\sqrt{\frac{0.2\times 10^{-3}}{0.04\times 10^{-6}}}$$

$$R = 92\ \Omega$$

Example 2.10.2 : *For the circuit shown in Fig. 2.10.3, the thyristor is operated at 2 kHz. The required* $\frac{dv}{dt}$ *is 100 V/μs. The discharge current is to be limited to 100 A. Determine*

i) Values of R_s *and* C_s

ii) Snubber loss

iii) Power rating of R_s

Load and stray inductances are negligible.

[Nov.-2007, 10 Marks]

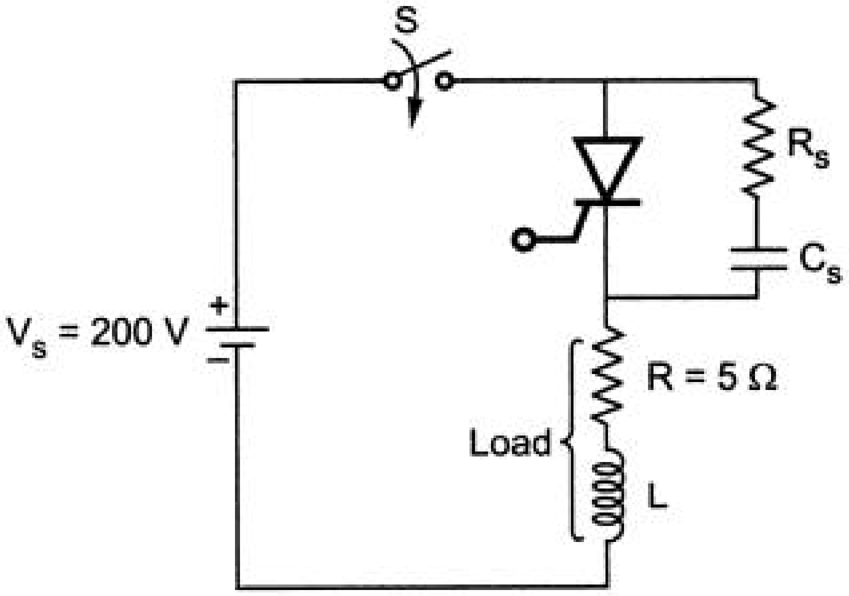


Fig. 2.10.3 Circuit of example 2.10.2

Solution : Given :

Load resistance, R = 5 Ω

Frequency, f = 2 kHz

V_s = 200 V

$$\frac{dv}{dt} = 100\ \text{V}/\mu\text{s}$$

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

$$\text{L} = 0$$

i) To obtain values of R_s and C_s

R_s limits the discharge current through T_1. From Fig. 2.10.3, T_1 - R_s - C_s forms a loop when T_1 turns-on. Prior to turn-on of T_1, C_s charges to 200 V. Fig. 2.10.4 shows this situation.

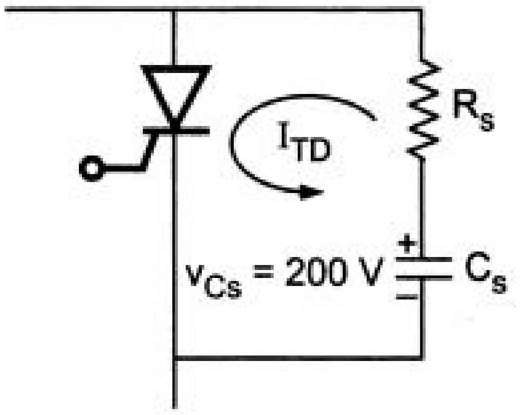


Fig. 2.10.4 Path of I_{TD}

From this figure we can write,

$$v_{Cs} = R_s I_{TD}$$

$$\therefore \qquad R_s = \frac{v_{Cs}}{I_{TD}} = \frac{V_s}{I_{TD}} = \frac{200}{100} = 2\ \Omega$$

The charging current of C_s can be expressed by KVL to V_s - R_s - C_s - R - L loop as,

$$V_s = R_s i_C(t) + \frac{1}{C_s}\int i_C(t)dt + v_C(t=0) + R\,i_C(t)$$

On solving above equation,

$$i_C(t) = \frac{V_s}{R_s + R}\, e^{-\frac{t}{\tau}}, \quad \text{Here } \tau = (R_s + R)C_s \text{ and } v_C(t=0) = 0.$$

Hence the voltage across the SCR can be expressed as,

$$v_{T_1}(t) = V_s - R\,i_C(t)$$

$$= V_s - \frac{RV_s}{R_s + R}\, e^{-\frac{t}{\tau}}$$

At t = 0, $$v_{T_1}(0) = V_s - \frac{RV_s}{R_s + R}\ \frac{R_s V_s}{R_s + R}$$

and at t = τ, $$v_{T_1}(\tau) = V_s - \frac{RV_s}{R_s + R}\, e^{-1} = V_s - \frac{0.3678\,RV_s}{R_s + R}$$

$$= \frac{R_s V_s + 0.6321\,RV_s}{R_s + R}$$

Now $\frac{dv}{dt}$ can be expressed as,

$$\frac{dv}{dt} = \frac{v_{T_1}(\tau)-v_{T_1}(0)}{\tau} = \frac{\frac{R_sV_s+0.6321\,RV_s}{R_s+R}-\frac{R_sV_s}{R_s+R}}{(R_s+R)C_s}$$

$$= \frac{0.632\,RV_s}{(R_s+R)^2C_s}$$

$$\therefore \qquad C_s = \frac{0.632\,RV_s}{\frac{dv}{dt}(R_s+R)^2} = \frac{0.632\times5\times200}{\frac{100}{1\times10^{-6}}(2+5)^2} = 0.1289\ \mu\text{F}$$

ii) To obtain snubber loss

The power stored in C_s is dissipated in R_s. Hence it is snubber loss

$$P_s = \frac{1}{2}C_sV_s^2f_s$$

$$= \frac{1}{2}\times0.1289\times10^{-6}\times200^2\times2\times10^3$$

$$= 5.2\ \text{W}$$

iii) To obtain power rating of R_s

The power stored in C_s is dissipated in R_s. It is 5.2 W. Hence power rating of R_s will be 5.2 W.

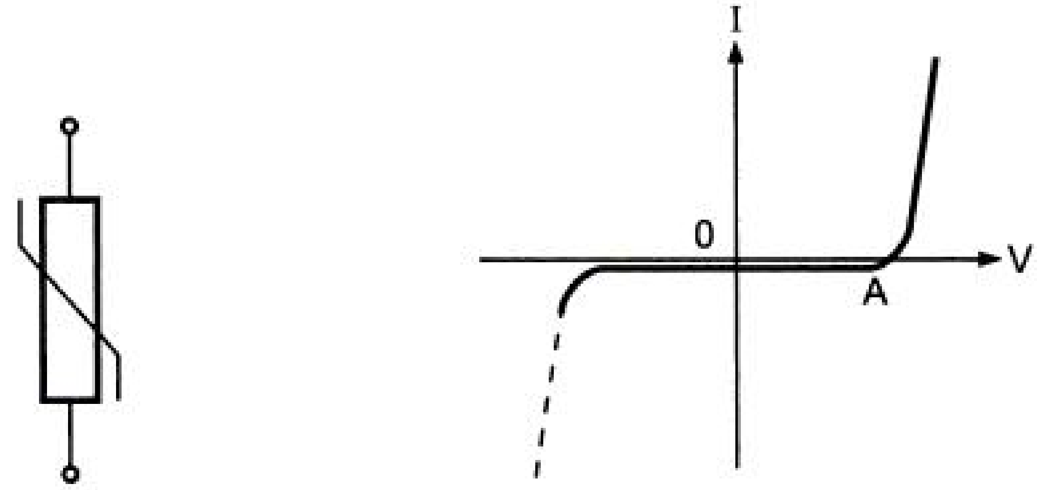
2.10.2 Metal Oxide Varistors (MOVs)

Answer following question after reading this topic

1. *Explain the use of Metal Oxide Varistors (MOV) for protection against overvoltages and voltage transients ?*

Most likely and **Important** Question

High $dv/_{dt}$ and transient over voltages can also be suppressed with the help of Metal Oxide Varistors (MOV). MOVs are also called varistors or nonlinear voltage dependent resistor. MOVs consists of metal oxide particles, which are separated by an oxide film or insulation. When the applied voltage is less than specific value, then MOV offers high impedence. When the applied voltage is more than specific value, the oxide film becomes conductive and current starts flowing. Thus the voltage spike is suppressed by the MOV. Fig. 2.10.5 shows the characteristics and symbol of MOV.



(a) Symbol of MOV **(b) V-I characteristics of MOV**

Fig. 2.10.5

In the Fig. 2.10.5 observe that voltage increases above point 'A', the MOV starts conducting heavily.

The current and voltage of MOV are related as,

$$I = KV^{\alpha}$$

Here K is the device constant and 'α' lies in the range of 30 to 40.

Normally MOVs are connected across the supply lines over which the voltage transients are to be suppressed.

2.10.3 Improving *dv/dt* Rating with the Help of Cathode Short

Answer following question after reading this topic.

1. *Explain the shorted emitter structure to improve the dv/dt rating of SCRs.* **Marks[4], May-2004, 2005**

Most likely and **asked in** previous University Exam

The Fig. 2.10.6 shows the modification in the structure of SCR to improve dv/dt capability.

- The cathode metallization is overlapped over the gate region, i.e. p2 region. It is called cathode short.
- The SCR turns on by dv/dt mainly due to lateral flow of current in the p-type region. This lateral current is intercepted in large amount mainly by the cathode

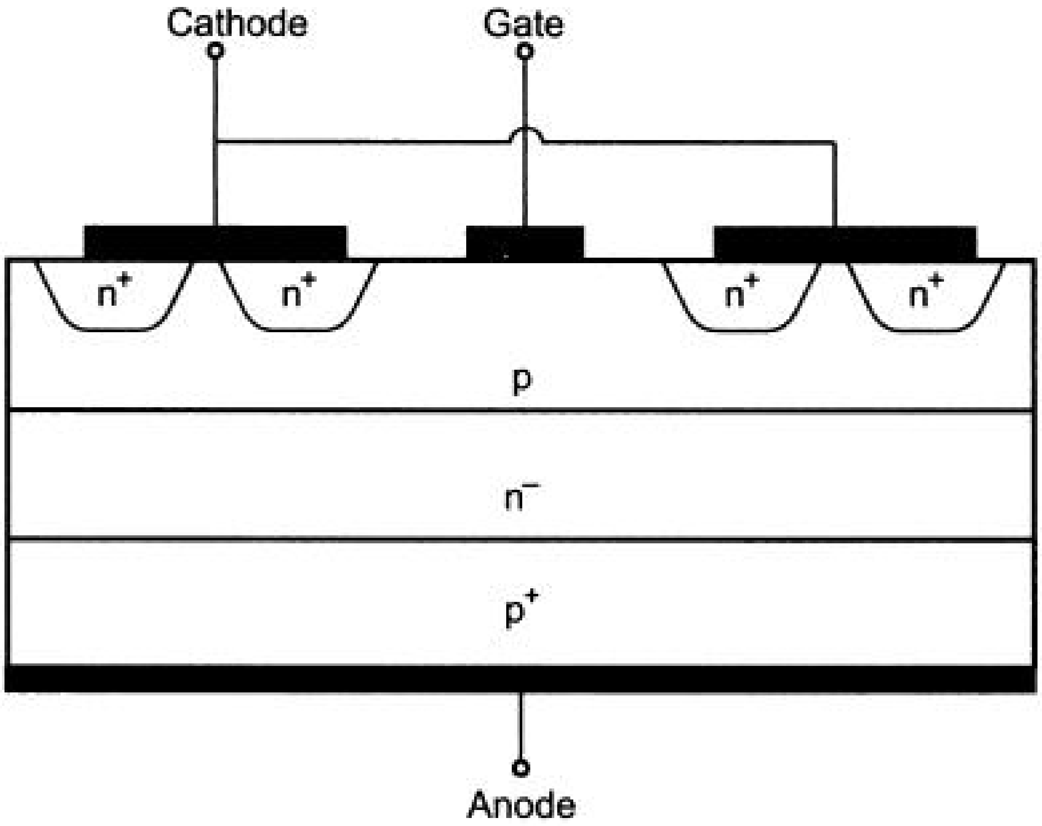


Fig. 2.10.6 Shorted emitter structure

shorts. It does not flow across the gate-cathode junction but flows directly to cathode.

- This intercept of lateral current improves dv/dt capability of the SCR.

Unsolved Example

1. *Calculate the required parameters for a snubber circuit to provide reliable* $\frac{dv}{dt}$ *protection to a SCR used in the single phase fully controlled bridge. The SCR has a maximum* $\frac{dv}{dt}$ *capability of 40 V/μs. The input line to line voltage has a peak value of 325V and the source inductance is 0.1 mH.*
[Ans. : R = 41 Ω and C = 0.1 μF]

2.11 $^{di}/_{dt}$ Protection with the Help of Inductor (Turn-on Snubber)

Answer following questions after reading this topic.

1. *Write short notes on : Turn-on and turn-off snubbers.*
Marks[8], May-2002; Marks[6], May-2004, 2005
2. *How the devices are protected against di/dt ?*

Most likely and **asked in** previous University Exam

We know that at the time of turn-on, anode current increases rapidly. This rapid variation of anode current doesnot spread across the junction area of the thyristor. This creates the local hot-spots in the junction and increases the junction temperature. If the junction temperature exceeds permissible value, then the thyristor is damaged. The rapid variations of the thyristor current are also called $\frac{di}{dt}$. Every thyristor has maximum permissible value of $\frac{di}{dt}$.

The thyristor can be protected from excessive $\frac{di}{dt}$ by using an inductor in series as shown in Fig. 2.11.1. The inductance opposes for rapid current variations $\left(\frac{di}{dt}\right)$. Whenever there is rapid current variation, the inductor smooths it and protects the thyristor from damage.

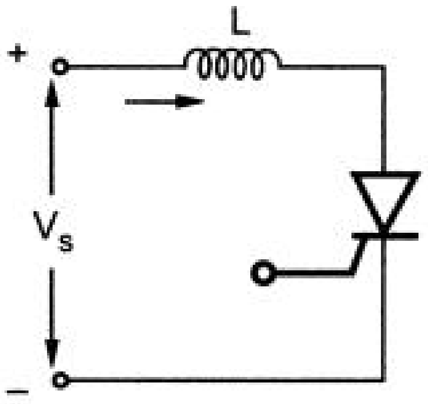


Fig. 2.11.1 An inductance in series with the thyristor provides protection against $\frac{di}{dt}$

The value of inductance can be calculated as,

$$L \geq \frac{V_s}{\frac{di}{dt}} \qquad \text{... (2.11.1)}$$

Here $\frac{di}{dt}$ is the maximum value and L is the series inductance including stray inductance.

Example 2.11.1 : *Design the snubber circuit elements R_s and C_s connected across the SCR given that $\frac{dv}{dt}$(max) = 180 V/ μ s and $\frac{di}{dt}$(max) = 45 A/ μ s. An inductance L = 0.1 H and a resistance $R << R_s$ are in series with the SCR with a 300 V DC applied to the circuit.*

Solution : The value of $\frac{di}{dt}$ is given. Hence let us determine the required value of series inductance. From equation (2.11.1), it is given as,

$$L \geq \frac{V_s}{\frac{di}{dt}}$$

Here V_s = 300 V and $\frac{di}{dt}$ = 45A/μs. putting these values in above equation,

$$L \geq \frac{300}{45/10^{-6}}$$

$$\geq \frac{300}{45} \times 10^{-6}$$

$$\geq 6.667 \times 10^{-6} H$$

This inductance includes stray inductance also. There is an inductance of 0.1 H (given) in series with the SCR. Since this is more than 6.667×10^{-6} H, there is no need to connect extra inductance. Thus $\frac{di}{dt}$ protection is obtained through existing 0.1 H inductance. The capacitance of the snubber is given by equation (2.10.1). as,

$$C = \frac{1}{2L}\left[\frac{0.564\,V_m}{\frac{dv}{dt}}\right]^2$$

Here V_m = 300 V, $\frac{dv}{dt} = 180$ V/μs and L = 0.1 H. Hence above equation becomes,

$$C = \frac{1}{2 \times 0.1}\left[\frac{0.564 \times 300}{180/10^{-6}}\right]^2$$

$$= \frac{1}{2 \times 0.1}\left[\frac{0.564 \times 300}{180} \times 10^{-6}\right]^2$$

$$= 4.418 \times 10^{-12} \text{ F or } 4.418 \text{ pF}$$

The resistance of the snubber is given by equation (2.10.2) as,

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

Here $\sigma = 0.65$ (damping factor) and putting values of L and C calculated earlier,

$$R = 2 \times 0.65\sqrt{\frac{0.1}{4.418 \times 10^{-12}}}$$

$$= 195.58\ k\Omega$$

It is mentioned in the example that series resistance is very very small than snubber resistance. Hence it can be neglected. Fig. 2.11.2 shows the snubber circuit.

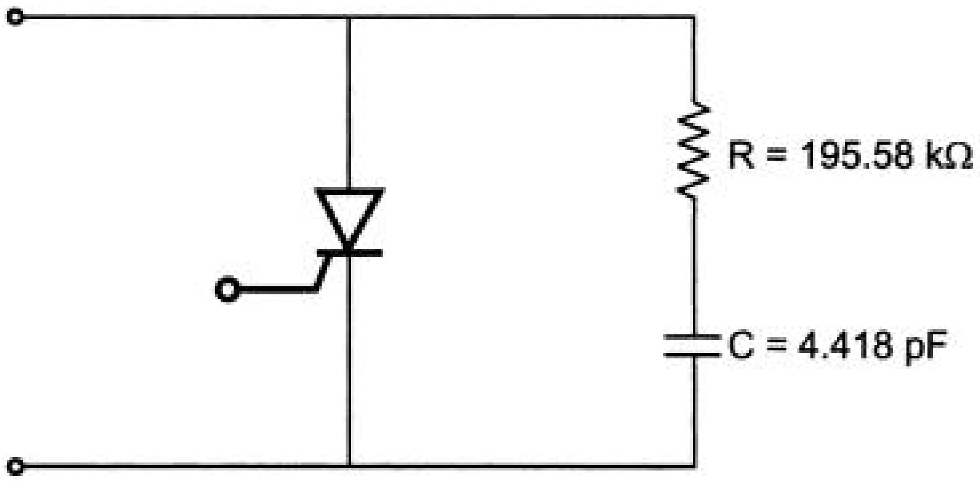


Fig. 2.11.2 Snubber circuit of example 2.11.1

Example 2.11.2 : *The capacitance of the reverse biased junction J_2 in a thyristor is 25 pF and can be assumed to be independent of the off-state voltage. The limiting value of the charging to turn-on the thyristor is 16 mA. Determine the critical value of* $\frac{dv}{dt}$.

Solution : The current through the junction J_2 capacitance is given as,

$$i = \frac{dQ}{dt}$$

$$= \frac{d}{dt}(C_{j_2} V_{j_2})$$

Here C_{j_2} is capacitance of J_2 and

V_{j_2} is voltage across J_2

$$\therefore \quad i = V_{j_2} \frac{dC_{j_2}}{dt} + C_{j_2} \frac{dV_{j_2}}{dt} \quad \text{... (2.11.2)}$$

The capacitance is independent of the off-state voltage. Hence $\frac{dC_{j_2}}{dt} = 0$. Hence above equation will be,

$$i = C_{j_2} \frac{dV_{j_2}}{dt}$$

Here V_{j_2} is the voltage across J_2. This voltage is nearly equal to applied voltage V. Hence,

$$i = C_{j_2} \frac{dv}{dt} \quad \text{... (2.11.3)}$$

$$\therefore \quad \frac{dv}{dt} = \frac{i}{C_{j_2}}$$

Here i = 16 mA is the limiting value of charging current and

C_{j_2} = 25 pF. Therefore above equation becomes,

$$\frac{dv}{dt} = \frac{16\times 10^{-3}}{25\times 10^{-12}}$$

$$= 6.4\times 10^{8} \text{ V/sec} = 640 \text{ V/}\mu\text{s}$$

This is the critical value of $\frac{dv}{dt}$.

Example 2.11.3 : *Calculate the required parameters for snubber circuit to provide* $\frac{dv}{dt}$ *protection to a SCR used in a single phase bridge converter. The SCR has a maximum* $\frac{dv}{dt}$ *capability of 60 V / μs. The input line to line voltage has a peak value of 425 volts and the source inductance is 0.2 mH.*

Solution : Given :

$$\frac{dv}{dt} = 60 \text{ V/}\mu\text{s}$$

$$V_m = 425 \text{ V}$$

$$\text{L} = 0.2 \text{ mH}$$

We have to calculate the values of R and C for the snubber. From equation (2.10.1), capacitor is given as,

$$\text{C} = \frac{1}{2L}\left[\frac{0.564V_m}{\frac{dv}{dt}}\right]^2$$

Putting the values in above equation,

$$\text{C} = \frac{1}{2\times 0.2\times 10^{-3}}\left[\frac{0.564\times 4.25}{60\times 10^{6}}\right]^2 = 0.04 \ \mu F$$

And the value of resistance is given by equation (2.10.2) as,

$$\text{R} = 2\sigma\sqrt{\frac{L}{C}}$$

Value of σ is normally taken as 0.65. Putting for L and C,

$$\text{R} = 2\times 0.65\sqrt{\frac{0.2\times 10^{-3}}{0.04\times 10^{-6}}} = 92 \ \Omega$$

Thus we obtained the values of snubber components as,

$$R = 92\,\Omega \quad \text{and} \quad C = 0.04\ \mu F$$

Example 2.11.4 : *The junction capacitance of the thyristor shown in Fig. 2.11.3 is 15 pF and is assumed to be independent of the off-state voltage. The value of charging current to turn-on the device is 5 mA and the critical value of* $\frac{dv}{dt} = 200\ V/\mu s$. *Determine the value of* C_s *so that the thyristor will not be turned on due to* $\frac{dv}{dt}$.

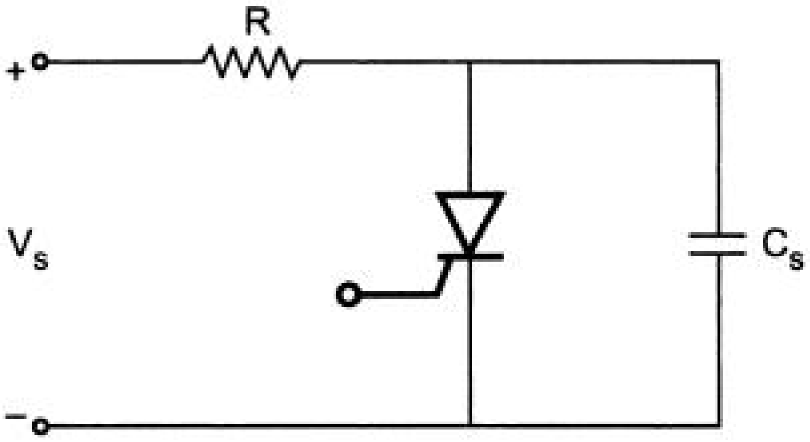


Fig. 2.11.3 Circuit of example 2.11.4

Solution : Here the junction capacitance of the thyristor and external capacitance (C_s) both will absorb the effect of $\frac{dv}{dt}$. These two capacitors will be in parallel. Hence charging current can be given as (using equation 2.11.3),

$$i = (C_s + C_j)\frac{dv}{dt}$$

The charging current should not exceed 5 mA. Hence above equation becomes,

$$5\text{ mA} \le (C_s + C_j)\frac{dv}{dt}$$

$$\text{or } C_s + C_j \ge \frac{5\ mA}{\frac{dv}{dt}}$$

$$\ge \frac{5 \times 10^{-3}}{200 \times 10^{6}}$$

$$\ge 25\ pF$$

Thus the total capacitance should be more than 25 pF. Out of this, $C_j = 15$ pF. i.e.,

$$C_s + 15\ pF \ge 25\ pF$$

$$\therefore \quad C_s \ge 10\,pF$$

Thus external capacitance of at least 10 pF is required to avoid false triggering due to $\frac{dv}{dt}$.

Example 2.11.5 : *Design the values of* $\frac{di}{dt}$ *inductor and RC snubber components for an SCR working in a 230 V system. Given* $\frac{di}{dt}$ *rating is 90 A/ μs and* $\frac{dv}{dt}$ *rating is 200 V/ μs. Effective series resistance is 1.5 Ω. Take damping factor is as 0.6.*

Solution : The given data is,

$$\text{Maximum voltage, } V_s = 230 \text{ V}$$

$$\frac{di}{dt} = 90\ A/\mu s$$

$$\frac{dv}{dt} = 200\ A/\mu s$$

$$\text{Series resistance } \quad R_s = 1.5\ \Omega$$

$$\text{Damping factor } \quad \sigma = 0.6$$

The circuit diagram will look like the one shown below

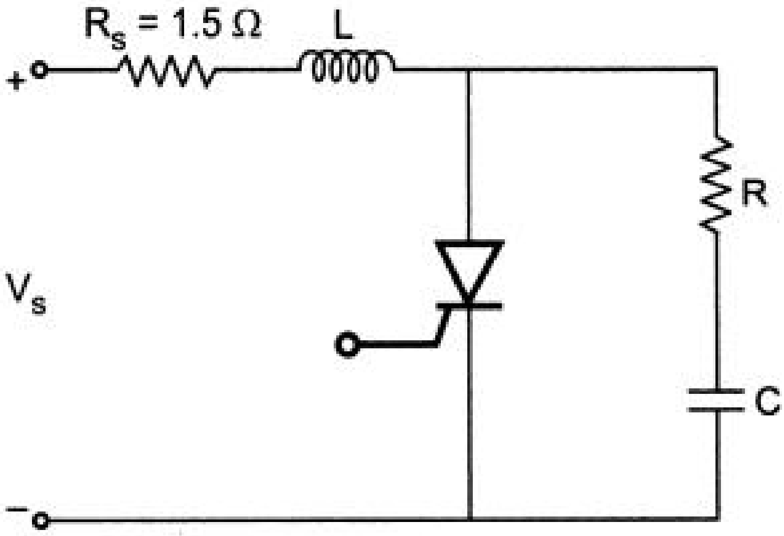


Fig. 2.11.4 Circuit of example 2.11.5

Let us calculate value of inductance for $\frac{di}{dt}$ protection. From equation 2.11.1 it is given as,

$$L \geq \frac{V_s}{\frac{di}{dt}}$$

$$\geq \frac{230}{90 \times 10^6}$$

$$= 2.556 \times 10^{-6} \text{ H}$$

$$\therefore \qquad L = 2.556 \times 10^{-6} \text{ H} = 2.556 \ \mu\text{H}$$

Since there is no stray inductance given, this value of inductance must be connected for $\frac{di}{dt}$ protection.

Now the value of capacitance C can be calculated from equation (2.10.1) as,

$$C = \frac{1}{2L}\left[\frac{0.564\, V_m}{\frac{dv}{dt}}\right]^2$$

Putting value in above equation,

$$C = \frac{1}{2 \times 2.556 \times 10^{-6}}\left[\frac{0.564 \times 230}{200 \times 10^{6}}\right]^2$$

$$= 0.08229 \ \mu F$$

In Fig. 2.11.4 observe that the resistance R_s and snubber resistance R are in series. These two resistors affect the charging rate of snubber capacitor. Hence, equation (2.11.2). must be written as,

$$(R_s + R) = 2\sigma\sqrt{\frac{L}{C}}$$

Putting values in above equation,

$$(1.5 + R) = 2 \times 0.6\sqrt{\frac{2.556 \times 10^{-6}}{0.08229 \times 10^{-6}}}$$

$$\therefore \qquad R = 5.18 \ \Omega$$

Thus the snubber components are,

$$R = 5.18 \ \Omega, \quad C = 0.08229 \ \mu F \quad \text{and} \quad L = 2.556 \ \mu H$$

➠ **Example 2.11.6 :** *A SCR circuit operates from 300 V DC supply, has series inductance of 4 μH. A resistance of 4 Ω and capacitance of 0.2 μF is connected across the SCR. Calculate the safe* $\frac{dv}{dt}$ *and* $\frac{di}{dt}$ *ratings of SCR.*

Solution : Here the given data is,

$$V_m = 300 \text{ V}$$

$$L = 4 \ \mu H$$

$$R = 4 \ \Omega$$

$$C = 0.2 \ \mu F$$

The value of series inductance for $\frac{di}{dt}$ protection is given by equation (2.11.1) as,

$$L \geq \frac{V_s}{\frac{di}{dt}}$$

Here $V_s = V_m = 300$ and L = 4 μH. Hence above equation becomes,

$$4\ \mu H \geq \frac{300}{\frac{di}{dt}}$$

$$\therefore \quad \frac{di}{dt} = \frac{300}{4 \times 10^{-6}} = 75\ \text{A}/\mu\text{s}$$

The value of snubber capacitor is given by equation (2.10.1) as,

$$C = \frac{1}{2L}\left[\frac{0.564\ V_m}{\frac{dv}{dt}}\right]^2$$

Putting values in above equation,

$$0.2 \times 10^{-6} = \frac{1}{2 \times 4 \times 10^{-6}}\left[\frac{0.564 \times 300}{\frac{dv}{dt}}\right]^2$$

$$\therefore \quad \frac{dv}{dt} = 133.76\ \text{V}/\mu\text{s}$$

➠ **Example 2.11.7 :** *An SCR can be triggered with a* $\frac{dv}{dt}$ *of 220 V/ µs. If the charging current flowing through the junction is 5 mA, calculate the equivalent capacitance of depletion layer.*

Solution : Equation (2.11.3) gives the charging current as,

$$i = C_{j2}\frac{dv}{dt}$$

Here i is the charging current and C_{j2} is the equivalent capacitance of depletion layer. Putting values in above equation,

$$5 \times 10^{-3} = C_{j2} \times 220 \times 10^{6}$$

$$\therefore \quad C_{j2} = 22\ \text{pF}$$

➠ **Example 2.11.8 :** *A SCR has a* $\frac{di}{dt}$ *= 120 A/μs and a* $\frac{dv}{dt}$ *of 300 V/μs. It operates on a 250 V DC source with a load resistance of 10 Ω. Find the suitable values for the components of the snubber circuit.*

Solution : The given data is,

$$\frac{di}{dt} = 120 \text{ A}/\mu s$$

$$\frac{dv}{dt} = 300 \text{ V}/\mu s$$

$$V_m = 250 \text{ V}$$

$$R_L = 10\,\Omega$$

The value of inductance for $\frac{di}{dt}$ protection is given by equation (2.11.1) as,

$$L \geq \frac{V_m}{\frac{di}{dt}}$$

$$\therefore \quad L \geq \frac{250}{120 \times 10^6}$$

$$\therefore \quad L \geq 2.08\ \mu H$$

The snubber circuit capacitor is given by equation (2.10.1) as,

$$C = \frac{1}{2L}\left[\frac{0.564\,V_m}{\frac{dv}{dt}}\right]^2$$

Putting values in above equation,

$$C = \frac{1}{2 \times 2.08 \times 10^{-6}}\left[\frac{0.564 \times 250}{300 \times 10^6}\right]^2$$

$$= 0.053\ \mu F$$

Here note that the load resistance is $R_L = 10\Omega$. This resistance appears in series with the snubber resistance. Hence the snubber resistance given by equation (2.10.2) can be given as,

$$R + R_L = 2\sigma\sqrt{\frac{L}{C}}$$

Let the damping factor σ = 0.65. Putting other values in above equation,

$$R+10 = 2\times 0.65\sqrt{\frac{2.08\times 10^{-6}}{0.053\times 10^{-6}}}$$

$$\therefore \quad R = -1.856\ \Omega$$

The negative snubber resistance indicates that the load resistance is more than sufficient for snubber action. There is no need to connect additional snubber resistance.

➠ **Example 2.11.9 :** *Calculate the values of snubber components R and C in Fig. 2.11.5 to protect SCR from reapplied dv/dt, if dv/dt rating of SCR is 100 V/ μsec.*

[May-2001, 5 Marks; Dec.-2008, 6 Marks]

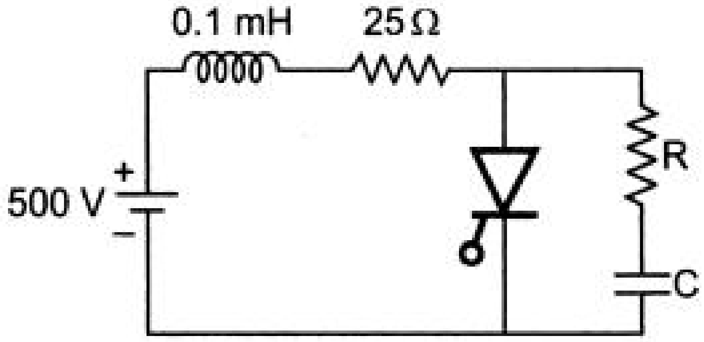


Fig. 2.11.5

Solution : Given :

$$L = 0.1 \text{ mH}$$

$$V_m = 500 \text{ V}$$

$$\frac{dv}{dt} = 100\ V/\mu\text{sec} = \frac{100}{10^{-6}}\ V/\mu\text{sec}$$

$$C = \frac{1}{2L}\left[\frac{0.564\,V_m}{dv/dt}\right]^2$$

$$= \frac{1}{2\times 0.1\times 10^{-3}}\left[\frac{0.564\times 500}{100}\times 10^{-6}\right]^2$$

$$= 0.04\ \mu\text{F}$$

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

$$= 2\times 0.65\sqrt{\frac{0.1\times 10^{-3}}{0.04\times 10^{-6}}} \quad \text{assuming } \sigma = 0.65.$$

$$= 65\ \Omega$$

Out of this, 25 Ω is already present in the circuit. Hence $R = 64 - 25 = 40\ \Omega$.