Snubber Circuits

Protection of switching devices and circuits: Switching devices and circuit components may fail due to the following reasons.

1. Overheating – thermal failure
2. Overcurrent
3. Overvoltage – usually happens during turn-off
4. Excessive $\frac{di}{dt}$
5. Excessive $\frac{dv}{dt}$
6. Switching loss –excessive switching loss is a major contributing factor of overheating.

Power electronic circuits and their switching devices and components can be protected from overcurrent by placing fuses at suitable locations. Heat sinks, fins and fans are used to take the excess heat away from switching devices and other components. Snubber circuits are required to limit $\frac{di}{dt}$, $\frac{dv}{dt}$ and overvoltage during turn-on and turn-off. Some typical snubber circuits are described below.

RC Snubber Circuits

RC snubber circuits are normally connected across a switching device to limit the $\frac{dv}{dt}$. An RC snubber circuit can be polarized or unpolarized. A forward-polarized RC snubber circuit shown in Figure 1 is appropriate when a thyristor or a transistor is connected with an anti-parallel diode. R limits the forward $\frac{dv}{dt}$ and R_1 limits the discharge current of the capacitor when Q_1 is turned on.

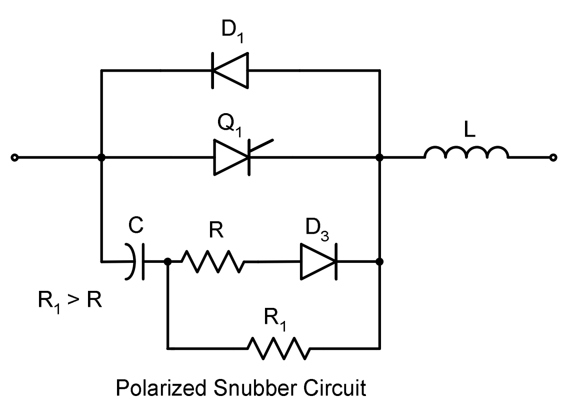

Figure 1. A forward polarized snubber circuit.

A reverse polarized snubber circuit as shown in Figure 2 is used to limit the reverse $\frac{dv}{dt}$. R_1 limits the discharge current of the capacitor.

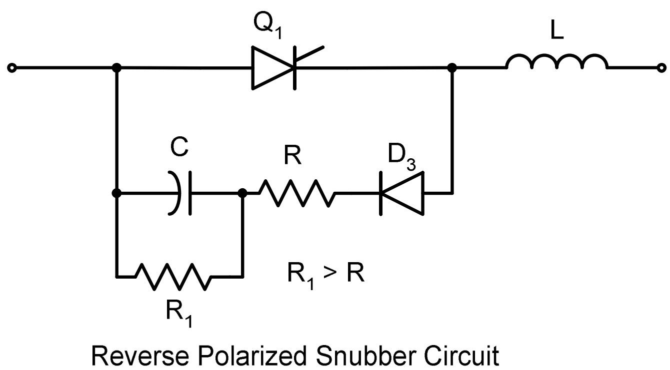

Figure 2. A reverse polarized snubber circuit.

An unpolarized snubber circuit as shown in Figure 3 should be used when a pair of switching devices is connected in anti-parallel.

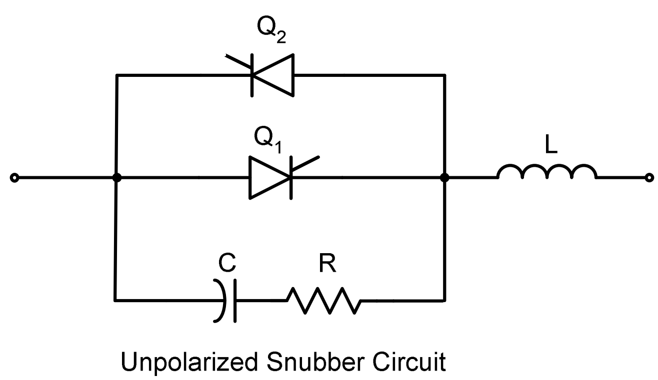

Figure 3. An unpolarized snubber circuit.

Diode Snubbers

Snubbers are needed in diode circuits to minimize overvoltages. Overvoltages usually occur during turn-off process. Figure 4 shows a diode with a snubber circuit.

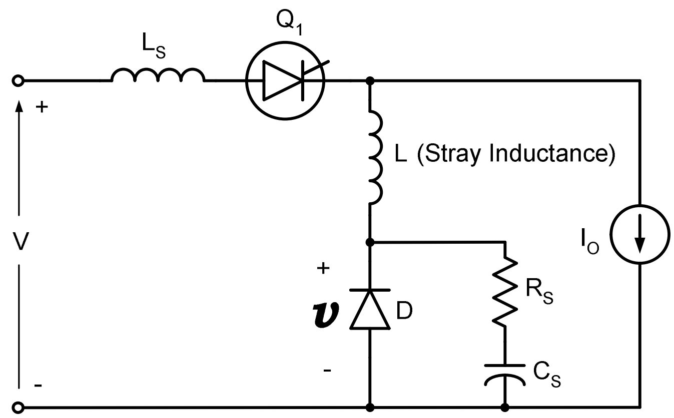

Figure 4. Diode, D with its snubber circuit

The voltage, v across the diode (D) during turn-off can be expressed as: $v = V - L\frac{di}{dt}$. The voltage rises above V due to the fact that during turn-off of **D** the current through the stray inductance is decreasing and hence making the $\frac{di}{dt}$ negative.

BJT Snubbers

A Bipolar junction transistor (BJT) experiences high stresses at turn-on and turn-off when both its voltage and current are high simultaneously, thus causing a high instantaneous power dissipation. Transistors require turn-off, turn-on and overvoltage snubbers.

Turn-off snubbers

A Turn-off snubber as shown in Figure 5 is used to provide a zero voltage across the transistor while the current turns off. At turn-off in the presence of this snubber, the transistor current i_C decreases with a constant $\frac{di}{dt}$ and $(I_O - i_C)$ flows into the capacitor through the snubber diode D_S. Figure 6 shows the voltage rise across the snubber capacitor C_S.

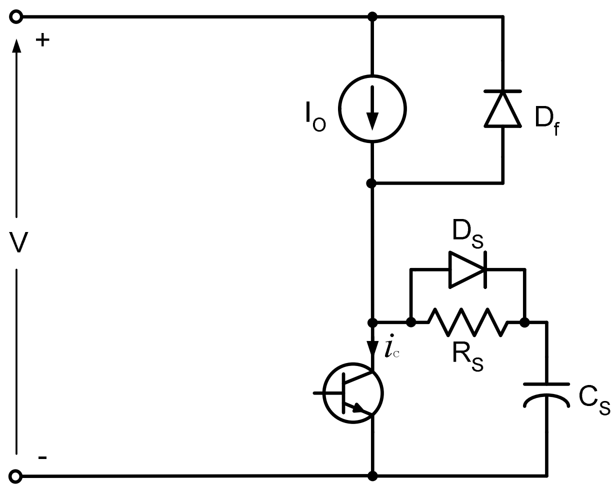

Figure 5. A turn-off snubber for a transistor.

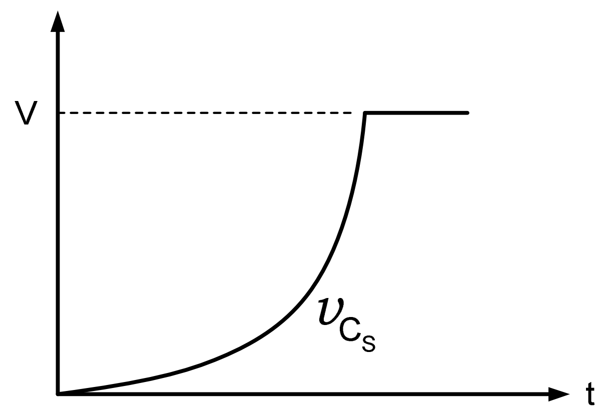

Figure 6. Voltage across the snubber capacitor.

Turn-on snubber

A turn-on snubber as shown in Figure 7 is used to reduce voltage across the BJT while the current builds up. The reduction in the voltage across the transistor during turn-on is due to the voltage drop across the snubber inductance L_S. When the transistor turns off, the energy stored in the snubber inductance, $\mathbf{0.5}\boldsymbol{L_S I_O^2}$ will be dissipated in the snubber resistance R_S.

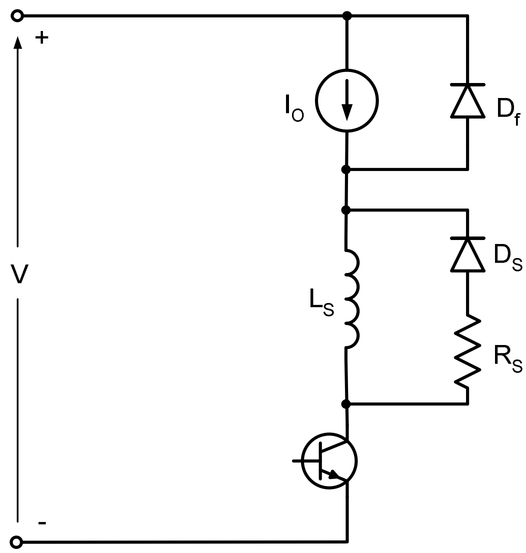

Figure 7. A turn-on snubber.

Overvoltage snubber

The overvoltage at turn-off due to stray inductance can be minimized by means of the overvoltage snubber circuit shown in Figure 8. At turn-off, assuming the BJT current fall time to be small, the current through the stray inductance, L_σ is essentially I_O and the output current then free-wheels through the free-wheeling diode.

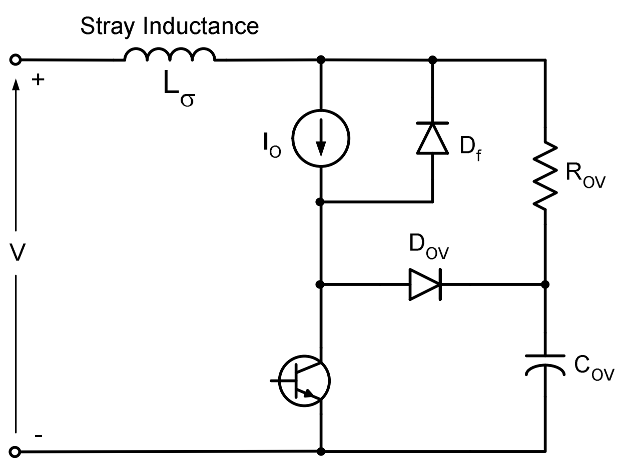

Figure 8. An overvoltage snubber.

When the load current free-wheels through D_f, the equivalent circuit is (Figure 9):

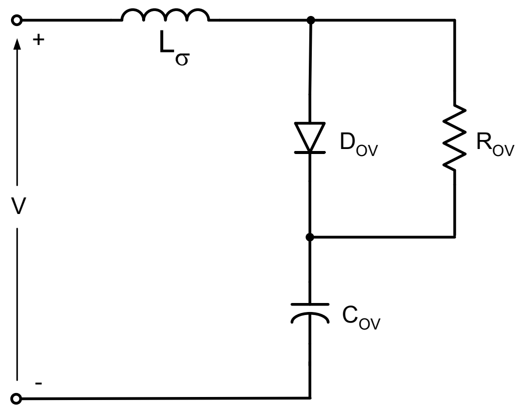

Figure 9. Equivalent overvoltage snubber during free-wheeling.

During the free-wheeling of D_f, the energy stored in the stray inductance gets transferred to the overvoltage capacitor through the diode D_{OV} and the overvoltage ΔV_{CE} across the transistor can be obtained by

$$\frac{C_{OV}\Delta V_{CE,\max}^2}{2} = \frac{L_\sigma I_O^2}{2} \quad \text{.....................................} \; (1)$$

Equation (1) shows that a large value of C_{OV} will minimize the overvoltage $\Delta V_{CE,\max}^2$. Once the current through L_σ has decreased to zero, it can reverse its direction due to the resistor R_{OV}, and the overvoltage on the capacitor decreases to V through the resistor R_{OV}.

Power MOSFETS

A small RC turn-off snubber as shown in Figure 10 can be used to prevent voltage spikes and voltage oscillations across a MOSFET during device turn-off. The large peak current handling capability of the MOSFET and the fact that its switching speed can be easily controlled by controlling the gate current eliminates the need for a turn-on snubber in most cases.

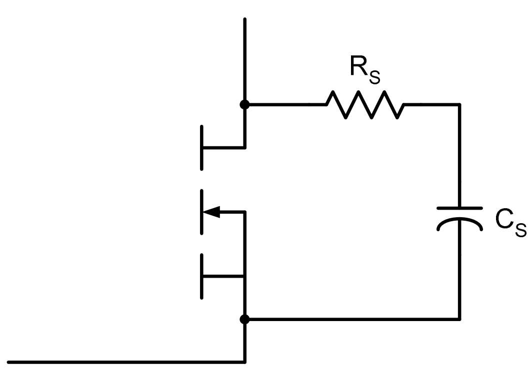

Figure 10. A turn-off snubber for a MOSFET.

Thyristors

Thyristors need $\frac{di}{dt}$ protection during turn-on and $\frac{dv}{dt}$ protection during turn-off. Figure 11 shows a thyristor circuit with its turn-on and turn-off snubbers. Typical values for C are between 0.01 to 1 μF, for R between 10 to 1000 Ω and for L between 50 to 100 μH.

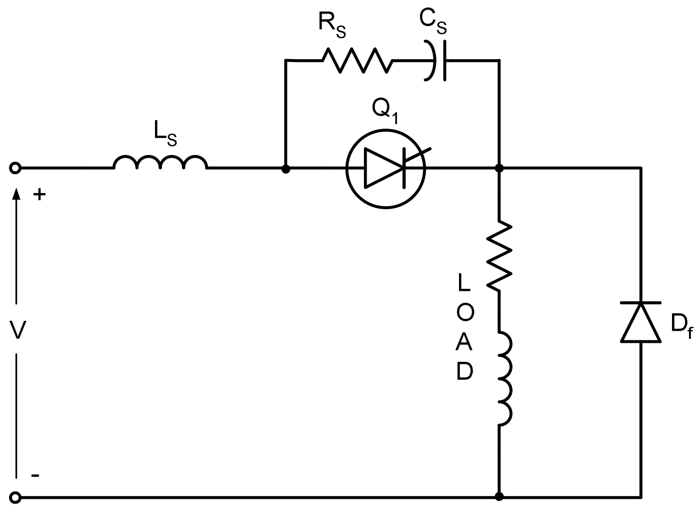

Figure 11. A thyristor circuit with turn-on and turn-off snubbers.

Gate-Turn-Off Thyristors

A gate-turn-off thyristor needs $\frac{di}{dt}$ and $\frac{dv}{dt}$ protections. During turn-off, the anode current falls rapidly. The current $(I_O - i_A)$ flows through the snubber capacitor C_S which is fairly large in GTO applications. Usually the peak current conduction capability in a GTO is much larger than in a BJT.

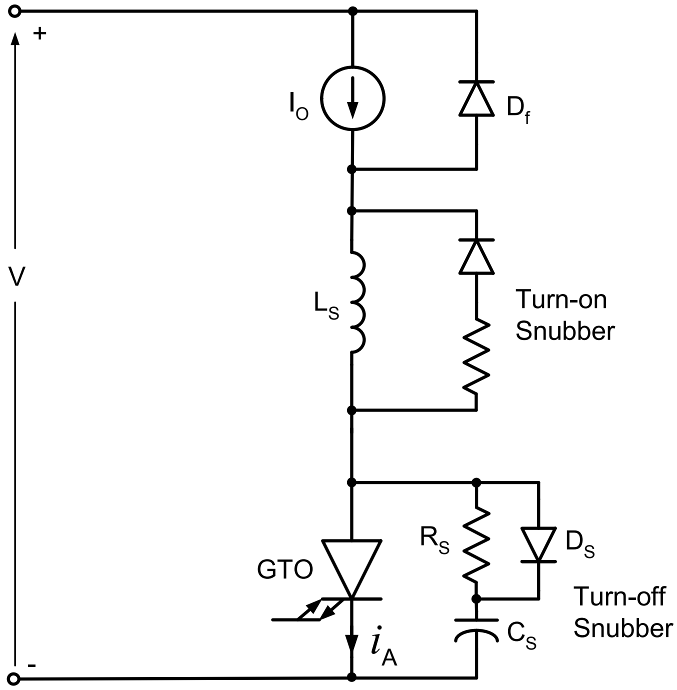

Figure 12. A GTO with its snubbers.

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