** Thermal runaway: collector current causes an increase in temperature which increases the conductivity of the bipolar transistor. More current then flows, further increasing the device temperature. This endless increasing of temperature results in thermal runaway and eventual device destruction. (Heat sink should be used).

** Second breakdown: If high voltage and high current occur simultaneously during turn-off, a hot spot may be formed and the device fails by thermal runaway, a phenomenon known as secondary breakdown.

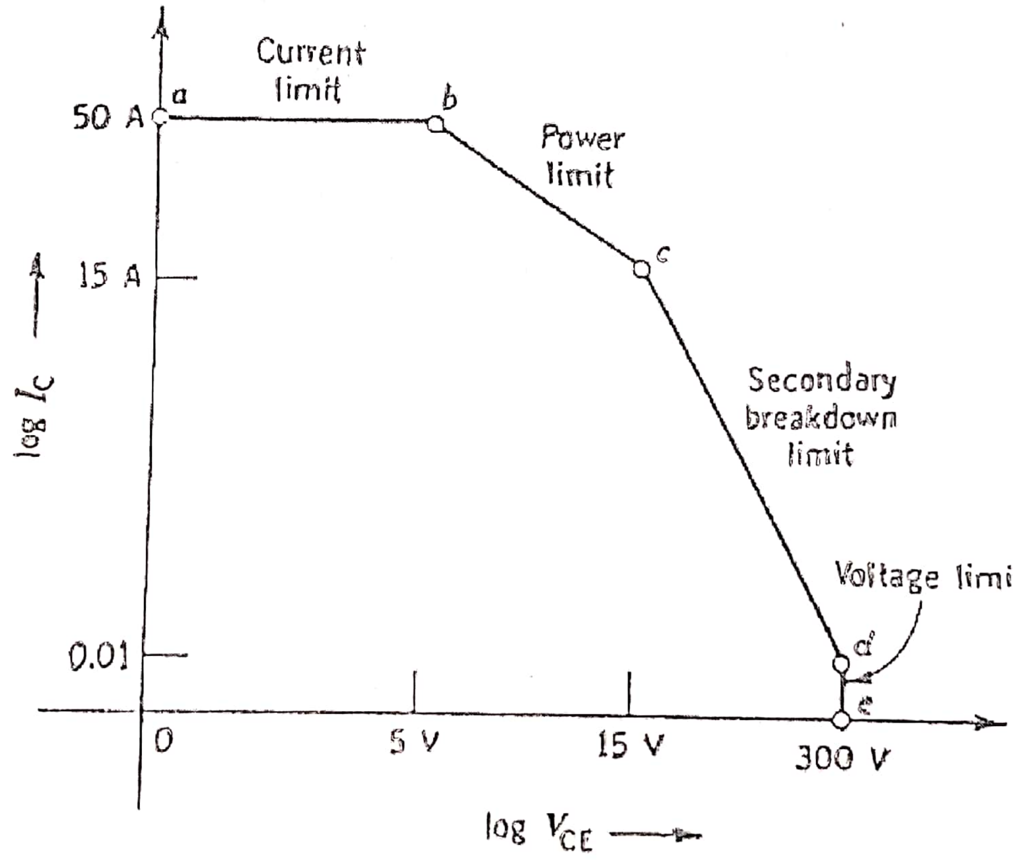

Figure (1.5)

During both the switch-on and the switch-off intervals, for an inductive load, an instant exist when the transistor simultaneously supports the supply voltage and conducts the full load current as shown in figure (1.6)

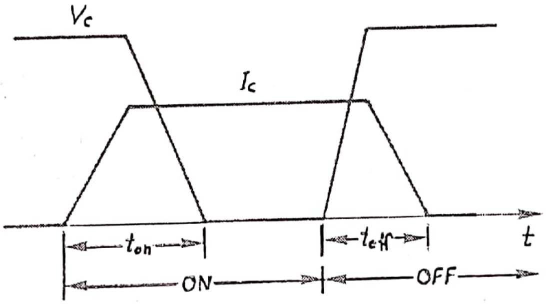

Figure (1.6)

Two snubber circuits can be employed on a power transistor, one operational during transistor turn-on, the other effective during turn-off.

The turn-off snubber circuit:

Figure (1.7) shows complete turn-off circuit, load current is diverted into the snubber capacitor via the diode, while the collector current decreases.

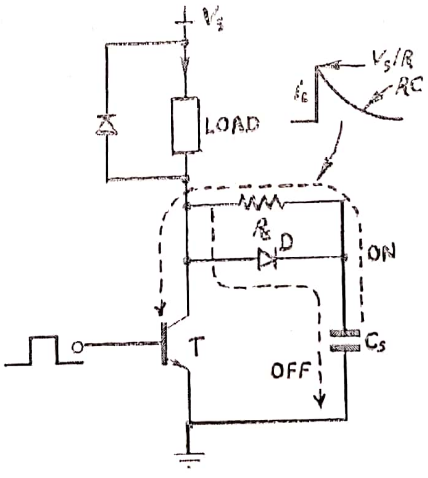

Figure (1.7)

The larger the capacitor, the slower the collector voltage rises for a given load current and, most importantly, turn-off occurs without a condition of simultaneous supply voltage and maximum load current. Figure (1.8) shows the collector turn-off waveforms for different magnitudes of snubber capacitance. Where t_{fi} is the current fall time and τ is the RC time constant. The snubber capacitor value for minimum total losses is calculated as:

$$C_s = \frac{I_m\, t_{fi}}{V_s} \times \frac{2}{9} \quad (F) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1.1)$$

Two factors specify the snubber circuit resistance value:

(a) The snubber R-C time constant must ensure that after turn-on the capacitor discharges before the next turn-off is required. If $t_{on(min)}$ is the minimum transistor on time, then $t_{on(min)} = 5\, R_s\, C_s$ is sufficient to ensure the correct snubber circuit initial conditions.

(b) The initial resistor current at capacitor discharge is given by V_s/R_s. This component is added to the load current at turn-on, hence adding to the turn-on stresses. The maximum collector rating must not be exceeded.

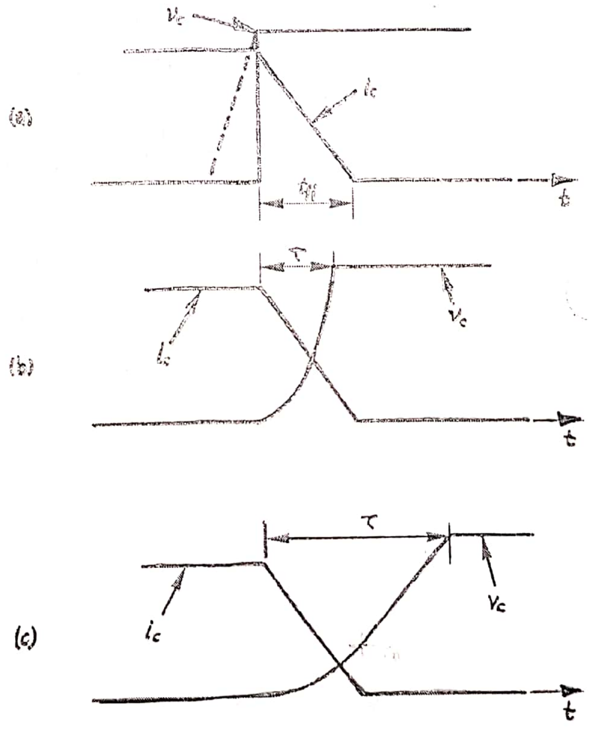

Figure (1.8) Transistor turn-off: (a) unaided turn-off; (b) turn-off with small snubber capacitance; (c) turn-off with large snubber capacitance.

The turn-on snubber circuit:

The purpose of a turn-on snubber circuit is to allow the transistor collector voltage to fall to zero while the collector current is low. Transistor turn-on losses are thus minimized, particularly for inductive loads. This effect can be achieved with a saturable inductor, which designed to saturate after the collector voltage has fallen to zero. Before saturation the saturable inductor presents high impedance and only low magnetizing current flows. As shown in figure (1.9).

$$V_s = \frac{2\,N\,B_{sat}\,A}{t_{fv}} \quad \text{(V)} \qquad \text{.......................(1.2)}$$

Where N is the number of turns, A is the core area, B_{sat} is the core saturation flux density and t_{fv} is the voltage fall time. The core magnetizing current I_{mag} should be low and is given by:

$$I_{mag} = \frac{H_s\,L_{eff}}{N} \quad \text{(A)} \qquad \text{.......................(1.3)}$$

Where L_{eff} is the effective core flux path and H_s is the magnetic flux intensity.

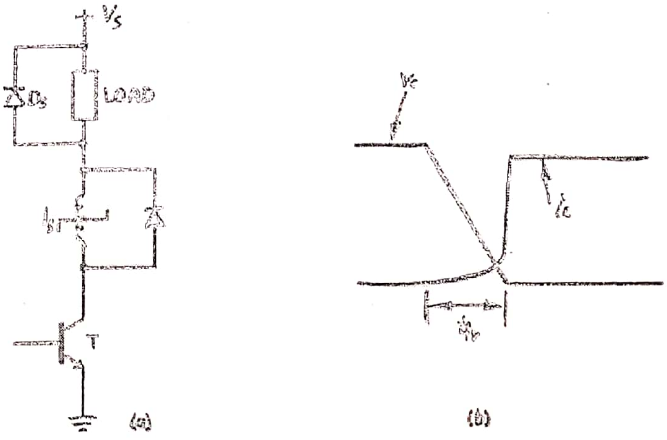

Figure (1.9) Transistor turn-on characteristics when a saturable inductor is used: (a) circuit diagram; (b) collector voltage and current waveforms.