

Switching Characteristics of Power Devices

Device utilization can be greatly improved by understanding the device switching characteristics.

The main performance switching characteristics of power devices:

- The safe operating area (SOA) of the device

- The turn-on and turn-off switching transients

- The switching trajectory

The safe operating area (SOA)

The area within the output characteristics of the device where it can be operated without failure due to power dissipation.

In general there are three boundary for the SOA:

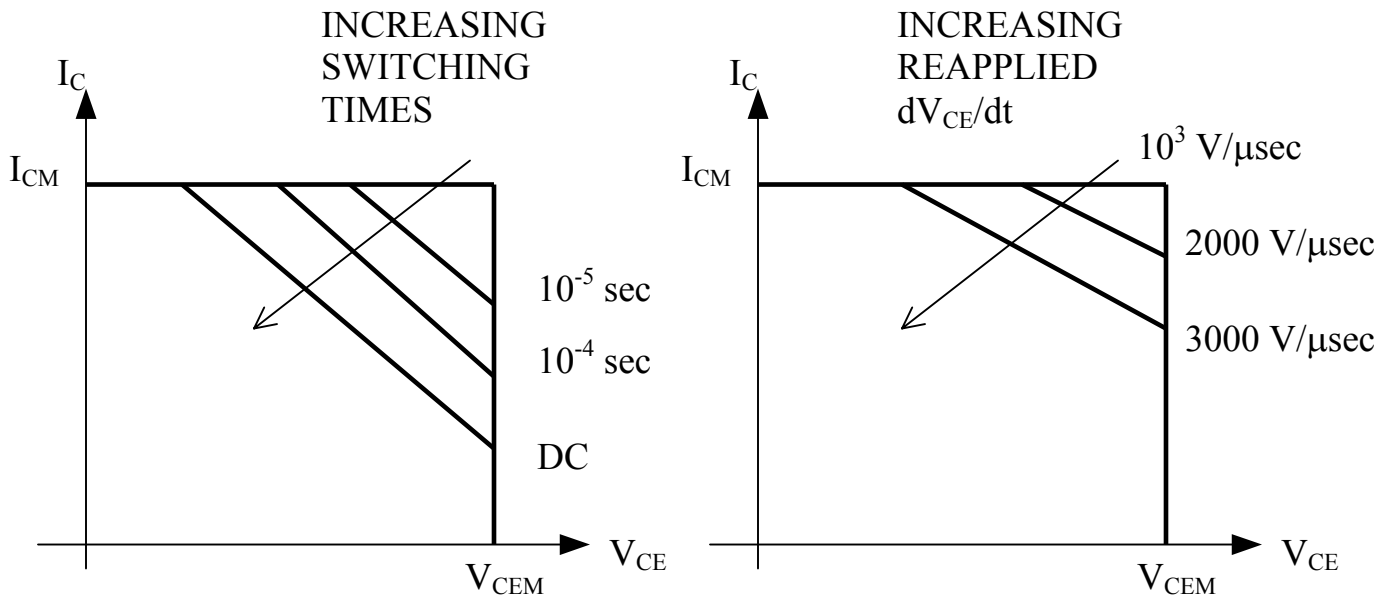
- The maximum operational voltage
- The maximum operational current (current limit)
- The boundary where both voltage and current become simultaneously large.

Two SOAs are defined for a power device:

- The Forward Bias SOA (FBSOA)
- The Reverse Bias SOA (RBSOA)

Different devices have different SOA.

SOA for IGBT



The Forward Bias SOA (FBSOA)

The Reverse Bias SOA (RBSOA)

The turn-on transient is subjected to FBSOA and the turn-off transient is subjected to RBSOA.

The FBSOA of IGBTs is square for short switching times, identical to the FBSOA in MOSFETs. Thus it has a minimal need for snubbers.

The higher rate dV_{CE}/dt (called reapplied rate) during turn-off flattens out the upper right corner in RBSOA.

The turn-on and turn-off switching transients

The real device require a finite time to switch from on-state to off-state and vice versa. The voltage and current vary during this transition.

The product of voltage and current gives instantaneous power dissipated in the device.

There are three types of power loss in the device:

- The turn-on transition power loss
- The turn-off transition power loss
- The conduction loss

The power devices experience high voltages and currents during both turn-on and turn-off transients.

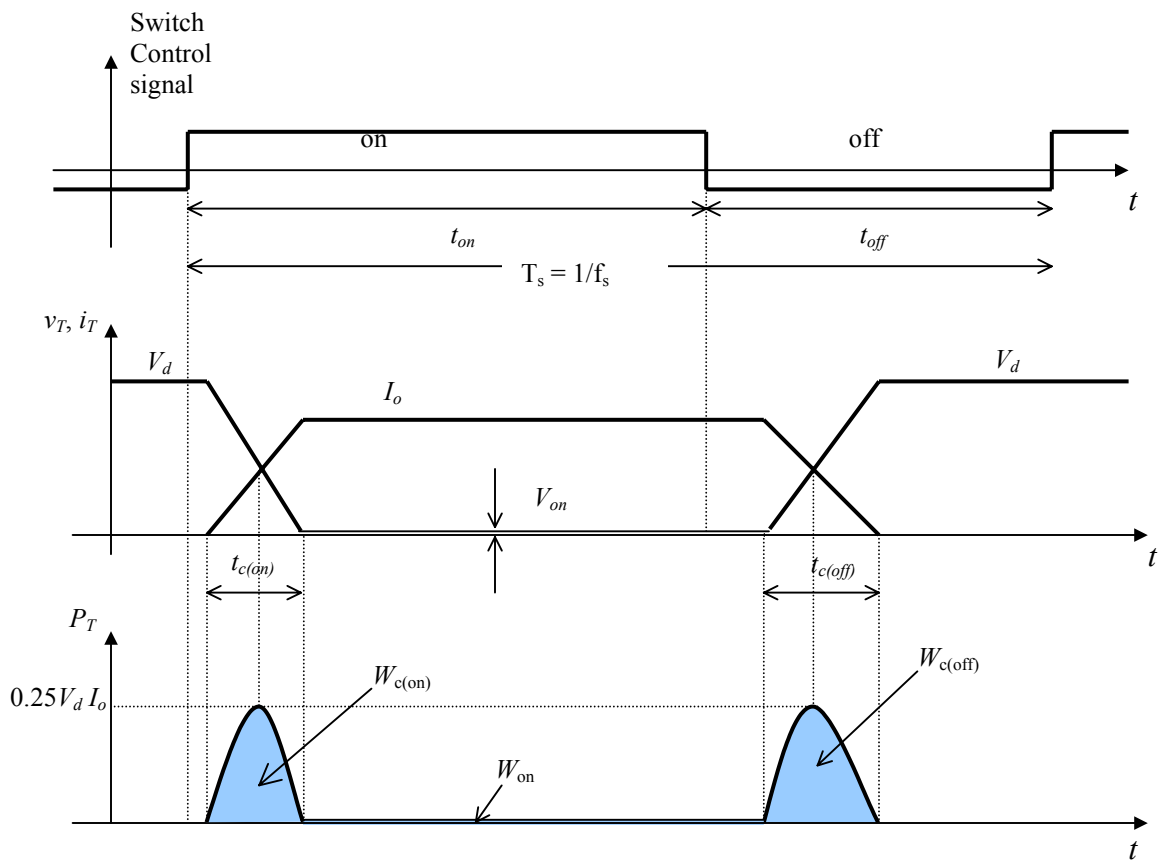
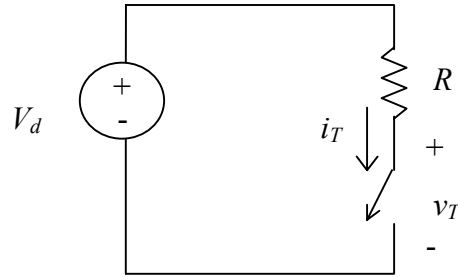
Parasitic effects (diode reverse recovery, parasitic device inductance) cause additional device voltage and current stresses.

Operating the device under this conditions requires large and square SOA.

Snubber circuits shape the volt-amp switching trajectory of power devices.

Snubber circuit allow the utilization of power devices with less than perfect square SOA.

SWITCHING WAVEFORMS FOR RESISTIVE LOAD



$$P_{on-loss} = \frac{1}{T_s} \int_0^{T_s} i_T(t)v_T dt = \frac{1}{T_s} [\text{Shaded area under graph}] = \frac{1}{T_s} \left[\frac{1}{6} V_d I_o t_{c(on)} \right] = \frac{1}{6} V_d I_o t_{c(on)} f_s$$

$$P_{off-loss} = \frac{1}{T_s} \int_0^{T_s} i_T(t)v_T dt = \frac{1}{T_s} [\text{Shaded area under graph}] = \frac{1}{T_s} \left[\frac{1}{6} V_d I_o t_{c(off)} \right] = \frac{1}{6} V_d I_o t_{c(off)} f_s$$

$$P_{conduction-loss} = V_{on} I_o t_{on} f_s$$

SIMPLIFIED SWITCHING WAVEFORMS FOR DIODE CLAMPED INDUCTIVE LOAD

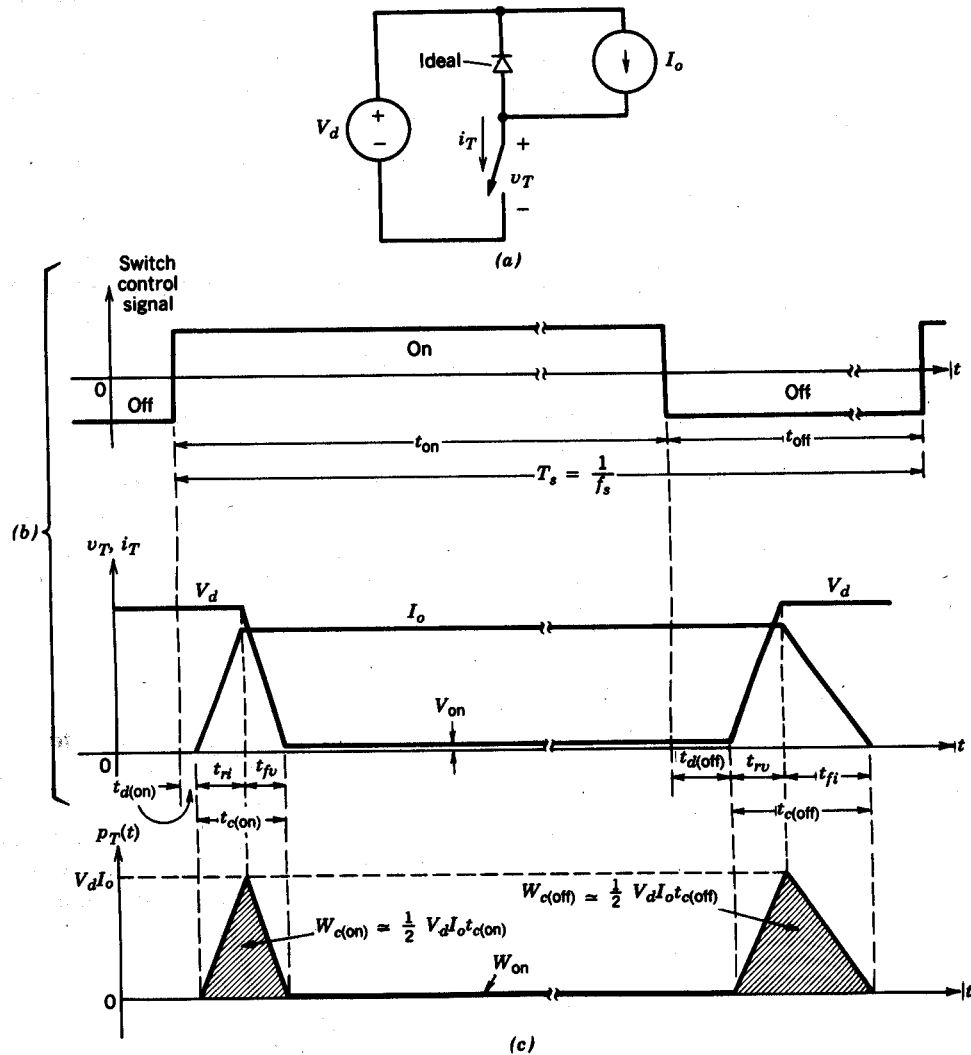


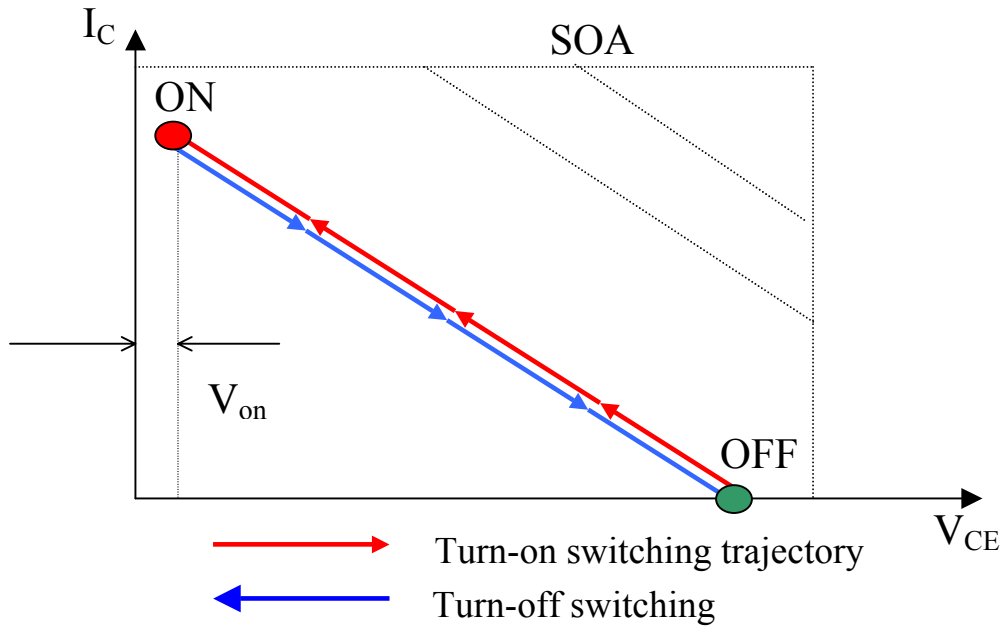
Figure 2-6 Generic-switch switching characteristics (linearized): (a) simplified clamped-inductive-switching circuit, (b) switch waveforms, (c) instantaneous switch power loss.

$$P_{on-loss} = \frac{1}{T_s} \int_0^{T_s} i_T(t)v_T dt = \frac{1}{T_s} [Shaded\ area\ under\ graph] = \frac{1}{T_s} \left[\frac{1}{2} V_d I_o t_{c(on)} \right] = \frac{1}{2} V_d I_o t_{c(on)} f_s$$

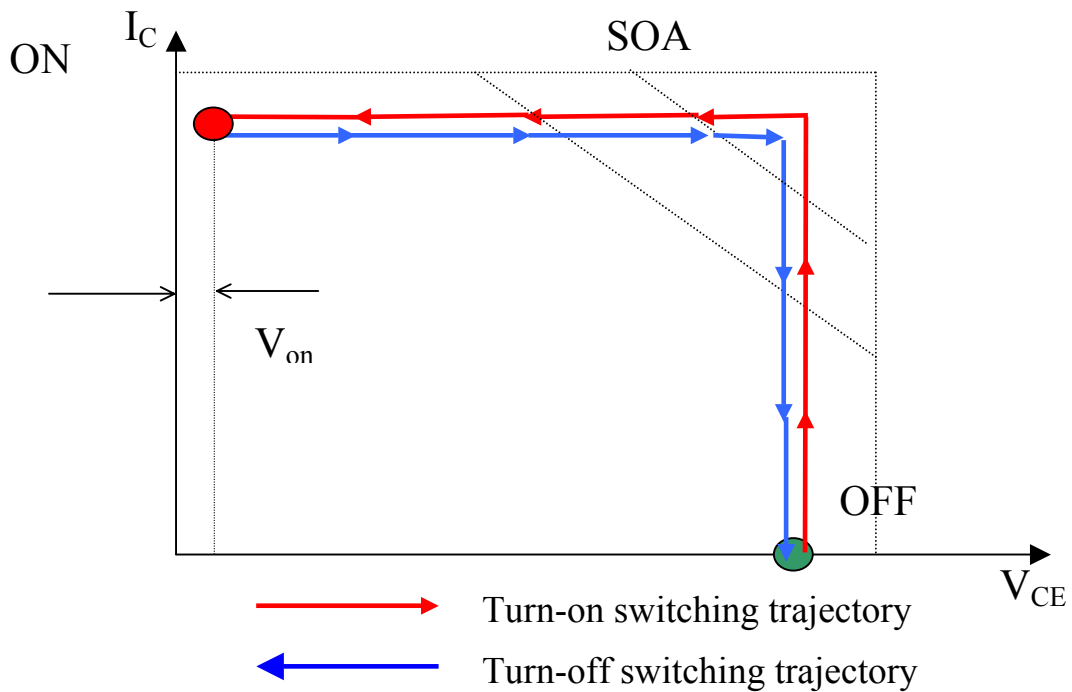
$$P_{off-loss} = \frac{1}{T_s} \int_0^{T_s} i_T(t)v_T dt = \frac{1}{T_s} [Shaded\ area\ under\ graph] = \frac{1}{T_s} \left[\frac{1}{2} V_d I_o t_{c(off)} \right] = \frac{1}{2} V_d I_o t_{c(off)} f_s$$

$$P_{conduction-loss} = V_{on} I_o t_{on} f_s$$

The Switching trajectory of power devices



The switching trajectory for resistive load



The switching trajectory for inductive load

Snubber Circuits

A snubber is a circuit connected around a power device for the purpose of altering its switching trajectory. Snubbers usually have the objective of reducing power loss in the power device.

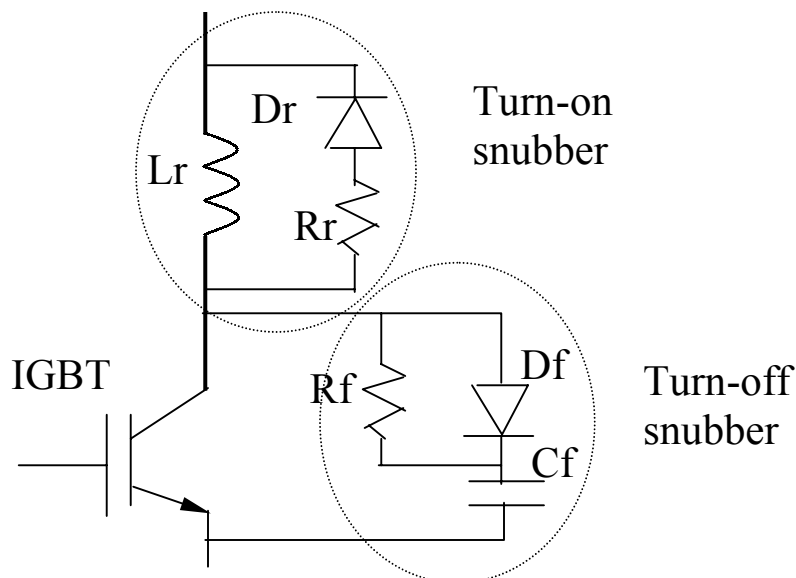
Snubber circuits are generally categorized into two basic categories:

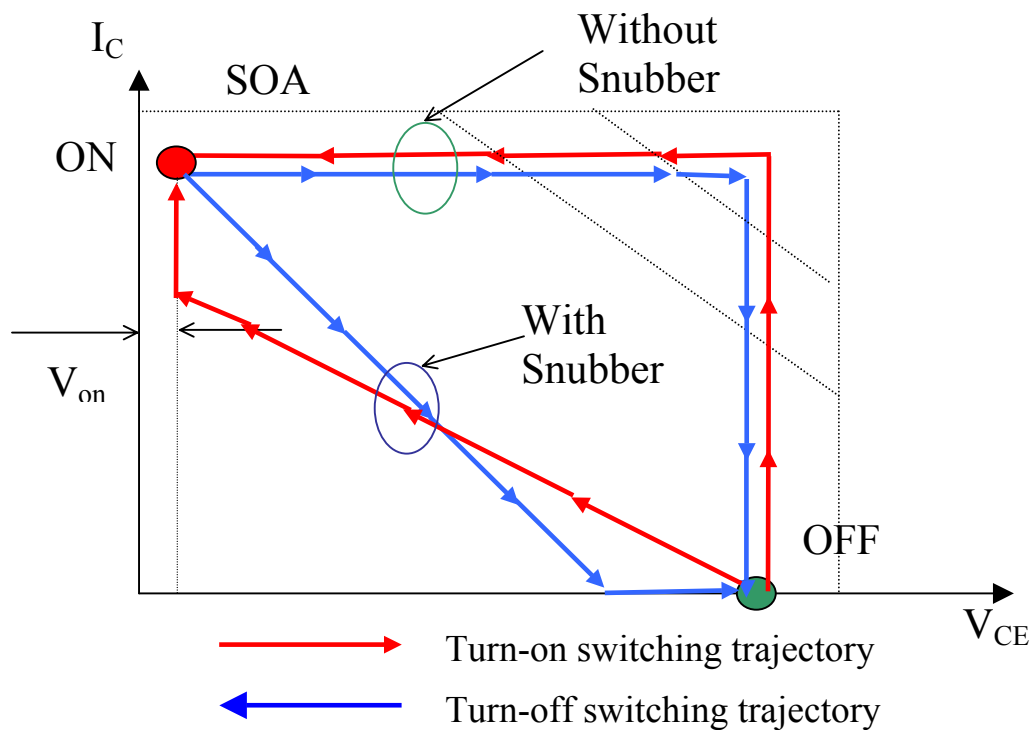
- Turn-off snubber
- Turn-on snubber

They are also classified as:

- lossy snubber (RCD and RLD snubber)
- lossless snubber (energy recovery snubber)

Snubber circuits act to prevent fast change of voltage (turn-off snubber) or current (turn-on snubber) during switching, so that the commutation process can become more nearly linear.





**The switching trajectory for inductive load
With and without snubber**

The power absorbed by the power device is reduced by the snubber circuit. A large capacitor reduces the power loss in the power device, but at the expense of power loss in the snubber resistor.

The use of the snubber may reduce or may not reduce the total power loss, but perhaps more important, the snubber can reduce the losses in the power device and reduces the cooling requirement for the device.

The power device is more prone to failure and is harder to cool than the resistor, so the snubber makes the design more reliable.