University of Technology
Laser and Optoelectronic Engineering Department
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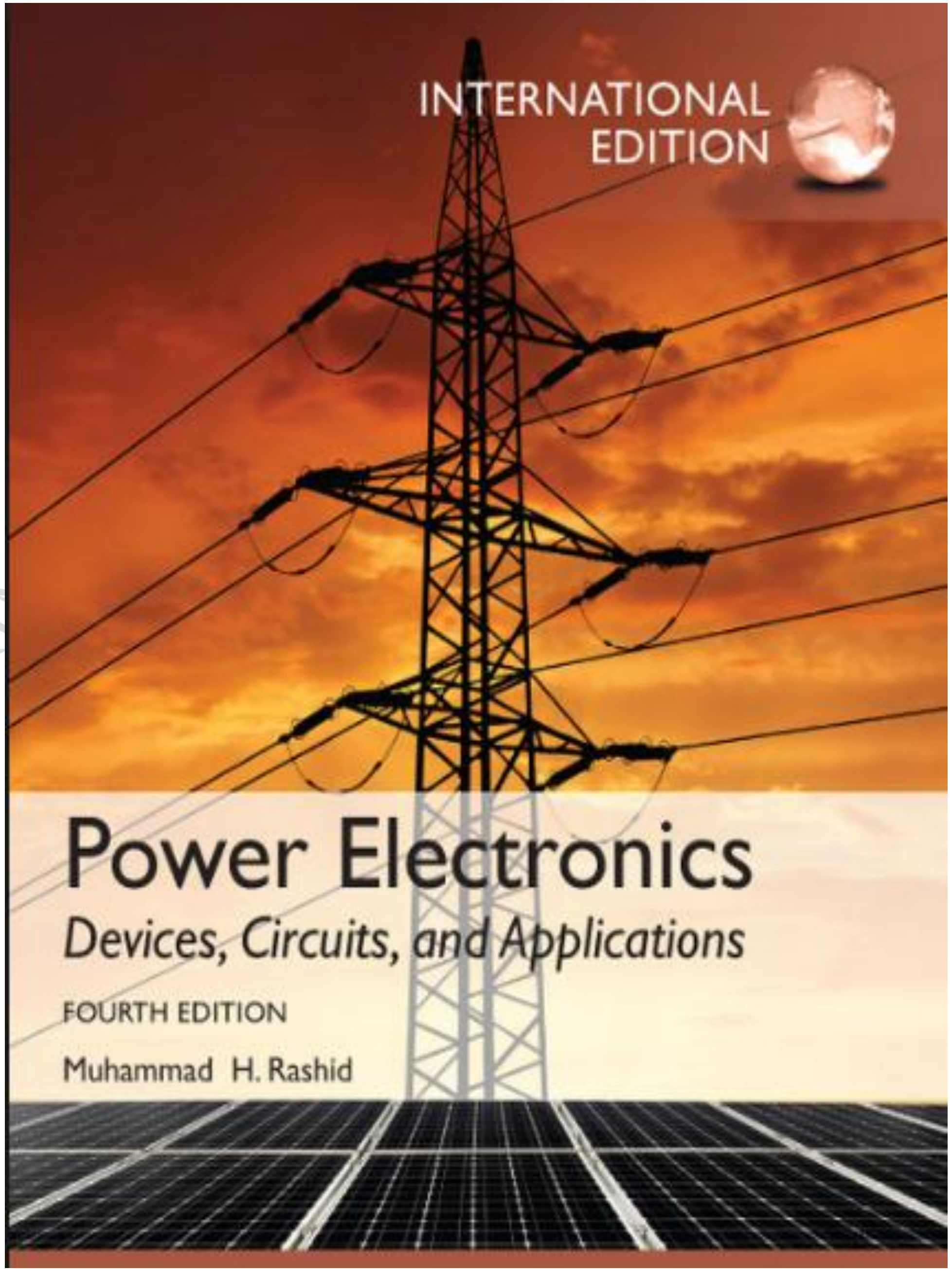
For the third years (Laser Engineering)



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Ref: Power Electronics 4th edition/ Muhammed H. Rashid

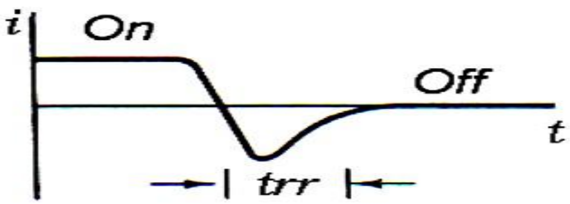
Lecture No.2

Reverse Recovery

- An important dynamic characteristic of a non-ideal diode is reverse recovery current
- When a diode turns off, the current in it decreases and momentarily becomes negative before becoming zero as shown in figure below.
- The diode continues to conduct due to minority carries that remain stored in the *pn*-junction.
- The minority carriers require a certain time (trr) to recombine with opposite charges and to be neutralized.

• Effects of reverse recovery:

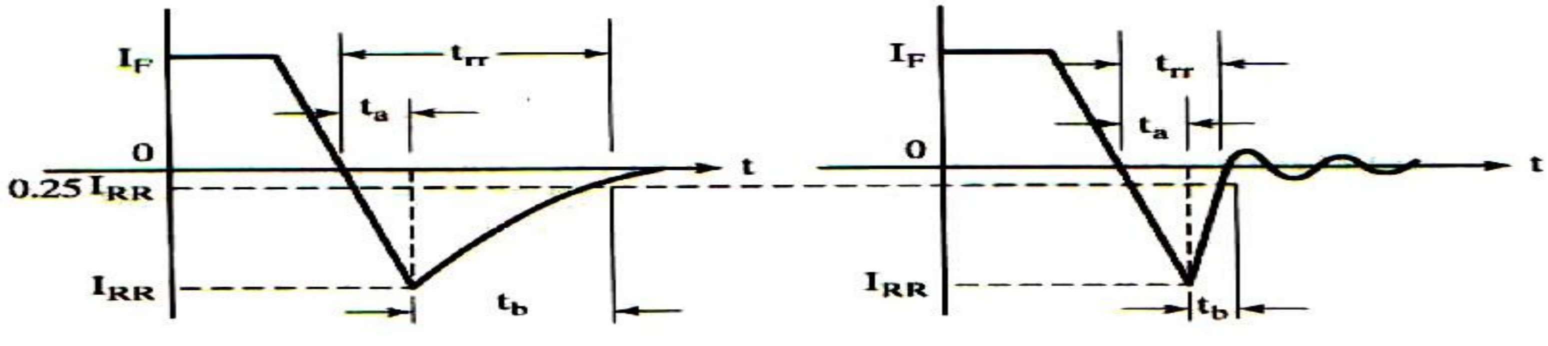
1. Switching losses increase – especially in high frequency applications,
2. Voltage rating increase,
3. Over voltage (spikes) in inductive loads.



Reverse recovery time

Reverse Recovery Characteristics

• Figure shows two reverse recovery characteristics of junction diodes.



(a) : Soft recovery **(b): Abrupt recovery**

- The reverse recovery time is denoted as t_{rr} and is measured from the initial zero crossing of the diode current to 25% of maximum (peak) reverse current, I_{RR}.
- t_{rr} consists of two components, t_a and t_b .
- t_a is due to charge storage in the depletion region of the junction and represents the time between the zero crossing and the peak reverse current, I_{RR}.
- t_b is due to charge stored in the bulk semiconductor material.
- The ratio t_b / t_a is known as ***softness factor***, ***SF***.
- For practical purposes, need to be concerned with the total recovery time t_{rr} and the peak value of the reverse current I_{RR}.

$$t_{rr} = t_a + t_b$$

- The peak reverse current can be expressed in reverse *di/dt* as:

$$I_{RR} = t_a \times \frac{di}{dt}$$

- ***trr*** is dependent on the *junction temperature*, *rate of fall of forward current*, and the *forward current* prior to commutation.
- ***Reverse recovery charge, QRR***, is amount of charge carriers that flow across the diode in the reverse direction due to changeover from
forward conduction to reverse blocking condition.
- ***QRR*** value is determined from the area enclosed by the path of the reverse recovery current.
- The storage charge, which is the area enclosed by the path of the recovery current, is approximately:

$$Q_{RR} \cong \frac{1}{2} I_{RR} t_a + \frac{1}{2} I_{RR} t_b = \frac{1}{2} I_{RR} t_{rr}$$

Or;

$$I_{RR} \cong \frac{2Q_{RR}}{t_{rr}}$$

Then;

$$t_{rr} t_a = \frac{2Q_{RR}}{di/dt}$$

If t_b is negligible as compared to t_a , which usually the case, $t_{rr} \approx t_a$, then;

$$t_{rr} \cong \sqrt{\frac{2Q_{RR}}{di/dt}}$$

And

$$I_{RR} = \sqrt{2Q_{RR}\frac{di}{dt}}$$

- The storage charge is dependent on the forward diode current, I_F.
- The ***peak reverse recovery current*** I_{RR}, *reverse charge* Q_{RR}, and the ***softness factor SF*** are very important parameters for circuit design and are normally included in the diodes specification sheets.
- A diode which is in a reverse-biased, then been forward-biased again. It also requires a certain time known as forward recovery (turn-on) time before all the majority carriers over the whole junction can contribute to the current flow.
- If the rate of rise of the forward current is high and the forward current is concentrated to a small area of the junction, the diode will fail.

Home Work:

The reverse recovery time of a diode is t_{rr} = 3 μs and the rate of fall of the diode current is *di/dt* = 30 A/μs. Determine:

(a) The storage charge Q_{RR}

(b) The peak reverse current I_{RR}

EXAMPLE (1): The manufacturer of a selected diode gives the rate of fall of the diode current *di/dt* = 20A/μs, and a reverse recovery time of t_{rr}=5 μs. What value of peak reverse current do you expect?

SOLUTION: The peak reverse current is given as:

$$I_{rr} = \sqrt{\frac{di}{dt}2Q_{RR}}$$

The storage charge Q_{RR} calculated as:

$$Q_{RR} = \frac{1}{2}\frac{di}{dt}t_{rr}^{2} = 1/2 \times 20\ \text{A}/\mu\text{s} \times (5 \times 10^{-6})^2 = 50\ \mu\text{C}.$$

$$I_{rr} = \sqrt{20\frac{a}{\mu s} \times 2 \times 50\ \mu C} = 44.72\ A$$

2. Thyristor (SCR)

2.1 Introduction

Thyristors are usually three-terminal devices with four layers of alternating p- and n-type material (i.e. three p-n junctions) in their main power handling section. The control terminal of the thyristor, called the gate (G) electrode, may be connected to an integrated and complex structure as part of the device. The other two terminals, anode (A) and cathode (K), handle the large applied potentials and conduct the major current through the thyristor. The anode and cathode terminals are connected in series

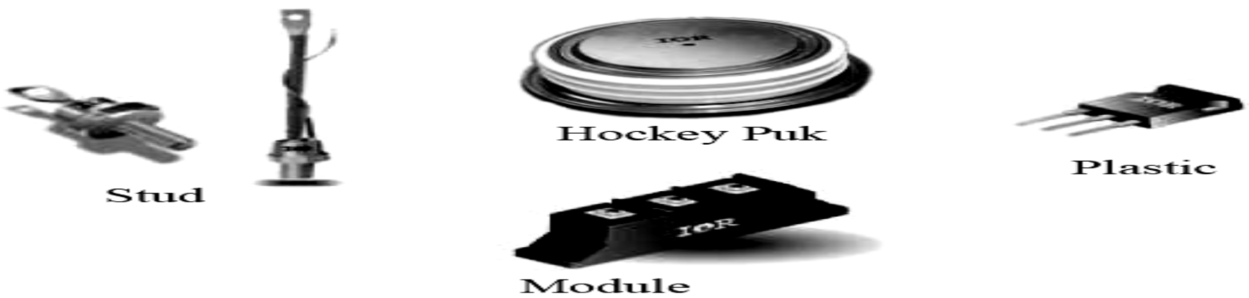
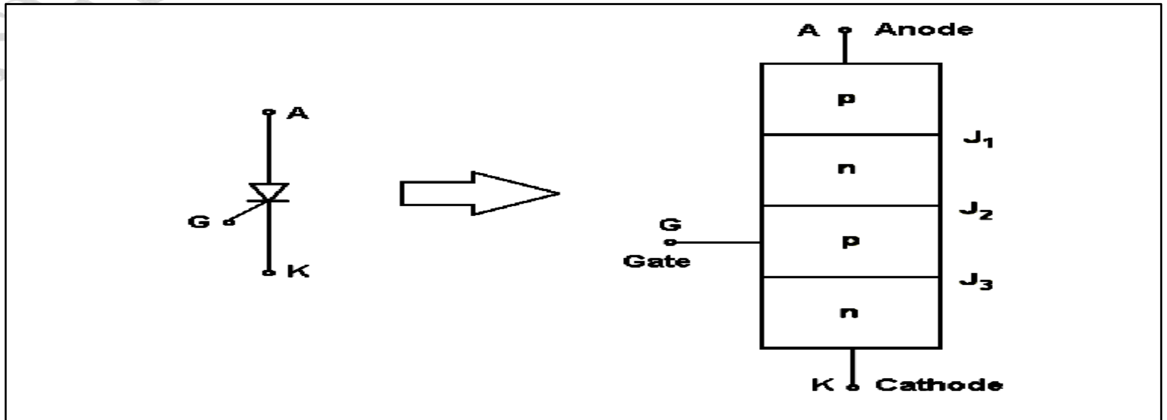


Figure 1.24 : Various thyristor configurations

2. Basic Structure and Operation

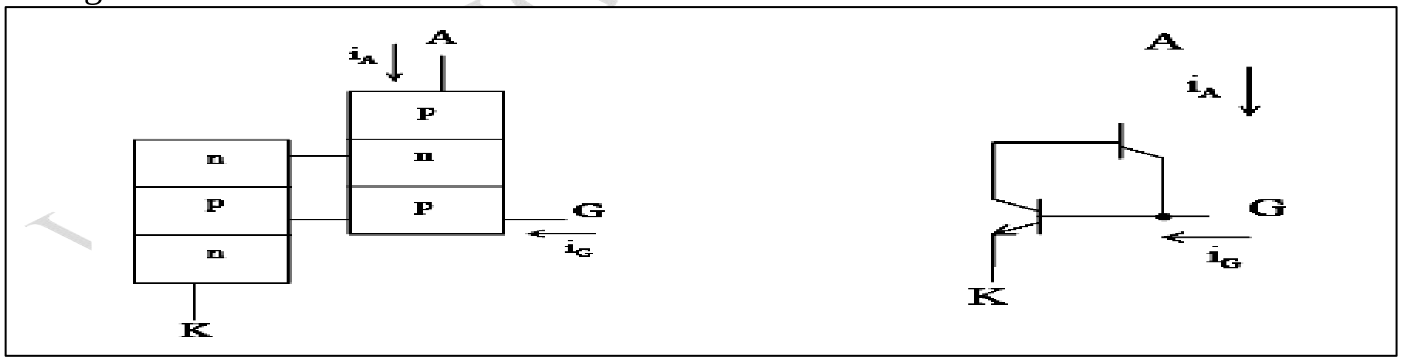
Figure below shows a conceptual view of a typical thyristor with the three p-n junctions and the external electrodes labeled. Also shown in the figure the thyristor circuit symbol used in electrical schematics.



The operation of thyristors is as follows. When a positive voltage is applied to the anode (with respect to a cathode), the thyristor is in its forward-blocking state. The center junction J_2 (see Figure above) is reverse-biased. In this operating mode, the gate current is held to zero (open-circuit). In this condition only thermally generated leakage current flows through the device and can often be approximate as zero in value. When a positive gate current is injected into the device J_3 becomes forward-biased and electrons are injected from the n-emitter into the p- base. The thyristor is latched in its on state (forward-conduction).

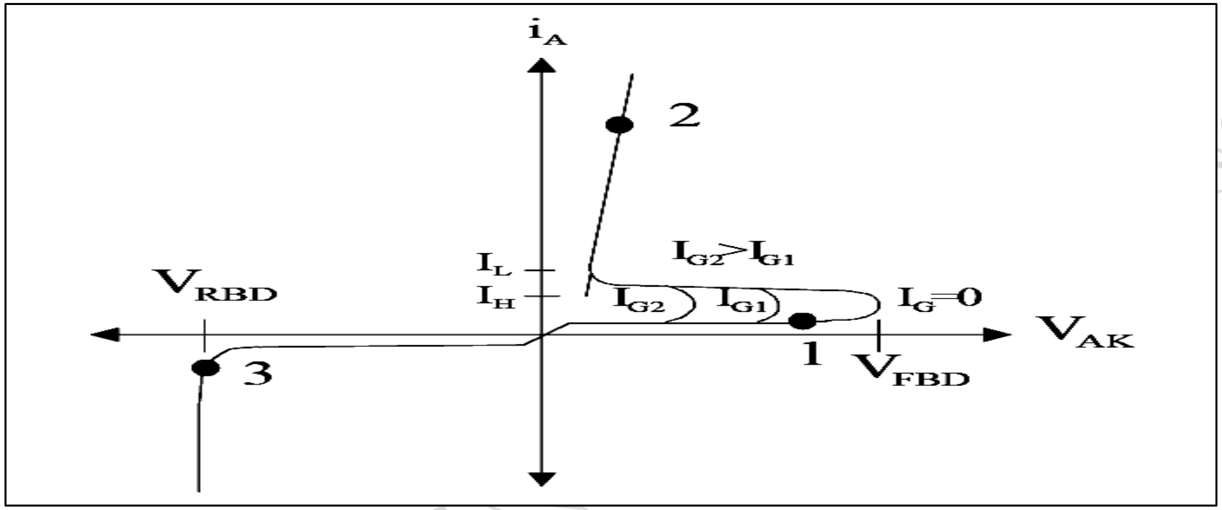
This switching behavior can also be explained in terms of the two- transistor analog shown in Figure below. The two transistors are regenerative coupled so that if the sum of their forward current gains (α's) exceeds unity, each drives the other into saturation. The forward current gain (expressed as the ratio of collector current to emitter current) of the pnp transistor is denoted by α_p, and that of the npn as α_n. The α's are current dependent and increase slightly as the current increases. The center junction J_2 is reverse-biased under forward applied voltage (positive V_{AK}).

When Gate current increases the current in both transistors are increased. Collector current in the npn transistor acts as base current for the pnp, and analogously, the collector current of the pnp acts as base current driving the npn transistor. The thyristor switches to its on-state (latches). This condition can also be reached, without any gate current, by increasing the forward applied voltage so that the internal leakage current increased.



Current-Voltage Curves for Thyristors

A plot of the anode current (i_A) as a function of anode cathode voltage (V_{AK}) is shown in Figure below. The forward blocking mode is shown as the low-current portion of the graph (solid curve around operating point "1"). With zero gate current and positive V_{AK} the forward characteristic in the "off state" or "blocking-state" is determined by the center junction J_2, which is reverse-biased. At operating point "1", very little current flows (I_{co} only) through the device. However, if the applied voltage exceeds the forward-blocking voltage, the thyristor switches to its "on-state" or "conducting-state" (shown as operating point "2") because of carrier multiplication. The effect of gate current is to lower the blocking voltage at which switching takes place.



The thyristor moves rapidly along the negatively sloped portion of the curve until it reaches a stable operating point determined by the external circuit (point “2"). The portion of the graph indicating forward conduction shows the large values of i_A that may be conducted at relatively low values of V_{AK}, similar to a power diode.