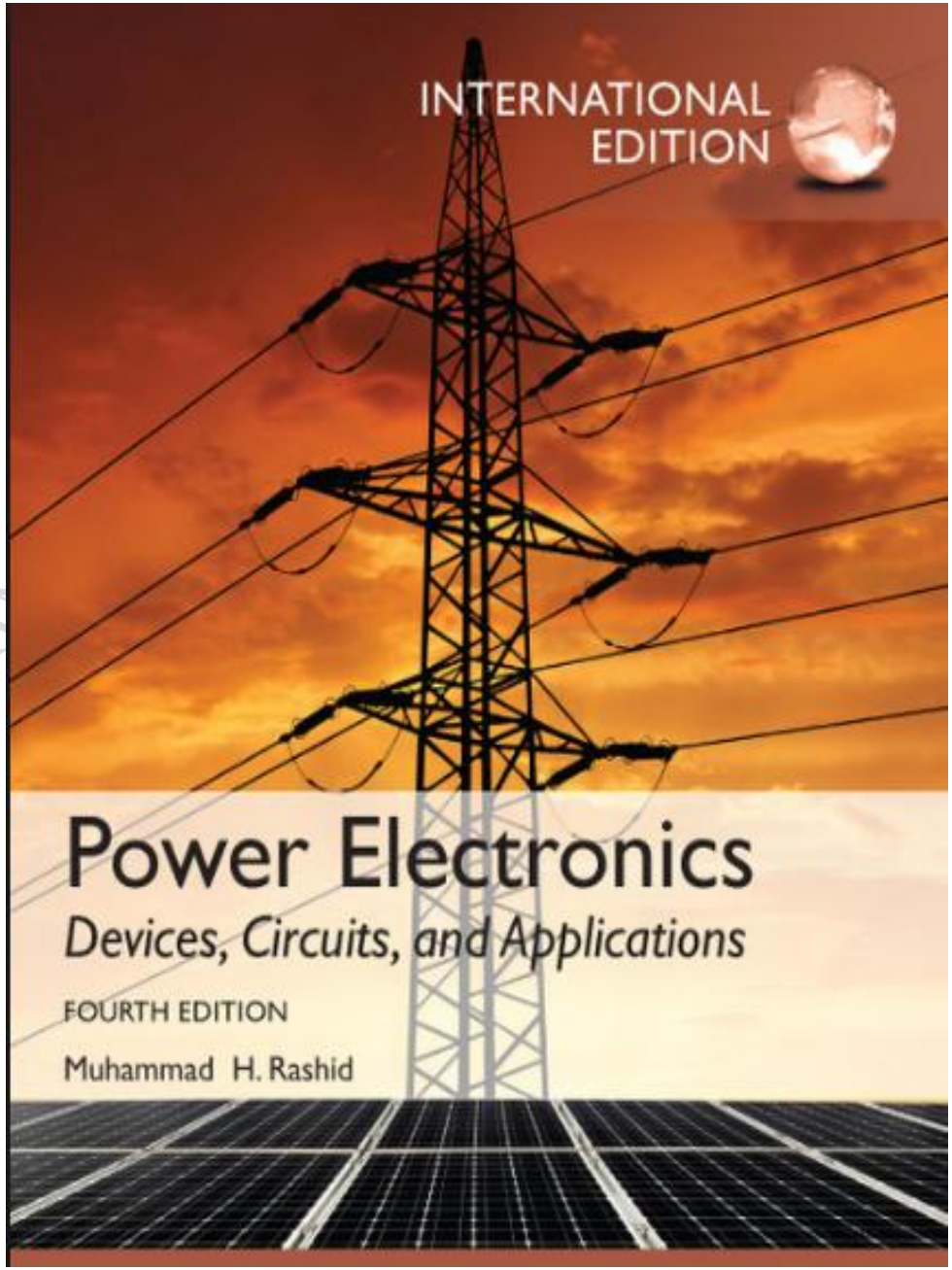
University of Technology
Laser and Optoelectronic Engineering Department
Power Electronics/2018-2019)
For the third years (Laser Engineering)



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

Lecture No.1

INTRODUCTION TO POWER ELECTRONICS

Definition

- Power electronics refers to control and conversion of electrical power by power semiconductor devices wherein these devices operate as switches.
- Advent of silicon-controlled rectifiers, abbreviated as SCRs, led to the development of a new area of application called the power electronics.
- Prior to the introduction of SCRs, mercury-arc rectifiers were used for controlling electrical power, but such rectifier circuits were part of industrial electronics and the scope for applications of mercury-arc rectifiers was limited.
- Once the SCRs were available, the application area spread too many fields such as drives, power supplies, aviation electronics & high frequency inverters.

Main Task of Power Electronics

- Power electronics has applications that span the whole field of electrical power systems, with the power range of these applications extending from a few VA/Watts to several MVA / MW.
- The main task of power electronics is to control and convert electrical power from one form to another.
- The four main forms of conversion are:

→ **Rectification referring to conversion of AC voltage to DC voltage,**
→ **DC-to-AC conversion,**
→ **DC-to DC conversion,**
→ **AC-to-AC conversion**

- "Electronic power converter" is the term that is used to refer to a power electronic circuit that converts voltage and current from one form to another.

These converters can be classified as:
→ Rectifier converting an ac voltage to a dc voltage,
→ Inverter converting a dc voltage to an ac voltage,
→ Chopper or a switch-mode power supply that converts a dc voltage to another dc voltage, and
→ Cycloconverter converts an ac voltage to another ac voltage.

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Rectification

- Rectifiers can be classified as uncontrolled and controlled rectifiers, and the controlled rectifiers can be further divided into semi-controlled and fully controlled rectifiers.

- Uncontrolled rectifier circuits are built with diodes, and fully controlled rectifier circuits are built with SCRs. Both diodes and SCRs are used in semi-controlled rectifier circuits.

- There are several rectifier configurations. The popular rectifier configurations are listed below.

→ Single-phase half wave rectifier,
→ Single-phase full wave rectifier,
→ Single-phase half wave controlled rectifier,
→ Single-phase semi-controlled full wave rectifier,
→ Single-phase fully controlled full wave rectifier,
→ Three-phase half wave rectifier,
→ Three-phase bridge rectifier,
→ Three-phase half wave controlled rectifier,
→ Three-phase semi-controlled bridge rectifier
→ Three-phase fully controlled bridge rectifier

•Power rating of a single-phase rectifier tends to be lower than 10 kW. Three-phase bridge rectifiers are used for delivering higher power output, up to 500 kW at 500 V dc or even more.

- There are many applications for rectifiers. Some of them are:

→ Variable speed dc drives,
→ Battery chargers,
→ DC power supplies and Power supply for a specific application like electroplating

DC-to-AC Conversion

- The converter that changes a dc voltage to an alternating voltage is called an inverter.
- Earlier inverters were built with SCRs.
- Since the circuitry required turning the SCR off tends to be complex, other power semiconductor devices such as bipolar junction transistors, power MOSFETs, insulated gate bipolar transistors (IGBT) and MOS- controlled thyristors (MCTs) are used nowadays.

- Some of the applications of an inverter are listed below:

→ Emergency lighting systems,
→ AC variable speed drives,

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→ Uninterrupted power supplies,
→ Frequency converters

DC-to-DC Conversion

- A SCR, power BJT or a power MOSFET is normally used in such a converter and this converter is called a switch-mode power supply.

- A switch-mode power supply can be of one of the types listed below:

→ Step-down switch-mode power supply,
→ Step-up switch-mode power supply,
→ Fly-back converter,
→ Resonant converter

- The typical applications for a switch-mode power supply or a chopper are:

→ DC drive
→ Battery charger
→ DC power supply

AC-to-AC Conversion

- A cycloconverter converts an ac voltage, such as the mains supply, to another ac voltage.
- The amplitude and the frequency of input voltage to a cycloconverter tend to be fixed values, whereas both the amplitude and the frequency of output voltage of a cycloconverter tend to be variable.
- A typical application of a cycloconverter is to use it for controlling the speed of AC traction motor and most of these cycloconverters have a high power output, of the order a few megawatts and SCRs are used in these circuits.

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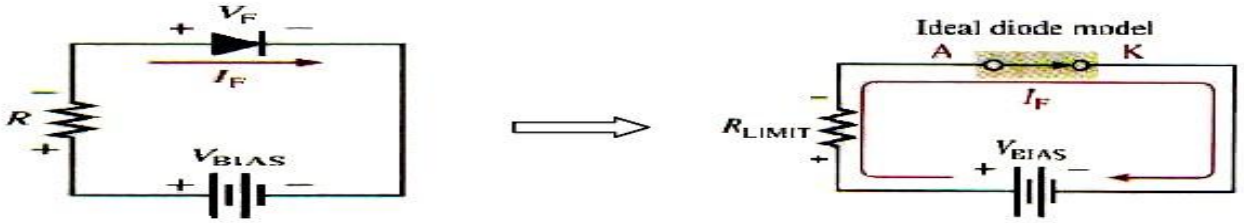
Power electronic devices (part I)

1. The power diode

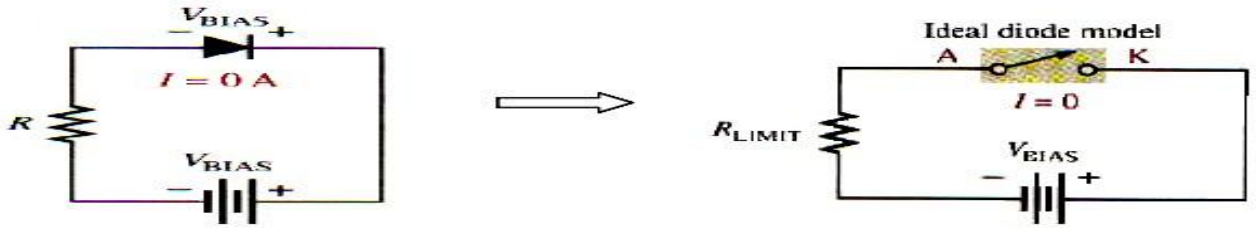
Diode Approximations

i. The Ideal Model

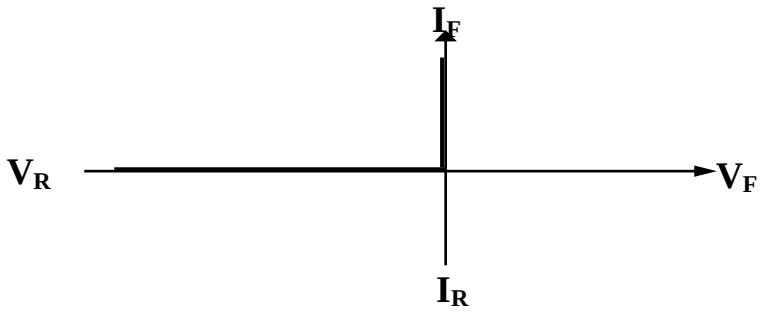
- Think it as switch
- When forward biased, act as a closed (ON) switch
- When reverse biased, act as open (off) switch



Ideal diode model for forward bias



Ideal diode model for reverse bias

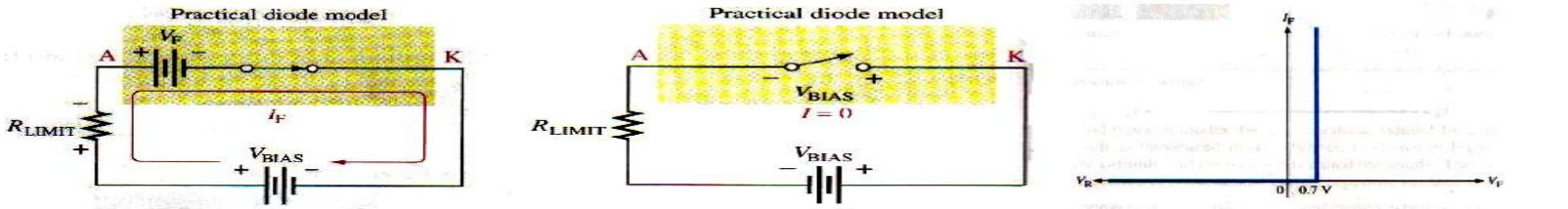


Ideal Characteristic curve (blue) for Ideal model

• This model neglects the effect of the barrier potential, the internal resistance, and other parameters.

ii. The Barrier Potential Model

• The forward biased diode is represented as a closed switch in series with a small 'battery' equal to the barrier potential VB (0.7 V for Si and 0.3 V for Ge)
• The positive end of the equivalent battery is toward the anode.
• This barrier potential cannot be measured by using a multimeter, but it has the effect of a battery when forward bias is applied.
• The reverse biased diode is represented by an open switch, because barrier potential does not affect reverse bias.

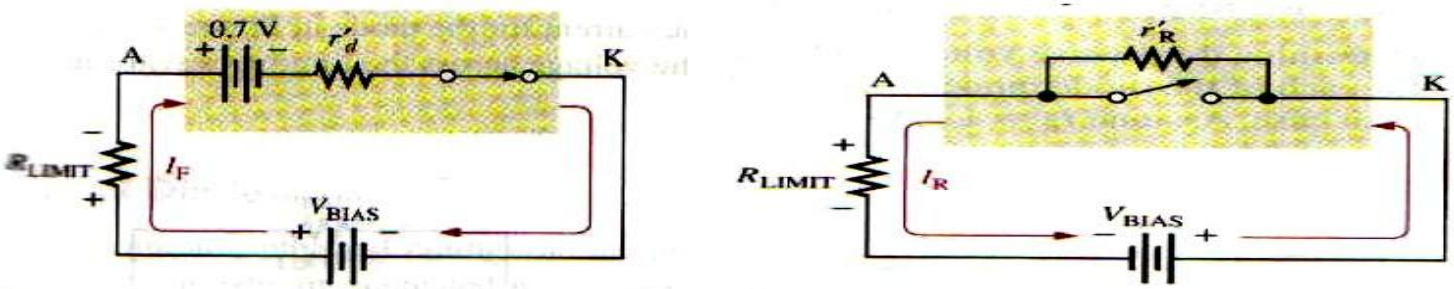


(a) : Forward bias (b) : Reverse bias (c) : Characteristic curve (silicon)

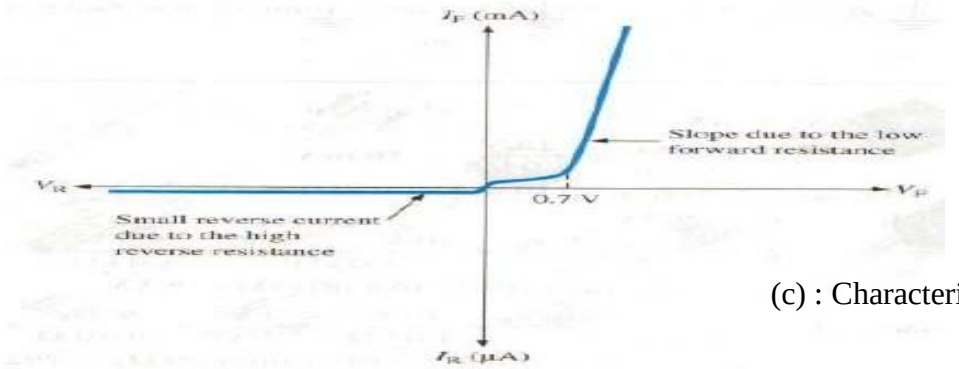
The practical model of a diode

The Complete Diode Model

•More accurate
•The forward biased diode model with both the barrier potential and low forward (bulk) resistance (r'_d)



(a) : Forward bias (b) : Reverse bias



(c) : Characteristic curve (silicon)

Diode Characteristics

- A power diode is a two terminal *pn* – junction device.
- The magnitude of this voltage drop depends on:
  a) on the manufacturing process
  b) junction temperature

- When the cathode potential is positive with respect to the anode:

⇒ The diode is said to be reverse biased

⇒ A small reverse current (also known as leakage current) in the range of micro or miliampere, flows through it.

⇒ It increases slowly in magnitude with the reverse voltage until the avalanche or zener voltage is reached.

- The *v – I* characteristics shown above can be expressed by an equation known as 'Schockley diode equation' and it is given under dc steady state operation by:

$$I_D = I_S\left(e^{V_D / nV_T} - 1\right)$$

- Where:
  I_D = Current through the diode, A
  V_D = Diode voltage (forward voltage)
  I_S = Leakage current (or reverse saturation). n = emission coefficient
  V_T = Thermal Voltage

$$V_T = \frac{kT}{q}$$

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q = electron charge : 1.6022×10^{-19} C T = absolute temperature in Klevin

k = Boltzman's constant : 1.3806×10^{-23} J / K

• The diode characteristics can be divided into three region:

1. Forward – biased region, where VD > 0
2. Reverse – biased region, where VD < 0
3. Breakdown region, where VD < -VBR

Forward – biased region

- VD > 0
- Diode current ID very small if VD is less than a specific value VT (0.7V)
- Diode conducts fully if VD is higher than this value VT, which is referred to as the threshold voltage or the turn-on voltage
- The threshold voltage is a voltage at which the diode conducts fully.

Reverse – biased region

$$I_D = I_S\left(e^{V_D / nV_T} - 1\right) \cong -I_S$$

- VD < 0
- If VD is negative and |VD| >> VT, which occurs for VD < -0.1, the exponential term in Schockley equation becomes negligibly small compared to unity and the diode current ID becomes:

Breakdown region

- Reverse voltage is high.
- Magnitude of reverse voltage exceeds a specified voltage known as the breakdown voltage, VBR
- IR increases rapidly with a small change in reverse voltage beyond VBR.
- The operation in this region will not be destructive provided that the power dissipation is within a 'safe level' that is specified in the manufacture's data sheet.
- But it has to limit I_R in order to limit the power dissipation within a permissible value

Home work :

The forward voltage drop of a power diode is $V_D = 1.2$ V at $I_D = 300$

A. Assuming that $n = 2$ and $V_T = 25.7$ mV, find the reverse saturation current I_S.

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