Lecture -1-

♦ Introduction to power electronics

Definition

- Power electronics circuits convert electric power from one form to another using electronic devices.
- Power electronics refers to control and conversion of electrical power by power semiconductor devices wherein these devices operate as switches.
- Electronic power conversion may be defined as the modification of one or more parameters of electrical energy using electronic devices, without significant power losses.

Main Task of Power Electronics

The objective of a power electronics circuit is to match the voltage and current requirements of the load to those of the source. Power electronics circuits convert one type or level of a voltage or current waveform to another and are hence called *converters*. Converters serve as an interface between the source and load (Fig. 1-1).

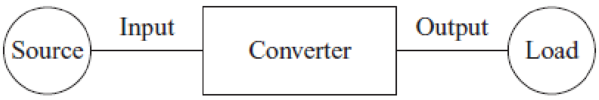


Fig. 1-1 A source and load interfaced by a power electronics converter.

Converters are classified by the relationship between input and output to four main forms of conversion are:

→ **AC -to- DC conversion** (Rectifier converting)
→ **AC-to-AC conversion** (Cycloconverters convert)
→ **DC-to-AC conversion** (Inverter converting)
→ **DC-to DC conversion** (Chopper)

– AC -to- DC Rectification

• ***Rectifiers*** can be classified as an uncontrolled and controlled rectifier, and the controlled rectifiers can be further divided into semi-controlled and fully controlled rectifiers.
• Uncontrolled rectifier circuits are built with diodes, it is not possible to control the turning on and off the circuit.
• fully controlled rectifier circuits are built with silicon-controlled rectifier SCR.
• Both diodes and SCRs are used in semi-controlled rectifier circuits (only turning on).
• 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 fully controlled full wave rectifier,

→ Three-phase half wave rectifier,
→ Three-phase bridge rectifier,
→ Three-phase half wave controlled 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

– AC-to-AC Conversion

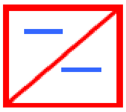
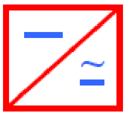
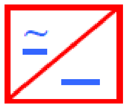
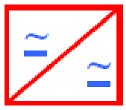
• A cycloconverter converts an ac voltage, such as the mains supply, to another ac voltage.
• The amplitude and the frequency of input voltage to a cycloconverter tend to be fixed values, whereas both the amplitude and the frequency of output voltage of a cycloconverter tend to be variable.
• A typical 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, SCRs are used in these circuits.

– 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,
→ 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
→Buck and Boost.

CONVERSION FROM/TO	NAME	FUNCTION	SYMBOL
DC to DC	Chopper	Constant to variable DC or variable to constant DC	
DC to AC	Inverter	DC to AC of desired voltage and frequency	
AC to DC	Rectifier	AC to unipolar (DC) current	
AC to AC	Cycloconverter, AC-PAC, Matrix converter	AC of desired frequency and/or magnitude from generally line AC	

♦ Power Electronic Devices History

Power electronics and converters utilizing them made a head start when the first device the Silicon Controlled Rectifier was proposed by Bell Labs and commercially produced by General Electric in the earlier fifties. The Mercury Arc Rectifiers were well in use by that time and the robust and compact SCR first started replacing it in the rectifiers and cycloconverters. The necessity arose of extending the application of the SCR beyond the line-commutated mode of action, which called for external measures to circumvent its turn-off incapability via its control terminals. Various turn-off schemes were proposed and their classification was suggested but it became increasingly obvious that a device with turn-off capability was desirable, which would permit it a wider application. The turn-off networks and aids were impractical at higher powers.

The Bipolar transistor, which had by the sixties been developed to handle a few tens of amperes and block a few hundred volts, arrived as the first competitor to the SCR. It is superior to the SCR in its turn-off capability, which could be exercised by its control terminals. This permitted the replacement of the SCR in all forced-commutated inverters and choppers. However, the gain (power) of the SCR is a few decades' superior to that of the Bipolar transistor and the high base currents required to switch the Bipolar gave rise to the Darlington.

The Power MOSFET burst into the scene commercially near the end seventies. This device also represents the first successful marriage between modern integrated circuits and discrete power semiconductor manufacturing technologies. Its voltage drive capability – giving it again a higher gain, the ease of its paralleling, and most importantly the much higher operating frequencies reaching up to a few MHz saw it replacing the Bipolar also at the sub-10 KW range mainly for SMPS type of applications.

Different versions of the Gate-turn-off device, the Gate turn-off Thyristors (GTO), were proposed by various manufacturers - each advocating their own symbol for the device. The requirement for an extremely high turn-off control current via the gate and the comparatively higher cost of the device restricted its application only to inverters rated above a few hundred KVA.

The lookout for a more efficient, cheap, fast, and robust turn-off-able device proceeded in different directions with MOS drives for both the basic Thyristors and the Bipolar. The Insulated Gate Bipolar

Transistor (IGBT) – basically a MOSFET driven Bipolar from its terminal characteristics has been a successful proposition with devices being made available at about 4 KV and 4 KA. Its switching frequency of about 25 KHz and ease of connection and drive saw it totally removing the Bipolar from practically all applications.
Industrially, only the MOSFET has been able to continue in the sub–10 KVA range primarily because of its high switching frequency. The IGBT has also pushed up the GTO to applications above 2-5 MVA.
The range of power devices thus developed over the last few decades can be represented as a tree, Fig. 1.2, on the basis of their controllability and other dominant features.

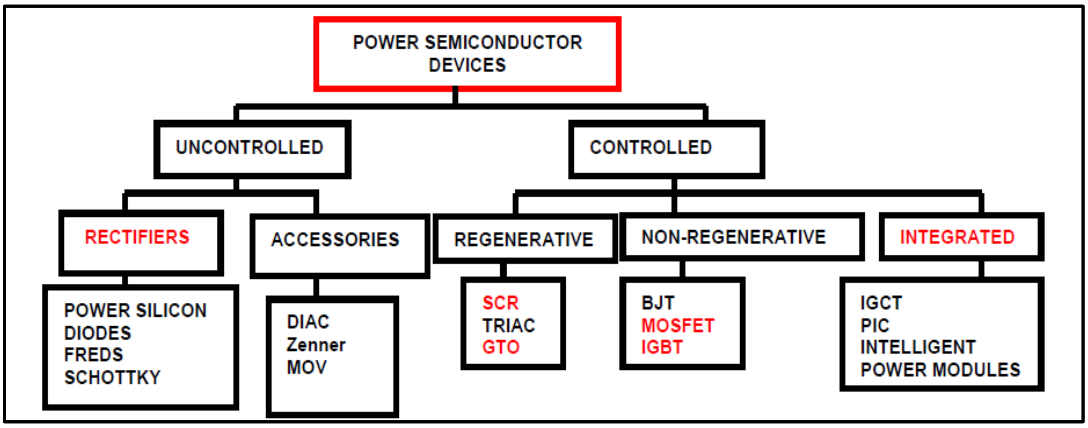


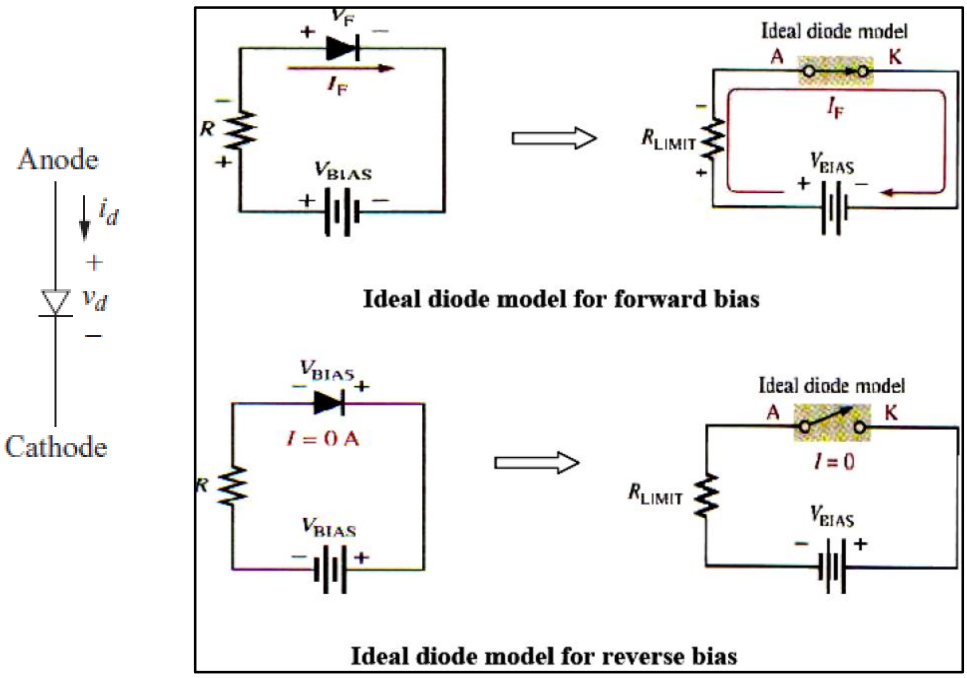
Fig. 1.2 Power semiconductor device variety

1. The power diode

A diode is the simplest electronic switch. It is uncontrollable in that the on and off conditions are determined by voltages and currents in the circuit. The diode is forward-biased (on) when the current *id* (Fig. 1-3) is positive and reverse biased (off) when *vd* is negative. In the ideal case, the diode is a short circuit.

• When forward biased, act as a closed (ON) switch.
• When reverse biased, act as open (off) switch
• This model neglects the effect of the barrier potential, the internal resistance, and other parameters.

(Fig. 1-3) diode Characteristic



♦ ***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.

2. Thyristor (SCR)

Thyristors are electronic switches used in some power electronic circuits where control of switch turn-on is required. The term thyristor often refers to a family of three-terminal devices that includes the silicon-controlled rectifier (SCR), the triac, the gate turnoff thyristor (GTO), the MOS-controlled thyristor (MCT), and others. *Thyristor* and *SCR* are terms that are sometimes used synonymously. The SCR is the device used in this textbook to illustrate controlled turn-on devices in the thyristor family. Thyristors are capable of large currents and large blocking voltages for use in high-power applications, but switching frequencies cannot be as high as when using other devices such as MOSFETs.

The three terminals of the SCR are the **anode**, **cathode**, and **gate**, Fig. 1-4*a*. it is normally **turned on** by the application of a ***gate pulse*** while it has a positive anode-to-cathode voltage (forward bias) at the main terminals. After conduction is established, the gate signal is no longer required to maintain anode current, SCR will continue to conduct as long as the anode current remains positive and above a minimum value called the ***holding level***. as well as, it cannot be **turned off** via the gate terminals, especially at the extremely high amplification factor of the gate.

The Gate Turnoff Thyristor (GTO) of Fig. 1-4*c*, like the SCR, is turned on by a short-duration gate current if the anode-to-cathode voltage is positive. However, unlike the SCR, the GTO can be turned off with a negative gate current. The GTO is therefore suitable for some applications where control of both turn-on and turnoff of a switch is required. The negative gate turnoff current can be of brief duration (a few microseconds), but its magnitude must be very large compared to the turn-on current. Typically, gate turnoff current is one third the on-state anode current. The idealized *i*-*v* characteristic is like that of Fig. 1-4*b* for the SCR.

The Triac (Fig. 1-4*d*) is a member of the thyristor family. But unlike a thyristor which conducts only in one direction (from anode to cathode) a triac can conduct in ***both directions***. Thus a triac is similar to two back to back (anti parallel) connected thyristors but with only three terminals. As in the case of a thyristor, the conduction of a triac is initiated by injecting a current pulse into the gate terminal. The gate loses control over conduction once the triac is turned on. The triac turns off only when the current through the main terminals become zero. Therefore, a triac can be categorized as a minority carrier, a bidirectional semi-controlled device. They are extensively used in residential lamp dimmers, heater control and for speed control of small single phase series and induction motors.

The MOS-controlled thyristor (MCT) in Fig. 1-4*e* is a device functionally equivalent to the GTO but without the high turnoff gate current requirement. The MCT has an SCR and two MOSFETs integrated into one device. One MOSFET turns the SCR on, and one MOSFET turns the SCR off. The MCT is turned on and off by establishing the proper voltage from gate to cathode, as opposed to establishing a gate current in the GTO.

Thyristors were historically the power electronics switch of choice because of high voltage and current ratings available. Thyristors are still used, especially in high-power applications, but ratings of power transistors have increased greatly, making the transistor more desirable in many applications.

- ✓ The primary function of a thyristor is to control electric power and current by acting as a switch

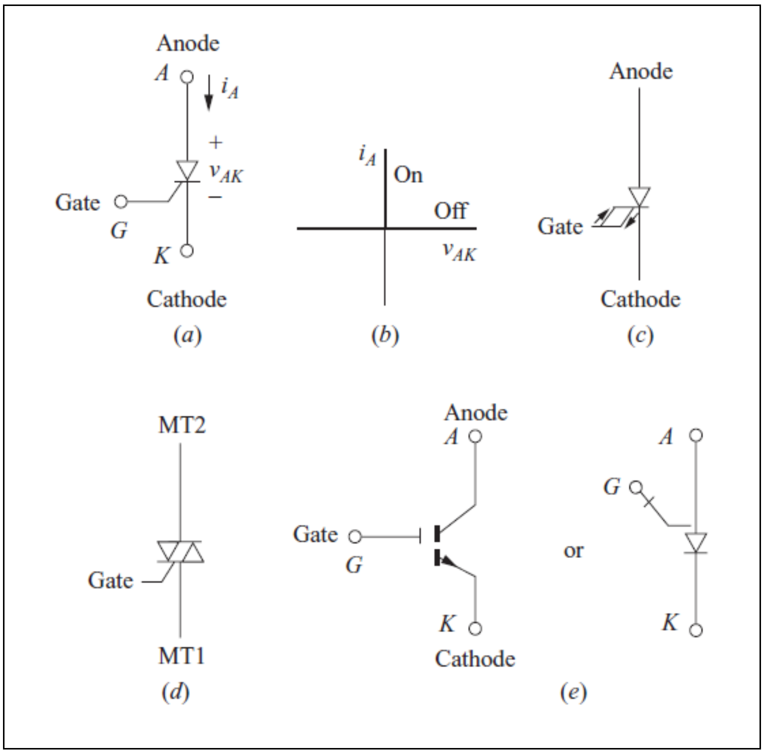


Figure 1-4 Thyristor devices: (a) silicon-controlled rectifier (SCR); (b) SCR idealized i-v characteristic; (c) gate turnoff (GTO) thyristor; (d) triac; (e) MOS-controlled thyristor (MCT).

Important features

1) Thyristor is a four layer, three terminals, minority carrier.
2) The three terminals of a thyristor are called the anode, the cathode and the gate.
3) A thyristor can be turned on by increasing the voltage of the anode with respect to the cathode beyond a specified voltage called the forward break over voltage.
4) A thyristor can also be turned on by injecting a current pulse into the gate terminal when the anode voltage is positive with respect to the cathode. This is called gate triggering.
5) A thyristor can block voltage of both polarities but conducts current only from anode to cathode.
6) After a thyristor turns on the gate loses control. It can be turned off only by bringing the anode current below holding current.
7) After turn on the voltage across the thyristor drops to a very low value (around 1 volt). In the reverse direction a thyristor blocks voltage up to reverse break down voltage.
8) A thyristor has a very low conduction voltage drop but large switching times. For this reason, thyristor are preferred for high power, low frequency line commutated application.
9) A thyristor is turned off by bringing the anode current below holding current and simultaneously applying a negative voltage (cathode positive with respect to anode) for a minimum time called “turn off time”.
10) A triac is functionally equivalent to two anti-parallel connected thyristor. It can block voltages in both directions and conduct current in both directions.
11) A triac has three terminals like a thyristor. It can be turned on in either half cycle by either a positive on a negative current pulse at the gate terminal.
12) Triacs are extensively used at power frequency ac load (e.g. heater, light, motors) control applications.