Republic of Iraq Ministry of Higher
Education and Scientific Research
Ashur University
Department of Medical Instrumentation
Technical Engineering College

POWER ELECTRONIC

Introduction of power electronic

المحاضرة الاولى

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Chapter 1

Introduction to Power Electronics

1.1 Introduction

The broad field of electrical engineering can be divided into three major areas electric power, electronics, and control. Power electronics deals with the application of power semiconductor devices, such as thyristors and transistors, for the conversion and control of electrical energy at high power levels, this conversion is usually from AC to DC or vice versa, while the parameters controlled are voltage, current, or frequency. For example, simple rectification from AC to DC is power conversion, but if voltage level adjustment is applied to rectification. Electronics, and control, as shown in Figure 1.1Power electronics: a combination.

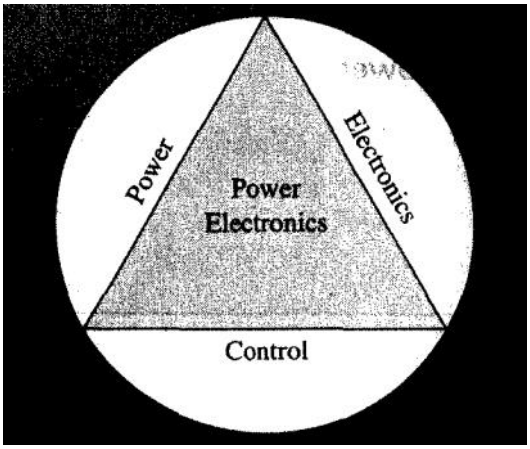
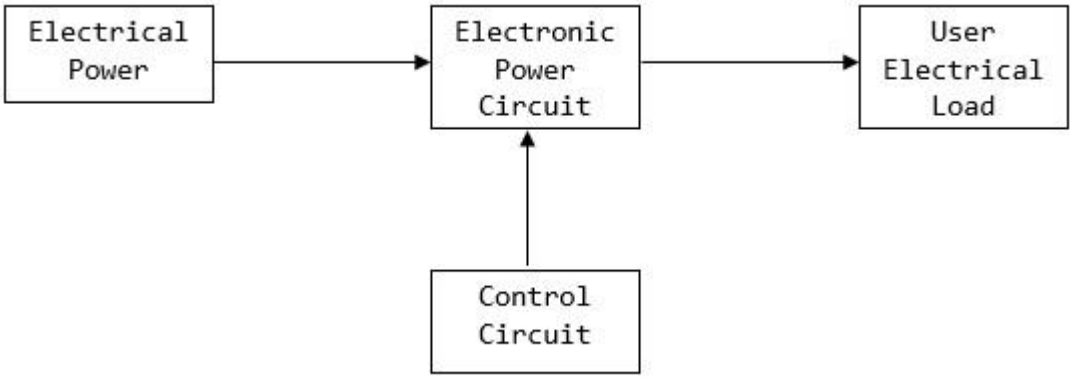


Figure 1.1 Power electronics: a combination of power, electronics and control

The following block diagram. It shows the components of a Power Electronic system and how they are interlinked.



A power electronic system converts electrical energy from one form to another and ensures the following is achieved –

- Maximum efficiency
- Maximum reliability
- Maximum availability
- Minimum cost
- Least weight
- Small size

1.2 classifications of power electronics the power electronics can be classified as: 1. ac to dc converters (rectifiers). Applications: battery chargers, high voltage dc (HVDC) transmission line.

2. DC to DC converters (choppers). Applications: space-satellite power system, robots, dc motor control.

3. DC to AC converters (inverters). Applications: photovoltaic cell, ups (uninterruptible power supplies).

4. AC to AC converters (ac power controllers).

1.2 Why Power Electronics?

Transfer of electrical power from a source to a load can be controlled either by varying the supply voltage (by using a variable transformer) or by inserting a regulator (such as a rheostat, variable reactor or switch). Semiconductor devices used as switches have the advantage of being relatively small, inexpensive, and efficient, and they can be used to control power automatically. is shown in the following section.

A Switch as a Control Device in Figure 1.2, a switch is used to control the load. When the switch is on, maximum power is delivered to the load. The power loss in the switch is zero since it has no voltage across it. When the switch is off, no power is delivered to the load. Again, the switch has no power loss since there is no current through it. The efficiency is 100% because the switch does not waste power in either of its two positions.

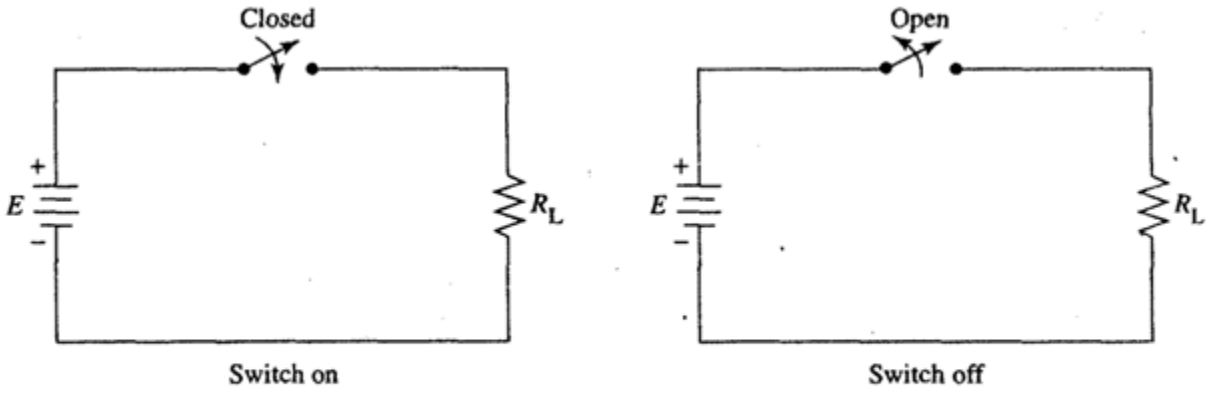


Figure 1.2
A switch controlling a load

1.3 Power Semiconductor Switches

Power semiconductor switches are the most important elements in a power electronics circuit. The major types of semiconductor devices used as switches in power electronics circuits are:

- Diodes.
- Bipolar junction transistors (BJT).
- Metal-oxide semiconductor field-effect transistors (MOSFET) .
- Insulated-gate bipolar transistors (IGBT).
- Silicon controlled rectifiers (SCR) .
- Triacs gate-turn off thyristors (GTO)
- MOS-controlled thyristors (MCT)

In power electronics, these devices are operated in the switching mode. These switches can be made to operate at high frequencies to convert and control electrical power with high efficiency and high resolution. The power loss in the switch itself is very small since either the voltage is nearly zero when the switch is on or the current is nearly zero when the switch is off.

1.4 An ideal switch satisfies the following conditions:

1. It turns on or turns off in zero time.
2. When the switch is on, the voltage drop across it is zero.
3. When the switch is off, the current through it is zero.
4. It dissipates zero power

In addition, the following conditions are desirable:

5. When on, it can carry a large current.

6. When off, it can withstand high voltage.

7. It uses little power to control its operation.

8. It is highly reliable.

9. It is small in size and weight.

10. It is low in cost.

11. It needs no maintenance.

1.5 Power Losses in Switches

Power losses in switches are the losses that occur when a switch is turned on or off. These losses are caused by the heat generated by the switch's internal resistance.

There are two main types of power losses in switches: conduction losses and switching losses.

- **Conduction losses**: Conduction losses occur when the switch is in the on state. The current flowing through the switch causes a voltage drop across the switch's internal resistance, which generates heat. The amount of conduction losses is proportional to the current flowing through the switch and the square of the switch's on-state resistance.

- **Switching losses**: Switching losses occur when the switch is turned on or off. The switching losses are caused by the current that flows through the switch during the transition from the on state to the off state, or vice versa. The amount of switching losses is proportional to the square of the switching frequency and the switch's on-state resistance.

1.6 SWITCHING DEVICES(ELECTRONIC SWITCHING)

Switching devices are the foundation of power electronics. They are used to control the flow of electric power in power converters. The most common switching devices in power electronics are:

Some of the most common electronic switching devices and useses

- **Diodes**: Diodes are unidirectional devices that allow current to flow in one direction only. They are used as rectifiers to convert AC to DC, and as clamping devices to protect other components from overvoltage.
- **Transistors**: Transistors are bidirectional devices that can be used to amplify or switch current. They are used in a variety of electronic applications, including amplifiers, oscillators, and logic gates.
- **Thyristors**: Thyristors are a type of transistor that can only be turned on by a control signal. They are used in high-power applications where it is important to *control the flow of current precisely.*
- **Insulated-gate bipolar transistors** (IGBTs): IGBTs are a type of transistor that combines the advantages of diodes and transistors. They are used in a wide variety of electronic applications, including power converters, inverters, and motor drives.
- **MOSFETs:** MOSFETs are a type of transistor that is made from metal-oxide-semiconductor technology. They are used in a variety of electronic applications, including amplifiers, oscillators, and logic gates.

The choice of electronic switching device for a particular application depends on a number of factors, including the power rating, voltage rating, switching speed, and cost.

1.7 Advantage of electronic switches

Electronic switches have many advantages over traditional mechanical switches. Here are some of the most important advantages:

- Faster switching speed: Electronic switches can switch much faster than mechanical switches. This is important in applications where the switching speed is critical, such as in power electronics.
- More precise switching: Electronic switches can switch more precisely than mechanical switches. This is important in applications where the switching needs to be controlled accurately, such as in digital circuits.
- No moving parts: electronic switches have any moving parts, which makes them more reliable than mechanical switches. Mechanical switches can wear out over time, but electronic switches do not.
- Smaller size and weight: Electronic switches are typically smaller and lighter than mechanical switches. This makes them ideal for applications where space and weight are limited.
- Lower cost: Electronic switches are typically lower cost than mechanical switches. This is due to the fact that they are simpler to manufacture.
- In automotive applications: Electronic switches are used in automotive applications to control the flow of power to different components. The reliability of electronic switches makes them ideal for use in harsh automotive environment

1.8 Classifications of power semiconductor switching devices:

Uncontrolled switch: the switch has no control terminal. The state of the switch is determined by the external voltage or current conditions of the circuit in which the switch is connected. A diode is an example of such switch.

Semi-controlled switch: in this case the circuit designer has limited control over the switch. For example, the switch can be turned-on from the control terminal. However, once on, it cannot be turned-off from the control signal. The switch can be switched off by the operation of the circuit or by an auxiliary circuit that is added to force the switch to turn-off. a thyristor or a SCR is an example of this switch type.

Fully controlled switch: the switch can be turned on and off via the control fully controlled switch: the switch can be turned-on and off via the control terminal. Examples of this switch are the BJT, the mosfet, the IGBT, the GTO thyristor, and the MOS-controlled thyristor

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Type and characteristic ,rating diode,transistor

المحاضرة الثانية

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CHAPTER 2

Power Semiconductor Switching Devices

Among all the static switching devices used in power electronics, the power diode is perhaps the simplest. Its circuit symbol shown in Figure 1.3 (a), is a two-terminal device involves the anode terminal **(A)** and the cathode terminal **(K).**

If anode terminal is at a higher potential compared to cathode terminal, the device is said to be forward biased and a forward current will flow through the device. This causes a small voltage drop across the device (<1 V), which under ideal conditions is usually ignored.

However, when cathode terminal is at a higher potential compared to anode terminal, the diode is reverse biased. It does not conduct, and the diode then experiences a small current flowing in the reverse direction called the leakage current. This current is dependent on the reverse voltage until the breakdown voltage is reached. After that, the

diode voltage remains essentially constant while the current increases dramatically. Only the resistance of the circuit limits the maximum value of the current. Simultaneous large current and large voltage in the breakdown operation lead to excessive power dissipation that could quickly destroy the diode. Therefore, the breakdown operation of the diode must be avoided. Figure 1.3 (b) illustrates diode characteristics where breakdown voltage is shown.

Both forward voltage drop and leakage current are ignored in an ideal diode. In power electronic applications, a diode is usually considered to be an ideal static

switch (Figure 1.3 (c).

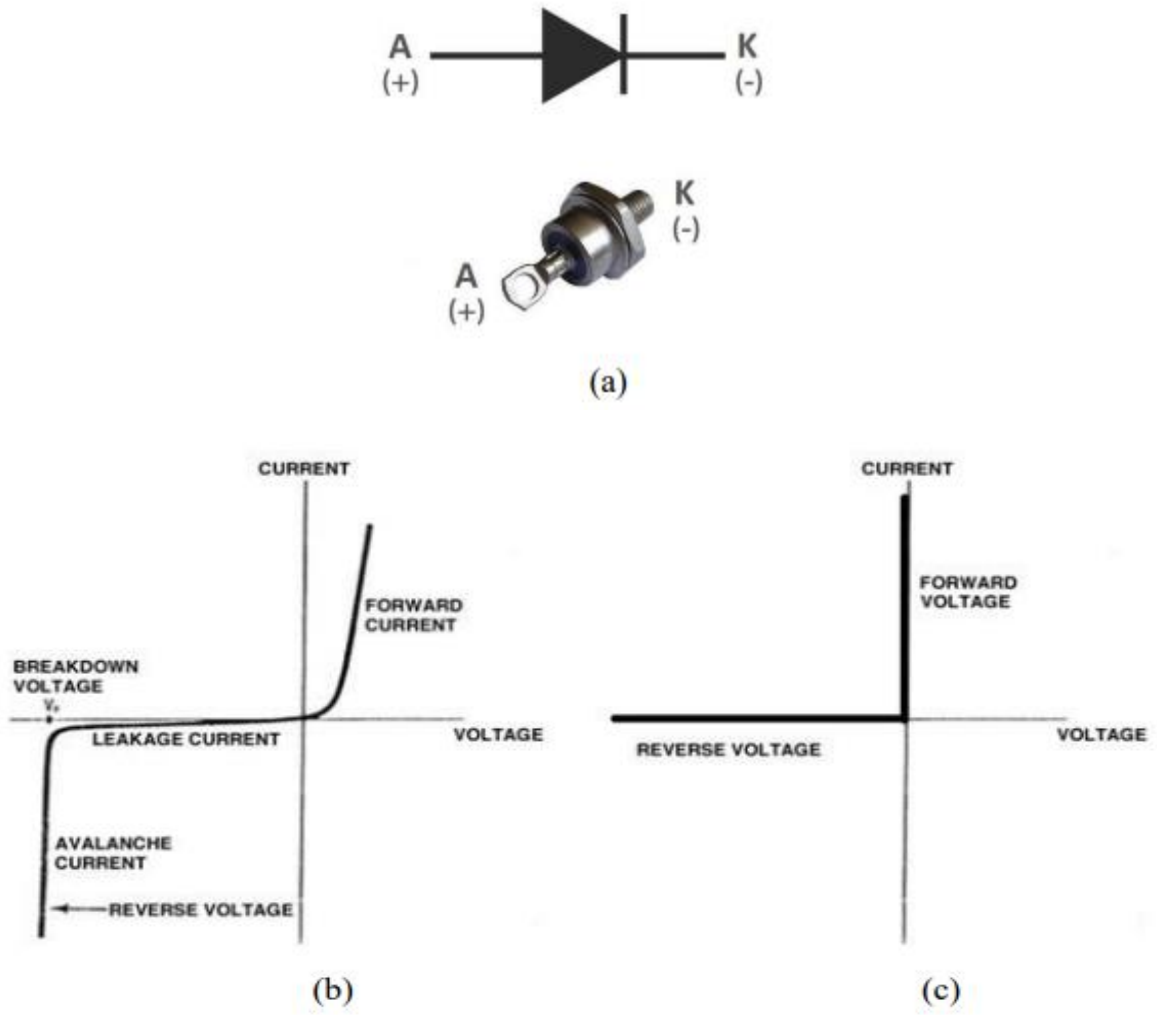


Figure 1.3: (a) Diode symbol, (b) Practical characteristics, and (c) Ideal characteristics.

A bi-directional diode that can be triggered into conduction by reaching a specific voltage (avalanche breakdown voltage), is called a **DIAC (diode for alternating current).**

When the applied voltage across the DIAC increases above the avalanche

The schottky diode

The schottky diode is a low-voltage, high-speed device that works on a different principle from that of the pn junction diode. It is constructed without the usual pn junction. Instead, a thin barrier metal (such as chromium, platinum, or tungsten) is interfaced with the n-type semiconductor. This construction results in a low on-state voltage (about 0.6 v) across the diode when it conducts. Furthermore, it can turn off much faster than a pn junction diode, so switching frequency can be high. however, the reverse leakage current is much higher, and the reverse breakdown voltage is lower compared with that of a pn junction diode. Schottky diodes are therefore used as rectifiers in low-voltage applications where the efficiency of conversion is important. These diodes are also widely used in switching power supplies that operate at frequencies of 20 KHZ or higher

1.3.2 Power Thyristors

Thyristors known as **Silicon-controlled rectifiers (SCR)** are usually three-terminal devices. 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 (often of both polarities) and conduct the major current through the thyristor. The anode and cathode terminals are connected with the load to which power is to be controlled.

Thyristors are capable of handling large blocking voltages and large currents for use in high-power applications, but their frequency capabilities are not very high, being lower than 10 kHz.

If positive voltage is applied without gate current, the thyristor constitutes the state of forward blocking. A low-power pulse of gate current switches the thyristor to the ON state. The output characteristic of a conducting thyristor in the forward bias is similar to the characteristic of the diode with a small leakage current. Thus, the thyristor assumes very low resistance in the forward direction. Once turned on, the thyristor remains in

this state after the end of the gate pulse if its current is higher than the latching value. If the current drops below the holding value, the device switches back to the non- conducting region. Switching off by gate pulse is impossible. Therefore, using the same arguments as for diodes, the thyristor can be represented by the idealized switch.

The output characteristic of SCR in the reverse bias is similar to the characteristic of the diode with a small leakage current. With negative voltage between anode and cathode, this corresponds to the reverse blocking state. If the maximum reverse voltage exceeds the permissible value, the leakage current rises rapidly, as with diodes, leading to breakdown and thermal destruction of the thyristor. Figure 1.4 (a) and (b) illustrate the SCR symbol and its practical characteristics, respectively.

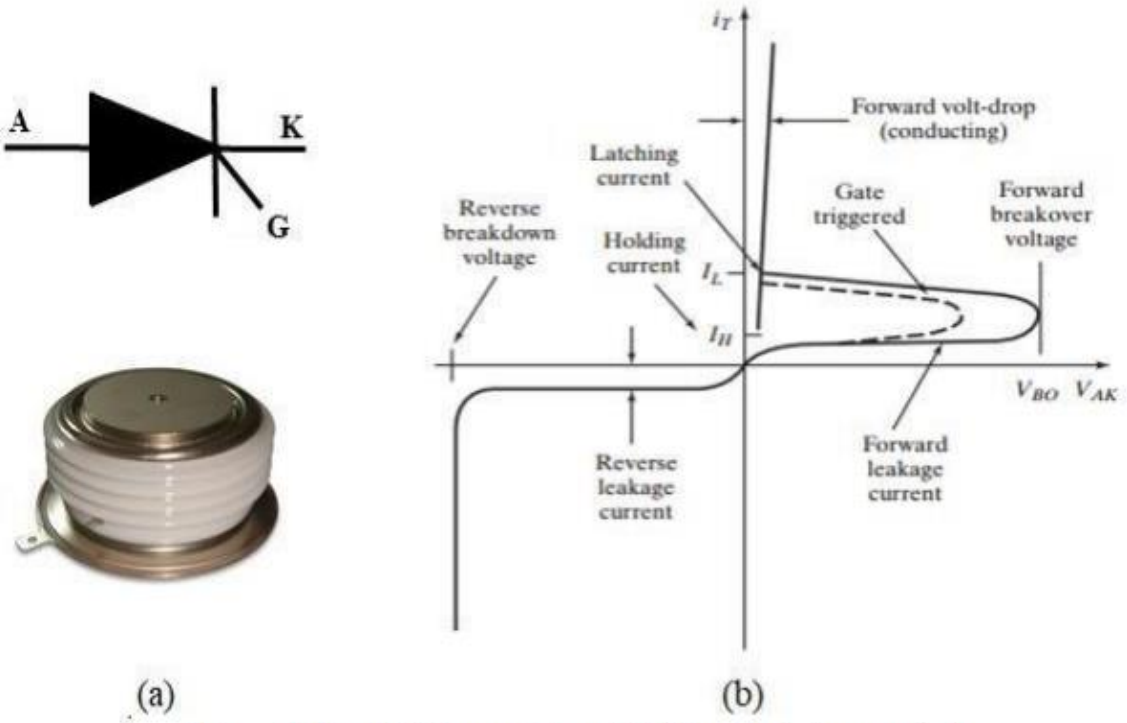


Figure 1.4: (a) SCR symbol, and (b) Practical characteristics.

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POWER ELECTRONIC

Transistor

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Chapter 3

Transistors

3.1 Introduction

Transistors with high voltage and current ratings are known as power transistors. A transistor is a three-layer PNP or NPN semiconductor device with two junctions. Transistors have two basic types of applications: amplification and switching. In power electronics, where the main objective is the efficient control of power, transistors are invariably operated as switches. They are mainly used in chopper and inverter applications.

Diodes are uncontrollable switches having only two terminals. They only respond to switch the voltage across them. Transistors, on the other hand, have three terminals. Two terminals act like switch contacts, while the third is used to turn the switch on and off. Thus, the control circuit can be independent-of the circuit being controlled.

Two types of power transistors are extensively used in power electronics circuits: the bipolar junction transistor (BJT) and the metal-oxide semiconductor field-effect transistor (MOSFET). Until the development of the power MOSFET, the BJT was the device of choice in power electronics applications.

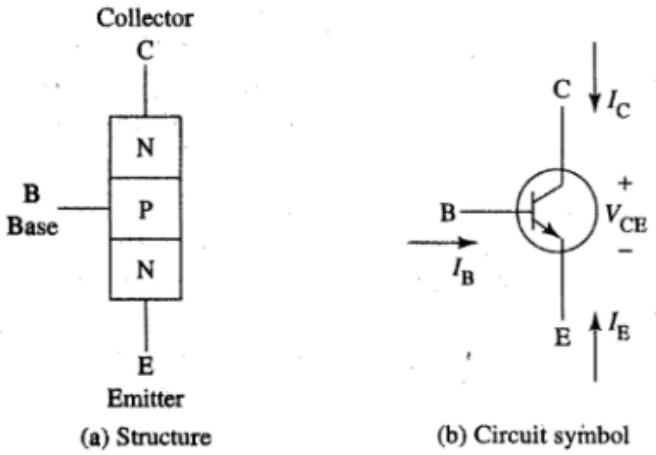
The switching speed of a BJT is many times slower than that of a MOSFET of similar size and rating. A BJT is a current-controlled device, and a large base current is required to keep the device in the on state. In addition, to obtain fast turnoff, a higher reverse base current is required. These limitations make the base drive circuit design more

complex and therefore more expensive than that of the MOSFET. Power MOSFETs, on the other hand, are voltage-controlled devices.

3.2 Power Bipolar Junction Transistors (BJTs)

Power transistors are available in both NPN and PNP types. However, we will concentrate on the NPN device, since it has a higher current and voltage rating than the PNP device. The structure and symbol of an NPN transistor are shown in Figure 3.1. This type of transistor is called a bipolar junction transistor {BJT). BJT is usually referred to as a transistor. A transistor has three terminals: the base (B), the collector (C)

Figure 3.1
An NPN transistor and its symbol



Thyristors (Silicon Controlled Rectifiers "SCRs")

The thyristor ,it is also called silicon controlled rectifier (SCR), is a four-layer, three terminal switching semiconductor device, with each layer consisting of an alternately N or P-type material, for example N-P-N-P. The main Terminals, labeled anode and cathode, are across the full four layers, and the control terminal, called the gate, is attached to one of the middle layers as shown in Fig 3.2

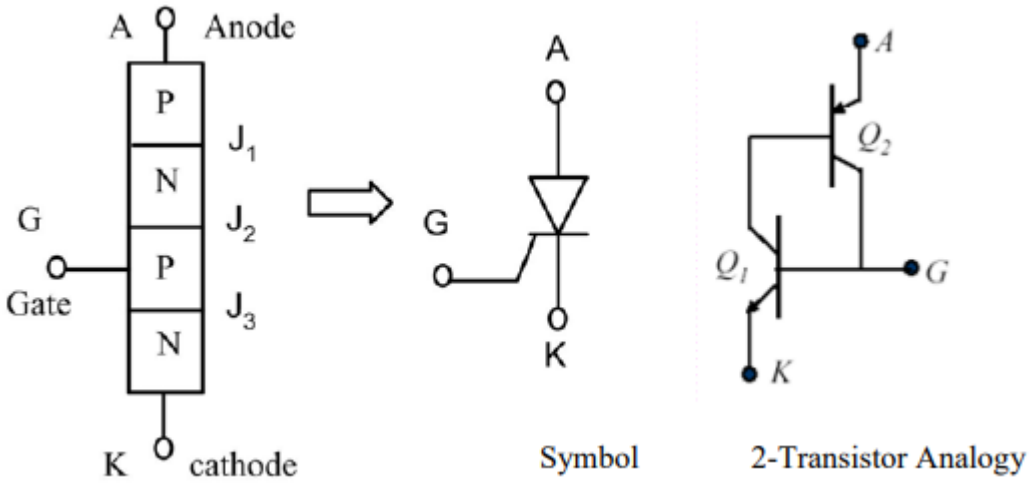
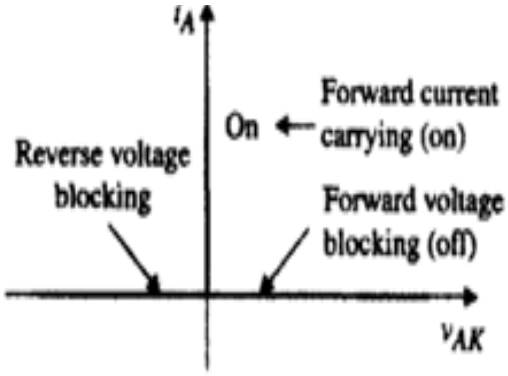


Fig.3.2: The thyristor and its equivalent 2-transistor circuit.

SCRs are mainly used where high currents and voltages are involved, and are often used to control alternating currents, where the change of sign of the current causes the device to automatically switch off. Like a diode, an SCR conducts only in one direction. The SCR symbol and its ideal characteristic are shown in Fig ,3.3 Modern SCRs can switch large amounts of power (up to megawatts). In the realm of very high power applications, they are still the primary choice. SCR is a controllable switch that usually required to be latched to conduct. This latching (triggering) process is carried out by injecting current to the gate terminal (i_g), Fig.3.4, at the required latching instant provided that the device is forward biased (v_{AK} is positive). Practically, the thyristor characteristic has three main regions as shown in Fig. 3.5;

- the Conduction Region where the thyristor is operating in its ON state,
- the Forward Blocking Region where the thyristor is forward biased but not yet triggered or the voltage didn't reach the forward breakover voltage, and
- the Reverse Region that consists of the reverse blocking region and the reverse avalanche region similar to the diode characteristic.



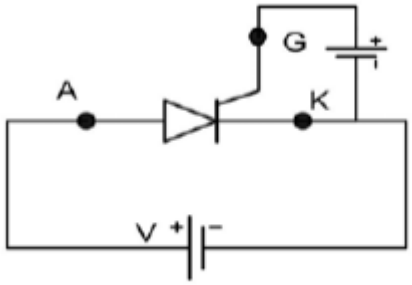


FIG. 3.3 thyristor:(a) symbol,

(b) Ideal characteristic,

Fig.3.4 thyristor gate CIRCUIT

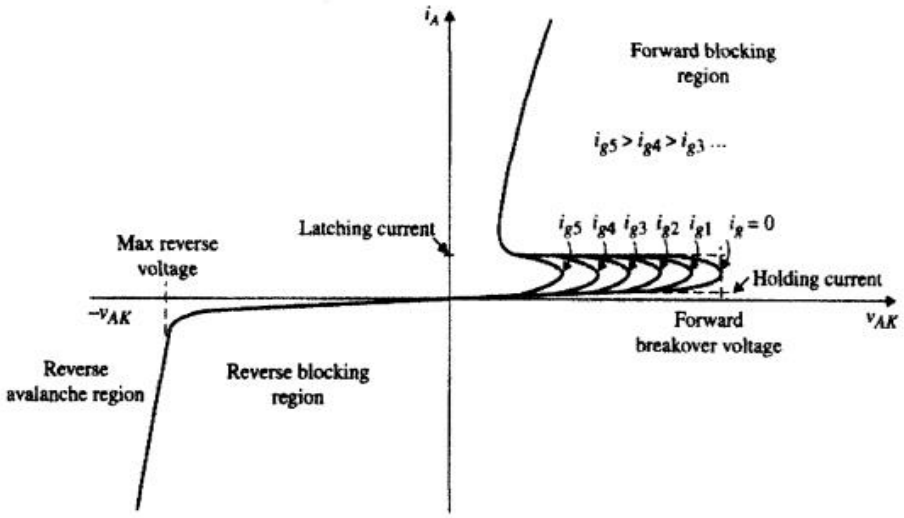


Fig.3.5 thyristor (scr) characteristic

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Thyristors can only be turned on with three conditions:

1. The device must be forward biased, i.e., the anode should be more positive than the cathode.
2. A positive gate current *(Ig)* should be applied at the gate.
3. the current through the thyristor should be more than the latching current.

Once conducting ,the anode current is LATCHED (continuously flowing).

Important points for the SCR characteristic:

- **Latching Current:** This is the minimum current required to turn on the SCR device and convert it from the Forward Blocking State to the ON State.
- **Holding Current:** This is the minimum forward current flowing through the thyristor in the absence of the gate triggering pulse.
- **Forward Breakover Voltage:** This is the forward voltage required to be applied across the thyristor to turn it ON without the gate signal application.
- **Max Reverse Voltage:** This is the maximum reverse voltage to be applied across the thyristor before the reverse avalanche occurs.

Ideally, SCRs are represented by a short circuit when operating within the conduction region and as an open circuit when operating within the blocking region. The ideal characteristic is shown in Fig. 2-b. It is also worth mentioning that once the SCR is triggered and turned ON the gate signal can be removed without turning it OFF. SCRs are turned OFF when reversing the terminal voltage and current.

Turning on/off mechanism

- Thyristor (SCR) Conduction
- In reverse -biased mode, the SCR behaves like a diode. It conducts a small leakage current which is almost dependent of the voltage, but increases with temperature. When the peak reverse voltage is exceeded, avalanche breakdown occurs, and the large current will flow.
- In the forward biased mode, with no gate current present (i.e. in the untriggered state, the device exhibits a leakage current. If the forward breakover voltage (Vbo) is exceeded, the SCR "self-triggers" into the conducting state and the voltage collapses to the normal forward volt-drop, typically 1.5-3V. The presence of any gate current i_g will reduce the forward breakover voltage and will trigger the thyristor at any required instant (α), see Fig.**3.6**

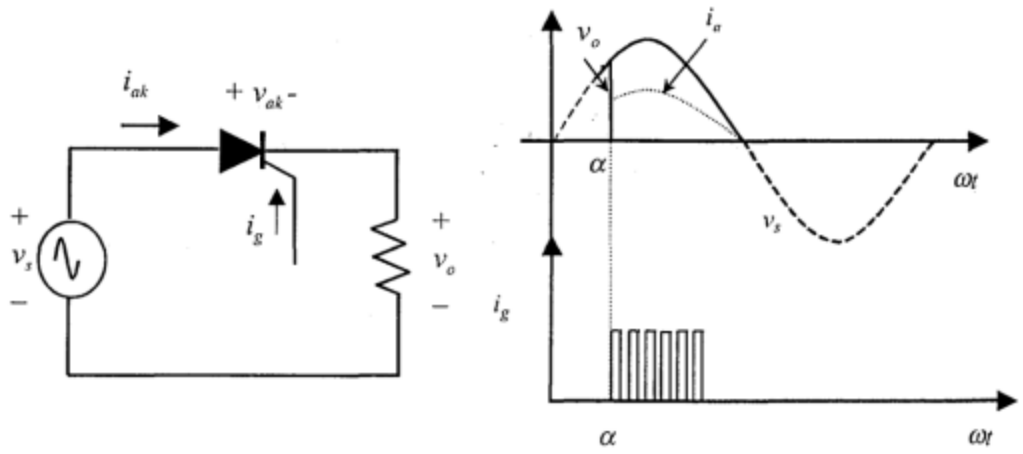


FIG 3.6

Fig.2.7

- Thyristor turn off

The process of turning OFF SCR is defined as "Commutation". Thyristor cannot be turned off by applying negative gate current. It can only be turned off if the current *I* through it goes negative (reverse). In all commutation techniques, a reverse voltage is applied across the thyristor during the turn OFF process.
There are two methods by which a thyristor can be turned OFF.

i. Natural Commutation
ii. Forced Commutation

Natural Commutation

In AC circuit, the current always passes through zero for every half cycle. As the current passes through natural zero, a reverse voltage will simultaneously appear across the device. This will turn OFF the device immediately. This happens when negative portion of the of sine-wave occurs. This process is called as "natural commutation" since no external circuit is required for this purpose.

Forced Commutation

Another method of turning off is known as "forced commutation". The anode Current is “diverted” to another circuitry. To turn OFF a thyristor, the forward anode current should be brought to zero for sufficient time to allow the removal of charged carriers. In case of DC circuits the forward current should be forced to zero by means of some external circuits.

1. **Phase controlled**

- rectifying line frequency voltage and current for ac and dc motor drives .
- large voltage (up to 7 kV) and current (up to 5 kA) type1 capability .
- low on-state voltage drop (1.5 to 3V).

2. **Inverter grade**

- used in inverter and chopper
- Quite fast. Can be turned-on using “force commutation” method.

3. **Light activated**

- Similar to phase controlled, but triggered by pulse of light .
- Normally very high power ratings.

SCR ratings for voltage and current approach those of diodes. Devices for high-voltage dc (HVDC) conversion have been built with simultaneous 12 kV and 6 kA type 2 ratings. Figure 3.7 below shows types of thyristors in practice.



Fig 3.7 Power semiconductor switches (thyristors).

3.3 The Triac

The triac is a two thyristors connected back – to – back, used for high or medium power control for both a.c and d.c applications, as shown in Fig. **3.8** Either of the electrodes MT1 and MT2 can act as anode and either is cathode. The device can be triggered by either positive or negative voltage on the gate with respect to MT1.This device is effectively two thyristors (SCR s) back- to-back in construction with an external n-region which is the gate.

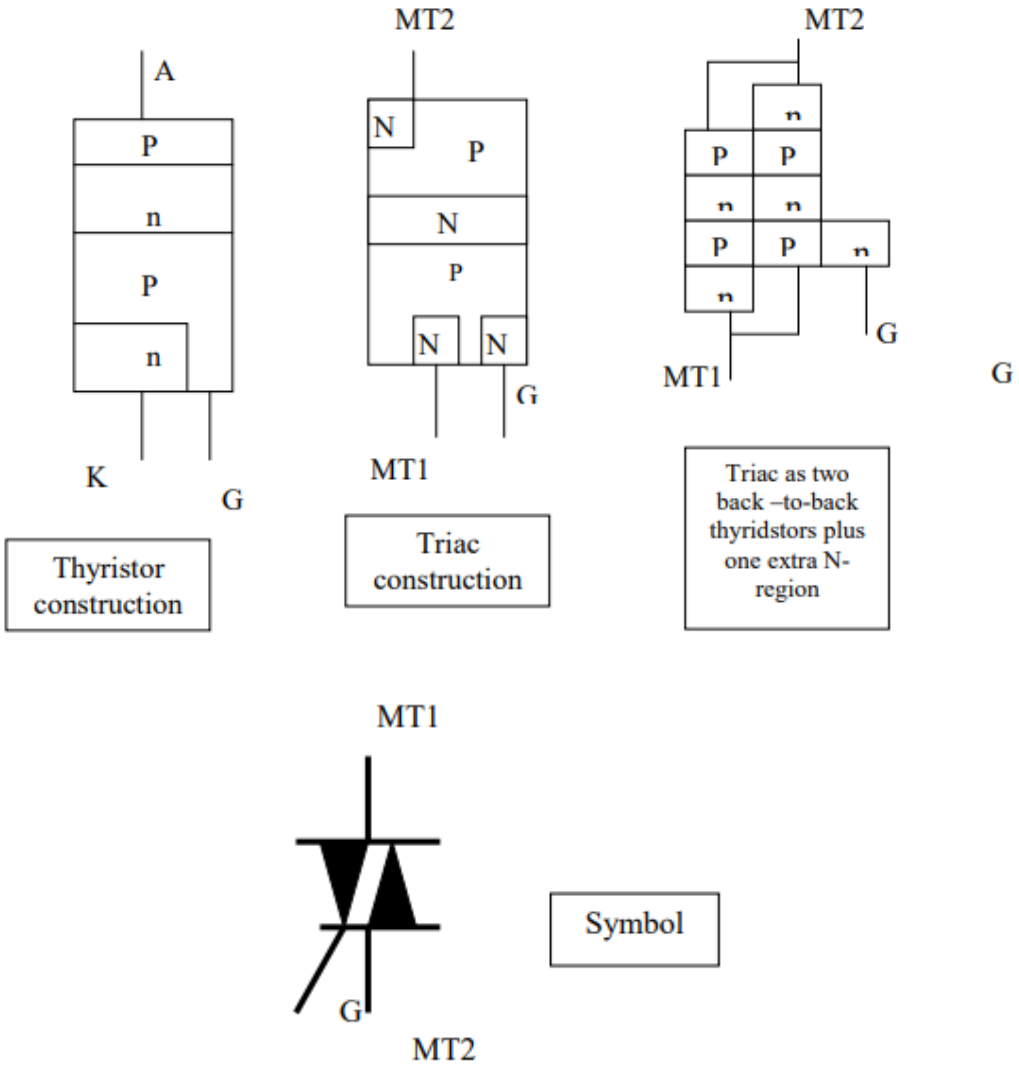
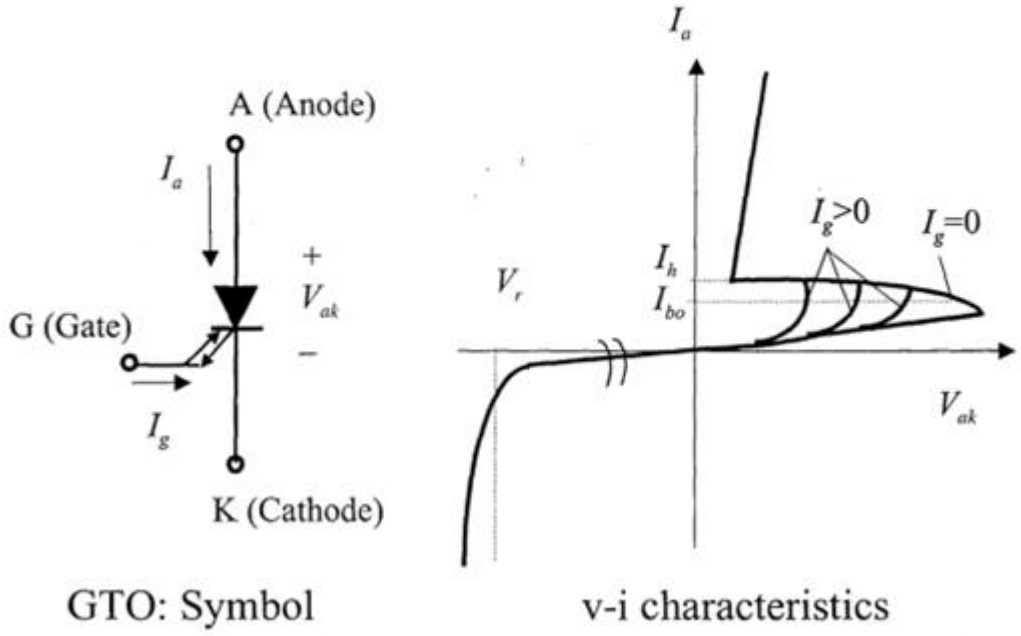


Fig 3.8

3.4 Gate Turn Off Thyristors (GTO Thyristors).

GTO behaves like normal thyristor, but can be turned off using gate signal. However turning off is difficult. Need very large reverse gate current (normally 1/5 of anode current).GTO symbol and characteristics are shown in Fig.3.9



GTO: Symbol v-i characteristics

Fig.3.9 Gate turns off thyristor

3.5 Metal Oxide Semiconductor Field Effect Transistors

"MOSFETs"

Three terminals are called the source, drain, and gate. The voltage applied to the gate controls the current flowing in the source-drain channel. No current flows through the gate electrode, thus the gate is essentially insulated from the source-drain channel. Because no current flows through the gate, the input impedance of the FET is extremely large (in the range of 1010–1015 Ω). The large input impedance of the A field-effect transistor is a semiconductor device that uses the electric field effect of the control input circuit to control the output circuit current and is named after it. Because it only depends on the majority carrier in the semiconductor to conduct electricity, it is also called the unipolar transistor. There are two main types: junction FET (JFET) and metal-oxide-semiconductor FET (MOSFET).

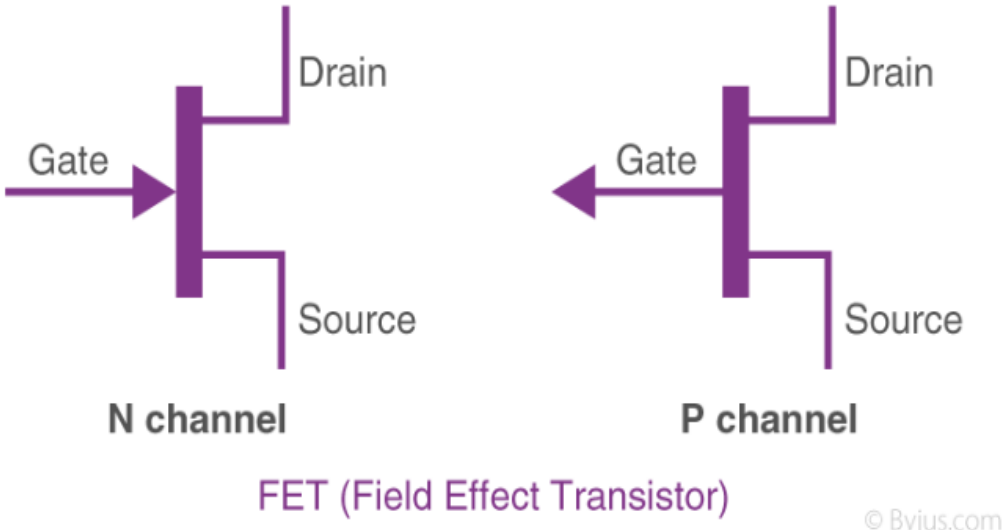


Fig 3.10

3.6 Field-effect transistors (FETs) have a number of advantages over other types of transistors, including:

- Low input current: FETs require a very small input current to control the flow of current. This makes them ideal for applications where power consumption is a concern.
- High input impedance: The input impedance of a FET is very high, which means that it does not load the circuit that it is connected to. This is also an advantage in applications where power consumption is a concern.
- Fast switching speed: FETs can switch very quickly, which makes them ideal for digital applications.
- High reliability: FETs are very reliable devices and can withstand a wide range of operating conditions.
- Small size: FETs are typically much smaller than other types of transistors, which makes them ideal for portable devices.
- Low cost: FETs are relatively inexpensive to manufacture, which makes them a cost-effective choice for many applications.

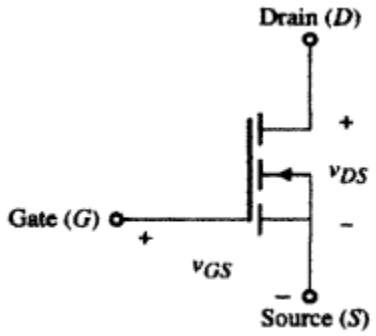


FIG.3.11 Mosfet: symbol (n-channel)

Mosfet characteristics**:**

- Turning on and off is very simple. Only need to provide v_{gs} = +15v to turn on and 0v to turn off. Gate drive circuit is simple.
- Basically low voltage device. High voltage device are available up to 600v but with limited current. Can be paralleled quite easily for higher current capability.
- Dominant in high frequency application (>100 KHF). Biggest application is in switched-mode power supplies.
- On state loss relatively high. v_{ds} > 3 v.

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3.7 PROTECTION OF POWER DEVICES

Power semiconductor devices are used in a wide variety of applications, including power converters, motor drives, and power supplies. These devices are subjected to a variety of stresses, including overvoltage's, overcurrent's, and transients. These stresses can damage the devices and lead to premature failure.

There are two main types of protection required for power semiconductor devices:

- **Overvoltage protection** is used to protect the devices from excessive voltage spikes. This can be achieved by using a variety of methods, such as zener diodes, varistors, and crowbar circuits.
- **Overcurrent protection** is used to protect the devices from excessive current. This can be achieved by using fuses, circuit breakers, and current-limiting resistors.

In addition to overvoltage and overcurrent protection, power semiconductor devices may also require protection from other stresses, such as:

- **Temperature rise**. Power semiconductor devices generate heat when they operate. If the heat is not dissipated properly, the devices can overheat and fail.
- **Transients**. Transients are short-duration voltage or current spikes that can occur in power systems. These transients can damage power semiconductor devices.
- **Electromagnetic interference (EMI).** EMI is a form of noise that can be generated by power semiconductor devices. This noise can interfere with the operation of other electronic devices.

The specific protection requirements for a power semiconductor device will depend on the application and the operating environment. It is important to consult with a power electronics engineer to determine the appropriate protection measures for a particular application.

Here are some additional details about the different types of protection for power semiconductor devices:

- **Overvoltage protection. Zener diodes** are the most common type of overvoltage protection device for power semiconductor devices. They are connected in parallel with the device and will conduct current if the voltage exceeds their breakdown voltage. Varistors are another type of overvoltage protection device. They are less sensitive to temperature than zener diodes and can handle larger currents. Crowbar circuits are used to protect devices from very high voltages. They are typically used in conjunction with zener diodes or varistors.
- **Overcurrent protection. Fuses** are the most common type of overcurrent protection device for power semiconductor devices. They are connected in series with the device and will melt if the current exceeds their rating. Circuit breakers are also used for overcurrent protection. They are more expensive than fuses, but they can be reset after they have tripped. Current-limiting resistors are used to limit the current that flows through a device. They are typically used in conjunction with fuses or circuit breakers.
- **Other protection measures**. In addition to overvoltage and overcurrent protection, power semiconductor devices may also require other protection measures, such as:
  - **Thermal protection**. This is used to protect devices from overheating. It can be achieved by using heat sinks, fans, or thermostats.
  - **EMI protection**. This is used to protect devices from electromagnetic interference. It can be achieved by using filters, shielding, or ground