Al-Mustaqbal University College
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Power Electronic
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Lecture: 1

Chapter 1

Introduction to Power Electronics

1.1 Introduction

Power electronics (PE): A field of Electrical Engineering that deals with the application of power semiconductor devices for the control and conversion of electric power.

Power electronics systems can operate in the range from few watts up to GW, with frequency range from 50 Hz up to more than 100 kHz, depending on the power handled and the requirements.

The goals of Power Electronics:

- To process and control the flow of electrical power by supplying voltages and currents in a form that is optimally suited for user loads.
- To convert electrical energy from one form to another with highest efficiency, availability and reliability, with the lowest cost, smallest size, and weight.

As shown in Figure 1.1, power electronics represents a median point at which the topics of energy systems, electronics, and control converge. Any useful circuit design for the control of power must address issues of both devices and control, as well as of the energy itself. Among the unique aspects of power electronics are its emphasis on large semiconductor devices, the application of magnetic devices for

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energy storage.

The development of semiconductor switches manufacturing regarding their very high ratings and their ability in high frequency systems are the basic keys in the development of power electronics engineering.

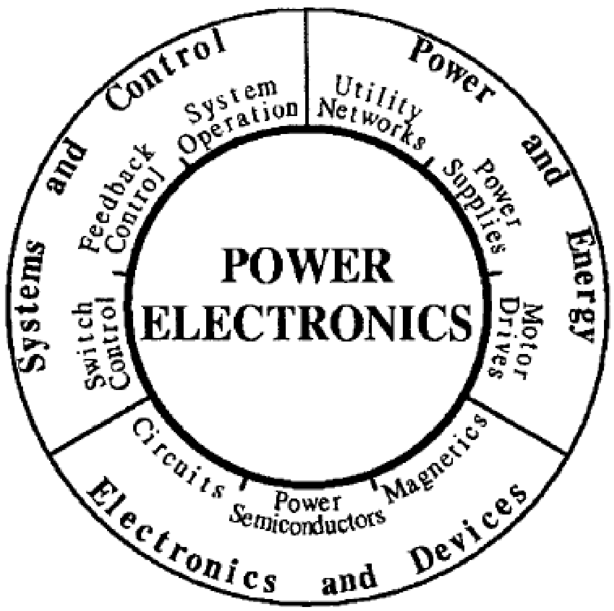


Figure 1.1: Control, energy, and power electronics are interrelated.

A basic power electronic system is shown in Figure 1.2. It consists of an energy source, an electrical load, a power electronic circuit, and control circuit. The function of the power electronic positioned at the middle is that of controlling energy flow between the energy load and the electrical load. The power electronic circuit contains high power switches, lossless energy storage elements, and magnetic transformers. The control circuit take information from the source, load, and designer and then determine how the switches operate to achieve the desired conversion. The control circuit is usually built up with conventional low-power analog and digital electronics.

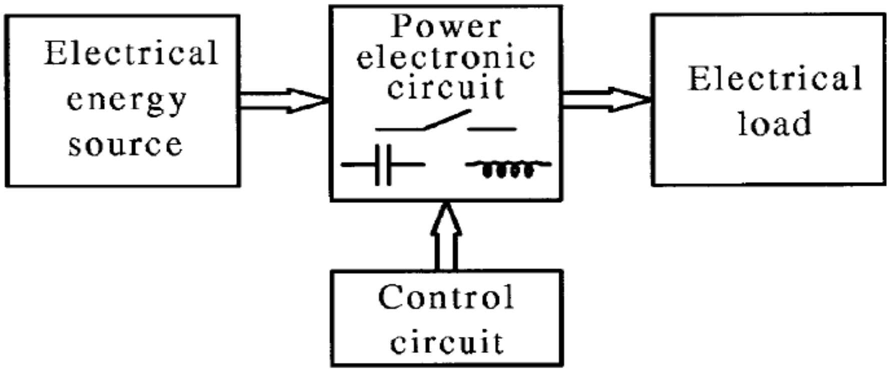


Figure 1.2: A basic power electronic system.

1.2 Classification 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).

   Applications: Fun regulator, Lighting system for theatres.

1.3 Power Semiconductor Switching Devices

At first, a power semiconductor switching device is either ON or OFF. An ideal switch, when ON, will carry the current without any voltage drop across the switch. When OFF, no current will pass through it. It is entirely lossless and changes from its ON state to its OFF state instantaneously. Those aspects of real switches that differ from the ideal include the following:

- ✓ Limits on the direction of on-state current.
- ✓ A nonzero on-state voltage drop (such as a diode forward voltage).
- ✓ Some level of leakage current when the device is supposed to be off.
- ✓ Limitations on the voltage that can be applied when off.
- ✓ Operating speed. The time of transition between the on and off states is significant (Not equal to zero).

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 terminal. Examples of this switch are the BJT, the MOSFET, the IGBT, the GTO thyristor, and the MOS-controlled thyristor (MCT).

1.3.1 Power Diodes

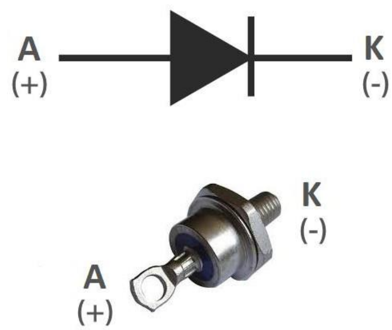
Among all the static switching devices used in power electronics, the power diode is perhaps the simplest. Its circuit symbol shown in Figure 1.3 (a), is a two-terminal device involves the anode terminal (**A)** and the cathode terminal (**K).**

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.

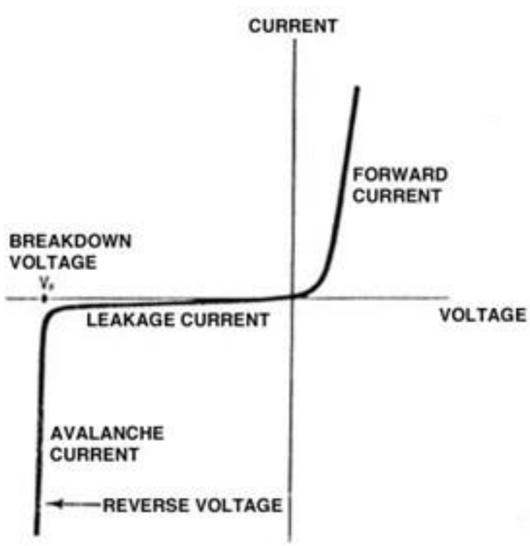
However, when cathode terminal is at a higher potential compared to anode terminal, the diode is reverse biased. It does not conduct, and the diode then experiences a small current flowing in the reverse direction called the leakage current. This current is dependent on the reverse voltage until the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

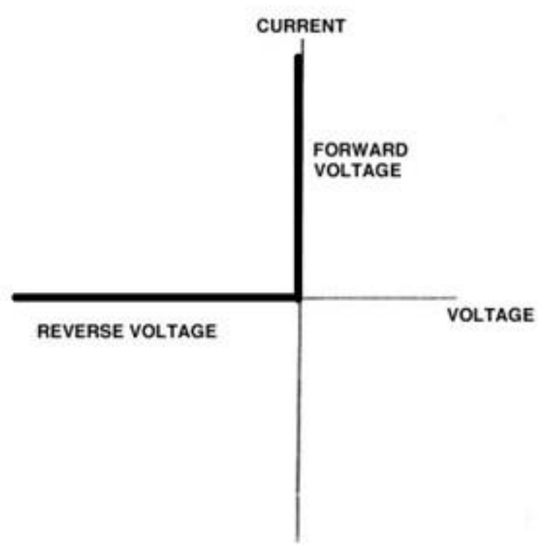
Both forward voltage drop and leakage current are ignored in an ideal diode. In power electronic applications, a diode is usually considered to be an ideal static switch (Figure 1.3 (c).



(a)



(b)



(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

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breakdown voltage, only then it can conduct. However, when the voltage across DIAC decreases below its avalanche breakdown voltage it will be turned OFF.

The DIAC symbol is a combination of two diodes in parallel with each other but connected in opposite directions. DIACs have no gate terminal, unlike some other thyristors that they are commonly used to trigger, such as TRIACs.

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

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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.

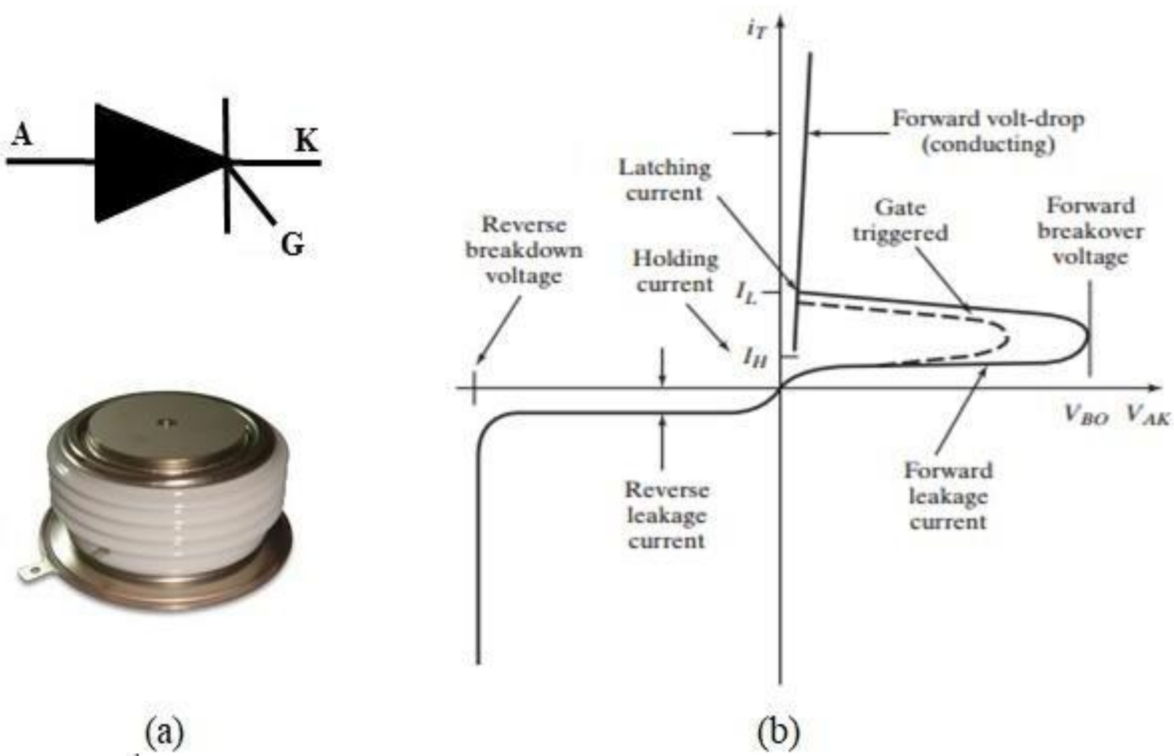

Figure 1.4: (a) SCR symbol, and (b) Practical characteristics.

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TRIAC (Triode for alternating current)

A TRIAC (bi-directional thyristor) is a member of the thyristor family which can conduct in both directions. It is the equivalent of two reverse parallel connected thyristors with the common gate.

TRIACs differ from SCRs in that they allow current flow in both directions, whereas an SCR can only conduct current in a single direction. Most TRIACs can be triggered by applying either a positive or negative voltage to the gate (an SCR requires a positive voltage).

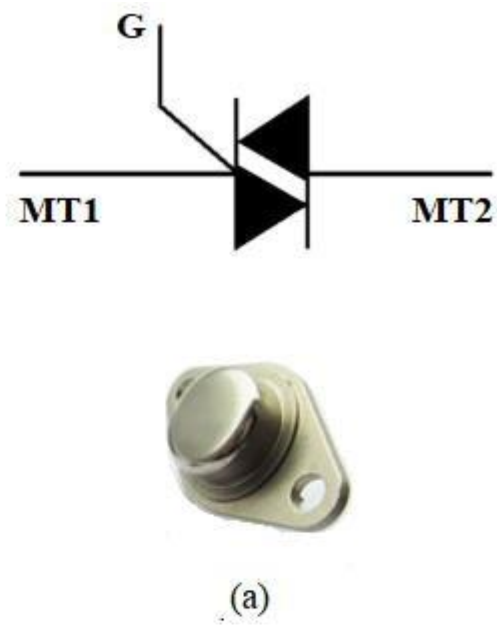
As the TRIAC can conduct in both the directions, the terms “anode” and “cathode” are not used for TRIACs. The three terminals are marked as MT1 (Main Terminal 1), MT2 (Main Terminal 2) and G (Gate Terminal). Figure 1.5 (a) shows the TRIAC symbol.

The conduction of a TRIAC is initiated by injecting a current pulse into the gate terminal. The TRIAC turns off only when the current through the main terminals become zero.

To understand how TRIACs work, consider the triggering in each of the four quadrants. The four quadrants are illustrated in Figure 1.5 (b). They are depending on the gate and MT2 voltages with respect to MT1, as given below.

- **Quadrant 1** operation occurs when the gate and MT2 are positive with respect to MT1.
- **Quadrant 2** operation occurs when the gate is negative and MT2 is positive with respect to MT1.
- **Quadrant 3** operation occurs when the gate and MT2 are negative with respect to MT1.
- **Quadrant 4** operation occurs when the gate is positive and MT2 is negative with respect to MT1.

In almost all applications, both gate and MT2 positive or negative against MT1, so quadrants 1 and 3 are the only operating modes. Figure 1.5 (c) illustrates the TRIAC practical characteristics.



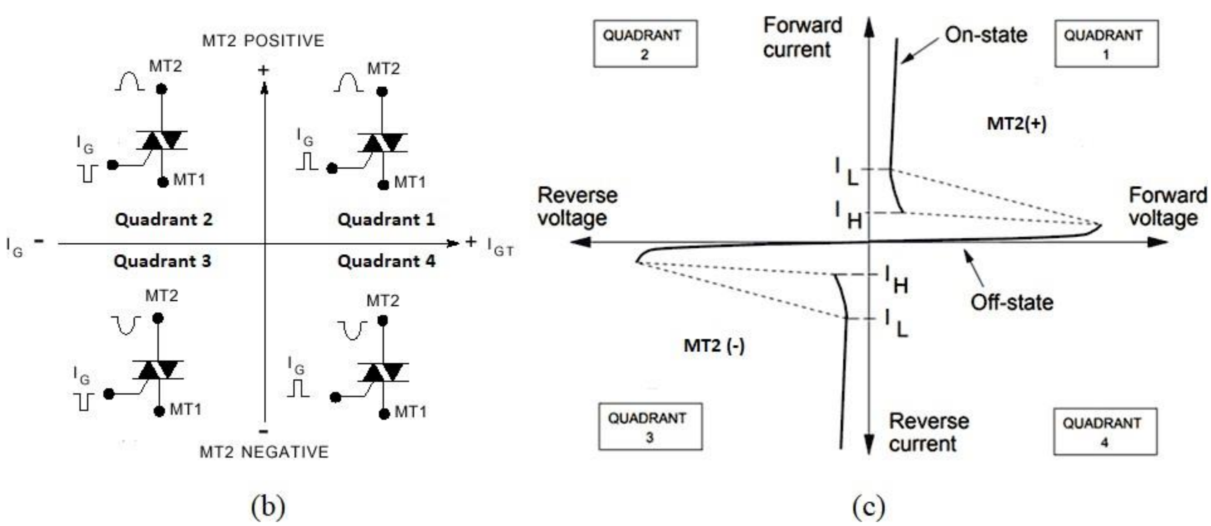


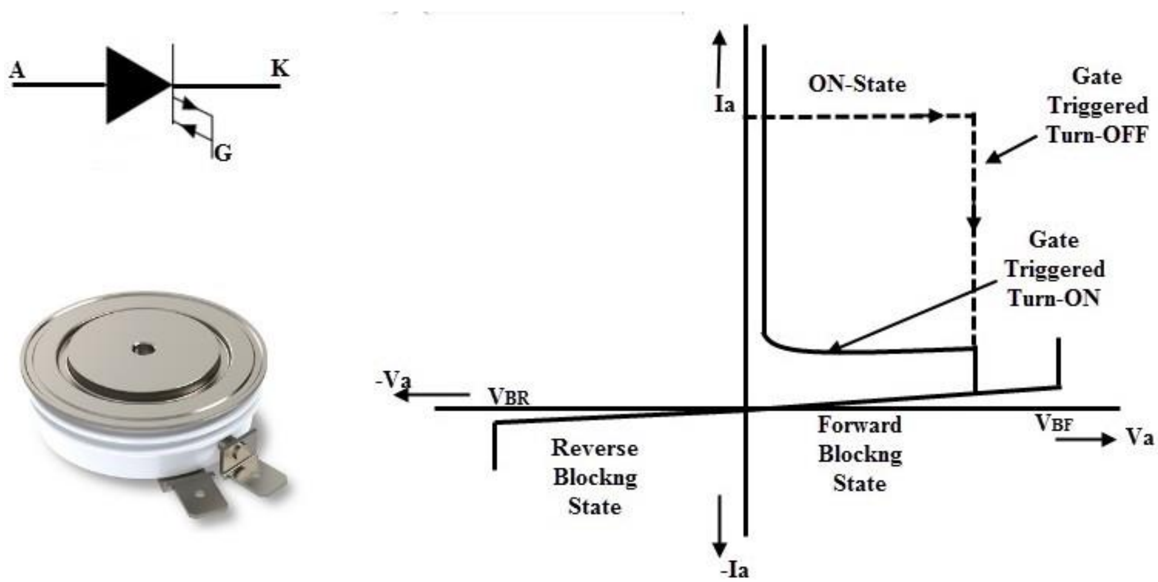
Figure 1.5: (a) TRIAC symbol, (b) Quadrant diagram, and (c) Practical characteristics.

Gate turn-off thyristor (GTO)

GTO is a special type of thyristor, which provides more control. As opposed to normal thyristors, GTOs are fully controllable switches which can be turned ON and OFF by switching the polarity of the gate signal.

The GTO thyristor turns ON similarly to the SCR thyristor, i.e. after a current pulse is applied to the gate terminal. To turn it OFF, a powerful negative current control pulse must be applied to the gate terminal.

Figure 1.6 (a) and (b) illustrate the GTO symbol and its practical characteristics, respectively.



(a) (b)

Figure 1.6: (a) GTO symbol, and (b) Practical characteristics.

The MOS-Controlled Thyristor (MCT)

The MCT has many of the properties of a GTO thyristor, including a low voltage drop at high current. Nevertheless, it is a voltage-controlled device. Here, turning ON is controlled by applying a positive voltage signal to the gate, and turning OFF by a negative voltage. Therefore, the MCT has two principle advantages over the GTO, including much simpler drive requirements (voltage instead of current) and faster switching speeds (few microseconds).

1.3.3 Power Transistors

Power transistors are three-terminal semiconductor electronic devices that can be used as switches. Transistors are turned ON when a current or voltage signal is applied to the control terminal. The transistor remains in the ON-state so long as control signal is present. When this control signal is removed, the power transistor is turned OFF. The switching speed of modern transistors is much higher than that of thyristors. In addition, the control circuit is much simpler than that used in thyristors. Power transistors are classified as follows:

Bipolar junction transistors (BJTs)

The power BJT has three terminals, Collector (C), Emitter (E) and Base (B), as shown in Figure 1.7 (a). BJT is a current-controlled device. The Base (B) is connected to the control signal, while the power terminals are the Collector (C) and the Emitter (E).

The device has three regions as shown in Figure 1.7 (b). However, the only two regions that are used in power electronics are, the on-state region where V_{CE} is less than $V_{CE(Sat)}$ and the off-state region where $I_B = 0$. Neglecting the middle region, the idealized device characteristics as a switch are shown in Figure 1.7 (c).

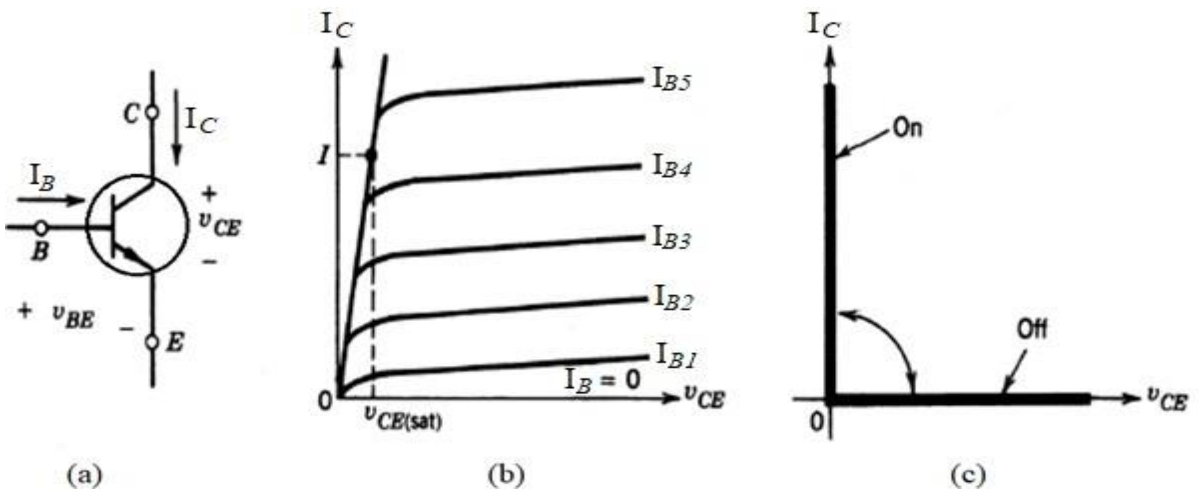


Figure 1.7: (a) BJT symbol, (b) practical characteristics of BJT, and (c) idealized characteristics of BJT.

Metal-oxide-semiconductor field-effect transistors (MOSFETs).

MOSFET is a voltage-controlled device which has three terminals. The Gate (G) is connected to the control signal, while the power terminals are the Drain (D) and Source (S), as shown in Figure 1.8 (a).

Similar to BJT, the MOSFET has three regions as shown in Figure 1.8 (b). The device is controlled by supplying a voltage (V_{GS}) between the gate and the source. To maintain the MOSFET in the off-state, V_{GS} must be less than a threshold voltage known as V_T. However, V_{GS} must be high enough (depending on its specifications) to make the MOSFET in on-state. Neglecting the middle region, the idealized device characteristics as a switch are shown in Figure 1.8 (c).

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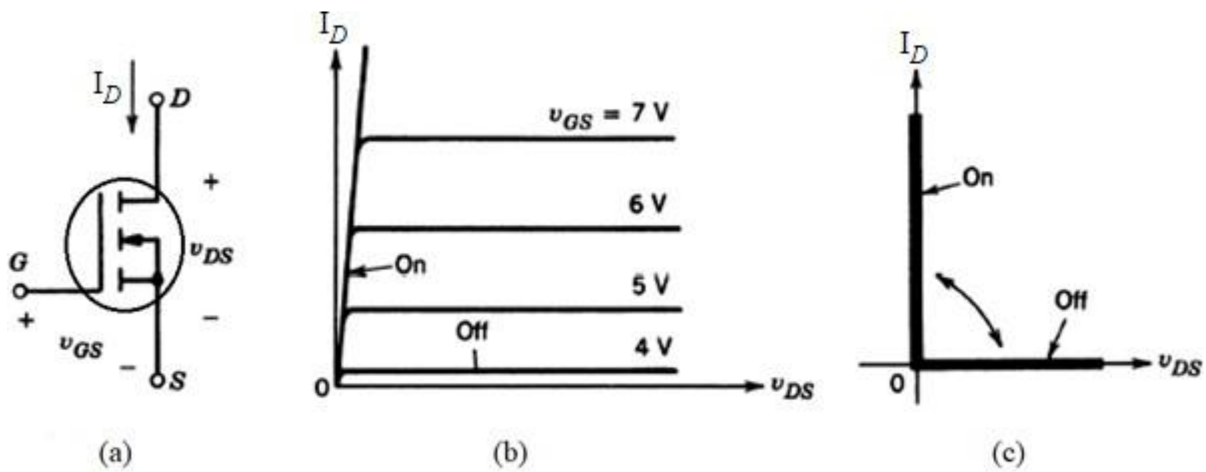

Figure 1.8: (a) MOSFET symbol, (b) practical characteristics of MOSFET, and (c) idealized characteristics of MOSFET.

Insulated gate bipolar transistors (IGBTs).

The IGBT Transistor takes the best parts of BJT and MOSFET, the high input impedance and high switching speeds of a MOSFET with the low saturation voltage of a bipolar transistor, and combines them together to produce another type of transistor

switching device that is capable of handling large collector-emitter currents with virtually zero gate current drive.

As shown in Figure 1.9 (a), the Gate (G) is connected to the control signal, while the power terminals are the collector (C) and emitter (E). The device is controlled by applying a voltage (V_{GE}) between the gate and the emitter. Figure 1.9 (b) and (c) illustrate the practical and idealized characteristics of the IGBT, respectively.

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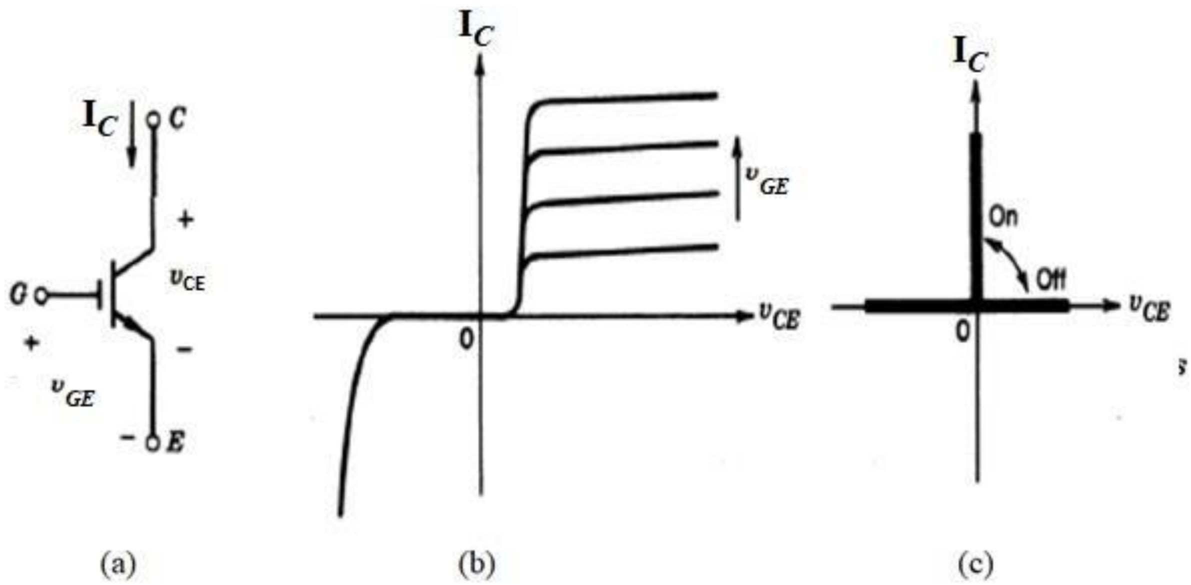

Figure 1.9: (a) IGBT symbol, (b) practical characteristics of IGBT, and (c) idealized characteristics of IGBT.

1.4 Recent power semiconductor switching devices

Diodes, thyristors and transistors are the essential component of the power electronic applications. Today, the single wafer diodes are able to block more than 9 kV over a wide temperature range. At the same time, thyristors withstand more than 10 kV. These devices conduct up to 5 kA. The levels of 6 kV and 0.6 kA are approachable by power

transistor. A comparative diagram of power ratings and switching speeds of the controlled semiconductor electronic devices is given in Figure 1.10.

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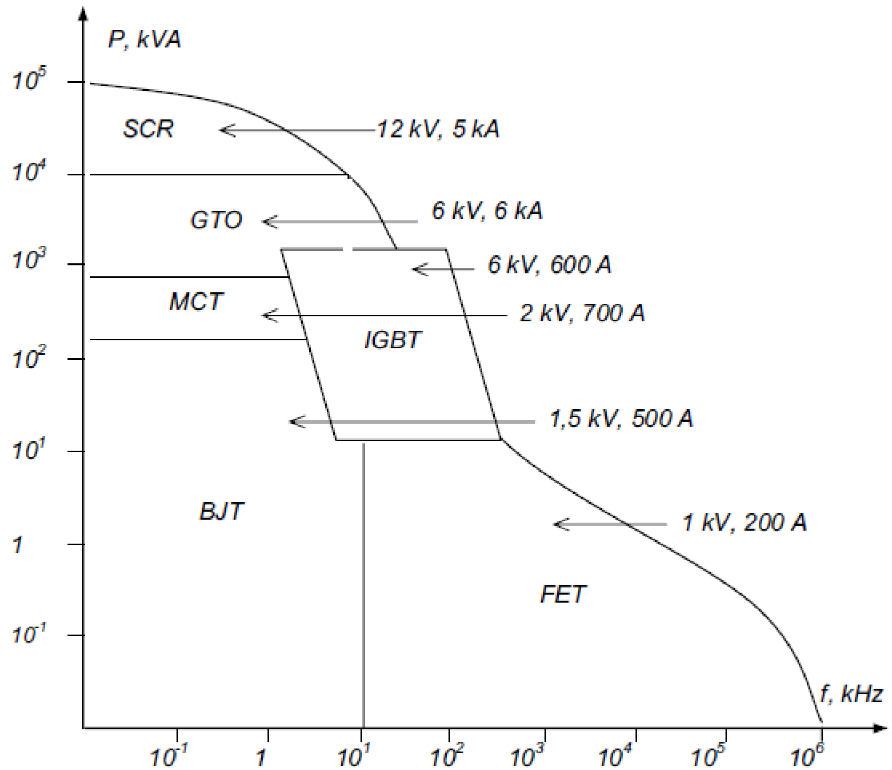

Figure 1.10: A comparative diagram of power ratings and switching speeds of the controlled semiconductor electronic devices.

Assignment 1

Browse internet for medical equipment that used power semiconductor switching device. Then make a table containing the medical equipment name, the name of the power semiconductor used, the specifications of this power semiconductor (Including: its voltage and current ratings as well as its frequency), its price, and the reference.

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