

Introduction

The task of power electronics is to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for user loads.

1.1 Block Diagram of Power Electronic Systems

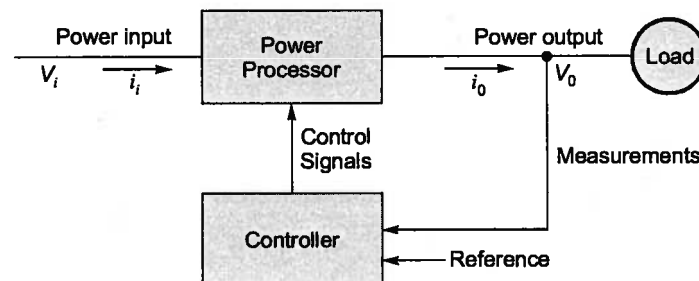


Figure-1.1

Power electronics may be defined as the application of solid state electronics for the control and conversion of electric power.

History of Power Electronics

The history of power electronics began with the introduction of the mercury arc rectifier in 1900. The first electronics revolution began in 1948 with the invention of the silicon transistor at Bell Telephone Laboratories by Bardeen, Brattain and Shockley. The next breakthrough, in 1956, was also from Bell Laboratories: the invention of the PNP triggering transistor, which was defined as a thyristor or silicon controlled rectifier (SCR). The second electronics revolution began in 1958 with the development of the commercial thyristor by the General Electric Company. That was the beginning of a new era of power electronics. The micro electronics revolution gave us the ability to process a huge amount of information at incredible speed. The power electronics revolution is giving us the ability to shape and control large amounts of power with ever increasing efficiency.

Scope and Applications

1. Switch Mode (DC) Power Supplies and Uninterruptible Power Supplies

Advances in micro electronics fabrication technology have led to the development of computers, communication equipment and consumer electronics, all of which require regulated dc power supplies and often uninterruptible power supplies.

2. Energy Conservation

Increasing energy costs and the concern for the environment have combined to make energy conservation a priority. Adjustable speed motor drives, load proportional, capacity modulated heat pumps and air conditioners are examples of applying power electronics to achieve energy conservation.

3. Process Control and Factory Automation

There is a growing demand for the enhanced performance offered by adjustable speed driven pumps and compressors in process control. Robots in automated factories are powered by electric servo (adjustable speed and position) drives. It should be noted that the availability of process computers is a significant factor in making process control and factory automation feasible.

4. Transportation

In many countries, electric trains have been in widespread use for a long time. Now, there is also a possibility of using electric vehicles in large metropolitan areas to reduce smog and pollution. Electric vehicles would also require battery chargers that utilize power electronics.

5. Electro Technical Applications

These include equipment for welding, electroplating, and induction heating.

6. Utility Related Applications

One such application is in transmission of power over high voltage dc (HVDC) lines. Power electronics is also beginning to play a significant role as electric utilities attempt to utilize the existing transmission network to a higher capacity. Potentially, a large application is in the interconnection of photo voltaic and wind electric systems to the utility grid.

Power Electronic Applications

1. Residential

Refrigeration and freezers, Space heating, Air conditioning, Cooking, Lighting, Electronics (personal computers, other entertainment equipment).

2. Commercial

Heating, Ventilating, and Air conditioning, Central refrigeration, Lighting, Computers and Office equipment, Uninterruptible Power Supplies (UPSs), Elevators.

3. Industrial

Pumps, Compressors, Blowers and Fans, Machine tools (Robots), Arc furnaces, Induction furnaces, Lighting, Industrial lasers, Induction heating, Welding.

4. Transportation

Traction control of electric vehicles, Battery chargers for electric vehicles, Electric locomotives, Street cars, Trolley buses, Subways, Automotive electronics including engine controls.

5. Utility Systems

High voltage dc transmission (HVDC), Static var compensation (SVC), Supplemental energy sources (wind, photovoltaic), Fuel cells, Energy storage systems, Induced draft fans and Boiler feedwater pumps.

6. Aerospace

Space shuttle power supply systems, Satellite power systems, Aircraft power systems.

7. Telecommunications

Battery chargers, Power supplies (DC and UPS).

Interdisciplinary Nature of Power Electronics

The study of power electronics encompasses many fields within electrical engineering. Combining the knowledge of these diverse fields makes the study of the subject challenging as well as interesting. There are many potential advances in all these fields that will improve the prospects for applying power electronics to new applications.

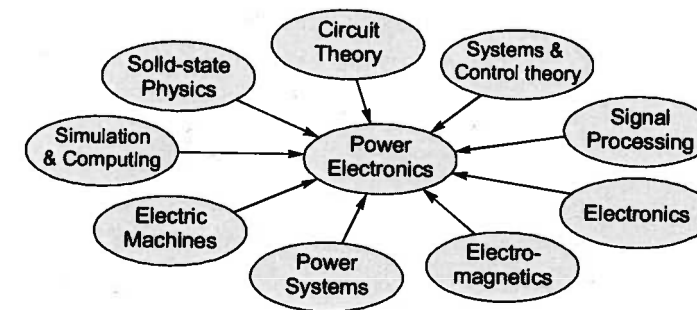


Figure-1.2: Interdisciplinary nature of power electronics

Types of Power Electronic Circuits

1. Diode Rectifiers

A diode rectifier circuit converts ac input voltage into a fixed dc voltage. The input voltage may be single-phase or three-phase. Diode rectifiers find wide use in electric traction, battery charging, electroplating, electrochemical processing, power supplies, welding and uninterruptible power supply (UPS) systems.

2. AC to DC Converters (Phase-controlled rectifiers)

These convert constant ac voltage to variable dc output voltage. These rectifiers use line voltage for their commutation, as such these are also called line-commutated or naturally-commutated ac to dc converters. Phase-controlled converters may be fed from single-phase or three-phase source. These are used in dc drives, metallurgical and chemical industries, excitation systems for synchronous machines etc.

3. DC to DC Converters (DC Choppers)

A dc chopper converts fixed dc input voltage to a controllable dc output voltage. The chopper circuits require forced, or load, commutation to turn-off the thyristors. For lower power circuits, thyristors are replaced by power transistors. Classification of chopper circuits is dependent upon the type of commutation and also on the direction of power flow. Choppers find wide applications in dc drives, subway cars, trolley trucks, battery-driven vehicles etc.

4. DC to AC Converters (Inverters)

An inverter converts fixed dc voltage to a variable ac voltage. The output may be a variable voltage and variable frequency. These converters use line, load or forced commutation for turning-off the thyristors. Inverters find wide use in induction motor and synchronous motor drives, induction heating, UPS, HVDC transmission etc. At present, conventional thyristors are also being replaced by GTOs in high power applications and by power transistors in low power applications.

5. AC to AC Converters

These convert fixed ac input voltage into variable ac output voltage. These are of two types as under:

AC voltage controllers (AC voltage regulators): These converter circuits convert fixed ac voltage directly to a variable ac voltage at the same frequency. AC voltage controllers employ two thyristors in antiparallel or a triac. Turn-off of both the devices is obtained by line commutation. Output voltage is controlled by varying the firing angle delay. AC voltage controllers are widely used for lighting control, speed control of fans, pumps etc.

Cycloconverters: These circuits convert input power at one frequency to output power at a different frequency through one-stage conversion. Line commutation is more common in these converters, though forced and load commutated cycloconverters are also employed. These are primarily used for slow-speed large ac drives.

6. Static Switches

The power semiconductor devices can operate as static switches or contactors. Static switches possess many advantages over mechanical and electromechanical circuit breakers. Depending upon the input supply, the static switches are called ac static switches or dc static switches.

- Power electronics is based primarily on the switching of the power semiconductor devices.
- Modern power electronics equipment uses,
 1. Power semiconductors that can be regarded as the muscle, and
 2. Microelectronics that have the power and intelligence of a brain.

1.2 Classification of The Power Semiconductors

The power semiconductor switching devices can be classified on the basis of

- Uncontrolled turn-on and turn-off (e.g., diode)
- Controlled turn-on and uncontrolled turn-off (e.g. SCR)
- Controlled turn-on and turn-off characteristics (e.g., BJT, MOSFET, GTO, SITH, IGBT, SIT, MCT)
- Continuous gate signal requirement (BJT, MOSFET, IGBT, SIT)
- Pulse gate requirement (e.g., SCR, GTO, MCT)
- Bipolar voltage withstanding capability (SCR, GTO)
- Unipolar voltage withstanding capability (BJT, MOSFET, IGBT, MCT)
- Bidirectional current capability (TRIAC, RCT)
- Unidirectional current capability (SCR, GTO, BJT, MOSFET, MCT, IGBT, SITH, SIT, Diode).

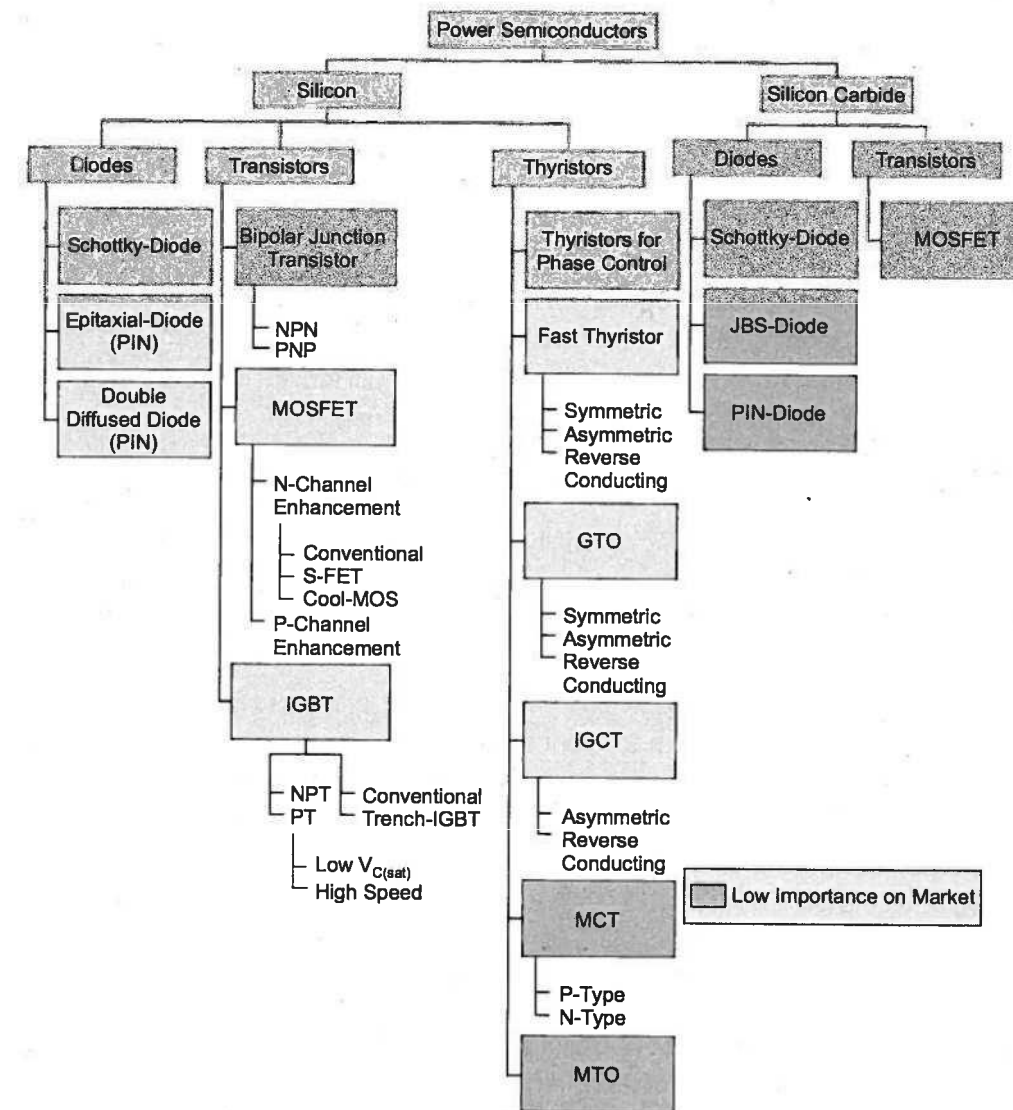


Figure-1.3 : Classification of the power semiconductors

Characteristics and Specifications of Switches

There are many types of power switching devices. Each device, however, has its advantages and disadvantages and is suitable to specific applications. The motivation behind the development of any new device is to achieve the characteristics of a "**Super device**". The characteristics of any real device can be compared and evaluated with reference to the ideal characteristics of a super device.

Ideal Characteristics

The characteristics of an ideal switch are as follows:

- In the on-state when the switch is on, it must have (a) the ability to carry a high forward current I_F , tending to infinity; (b) a low on-state forward voltage drop V_{ON} , tending to zero; and (c) a low on-state resistance R_{ON} , tending to zero. Low R_{ON} causes low on-state power loss P_{ON} . These symbols are normally referred to under dc steady state conditions.

- In the off-state when the switch is off, it must have (a) the ability to withstand a high forward or reverse voltage V_{BR} , tending to infinity; (b) a low off-state leakage current I_{OFF} , tending to zero, and (c) a high off-state resistance R_{OFF} , tending to infinity. High R_{OFF} cause low off-state power loss P_{OFF} . These symbols are normally referred to under dc steady-state conditions.
- During the turn-on and turn-off process, it must be completely turned on and off instantaneously so that the device can be operated at high frequencies. Thus it must have (a) a low delay time t_d , tending to zero; (b) a low rise time t_r , tending to zero; (c) a low storage time t_s , tending to zero; and (d) a low fall time t_f , tending to zero.
- For turn-on and turn-off, it must require (a) a low gate-drive power P_G , tending to zero; (b) a low gate-drive voltage V_G , tending to zero; and (c) a low gate-drive current I_G , tending to zero.
- Both turn-on and turn-off must be controllable. Thus, it must turn-on with a gate signal (e.g., positive) and must turn-off with another gate signal (e.g., zero or negative).
- For turning on and off, it should require a pulse signal only, that is a small pulse with a very small width t_{wp} , tending to zero.
- It must have a high dv/dt , tending to infinity. That is, the switch must be capable of handling rapid changes of the voltage across it.
- It must have a high di/dt , tending to infinity. That is, the switch must be capable of handling a rapid rise of the current through it.
- It requires very low thermal impedance from the internal junction to the ambient R_{JA} , tending to zero so that it can transmit heat to the ambient easily.
- The ability to sustain any fault current for a long time is needed; that is, it must have a high value of i^2t , tending to infinity.
- Negative temperature coefficient on the conducted current is required to result in an equal current sharing when the devices are operated in parallel.
- Low price is a very important consideration for reduced cost of the power electronics equipment.

Switch Specifications

There are many parameters that are important to the devices. The most important among these are:

- **Voltage ratings:** Forward and reverse repetitive peak voltages, and an on-state forward voltage drop.
- **Current ratings:** Average, root-mean-square (rms), repetitive peak, non-repetitive peak, and off-state leakage currents.
- **Switching speed or Frequency:** Transition from a fully non-conducting to a fully conducting state (turn-on) and from a fully conducting to a fully non-conducting state (turn-off) are very important parameters. The switching period T_S and frequency f_S are given by

$$f_S = \frac{1}{T_S} = \frac{1}{t_d + t_r + t_{on} + t_s + t_f + t_{off}}$$

where t_{off} is the off time during which the switch remains off.

- **di/dt Rating:** The device needs a minimum amount of time before its whole conducting surface comes into play in carrying the full current. If the current rises rapidly, the current flow may be concentrated to a certain area and the device may be damaged. The di/dt of the current through the device is normally limited by connecting a small inductor in series with the device, known as a series snubber.

- **dv/dt Rating:** A semiconductor device has an internal junction capacitance C_j . If the voltage across the switch changes rapidly during turn-on, turn-off and also while connecting the main supply the initial current, the current $C_j dv/dt$ flowing through C_j may be too high, thereby causing damage to the device. The dv/dt of the voltage across the device is limited by connecting an RC circuit across the device, known as a shunt snubber, or simply snubber.
- **Switching losses:** During turn-on the forward current rises before the forward voltage falls, and during turn-off the forward voltage rises before the current falls. Simultaneous existence of high voltage and current in the device represents power losses. Because of their repetitiveness, they represent a significant part of the losses, and often exceed the on-state conduction losses.
- **Gate drive requirements:** The gate-drive voltage and current are important parameters to turn-on and turn-off a device. The gate-driver power and the energy requirement are very important parts of the losses and total equipment cost. With large and long current pulse requirements for turn-on and turn-off, the gate drive losses can be significant in relation to the total losses and the cost of the driver circuit can be higher than the device itself.
- **Safe Operating Area (SOA):** The amount of heat generated in the device is proportional to the power loss, that is the voltage current product. For this product to be constant $P = vi$ and equal to the maximum allowable value, the current must be inverse proportional to the voltage. This yields the SOA limit on the allowable steady-state operating points in the voltage current coordinates.
- **$I^2 t$ for fusing:** This parameter is needed for fuse selection. The $I^2 t$ of the device must be less than that of the fuse so that the device is protected under fault current conditions.
- **Temperatures:** Maximum allowable junction, case and storage temperatures, usually between 150°C and 200°C for junction and case, and between -50°C and 175°C for storage.
- **Thermal resistance:** Junction to case thermal resistance, Q_{JC} , case to sink thermal resistance, Q_{CS} , and sink ambient thermal resistance, Q_{SA} . Power dissipation must be rapidly removed from the internal wafer through the package and ultimately to the cooling medium. The size of semiconductor power switches is small, not exceeding 150 mm, and the thermal capacity of a bare device is too low to safely remove the heat generated by internal losses. Power devices are generally mounted on heat sinks. Thus, removing heat represents a high cost of equipment.

Summary



With ' n ' number of variables the maximum possible minterm or maxterm is equal to ' 2^n '. As the technology for the power semiconductor devices and integrated circuits develops, the potential for the applications of power electronics becomes wider. The power converters fall generally into six categories:

- Rectifiers
- AC-DC converters
- AC-AC converters
- DC-DC converters
- DC-AC converters and
- Static switches

The design of power electronics circuits requires designing the power and control circuits. The voltage and current harmonics that are generated by the power converters can be reduced (or minimized) with a proper choice of the control strategy.