

Power Electronics - Basics

Introduction

Power electronics is the applications of solid-state electronics for the control and conversion of electric power.

Power electronic converters - to modify the form of electrical energy (voltage, current or frequency).

Power range - from some milliwatts (mobile phone) to hundreds of megawatts (HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Thus, the main metric of power electronics becomes the efficiency.

The first very high power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed.

An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, e.g., television sets, personal computers, battery chargers, etc. The power range is typically from tens of watts to several hundred watts. In industry the most common application is the variable speed drive (VSD) that is used to control an induction motor. The power range of VSDs start from a few hundred watts and end at tens of megawatts.

The power conversion systems can be classified according to the type of the input and output power

- AC to DC (rectification)
- DC to AC (inversion)
- DC to DC (chopping)
- AC to AC (transformation)

PRINCIPLE

The instantaneous dissipated power of a device $P = V \cdot I$

Thus, losses of a power device are at a minimum when the voltage across it is zero (the device is in the On-State) or when no current flows through it (Off-State). Therefore, a power electronic converter is built around one (or more) device operating in switching mode (either On or Off).

APPLICATIONS

Power electronic systems are found in virtually every electronic device. For example:

- DC/DC converters are used in most mobile devices (mobile phones, PDA etc.) to maintain the voltage at a fixed value whatever the voltage level of the battery is. These converters are also used for electronic isolation and power factor correction.
- AC/DC converters (rectifiers) are used every time an electronic device is connected to the mains (computer, television etc.). These may simply change AC to DC or can also change the voltage level as part of their operation.
- AC/AC converters are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency 50 Hz and 60 Hz power grids.
- DC/AC converters (inverters) are used primarily in UPS or emergency lighting systems. When mains power is available, it will charge the DC battery. If the mains fails, an inverter will be used to produce AC electricity at mains voltage from the DC battery.

COMMON POWER DEVICES

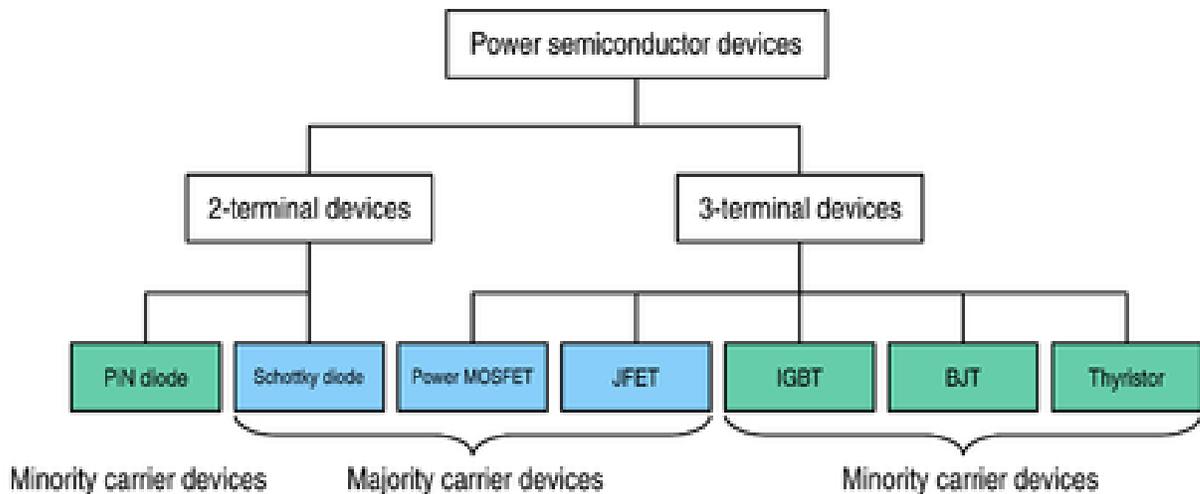
Some common power devices are the power diode, thyristor, power MOSFET and IGBT (insulated gate bipolar transistor). A power diode or MOSFET operates on similar principles to its low-power counterpart, but is able to carry a larger amount of current and typically is able to support a larger reverse-bias voltage in the off-state.

Structural changes are often made in power devices to accommodate the higher current density, higher power dissipation and/or higher reverse breakdown voltage. The vast majority of the discrete (i.e. non integrated) power devices are built using a vertical structure, whereas small-signal devices employ a lateral structure. With the vertical structure, the current rating of the device is proportional to its area, and the voltage blocking capability is achieved in the height of the die. With this structure, one of the connections of the device is located on the bottom of the semiconductor [die].

Power semiconductor devices

These are semiconductor devices used as switches or rectifiers in power electronic circuits (switch mode power supplies for example). They are also called **power devices** or when used in integrated circuits, called **power ICs**.

Most power semiconductor devices are only used in commutation mode (i.e. they are either on or off), and are therefore optimized for this. Most of them should not be used in linear operation.



COMMON POWER SEMICONDUCTOR DEVICES

The realm of power devices is divided into two main categories (see figure 1):

- The two-terminal devices (diodes), whose state is completely dependent on the external power circuit they are connected to;
- The three-terminal devices, whose state is not only dependent on their external power circuit, but also on the signal on their driving terminal (gate or base). Transistors and thyristors belong to that category.

A second classification is less obvious, but has a strong influence on device performance: Some devices are majority carrier devices (Schottky diode, MOSFET), while the others are minority carrier devices (Thyristor, bipolar transistor, IGBT). The former use only one type of charge carriers, while the latter use both (i.e electrons and holes). The majority carrier devices are faster, but the charge injection of minority carrier devices allows for better On-state performance.

Diodes

An ideal diode should have the following behaviour:

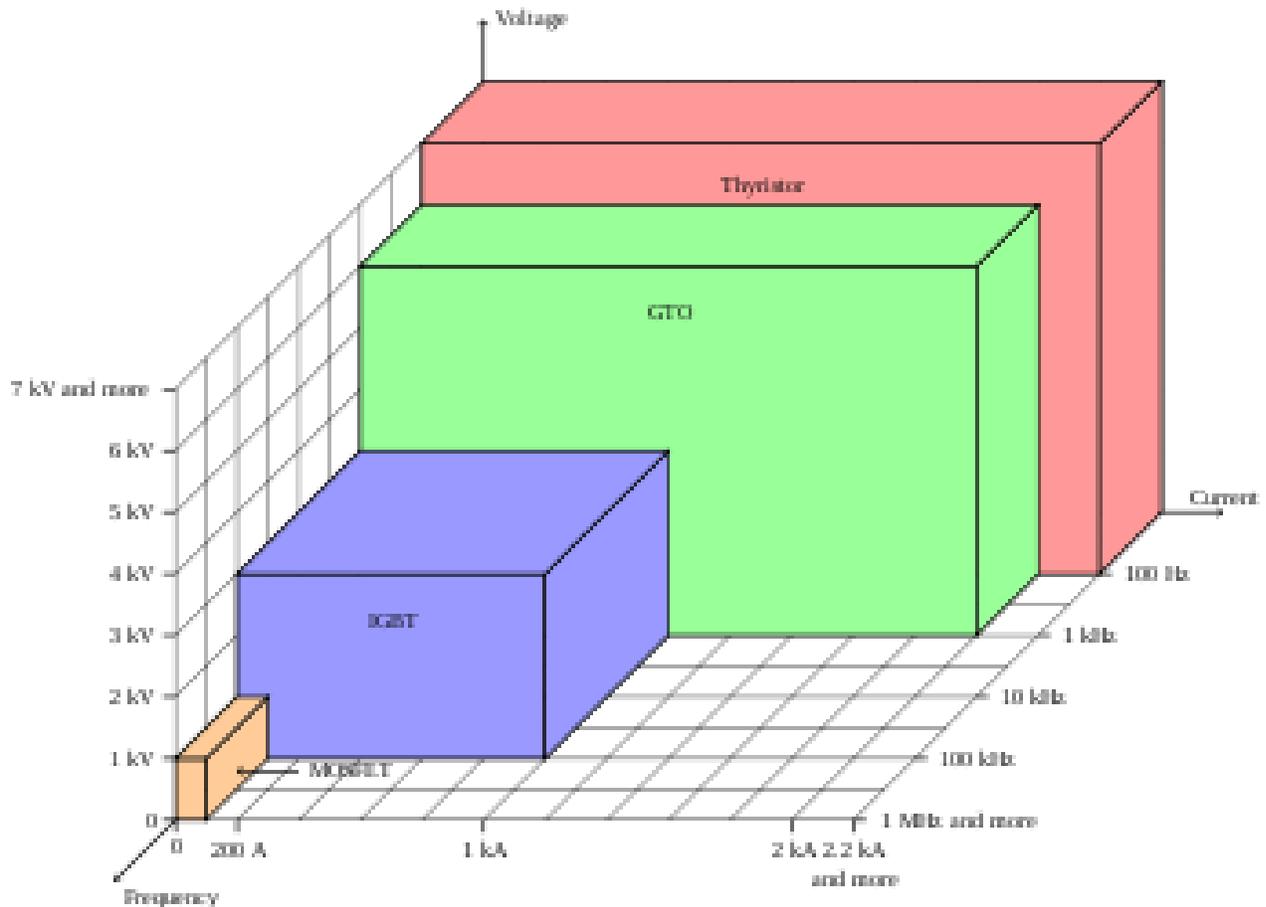
- When forward-biased, the voltage across the end terminals of the diode should be zero, whatever the current that flows through it (on-state);
- When reverse-biased, the leakage current should be zero whatever the voltage (off-state).

Moreover, the transition between on and off states should be instantaneous.

In reality, the design of a diode is a trade-off between performance in on-state, off-state and commutation. Indeed, it is the same area (actually the lightly-doped region of a PiN diode) of the device that has to sustain the blocking voltage in off-state and allow current flow in the on-state. As the requirements for the two state are completely opposite, it can be intuitively seen that a diode has to be either optimised for one of them, or time must be allowed to switch from one state to the other (i.e slow down the commutation speed).

This trade-off between on-state, off-state and switching speed is the same for all power devices. A Schottky diode has excellent switching speed and on-state performance, but a high level of leakage current in off-state. PIN diodes are commercially available in different commutation speeds (so-called fast rectifier, ultrafast rectifier...), but any increase in speed is paid by lower performance in on-state.

Switches



The trade-off between voltage, current and frequency ratings also exists for the switches. Actually, all power semiconductors rely on a PiN diode structure to sustain voltage. This can be seen in figure 2. The power MOSFET has the advantages of the majority carrier devices, so it can achieve very high operating frequency, but can't be used with high voltages. As it is a physical limit, no improvement is expected from silicon MOSFET concerning their maximum voltage ratings. However, its excellent performance in low voltage make it the device of choice (actually the only choice) for applications below 200 V. By paralleling several devices, it is possible increase the current rating of a switch. The MOSFET is particularly suited to this configuration because its positive thermal coefficient of resistance tends to balance current between individual devices.

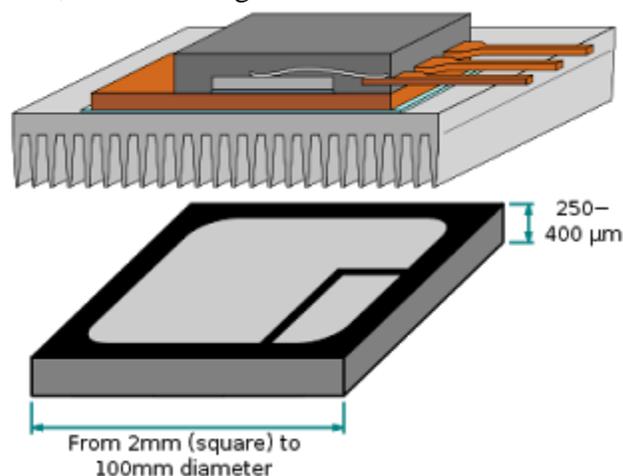
The IGBT is a recent component, so its performance improves regularly as technology evolves. It has already completely replaced the bipolar transistor in power applications, and

the availability of power modules (in which several IGBT dice are connected in parallel) makes it attractive for power levels up to several megawatts, pushing further the limit where thyristors and GTO become the only option. Basically, an IGBT is a bipolar transistor driven by a power MOSFET: it has the advantages of being a minority carrier device (good performance in on-state, even for high voltage devices), with the high input impedance of a MOSFET (it can be driven on or off with a very low amount of power). Its major limitation for low voltage applications is the high voltage drop it exhibits in on-state (2 to 4 V). Compared to the MOSFET, the operating frequency of the IGBT is relatively low (few devices are rated over 50 kHz), mainly because of a so-called 'current-tail' problem during turn-off. This problem is caused by the slow decay of the conduction current during turn-off resulting from slow recombination of large number of carriers, which flood the thick 'drift' region of the IGBT during conduction. The net result is that the turn-off switching loss of an IGBT is considerably higher than its turn-on loss. Generally, in datasheet, turn-off energy is mentioned as a measured parameter and one has to multiply that number with the switching frequency of the intended application to estimate the turn-off loss.

At very high power levels, thyristor-based devices (SCR, GTO, MCT) are still the only choice. Though driving a thyristor is somewhat complicated, as this device can only be turned on. It turns off by itself as soon as no more current flows through it. This requires specific circuit with means to divert current, or specific applications where current is known to cancel regularly (i.e Alternating Current). Different solution have been developed to overcome this limitation (Mos Controlled Thyristors, Gate Turn Off thyristor...). These components are widely used in power distribution applications.

PARAMETERS OF POWER SEMICONDUCTOR DEVICES

The power semiconductor die of a three-terminal device (IGBT, MOSFET or BJT). Two contacts are on top of the die, the remaining one is on the back.



Breakdown voltage: Often the trade-off is between breakdown voltage rating and on-resistance because increasing the breakdown voltage by incorporating a thicker and lower doped drift region leads to higher on-resistance.

On-resistance: Higher current rating lowers the on-resistance due to greater numbers of parallel cells. This increases overall capacitance and slows down the speed.

Rise and fall times for switching between on and off states.

Safe-operating area (from thermal dissipation and "latch-up" consideration)

Thermal resistance: This is actually an often-ignored but extremely important parameter from practical system design point of view. Semiconductors do not perform well at elevated temperature but due to large current conduction, all power semiconductor device heat up. Therefore it needs to be cooled by removing that heat continuously. Packaging interface provides the path between the semiconductor device and external world to channelize the heat outside. Generally, large current devices have large die and packaging surface area and lower thermal resistance.

Source: <http://electrical-all.blogspot.in/p/power-electronics-basics.html>