POWER SEMICONDUCTOR DEVICES

Power Electronics

- Power Electronics is the art of converting electrical energy from one form to another in an efficient, clean, compact, and robust manner for convenient utilization.

Power Electronics

- Power electronics combine power, electronics, and control.
- Control deals with the steady-state and dynamic characteristics of closed-loop system.
- Power deals with static and rotating power equipment.
- Electronics deals with the solid-state devices and circuits for signal processing to meet the desired control objectives.

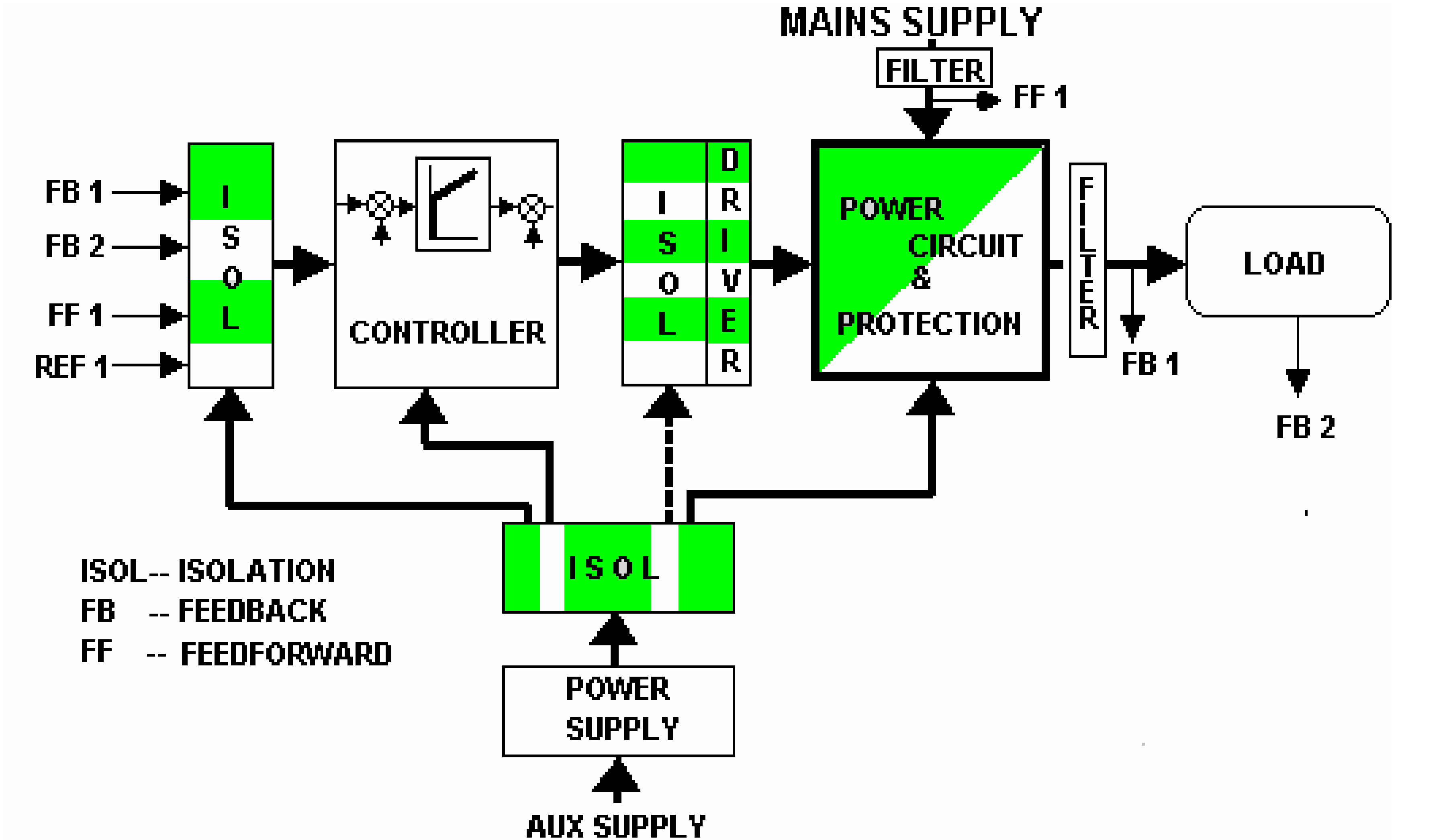
Cont.

- Therefore, power electronics is defined as the applications of solid-state electronics for control and conversion of electric power.

- Power electronics is based on switching of the power semiconductor devices.

- It covers a variety of switching circuits.

The block diagram of a typical Power Electronic converter



Applications of Power Electronics:

- We can realise the applications of Power Electronics everywhere in our day-to-day life (home, office, factory, car, hospital, theatre etc.)

Some of the typical applications are

- Domestic and theatre lighting
- Industrial Process in the chemical, paper and steel industries
- Motor drives from food mixers, washing machines through to lifts and locomotives
- Power supplies for laboratories and uninterruptible power for vital loads
- Generation and transmission control

Applications of Power Electronics:

Industrial Applications:

- Industrial applications mainly consist of two areas, motor control and power supplies.
- The motors which are controlled vary from very large(used in steel mills) to smaller ones(used in machine tools).
- Power supplies for battery charging, induction heating, electroplating and welding.

Consumer Applications:

- Consumer applications cover many different areas in the home, such as audio amplifiers, heat controls, light dimmers, security systems, motor control for food mixers and hand power tools.

Applications of Power Electronics:

Transportation Applications:

- Transportation applications like motor drives for electric vehicles, locomotives. In addition to this non-motor drive applications like traffic signal control, vehicle electronic ignition and vehicle voltage regulation.

Aerospace Applications:

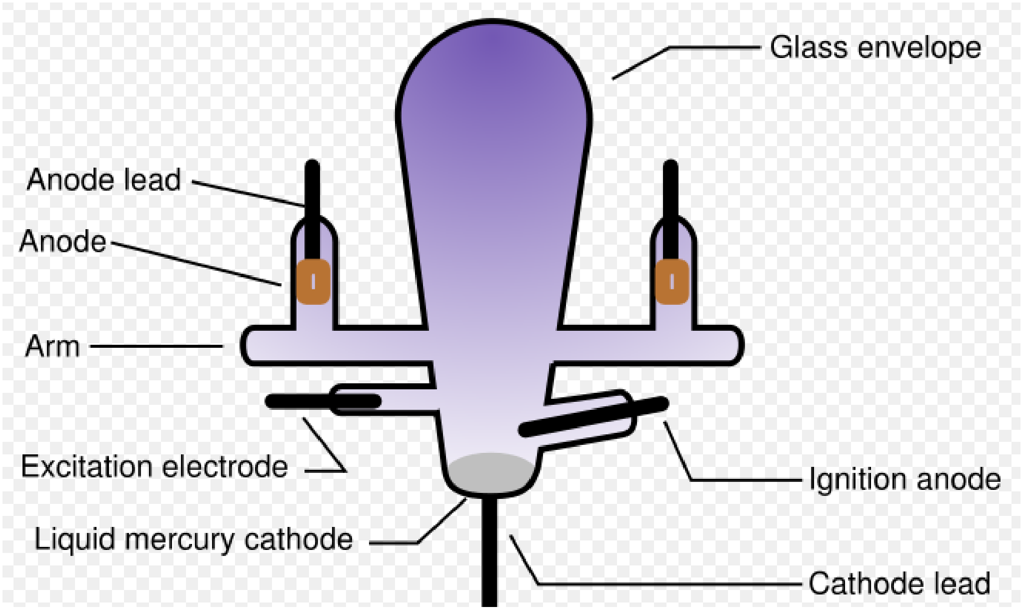
- Aerospace and defence applications include VLF transmitters, power supplies for space and aircraft; and switching using solid state relays and contactors.

Power Electronics involves the study of

- Power semiconductor devices - their physics, characteristics, drive requirements and their protection for optimum utilization of their capacities
- Power converter topologies
- Control strategies of the converters
- Digital, analogue and microelectronics
- Capacitive and magnetic energy storage elements
- Rotating and static electrical devices
- Quality of waveforms generated
- Thermal Management
- Electro Magnetic and Radio Frequency Interference

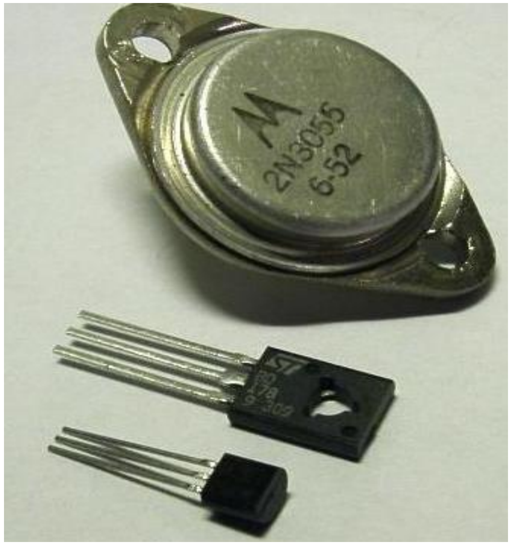
Power Semiconductor device - history

- Power electronics started with the development of the mercury arc rectifier.
- Invented by Peter Cooper Hewitt in 1902, it was used to convert alternating current (AC) into direct current (DC).



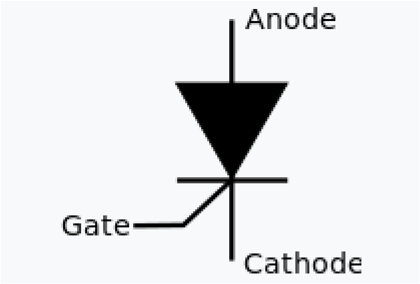
Power Semiconductor device - history

- In 1947 the bipolar point-contact transistor was invented by Walter H. Brattain and John Bardeen under the direction of William Shockley at Bell Labs.
- In 1948 Shockley's invention of the bipolar junction transistor (BJT) improved the stability and performance of transistors, and reduced costs.



Power Semiconductor device - history

- By the 1950s, higher power semiconductor diodes became available and started replacing vacuum tubes. In 1956 the silicon controlled rectifier (SCR) was introduced by General Electric, greatly increasing the range of power electronics applications.



Power Semiconductor device - history

- By the 1960s the improved switching speed of bipolar junction transistors had allowed for high frequency DC/DC converters.
- In 1976 power MOSFETs became commercially available.
- In 1982 the Insulated Gate Bipolar Transistor (IGBT) was introduced.

Power Semiconductor device

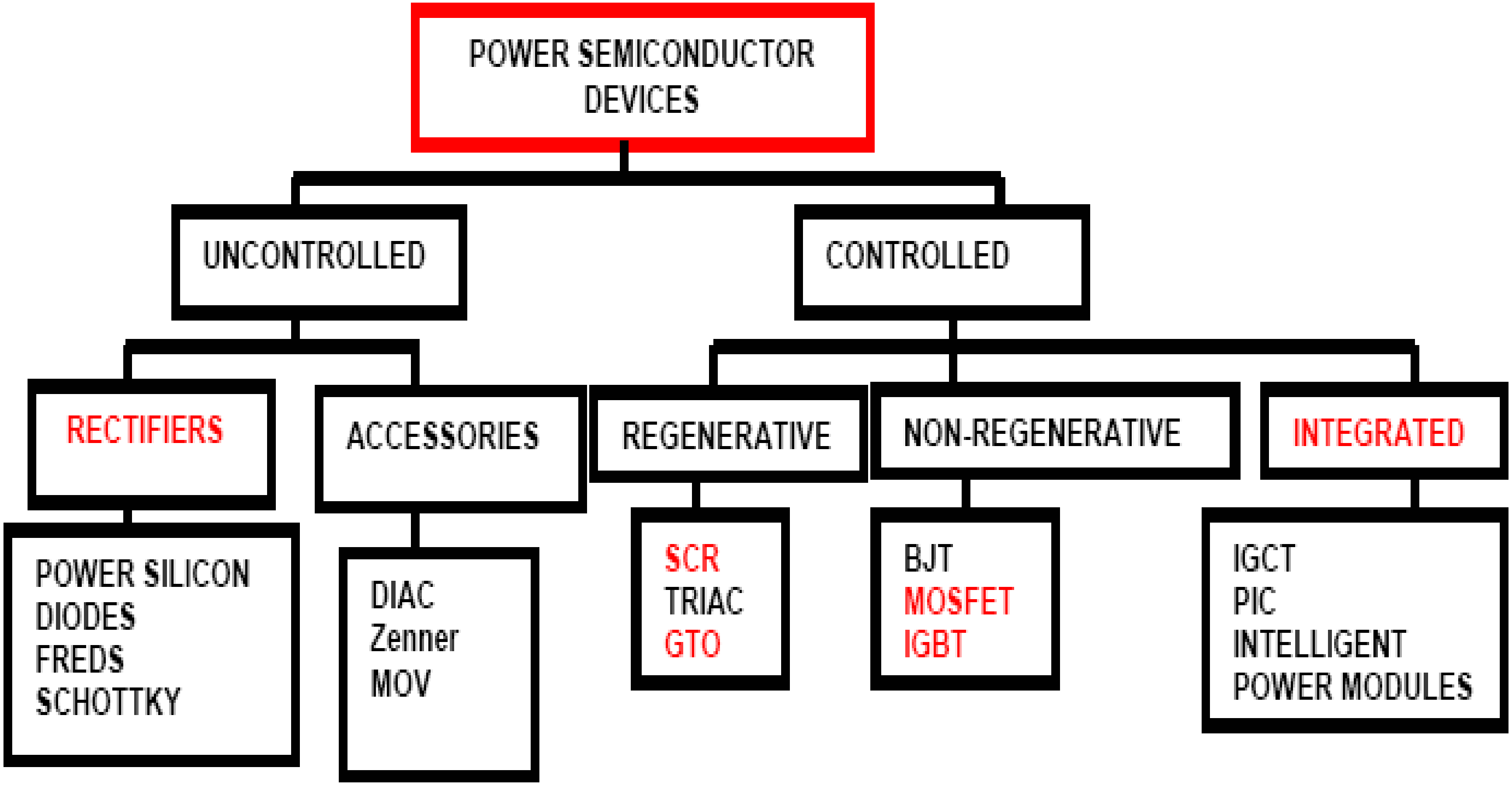
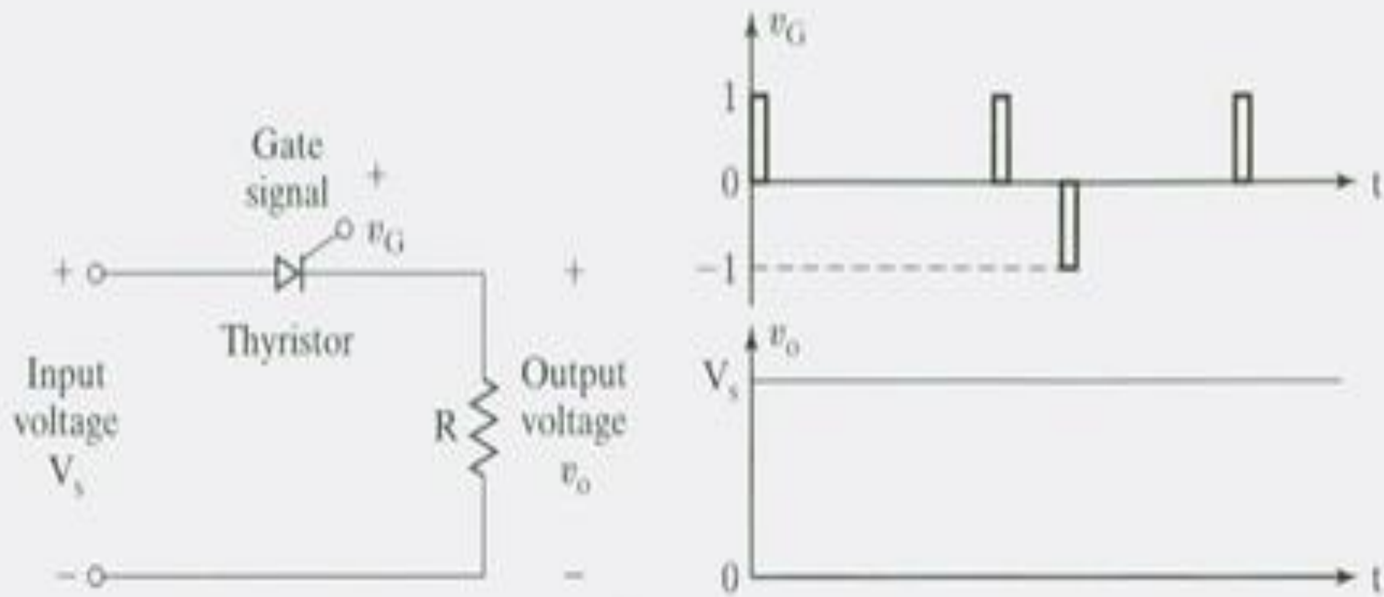


Fig. 1.5 Power semiconductor device variety

Control Characteristics

- The power semiconductor devices can be operated as switches by applying a control signals to gate.



(a) Thyristor switch

Classification

- Power semiconductor switching devices can be classified on the basis of:
  - Uncontrolled turn on and off (diodes)
  - Controlled turn on and uncontrolled turn off (SCR)
  - Controlled turn on and off (BJT, MOSFET, GTO, IGBT)
  - Continuous gate signal requirement (BJT, MOSFET, IGBT)
  - Pulse gate requirement (SCR, GTO)
  - Bipolar voltage-withstanding capability (SCR, GTO)
  - Unipolar voltage withstanding capability (BJT, MOSFET, GTO)
  - Bidirectional current capability (TRIAC)
  - Unidirectional current capability (SCR, GTO, BJT, MOSFET, DIODE)

Ideal Switches

- **In the on-state: carry high forward current, low forward voltage drop, and low resistance**
- **In the off-state: withstand a high voltage, lowleakage current, and high resistance**
  - During turn-on and turn-off process instantaneously turn on and off
  - Low gate power for turn on and off Controllable turn on and off
  - Turn on and off require a small pulse High dv/dt & di/dt
  - Low thermal impedance
  - Sustain any fault current (i^2t)
  - Equal current sharing for parallel operation
  - Low price

Characteristics of Practical Devices

- During the turn-on and turn-off process a practical device requires:
  - a finite delay time
  - rise time
  - storage time
  - fall time

Power Diodes

There are broadly three types of diodes used in Power electronic applications:

- Line-frequency diodes:
  - These PIN diodes with general-purpose rectifier type applications, are available at the highest voltage (~5kV) and current ratings (~5kA) and have excellent over-current (surge rating about six times average current rating) and surge-voltage withstand capability.

Power Diodes

- Fast recovery diodes:
  - Fast recovery diffused diodes and fast recovery epitaxial diodes
  - They are available at high powers and are mainly used in association with fast controlled-devices as free-wheeling or DC-DC choppers and rectifier applications.
  - Fast recovery diodes also find application in induction heating, UPS and traction.

Power Diodes

- Schottky rectifiers:
  - These are the fastest rectifiers .However, they are available with voltage ratings up to a hundred volts only though current ratings may be high.
  - Their conduction voltages specifications are excellent (~0.2V).
  - The freedom from minority carrier recovery permits reduced snubber requirements.
  - Schottky diodes face no competition in low voltage SMPS applications and in instrumentation.

Silicon Controlled Rectifier (SCR)

The Silicon Controlled Rectifier is the most popular of the thyristor family of four layer regenerative devices.

- It is normally turned on by the application of a gate pulse when a forward bias voltage is present at the main terminals.

- However, being regenerative or 'latching', it cannot be turned off via the gate terminals specially at the extremely high amplification factor of the gate.

SCR

There are two main types of SCR's

Converter grade or Phase Control thyristors :

- They are turned off by natural (line) commutation and are reverse biased at least for a few milliseconds subsequent to a conduction period.
- No fast switching feature is desired of these devices. They are available at voltage ratings in excess of 5 KV starting from about 50 V and current ratings of about 5 KA.
- Conduction voltages are device voltage rating dependent and range between 1.5 V (600V) to about 3.0 V (+5 KV).
- These devices are unsuitable for any 'forced-commutated' circuit requiring unwieldy large commutation components.

Inverter grade thyristors

- Turn-off times of these thyristors range from about 5 to 50 µsecs when hard switched. They are thus called fast or 'inverter grade' SCR's.
- The SCR's are mainly used in circuits that are operated on DC supplies and no alternating voltage is available to turn them off.
- Commutation networks have to be added to the basic converter only to turn-off the SCR's.
- The efficiency, size and weight of these networks are directly related to the turn-off time, tq of the SCR.
- The commutation circuits utilised resonant networks or charged capacitors..

MOSFET

- The Power MOSFET technology has mostly reached maturity and is the most popular device for SMPS, lighting ballast type of application where high switching frequencies are desired but operating voltages are low.
- Being a voltage fed, majority carrier device (resistive behaviour) with a typically rectangular Safe Operating Area, it can be conveniently utilized.
- For low frequency applications, where the currents drawn by the equivalent capacitances across its terminals are small, it can also be driven directly by integrated circuits.

MOSFET

- At high current low voltage applications the MOSFET offers best conduction voltage specifications as the RDS(ON) specification is current rating dependent.
- However, the inferior features of the inherent anti-parallel diode and its higher conduction losses at power frequencies and voltage levels restrict its wider application.

The IGBT

- It is a voltage controlled four-layer device with the advantages of the MOSFET driver and the Bipolar Main terminal.
- IGBTs can be classified as punch-through (PT) and non-punch-through (NPT) structures.
- In the punch-through IGBT, a better trade-off between the forward voltage drop and turn-off time can be achieved.
- Punch-through IGBTs are available up to about 1200 V.
- NPT IGBTs of up to about 4 KV have been reported in literature and they are more robust than PT IGBTs particularly under short circuit conditions.
- However they have a higher forward voltage drop than the PT IGBTs.

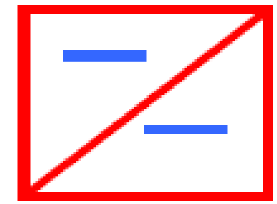
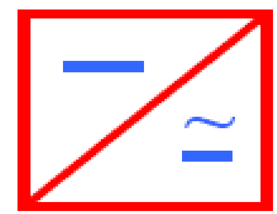
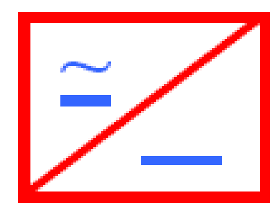
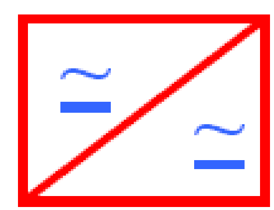
The IGBT

- Its switching times can be controlled by suitably shaping the drive signal.
- This gives the IGBT a number of advantages: it does not require protective circuits, it can be connected in parallel without difficulty, and series connection is possible without dv/dt snubbers.
- The IGBT is presently one of the most popular device in view of its wide ratings, switching speed of about 100 KHz a easy voltage drive and a square Safe Operating Area devoid of a Second Breakdown region.

GTO

- The GTO is a power switching device that can be turned on by a short pulse of gate current and turned off by a reverse gate pulse.
- This reverse gate current amplitude is dependent on the anode current to be turned off. Hence there is no need for an external commutation circuit to turn it off.
- For reliable operation of GTOs, the critical aspects are proper design of the gate turn-off circuit and the snubber circuit.

Power Converter Topologies

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	

Base / gate drive circuit

- All discrete controlled devices, regenerative or otherwise have three terminals.
- Two of these are the Main Terminals. One of the Main Terminals and the third form the Control Terminal.
- The amplification factor of all the devices (barring the now practically obsolete BJT) are quite high, though turn-on gain is not equal to turn-off gain.
- The drive circuit is required to satisfy the control terminal characteristics to efficiently tun-on each of the devices of the converter, turn them off, if possible, again optimally and also to protect the device against faults, mostly over-currents.

Base / gate drive circuit

- Being driven by a common controller, the drives must also be isolated from each other as the potentials of the Main Terminal which doubles as a Control terminal are different at various locations of the converter.
- Gate-turn-off-able devices require precise gate drive waveform for optimal switching. This necessitates a wave-shaping amplifier. This amplifier is located after the isolation stage.

Base / gate drive circuit

- Thus separate isolated power supplies are also required for each Power device in the converter (the ones having a common Control Terminal - say the Emitter in an IGBT - may require a few less).
- There are functionally two types of isolators: the pulse transformer which can transmit after isolation, in a multi-device converter, both the un-shaped signal and power and optical isolators which transmit only the signal. Fig. 1.7 illustrates to typical drive circuits for an IGBT and an SCR.

Protection of Power devices and converters

Power semiconductor devices are commonly protected against:

1. Over-current;
2. di/dt;
3. Voltage spike or over-voltage;
4. dv/dt ;
5. Gate-under voltage;
6. Over voltage at gate;
7. Excessive temperature rise;
8. Electro-static discharge;