Study of Power Electronics Devices

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Abstract: Power Electronics is a branch which combines Power (electric power), Electronics and Control systems. Power engineering deals with the static and rotating power equipment for the generation, transmission and distribution of electric power. Electronics compromise with the study of solid state semiconductor power devices and circuits for Power conversion to meet the desired control objectives (to command the output voltage and output power). Power electronics may be defined as the subject of applications of solid state power. Power electronics deals with the study and design of Thyristorised power controllers for many of application like Heat control, Light/Illumination control, and Motor control - AC/DC motor drives used in industries, High voltage power supplies, Vehicle propulsion systems, High voltage direct current (HVDC) transmission. Semiconductor devices (Thyristors) for the control and conversion of electric power.

***Keywords*— Electric Power, Control System, Semiconductor.**

I. INTRODUCTION

The first Power Electronic Device invented was the Mercury Arc Rectifier during the year 1900. Then the other Power devices like metal tank rectifier, grid controlled vacuum tube rectifier, ignitron, phanotron, thyratron and magnetic amplifier, were invented & used gradually for power control applications until 1950. The first SCR (silicon controlled rectifier) or Thyristor was found and developed by Bell Lab's in 1956 which was the first PNPN transistor. The second electronic revolution began in the year 1958 with the development of the commercial grade Thyristor by the General Electric Company (GE). Thus the new area of power electronics was born. After that many different types of power semiconductor devices & power conversion methods have been introduced. The power electronics innovation is giving us the ability to convert shapes and control large amounts of power.

A) SOME APPLICATION OF POWER ELECTRONICS

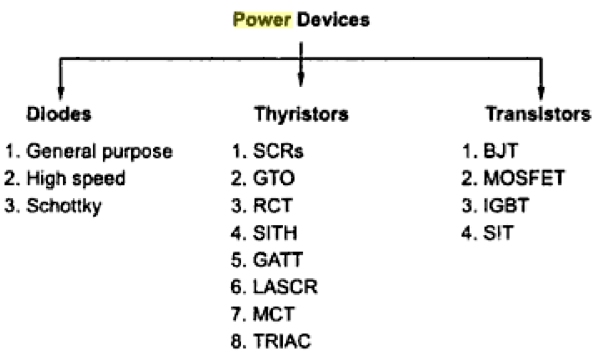
Appliances – (domestic and industrial), battery chargers, audio amplifiers, , blenders, blowers, boilers, burglar alarms, cement kiln, chemical processing, Advertising, air conditioning, aircraft, alarms, power supplies, clothes dryers, conveyors, , computers ,cranes and hoists, dimmers (light dimmers), elevators, fans, flashers, food mixers, food warmer trays, fork lift trucks, furnaces, games, garage door openers, gas turbine starting, generator exciters, grinders, hand power tools, heat controls, high frequency lighting, HVDC transmission, induction heating, laser power supplies, latching relays, light flashers, linear induction motor controls, locomotives, displays, electric door openers, electric dryers, electric fans, electric vehicles, electromagnets, electro mechanical, electronic plating, electrostatic precipitators, electronic ignition, machine tools, magnetic recording, magnets, mass transit railway system, mercury arc lamp ballasts, mining, model trains, motor controls, motor drives, movie projectors, nuclear reactor control rod, oil well drilling, oven controls, paper mills, particle accelerators, servo systems, sewing machines, VLF transmitters, voltage regulators, washing machines, welding equipment , solar power supplies, solid-state contactors, synchronous motor starting, solid-state relays, static circuit breakers, static relays, steel mills, phonographs, photo copiers, power suppliers, printing press, pumps and compressors, radar/sonar power supplies, refrigerators, regulators, security systems, TV circuits, temperature controls, timers and toys, traffic signal controls, trains, RF amplifiers, TV deflection circuits, ultrasonic generators, UPS, vacuum cleaners, VAR compensation, vending machines.

B) POWER ELECTRONIC APPLICATIONS

DOMESTIC APPLICATIONS:
Lighting, Cooking Equipments, Personal Computers, Entertainment Equipments, UPS, Heating, Air Conditioners, Refrigerators & Freezers.
COMMERCIAL APPLICATIONS:
Lighting, Computers and Office equipments, Uninterruptible Power Supplies (UPS), Heating Systems Ventilating, Air Conditioners, Central Refrigeration, Elevators, and Emergency Lamps.
INDUSTRIAL APPLICATIONS
Pumps, induction furnaces, lighting control circuits, industrial lasers, induction heating, compressors, blowers and fans, Machine tools, arc furnaces, welding equipments.
AEROSPACE APPLICATIONS:
Satellite power systems, aircraft power systems, Space shuttle power supply systems,.
TELECOMMUNICATIONS
Mobile cell phone battery chargers, Battery chargers, power supplies (DC and UPS).
TRANSPORTATION
Electric locomotives, street cars, trolley buses, Traction control of electric vehicles, battery chargers for electric vehicles, automobile electronics including engine controls.
UTILITY SYSTEMS
Alternative energy sources (wind, photovoltaic), fuel cells, High voltage DC transmission (HVDC), static VAR compensation (SVC), , energy storage systems, induced draft fans and boiler feed water pumps.

II.POWER SEMICONDUCTOR DEVICES

The power semiconductor devices are handeled as on-off switches in power control circuit. These devices are classified as follows.



A) Power Diode

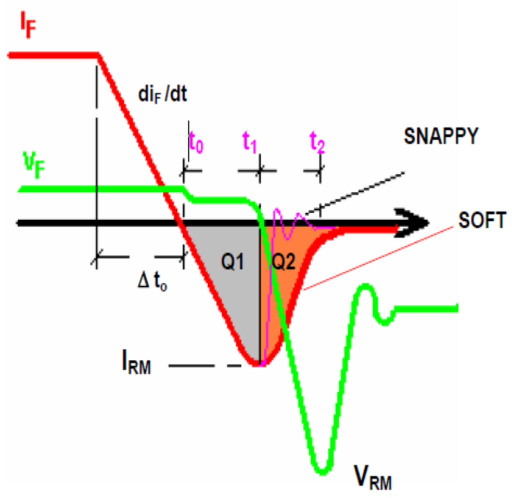


Fig.1 Typical turn-off dynamics of a soft and a 'snappy' diode'

Silicon Power diodes are the replacement of Selenium rectifiers having significantly improved forward characteristics and voltage ratings. They are classified mainly by their turn-off (dynamic) characteristics Fig. 1. The minority carriers in the diodes require finite time - t_{rr} (reverse recovery time) to recombine with opposite charges and neutralize. Large values of Q_{rr} =(Q_1 + Q_2) - the charge to be dissipated as a negative current when the and diode turns off and t_{rr} (= t_2 - t_0) - the time it takes to regain its blocking features, impose capable current stresses on the controlled device in series. A 'snappy' type of recovery of the diode effects high di/dt voltages on all associated power device in the converter because of load or stray inductances available in the network. There are mostly 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 largest voltage (~5kV) and current ratings (~5kA) and have excellent over-current (surge rating about six times average current rating) and surge-voltage hold off capability. They have relatively high Q_{rr} and t_{rr} specifications.

Fast recovery diodes: Fast recovery diffused diodes and fast recovery epitaxial diodes, FRED's, have significantly lower Q_{rr} and t_{rr} (~ 1.0 msec). They are available at large powers and are mainly used in association with fast controlled-devices as free-wheeling or DC-DC choppers and rectifier applications. Fast recovery diodes have application in induction heating, UPS and traction.
Schottky rectifiers: These are the fastest rectifiers being majority carrier devices without any $Q_{rr.}$ However they are accessible 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 low snubber requirements. Schottky diodes face no competition in low voltage SPMS applications and in instrumentation.

B) Silicon Control Rectifier

The Silicon Controlled Rectifier is the most famous 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 available at the main terminals. However, being artistic or 'latching', it cannot be turned off via the gate terminals especially at the extremely high amplification factor of the gate. There are two main types of SCR's is available.

Converter grade or Phase Control thyristors These devices are the work horses of the Power Electronics. They are turned off by natural (line) commutation and are reverse biased slightly for a few milliseconds following 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. The largest converters for HVDC transmission are built with series-parallel combination of these devices. Conduction voltages are device voltage rating relient and range between 1.5 V (600V) to about 3.0 V (+5 KV). These devices are not suitable for any 'forced-commutated' circuit requiring unwieldy large commutation components. The dynamic di/dt and dv/dt availabilities of the SCR have largely improved over the years borrowing emitter shorting and other techniques adopted for the faster variety. The requirement for hard gate drives and di/dt limting inductors have been removed in the process.

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 serviced in circuits that are operated on DC supplies and no alternating voltage is find to turn them off. Commutation networks have to be combined to the basic converter only to turn-off the SCR's. The efficiency, size and weight of these networks are directly reveled to the turn-off time, t_q of the SCR. The commutation circuits used resonant networks or charged capacitors. Quite a few commutation networks were designed and some like the McMurray-Bedford became largely accepted.

Asymmetrical, light-activated, reverse conducting SCR's: Quite a few varieties of the basic SCR have been developed for specific applications. The Asymmetrical thyristor is acceptable when reactive powers are involved and the light activated SCR assists in paralleling or series operation.

C) MOSFET

The Power MOSFET technology has largely reached maturity and is the most famous 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 behavior) with a typically rectangular Safe Operating Area, it can be conveniently utilized. Utilizing shared manufacturing processes, comparative costs of MOSFETs are low. For low frequency applications, where the currents drawn by the similar capacitances across its terminals are small, it can also be forced directly by integrated circuits. These capacitances are the main hindrance to operating the MOSFETS at speeds of several MHz. The resistive characteristics of its main terminals allow easy paralleling externally also. At high current low voltage applications the MOSFET offers best conduction voltage specifications as the $R_{DS(ON)}$ specification is current rating dependent. However, the lesser features of the inherent anti-parallel diode and its higher conduction losses at power frequencies and voltage levels limited its wider application.

D) THE IGBT

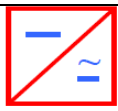
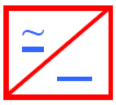
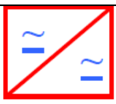
It is a voltage controlled four-layer device with the benefits of the MOSFET driver and the Bipolar Main terminal. IGBTs can be classified as punch-through (PT) and non-punch-through (NPT) structures. In the punch-through IGBT, a superior trade-off between the forward voltage drop and turn-off time can be achieved. Punch-through IGBTs are available up to about 1200 V. NPT IGBTs of up to about 4 KV have been exposed 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. Its switching times can be controlled by suitably shaping the drive signal. This gives the IGBT a number of advantages: it doesn't 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 devices 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.

E) THE 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. Because turn-off is provided by bypassing carriers directly to the gate circuit, its turn-off time is short, thus giving it more capability for high frequency operation than thyristors.

III.POWER CONVERTER TOPOLOGIES

A Power Electronic Converter processes the available form to another having a different frequency and/or voltage magnitude. There can be four basic types of converters depending upon the function performed.

CONVERSION FROM/TO	NAME	FUNCTION	SYMBOL
DC to DC	Chopper	Constant to variable DC or variable to constant DC converter	
DC to AC	Inverter	DC to AC of desired voltage and frequency converter	
AC to DC	Rectifier	AC to unipolar (DC) current converter	
AC to AC	Cycloconverter, AC-PAC, Matrix converter	AC of desired frequency and/or magnitude from generally line AC converter	

III.BASE/GATE DRIVE CIRCUIT

All discrete controlled devices, regenerative have three terminals. Out of them two are the Main Terminals. One of the Main Terminals and the third form the Control Terminal. The amplification factors 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 amuse the control terminal characteristics to efficiently turn-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. Being driven by a common controller, the drives must also be separated 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. 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. The former is acceptable for a SCR without isolated power supplies at the secondary. The latter is a must for practically all other devices.

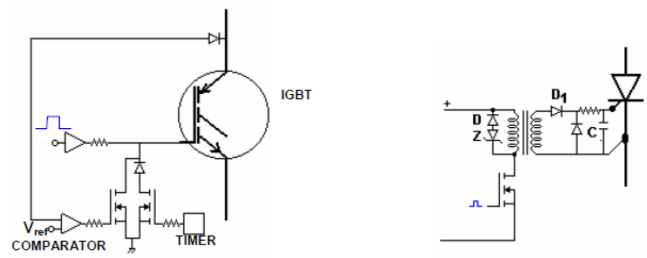


Fig.2: Simple gate-drive and protection circuit for a stand-alone IGBT and a SCR

V. conclusion:

Thus we have studied some power electronics devices like DC to Dc Converter, DC to AC converter, AC to AC converter and AC-AC Converter. Electronics compromise with the study of solid state semiconductor power devices and circuits for Power conversion to meet the desired control objectives (to command the output voltage and output power)

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