

# Power electronics essay sample



**ASSIGN  
BUSTER**

- \* The control and conversion of electrical power by power semiconductor devices (wherein these devices operate as switches) \* To control and convert electrical power from one form to another \* Power range: from a few VA/Watts to several MVA / MW

- \* The primary 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.

### Interdisciplinary Nature of Power Electronics

Power electronics is currently the most active discipline in electric power engineering.

#### \* Power Electronic Controllers

- \* The control and conversion of electric power is performed with the help of power electronic controllers \* Power electronic system consists of controllers

- \* The power electronic controllers are also called as power electronic converters

#### \* Advantages

- \* Fast dynamic response due to static devices

- \* High efficiency of conversion

- \* Compact size and light weight of the controllers

- \* Increased operating life and reduced maintenance

- \* Highly flexible-PEC uses digital or microprocessor based controls \* The electromagnetic interference and acoustic noise is reduced.

- \* Disadvantages

- \* PEC generate harmonics, these affects the performance of other loads \*

The power factor of some power electronic controllers is very low. Hence

power factor correction is necessary to reduce reactive power \*

Power electronic converters are costly for the simple requirements

## The Four Main Forms of Conversion

### Example

- \* Conversion of electric power

Other names for electric power converter:

- Power converter

- Converter

- Switching converter

- Power electronic circuit

- Power electronic converter

- \* The electric energy in one form is given at the input

- \* The power electronic system converts the electric energy in the other form

- \* Example is AC to DC conversion

### Power Electronic Systems

- \* Assembly of components that are connected together to form a functioning machine or an operational procedure. \*

Assembles next general building blocks:

- \* AC/DC Converters- rectifiers that transform ac to dc with adjustment of voltage and current \*

- \* DC/AC converters- inverters that produce ac of

controllable magnitude and frequency particular with galvanic isolation via a

transformer \* AC/AC converters- ac frequency, phase, magnitude and power converters, both without and with an intermediary dc link \* DC/DC converters- linear regulators and switching choppers Generic structure of a power electronic system

\* The power source can be AC mains, generator or batteries. The power controller converts the input power which is suitable for the load \* The sensing and feedback circuits monitor the load conditions \* The control unit consists of drive circuits of the power controller. The drives of the switches are adjusted according to feedback and the reference settings \* The control unit adjusts the drives whenever there is difference between feedback (actual) speed and reference speed. The control unit also accepts commands from the user. These commands are given for the proper functioning of the power electronic system and the load. History

\* 1882- French physicist J. Jasmin discovered a phenomenon of semiconductance and proposed this effect used for ac rectifying \* 1892- German researcher L. Arons invented the first mercury arc vacuum valve \* 1901- P. C. Hewitt developed the first valve in 1901 in USA and he also patented the mercury rectifier \* 1906-John Ambrose Fleming

Position and Significance in the Human Society of Power Electronics \* Electric power is used in almost every part and everywhere of modern human society. \* Electric power is the major form of energy source used in modern human society. \* The objective of power electronics is right on how to use electric power, and how to use it effectively and efficiently, and how to improve the quality and utilization of electric power. \* Power electronics and

information electronics make two poles of modern technology and human society: information electronics is the brain, and power electronics is the muscle. Areas of Application of Power Electronics Areas of Application of Power Electronics High frequency power conversion

- Power Transmission
  - HVDC
  - DC/DC, inverters
- Low frequency power conversion
  - HVAC
- Power quality
  - Power factor
  - Line rectifiers
- Distributed power
  - Power factor correction
  - Harmonic reduction
- Power devices
- Passive filtering
- Active filtering

#### Applications

- \* Heating and lighting control
- \* Induction heating
- \* Uninterruptible power supplies (UPS)
- \* Fluorescent lamp ballasts: Passive; Active
- \* Electric power transmission
- \* Automotive electronics

- \* Electronic ignitions
- \* Motor drives
- \* Battery chargers
- \* Alternators
- \* Energy storage
- \* Electric vehicles
- \* Alternative power sources: Solar; Wind; Fuel Cells
- \* And more!

Industrial applications

Motor drives

Electrolysis

Electroplating

Induction heating

Welding

Arc furnaces and ovens

Lighting

- \* Other Applications

Nuclear reactor control

Power systems for particle accelerators

Environmental engineering

- \* Trends

\* It is estimated that in developed countries now 60% of the electric energy goes through some kind of power electronics converters before it is finally used. \* Power electronics has been making major contributions to

- better performance of power supplies and better control of electric equipment
- energy saving

- environment protection

- \* Reduction of energy consumption leads to less pollution
- \* Reduction of pollution produced by power converters

- \* Direct applications to environment protection technology

Power Electronic Devices

### Power Semiconductor Device Variety

Comparative diagram of power ratings and switching speeds of semiconductor electronic devices

Thyristor

- \* Another name: SCR—silicon controlled rectifier

- \* Thyristor Opened the power electronics era

- 1956, invention, Bell Laboratories

- 1957, development of the 1st product, GE

- 1958, 1st commercialized product, GE

- Thyristor replaced vacuum devices in almost every power processing area.

- \* 4-layer, 3-junction pnpn device

- \* Has 3 terminals: anode, cathode and gate

- \* Turn ON: applying a short pulse across the gate and cathode, once turn on, the gate loses its control to turn off the device
- \* Turn OFF: applying a reverse voltage across the anode and cathode

Still in use in high power situation.

Thyristor still has the highest power-handling capability.

### Two Classifications of Thyristor

- \* Converter grade thyristor

- \* Slow type and are used in natural commutation(or phase controlled) applications
- \* Inverter grade thyristor
- \* Used in forced commutation applications b

### Appearance and symbol of thyristor

- \* Structure and equivalent circuit of thyristor
- \* Other methods to trigger thyristor ON
- \* High voltage across anode and cathode—avalanche breakdown \*
- High rising rate of anode voltage
- \* High junction temperature
- \* Light activation
- \* Static characteristics of thyristor
- \* Blocking when reverse biased, no matter if there is gate current applied. \*
- Conducting only when forward biased and there is triggering current applied to the gate. \*
- Once triggered on, will be latched on conducting even when the gate current is no longer applied.
- \* Physics of thyristor operation

### Unilateral Switching Devices

- \* Shockley Diode
- \* Invented by William Shockley
- \* A two-terminal four-layer thyristor
- \* Sometimes referred to as the four-layer diode, PNPN diode, or reverse-blocking diode thyristor. \*
- Can be turned ON through the application of sufficient voltage between anode and cathode \*
- Can be turned off through



the reduction of the applied voltage to a much lower point where there is too little current to maintain transistor bias Shockley Diode: Basic Operation

\* If a positive voltage is applied from anode-to-cathode; junctions 1 & 3 will be forward biased and junction 2 will be reversed biased. Thus, the two transistors Q1 & Q2 will be operating on the active region. \* At low values of bias voltages, the two transistors are barely forward biased, therefore very little current flows.

\* OFF State. If the bias voltage applied is very low, transistor currents are also very low, thus,  $\alpha_{DC}$ 's will also be very low. With this,  $I_{AK}$  will be very small (usually in  $\mu A$ ) and the resistance will be very high. (usually in  $M\Omega$ ). \* ON State. If the bias voltage applied is increased,  $\alpha_{DC}$ 's also increases until their sum becomes equal to 1. With this the diode current is maximum (both transistors are saturated) and its resistance will be very low (approximately  $0\Omega$ ). \* Ways of Increasing  $\alpha_{DC}$

\* increasing device temperature

\* increasing the bias voltage

\* incident light energy

\* Important Parameters and Specifications:

\* Forward Breakover (or Switching) Voltage [ $V_s$  or  $V_{BR}$ ] – the voltage at which the Shockley diode enters the forward conduction region. \* Switching Current [ $I_s$ ] – the value of diode current at which switching occurs. \* Holding Current [ $I_H$ ] – the current needed to hold the diode on, or the current below which the Shockley diode switches from forward conduction region to forward blocking region. \* Special terms applied to Shockley diode:

- \* Latch
- \* Firing
- \* Breakover
- \* Critical rate of voltage rise
- \* Characteristic Curve

1. Over-voltage Indicator. The Shockley diode is used to protect the sensitive load from possible damage due to excessive voltage.

## 2. Relaxation Oscillator

Operation:

1. Capacitor is initially uncharged, diode is OFF.
2. When the switch S is closed, diode still OFF, the capacitor will begin to charge to  $E_s$ . The voltage across the capacitor is given by:
3.  $V_c$  increases and reaches a value equal to  $V_s$ ; that is at  $t = T$ , the diode turns ON (short circuit). The capacitor discharges to the diode.
4. When the diode current falls below the holding current  $I_H$ , the diode turns OFF again and capacitor will again charge to  $E_s$ .
5. Sequence is repeated.

3. Time Delay Circuit. The function of this circuit shown in Figure 1. 6 is to provide a sharp positive pulse output that occurs a certain time delay after the application of input voltage. The time delay will be essentially the capacitor charge-up time given by Equation 1. 3

## Summary

- \* Shockley diodes are 4-layer PNP semiconductor devices. They have as a pair of interconnected PNP and NPN transistors.
- \* Shockley diodes tend to

stay ON once they've been turned on and stay once they've been turned off

\* There are two ways to latch a Shockley diode: exceed the anode-to-cathode breakover voltage, or exceed the anode to cathode critical rate of voltage rise. \* There is only one way to cause a Shockley diode to stop conducting and that is to reduce the current going through it to a level below its low-current dropout threshold.

### Power Diodes

\* They are mainly used as uncontrolled rectifiers to convert single-phase or three-phase AC voltage to DC. \* They are also used to provide a path for the current flow in inductive loads. \* Typical types of semiconductor materials used to construct diodes are silicon and germanium. \* Power diodes are usually constructed using silicon because silicon diodes can operate at higher current and at higher junction temperatures than germanium diodes.

### \* Symbol and Structure

### \* PN Junction

\* The diode is constructed by joining together two pieces of semiconductor material—a p-type and an n-type—to form a pn-junction. \* When the anode terminal is positive with respect to the cathode terminal, the pn-junction becomes forward-biased and the diode conducts current with a relatively low voltage drop. \* When the cathode terminal is positive with respect to the anode terminal, the pn-junction becomes reverse-biased and the current flow is blocked \* The arrow on the diode symbol in shows the direction of conventional current flow when the diode conducts

### \* Examples of commercial power diodes

## Silicon Controlled Rectifier (SCR)

\* A four-layer (pnpn) device similar to the Shockley diode except that it has a third terminal called gate. \* SCR is a switching device for high voltage and current operations. \* It's a four layer device with three terminals, anode, cathode, and gate. \* In off state, it act ideally as an open circuit between A and K, and high resistance. \* In on state it's act as short between A and K and small forward resistance. \* Some application are motor control, time delay, heater control, relay control and phase control.

### \* Principle of Operation

\* Operates on the principle of current conduction when the break over voltage is reached or gate triggering even though the break over voltage is not reached. \* SCR Waveforms

\* The popular terms used to describe how an SCR is operating are conduction angle and firing delay angle. \* Conduction Angle is the number of degrees of an ac cycle during which the SCR is turned ON. \* The firing delay angle is the number of degrees of an ac cycle that elapses before the SCR is turned ON. Equivalent Circuit

\* When the gate current,  $I_G$ , is zero, the device acts as diode in the off state when the very high resistance between the anode and can be approximated by an open switch. \* When a positive pulse of current (trigger) is applied to the gate, both transistors turn on (the anode must be more positive than the cathode). \* Then,  $I_{B2}$  turns on Q2, providing a path for  $I_{B1}$  into the Q2 collector, turning on Q1. \* The collector current of Q1 provides additional base current for Q2 so that Q2 stays in conduction after the trigger pulse is removed from the gate. \* Through such regenerative action, Q2 sustains the

saturated conduction of Q1 by providing a path for IB1. \* Q1, in turn, sustains the saturated conduction of Q2 by providing IB2. \* The device stays on (latches) once it is triggered on and the very low resistance between the anode and cathode can be approximated by a closed switch.

### Turning the SCR ON

#### 1. Gate Triggering

\* When  $I_G = 0$ ;  $V < V_{BRF}$ ; SCR is OFF

\* When a pulse is applied at the gate;  $I_G \neq 0$ ;  $V < V_{BRF}$ , SCR turns ON 2.

#### Increasing the bias voltage

\*  $V_{AK} < V_{BRF}$ ; SCR is OFF

\*  $V_{AK} \geq V_{BRF}$ ; SCR turns ON

\* Like the 4-layer diode, an SCR can also be turned on without gate triggering by increasing the anode-to-cathode voltage to a value exceeding the forward-breakover voltage. \* The forward-breakover voltage decreases as  $I_G$  is increased above 0 V. \* Eventually, a value of  $I_G$  is reached at which the SCR turns on at a very low anode-to-cathode voltage. \* The gate current controls the value of forward breakover voltage required for turn-on. \*

Although anode-to-cathode voltages in excess of the forward breakover voltage will not damage the device if current is limited, this situation should be avoided because the normal control of the SCR is lost. \* The SCR should normally be triggered on only with a pulse at the gate.

### Turning the SCR OFF

#### 1. Anode Current Interruption

a. Series Switching (Figure 1. 7)

b. Parallel Switching (Figure 1. 8)

- \* When  $V_G$  returns to 0 V after the trigger pulse is removed, the SCR cannot turn off.
- \* It stays in the forward-conduction region.

- \*  $I_A$  must drop below the value of  $I_H$  for it to turn off.

## 2. By Forced Commutation

- \* Requires momentary forcing the current through the SCR to flow in a direction opposite to the forward conduction so that the net forward current is reduced below the holding value.
- \* This method requires momentarily forcing current through the SCR in the direction opposite to the forward conduction so that the net forward current is reduced below  $I_H$ .
- \* While SCR is conducting, the switch is open.

- \* To turn off the SCR, the switch is closed, placing the battery across the SCR and forcing current through it opposite to the forward current.

(Typical turn-off times: few  $\mu s$  to about 30  $\mu s$ .)

## Regions of Operation

1. Forward Conduction Region (FCR)- region that corresponds to the ON state of the SCR where there is forward current from anode-to-cathode. 2. Forward and Reverse Blocking Regions (FBR and RBR) – regions corresponding to the OFF condition of the SCR where the forward current from anode-to-cathode is blocked.

### Characteristic Curve

## Important Parameters and Specifications

1. Forward Breakover Voltage ( $V_{BRF}$ ) – voltage at which the SCR enters the forward conduction region. 2. Holding Current ( $I_H$ ) – value of anode current below which the SCR switches from forward conduction region to the forward blocking region. 3. Gate Trigger Current [voltage] ( $I_{GT}$ ,  $V_{GT}$ ) – value of gate

current [voltage] needed to trigger the SCR from forward blocking region to the forward conduction region under specified condition. 4. Average Forward Current (IFAVE) – maximum continuous DC anode current that the device can withstand in the conduction state under specified condition. 5. Reverse Breakdown Voltage (VBDR) – parameter that specifies the value of reverse voltage from cathode to anode at which the device breaks into the avalanche region and begins to conduct heavily. 6. Average Gate Power Dissipation (PGAVE) – maximum value of average power dissipated between gate and cathode. 7. Instantaneous “ on” voltage ( $V_F$ ) – voltage drop between anode and cathode in “ on” state at a given current level.

#### Typical Packages

- \* Other types of thyristors are found in the same or similar packages.

#### The Silicon-Controlled Switch (SCS)

- \* Has similarities with the SCR in terms of construction

- \* Has two gate terminals:

- a. cathode gate

- b. anode gate

- \* Can be turned on and off using either of the gate terminals \* Can be turned OFF in any of the following ways:

- \* 1. reducing its anode current below  $I_H$

- \* 2. Applying a negative pulse at the cathode gate (GC) \* 3. Applying a

- positive pulse at the anode gate (GA) \* Available in power ratings lower than those of the SCR

- \* a four-terminal thyristor that has two gate terminals used to trigger the device on and off
- \* has schematic symbol and terminal identification as shown above

Basic Operation

- \* Assuming Q1 and Q2 are off, the SCS is not conducting.

- \* A (+) pulse on GK drives Q2 into conduction, providing a path for Q1 base current.
- \* When Q1 turns on, its IC provides IB for Q2, sustaining the “on” state of the device.
- \* The SCS can also be activated with a (-) pulse on the GA.
- \* The said (-) pulse drives Q1 to conduct, providing IB for Q2.
- \* Q2 provides a path for Q1 base current, sustaining the “on” state.
- \* The SCS can be turned off by applying a (+) pulse to GA.
- \* This makes the B-E junction of Q1 reverse-biased, thus turning Q1 off.
- \* Q2 cuts off and the SCS ceases conduction

- \* It can also be turned off by applying a (-) pulse on GK.
- \* The SCS typically has a faster turn-off time than the SCR.

#### Other Methods for Turning Off an SCS

- \* These are switching methods to reduce the IA below IH.
- \* The BJT acts as a switch.

#### SCS Applications

- \* SCS and SCR are used in similar applications.
- \* SCS has the advantage of faster turn-off with pulses on either gate terminals, but it is more limited in terms of maximum current and voltage ratings.
- \* SCS is sometimes used in digital applications: counters, registers, and timing circuits.

#### Gate Turned-Off Switch (GTO)



- \* Major difference from conventional thyristor:

- \* The gate and cathode structures are highly interdigitated, with various types of geometric forms being used to layout the gates and cathodes.

#### Physics of GTO operation

- \* The basic operation of GTO is the same as that of the conventional thyristor. The principal differences lie in the modifications in the structure to achieve gate turn- off capability. -Large  $\alpha_2$

- $\alpha_1 + \alpha_2$  is just a little larger than the critical value 1. -Short distance from gate to cathode makes it possible to drive current out of gate.

#### Giant Transistor (GTR)

- \* GTR is actually the bipolar junction transistor that can handle high voltage and large current. So GTR is also called power BJT, or just BJT.

- \* Static characteristics of GTR

#### Light Activated SCR (LASCR)

- An SCR that can be triggered ON by the application of light energy. • Can be triggered also by a positive signal at the gate. \* Stays ON even if the light disappears and turns OFF only when the IAK falls below  $I_H$ . Diode Alternating Current (DIAC)

- \* Similar to SBS in operation, but it can have higher switching voltages (up to a few hundreds) \* Diac function basically like two parallel 4-layer diode turned in opposite direction. The triac function basically like two parallel SCR turned in opposite directions with a common gate terminal. \* Diac turns on when breakover voltage is reached in either direction. \* Diac is also a

breakover type device. It's has two terminals A1 and A2. When breakover voltage reach conduction occur with either polarity across the two terminals.

### Characteristic Curve

\* Once breakover occurs, current direction depending on the polarity of the voltage across the terminal. The device turn off when the current drops below the holding value. \* The breakover voltage is approximately symmetrical for a positive and a negative breakover voltage.

\* When Diac is biased, the pnpn structure from A1 to A2 (positive direction) provide the same operation as 4-layer diode. \* In equivalent circuit Q1 and Q2 are fwd-bias, Q3 and Q4 are rev-bias. The other way around if Diac is biased from A2 to A1.

### Triode Alternating Current (TRIAC)

\* A triac is somewhat like a diac with a gate terminal.  
\* It can be activated by a pulse of gate current.  
\* Unlike the diac, it does not require the breakover voltage to initiate conduction. \* A bidirectional latching device whose operation approximates that of the inverse parallel SCRs. \* It is similar to two SCRs connected in parallel and in opposite directions with a common gate terminal. \* Unlike the SCR, it can conduct current in either direction when triggered on, depending on the polarity of the voltage across its terminals. \* It has relatively low current capability compared to SCRs (< 50A) \*

### Basic Operation

• The gate controls the state of the device between A1 & A2. • The device is

normally OFF and acts as an open circuit between A1 & A2. • When the appropriate gate voltage or current is applied, the TRIAC will latch into conduction for either polarity of applied voltage between A1 & A2. • Once the TRIAC has been triggered ON by a gate signal, the gate has no further control over the device. The device can only be turned OFF by reducing the current through A1 & A2 below the holding value,  $I_H$

The figure shows the triac characteristic curve

\* From the characteristic curve, notice that the break over potential decreases as the gate current increases. This is also a property of the SCR. \* The triac is non-conducting when  $I_A$  drops below  $I_H$ .

\* Again, as with SCRs, the only way to turn off the triac is to reduce the current to a sufficiently low level.

Applications:

1. Phase Controller
2. Static Switch
3. Minimizing radio interference
4. Light control (dimmer)
5. Motor speed controller

\* Triacs are also used to control the average power delivered to a load by method of phase control. \* It can be triggered such that the ac power is supplied to the load for a controlled portion of each half-cycle. \* During each positive half-cycle, the triac is off for certain interval called the delay angle (measured in degrees). \* It is triggered on and conducts current through the load for the remaining portion of the positive half-cycle, called the

conduction angle. \* It is operating at the same principle at the negative half-cycle but then current is conducted in the opposite direction through the load. \* The following figures illustrates the said operation.

### The Unijunction Transistor (UJT)

\* UJT does not belong to the family of thyristors because it does not have a 4-layer type of construction. \* Unijunction means there is only 1 pn junction. \* UJT is a three-terminal device, single junction device whose operation is similar to a Shockley diode. \* its switching voltage can be easily varied by the designer

### Equivalent Circuit

\* The diode represents the pn junction.  
\*  $r'_{B1}$  represents the internal dynamic resistance of the silicon bar between the emitter and base 1. \*  $r'_{B2}$  represents the dynamic resistance between the emitter and base 2. \* The total resistance between base terminals is called the interbase resistance  $r'_{BB}$ . \*  $r'_{BB} = r'_{B1} + r'_{B2}$   
\*  $r'_{B1}$  varies inversely with  $I_E$ , the reason why it is shown as a variable resistor. \*  $r'_{B1}$  can vary from several thousand ohms down to tens of ohms.  
\* The voltage across  $r'_{B1}$  is given by a voltage-divider principle:  $V_{BB} (r'_{B1} / r'_{BB})$

### Characteristic Curve

\* Beyond the valley point, the UJT is in saturation, and  $V_E$  increases very little with increasing  $I_E$ .

## UJT Applications

- \* Trigger device for SCRs and TRIACs
- \* Sawtooth generators
- \* Non-sinusoidal oscillator
- \* Phase controller
- \* Timing circuit

## Programmable Unijunction Transistor (PUT)

- \* PUT is also a type of thyristor.
- \* It is completely different to UJT in terms of structure. \* It is only similar to UJT in terms of some oscillator applications. \* It is similar to SCR but PUT's VAG can be used to both turn it on and off. \* It is a type of three-terminal thyristor that conducts when the voltage at the anode exceeds the voltage at the gate.
- \* The gate is connected to the n-region adjacent to the anode. \* The said pn junction controls the on and off states of the device. \* The gate is always biased positive with respect to the cathode. \* When the anode voltage exceeds the gate voltage by approximately 0.7 V, the pn junction is forward-biased, turning on the PUT. \* The PUT stays in conduction until the anode voltage falls back below 0.7 V, turning off the PUT.

## Setting the Trigger Voltage

- \* The gate can be biased to a desired voltage with an external voltage divider.
- \* When the anode voltage exceeds this “programmed” gate voltage level, the PUT conducts.

### Advantages of PUT over the UJT

1.  $V_s$  is easily varied by changing  $V_G$  through the voltage divider ratio. 2. It can operate at low voltage making it compatible with Integrated Circuits. 3. It has low peak point current and therefore dissipates less power. Power metal- oxide- semiconductor field effect transistor—Power MOSFET

#### \* Physics of MOSFET operation (Off- state)

p-n- junction is reverse-biased off-state voltage appears across n-region. p-n- junction is slightly reverse biased positive gate voltage induces conducting channel drain current flows through n- region an conducting channel on resistance = total resistances of n- region, conducting channel, source and drain contacts, etc.

#### \* Current-Voltage limitations of BJTs and MOSFETs

### Examples of commercial power MOSFET

#### Insulated-Gate Bipolar Transistor

\* IGBT has both MOSFET and BJT features making it useful in high-voltage and high-current switching applications. \* It can replace MOSFET and BJT in the said applications. \* It has the output conduction characteristics of a BJT.

\* It is voltage-controlled like a MOSFET.

\* It is an excellent choice for many high-voltage switching applications. \*

Gate, collector, and emitter are the three IGBT terminals. \* IGBT schematic symbol is similar to that of BJT with an extra bar representing the gate structure of a MOSFET rather than a base. \* It has MOSFET input characteristics.

- \* It has BJT output characteristics.
- \* Recall that BJTs are capable of higher currents than FETs, but MOSFETs have no gate current because of the insulated gate structure. \* IGBTs exhibit a lower saturation voltage than MOSFETs and have about the same saturation voltage as BJTs. \* They are superior to MOSFETs in some applications because they can handle high VCE exceeding 200 V and exhibit less saturation voltage when they are conducting. \* They are superior to BJTs in some applications because they can switch faster, but they are slower than MOSFETs. \* In terms of features for switching applications, the following table shows the comparison: \*

#### IGBT Operation

- \* IGBT is controlled by the gate voltage (like MOSFETs).
- \* It is a voltage-controlled BJT, but with faster switching speeds. \* It is controlled by the insulated gate voltage, thus it has essentially no input current and does not load the driving source.

#### \* Features

- \* On- state losses are much smaller than those of a power MOSFET, and are comparable with those of a GTR \* Easy to drive —similar to power MOSFET
- \* Faster than GTR, but slower than power MOSFET
- \* Structure and operation principle of IGBT
- \* Also multiple cell structure Basic structure similar to power MOSFET, except extra p region On- state: minority carriers are injected into drift region, leading to conductivity modulation compared with power MOSFET: slower switching times, lower on- resistance, useful at higher voltages (up to 1700V)

## Other New Power Electronic Devices

- \* Static induction transistor —SIT
- \* Static induction thyristor —SITH
- \* MOS controlled thyristor —MCT
- \* Integrated gate- commutated thyristor —IGCT
- \* Power integrated circuit and power module

### 1) Static induction transistor—SIT

Another name: power junction field effect transistor—power JFET Features

- Major- carrier device
  - Fast switching, comparable to power MOSFET
  - Higher power- handling capability than power MOSFET
  - Higher conduction losses than power MOSFET
  - Normally- on device, not convenient (could be made normally- off, but with even higher on-state losses)
- ### 2) Static induction thyristor—SITH other names
- Field controlled thyristor—FCT
  - Field controlled diode

### Features

- Minority- carrier device, a JFET structure with an additional injecting layer
- Power- handling capability similar to GTO
- Faster switching speeds than GTO
- Normally- on device, not convenient (could be made normally- off, but with even higher on- state losses)

### 3) MOS controlled thyristor—MCT

- \* Essentially a GTO with integrated MOS- driven gates controlling both turn-on and turn- off that potentially will significantly simplify the design of circuits using GTO. \* The difficulty is how to design a MCT that can be turned on and



turned off equally well. \* Once believed as the most promising device, but still not commercialized in a large scale. The future remains uncertain. 4)

#### Integrated gate- commutated thyristor — IGCT

\* The newest member of the power semiconductor family, introduced in 1997 by ABB \* Actually the close integration of GTO and the gate drive circuit with multiple MOSFETs in parallel providing the gate currents

Short name: GCT

\* Conduction drop, gate driver loss, and switching speed are superior to GTO

\* Competing with IGBT and other new devices to replace GTO General

#### Principles of Power Switches

\* Practical power electronic converters are based on semiconductor power switches. \* Directionality

##### 1. Unilateral Devices

\* A device that transmits energy in one direction only. Ex. PN

diodes, SCR, Shockley diode, GTO, Zener, Schottky

##### 2. Bilateral Device

\* A device that transmits energy in both directions. It is usually formed by placing two unilateral devices in inverse parallel or series mode. Ex. DIAC, TRIAC, Varistor, Relays, Mechanical switches \* Control

##### 1. Uncontrolled Device

\* Two-terminal devices lacking a control electrode. The device can be turned on or off in reference with a fixed current or voltage. Ex. PN diode, Shockley, DIAC, Schottky diode

##### 2. Semi -controlled

\* Devices that are formed such that the gate terminal can turn on a device but has no turn-off capability. Ex. SCR, TRIAC

### 3. Fully-controlled

\* The gate has full control over the device which means that a third terminal could be used to turn on or turn off the device. Ex. GTO, BJT, MOSFET \*

#### Latching or Non-Latching

\* Either of these properties will only apply to devices having a gate terminal.

- Latching – a characteristic that enables a device to remain in ON state even when the excitation or gate signal has been removed.

#### (a) Latching Devices

\* SCR, TRIAC, GTO

#### (b) Non-Latching Devices

\* BJTs, MOSFETS