Unit-1 Introduction

What is power electronics?

Electric power containing generation, transmission & distribution. After this utilization of power for variety of applications. By using natural resources we are generating power. It should utilized properly to meet our needs. It should be used effectively & environment friendly. Power electronics helps us to achive this.

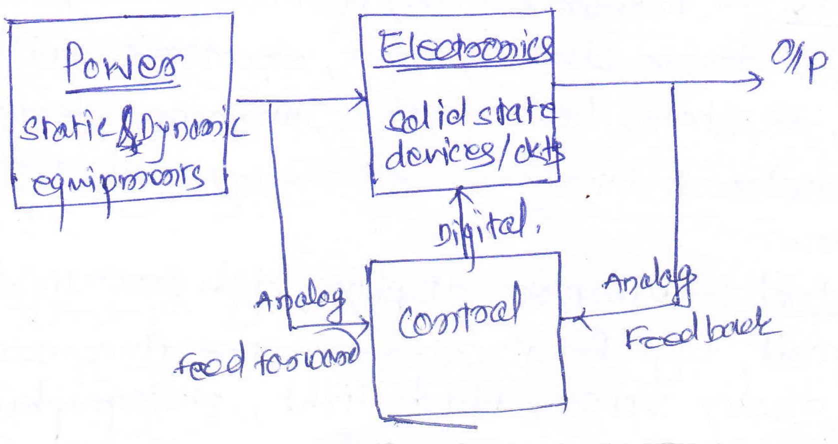
Definations

Application of power electronics circuit for conversion of energy is known as power electronics.

Use of ~~power~~ electronics for large power control is known as power electronics.

Application of semiconductor devices to control & conversion of electric power.

Power electronic combines power, electronics & control. Power deals with static & dynamic power equipments for generation, transmission & distribution of power. Electronics deals with the solid state devices & circuits for processing power to get desired o/p. And control deals with steady state & dynamic characteristick's of a closed loop system. Relationship between power, electronics & control is as shown below.

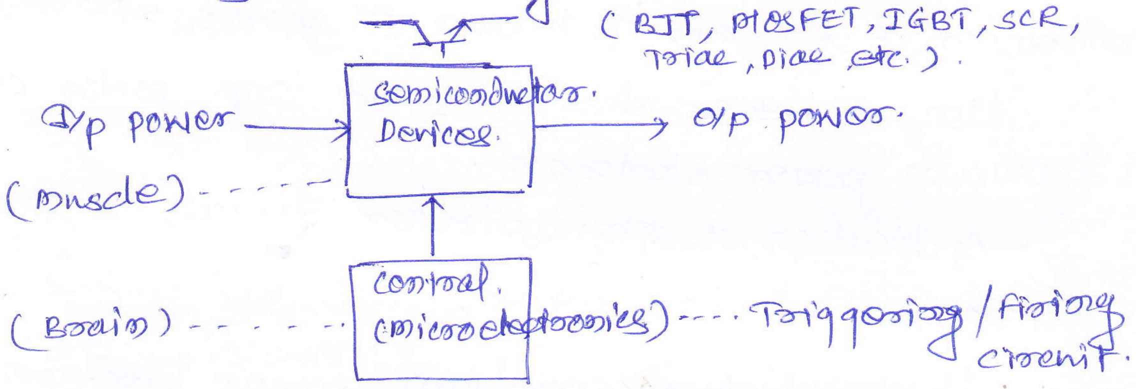


Power electronics controls the power by switching the semiconductor devices.

Thus the scope of power electronics is the application of power electronics for conversion processing and control electric power.

As technology is goes on developing, the switching speed & power handling capacity of semiconductor devices are greatly improved. Development in microcontroller & microcomputer controlling of power get improved.

In power electronics there are main two parts 1st semiconductor devices & 2nd controlling of that devices.



I/p power is controlled by switching the semiconductor devices by appling trigger pulses from firing circuit.

Application of Power Electronics :-

Power electronics is more important in modern technology. It has great variety of applications, some of fields are as -

1. * Heat control
2. * Light control.
3. * Speed control
4. * Power supplies
5. * Audio & video applications
6. * Other.

① **Heat control** :- microwave oven, furnace control, AC, Refrigirator room heater, electronic blanket, dryer, electronic ignition of automobiles, resistance heating (ovens) furnaces, electron arc furnaces, electronic bumbardment heating, high freqn heating, Defreezer.

② **Light control** :- Dimmer, displays, high freqn lighting, flashers, ballest circuit, high freqn convertor for fluorescent tubes, CFL, LED bulbs, display copier, flash light, photographic processors

Food warmer trays, traffic signal control, night vision equipments electronic toys.

3. Speed control :- Fan speed control, food mixer, locomotives, electric trains, printing press, EBS, (electronic breaking system) belt driven systems,

4. Power supplies :- Regulated AC power supplies, DC power supplies, SMPS, UPS, HVDC, Flexible AC transmission systems (FACTS), High performance battery chargers, in modern hybrid cars, power electronic boost converters, P.S. for telephone exchanges, P.S. for space systems.

5. Audio and video applications :- Audio amplifiers, Telephone, T.V. receivers, projectors.

6. Other applications :- Relays, Alarms, Blowers, vaccume cleaners, cranes, hoists, pumps & compressors.

Power Semiconductor Devices:

Following are the important power semiconductor devices used in modern power converters.

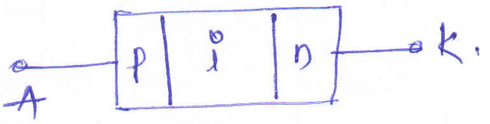
- Diodes,
  SCR LASCR, TRIAC,
  BJT, MOSFET, IGBT, GTO, SITH, MCT.

All these devices based on silicon material, germanium is never used in power semiconductor devices as its temperature withstanding cabability is lower

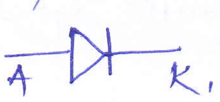
1. Power Diode :-

It is simplest power semiconductor device. It has p-i-n structure. In this i-layer is very lightly dopped almost intrensic semiconductor. A typical power diode has p-i-n structure. In this i-layer. This i-layer is sandwitched between the p-layer & n-layer. This i-layer helps in blocking reverse voltage. It has two terminals called anode (A) & cathode (K). There is no control terminal & hence it is uncontrolled device.

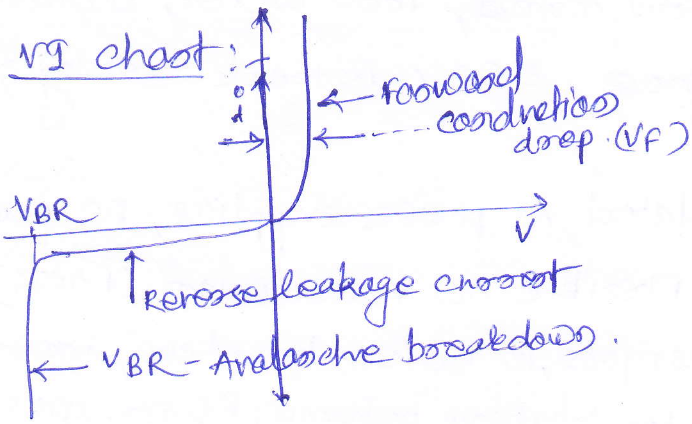
Structure:-

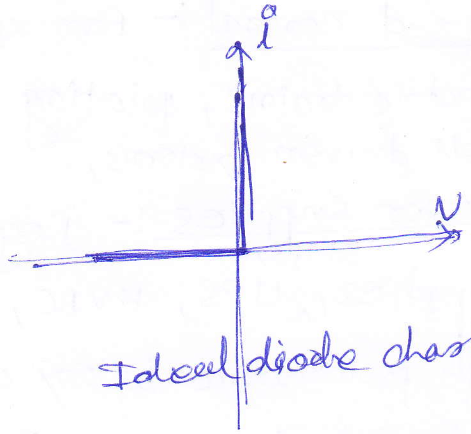


Symbol



VI chart:-





Ideal diode chart.

Power diodes are three types:

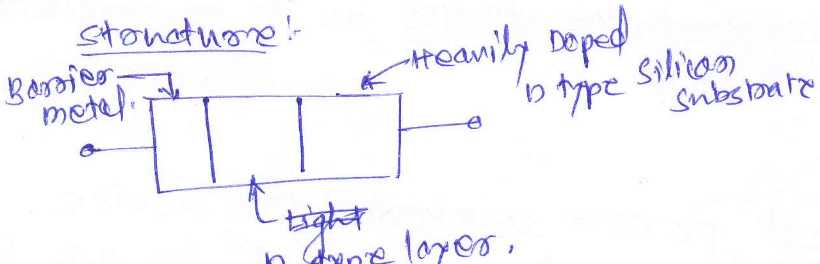
i) General purpose, ii) high speed or (Fast recovery), iii) Schottky
(6000V/4500A) (6000V/1100A) 100V/30A

1) General purpose diodes - They are available up to 6000V 4500 Amp. They have t_{rr} @ 25 μs. Their freqⁿ operation 50 to 60Hz. Applications - battery charger converter, power supplies, m/c tool controllers etc.

ii) Fast recovery diodes - are available upto 6000V/1100A. their reverse recovery time is 0.1 μs to 5 μs. They are required for high freqⁿ operation. Modern high speed diodes t_{rr} = 50ns. Application - choppers, inverters. But they have relatively higher ON-state voltage drop. They have low on state voltage drop.

iii) Schottky diodes:- They have low on state voltage drop, typically in nano seconds & very small reverse recovery time. They have more leakage current & hence the ~~for~~ voltage rating is limited to 100V, 30A. forward voltage drop is 0.5V to 1.2V. is very low.

Structure:-

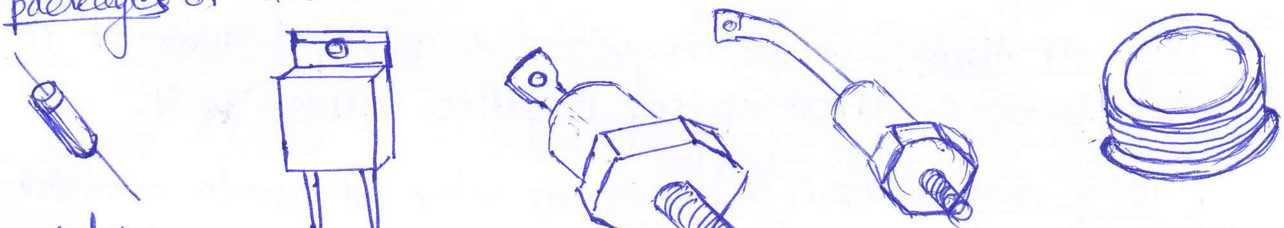


A metal layer such as - chromium, platinium, tungsten or molybdenum is used. Junction between this metal & n type layer has barrier potential which provides forward & reverse characteristics of diode.

In forward conduction mode - electrons are emitted from the n type into metal, they cross the barrier bet metal & n type.

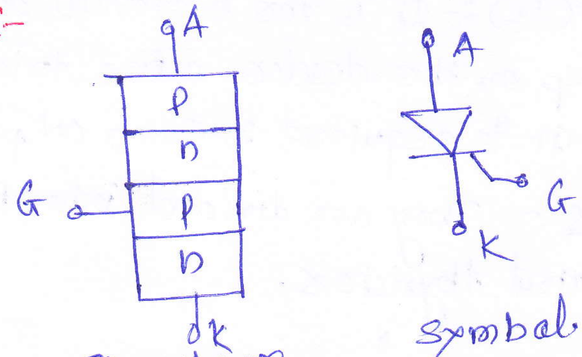
Here electrons are only carriers, hence it is called as a unipolar device. Forward on-state voltage is proportional to barrier potential & reverse leakage current is inversely proportional to barrier potential. Hence for low on state voltage drop & leakage current more. The leakage current in schottky is max up to 100 mA & in general purpose diode leakage current is few µA. Leakage current is not dependent on minority carrier but is due to majority & it is not varies with temperature. There is minimum recombination of minority carriers, hence it has less reverse recovery time, trr is about few nanosec. Schottky diode has on state resistance typically 0.3 V. They have low voltage range about 50-200V.

Applications – switching power supplies, converters, freewheeling diodes & reverse battery protection. Following are the some packages of diode.



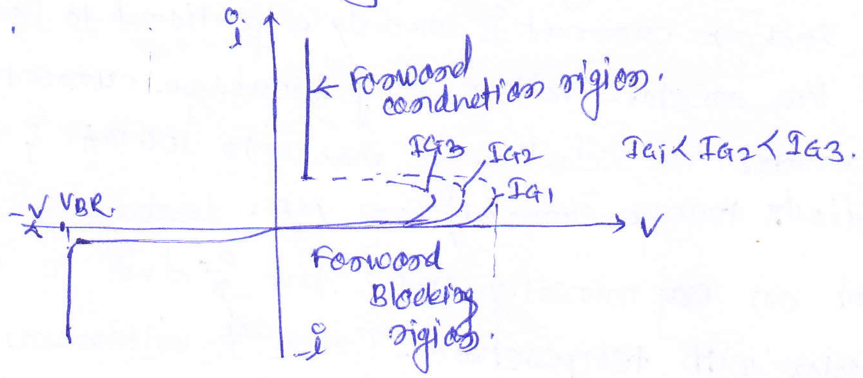
Axial type. Plastic pack. Stud type. Hocky puk Type. DBE Type.

Thyristor :-



Structure Symbol

It is 4 layer, 3 terminal, current controlled device. It is also called as SCR (silicon controlled device). It is semicontrolled device. It has pnpn structure & 3 terminal named anode (A), catode (K) & gate (G). It can be turned by injection small amount of current into gate & positive voltage is applied between Anode & catode. (i.e anode is more +ve than catode). Once SCR turned on, even though its gate pulse voltage is removed, it continues to conduct. To stop conducting either its voltage has to remove or cathode voltage should be more positive than anode voltage. It's characteristice is as shown below.



Commutation circuit :- Extra circuit required to make SCR off is called commutation circuit. It forces SCR to turn off.

Line commutation :- Ac line voltage varies in every half cycle ~~to~~ from +ve half to -ve half. It forces SCR to turn off.

Turn off time :- Time required to principal current to reduce zero, after appling negative voltage to it.

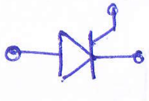
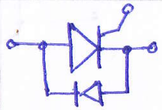
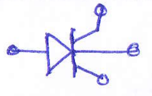
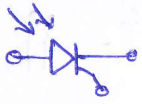
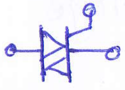
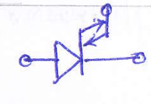
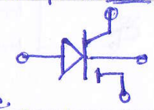
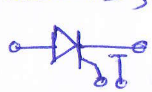
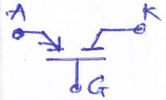
Holding current (IH) :- It is the Minimum value of anode current below which device stops conducting & returns to forward blocking state. It is required in Turn OFF process.

Latching current (IL) :- It is the minimum on state current required to keep on the device after trigger pulse has been removed. It is required in Turn ON process.

Types of Thyristors :- They are divided into following groups.

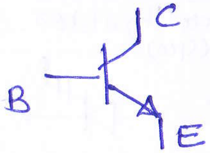
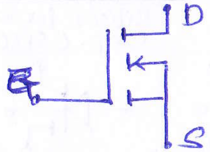
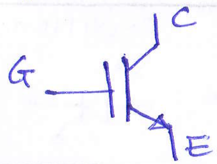
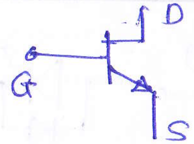
1. Forced commutated thyristors.
2. Line " " .
3. Gate Turn Off " (GTO).
4. Reverse conducting " (RCT).
5. Static Induction " (SITH).
6. Gate Assited Turn Off " (GATT).
7. ~~Light~~ MOS controlled ~~Turn off~~ " (MCT)
8. Emitter " Turn off " (ECT)
9. Integrated gate commutated " (IGCT).
10. MOS Turn off " (MTO).
11. Light activated silicon controlled Rectifier (LASCR).

Thyristors :—

	Natural/ Line Commutated Thyristor.	RCT's Reverse conducting Thyristor	GATT Gate Assisted Turn Off Thyristor	LASCR Light Activated Silicon Controlled Rectifier.	TRIAC	GTO Gate Turn Off Thyristor.	SITH. Static Induction Thyristor.	MTO. MOS Turn Off Thyristor. Silicon Power Corp. (SPCO)	ETO Emitter Turn Off Thyristor. Virginia Power Electronics (SPCO)	IGCT Integrated Gate Commutated Thyristor. (Mitsubishi & ABB.)	MCTs MOS controlled Thyristor.
Symbol							 • Normally ON device.				
Explanation.		• Antiparallel diode in a single silicon chip. • Bidirectional S/W.		• Similar to SCR. It has window through light radiation fall near gate to turn on it. • Higher degree of isolation.	• Semicontrolled, Bidirectional S/W. • Two SCR's connected back to back.	• Self turn off. • +ve pulse to turn on. • short –ve pulse to turn off. • Faster switching speed. • Withstand higer voltage & current.	• Self turn off. • In 1988 by Toyo Electric company of Japan. • Turn on by +ve pulse • Turn off by –ve voltage to gate. • FET - Field control thyristor current.	• Combination of a GTO + MOSFET to overcome limitation of GTO — • No need of high current to turn off like GTO. • high power i.e. high voltage current,	• GTO + MOSFET hybrid device • Turn off GTO under unity gain • Fast switching speed, snubber less turn off & voltage control. • High power high freq appⁿ	• Hard driven GTO • Snubberless switching • Fast commutation of the cathode to the gate • Power, reliability speed, effi cost, weight & volume.	• Fully Controlled • Load char of thyristor • Control char. of MOSFET. • Low on state losses & high current capacity. • Simple driving char, Fast switching
Applications	General Purpose	High Speed Switching e.g. Traction	High Speed Switching e.g. Traction	H.V.D.C. Systems. → Low line voltage drop – less conductors requiries.	Low power applⁿ Heat, light, motor control, A.C. Swiches washing m/c	Medium Power applⁿ at freq 100 KHz UPS, motor control. Ele. Car,	Medium Power appⁿ at freqn 100 KHz. Fast. Switching.	High Power Applications (1–20 MVA)	High Power Applⁿ.	Medium Power Applications	Medium Power Applications UPS, static VAR, harmonic compensators, AC motor drives.
Voltage	6000 V	4000 V	1200 V	6000 V.	1200 V	6000 V	1200 V	10 KVA	6 KV	4500 V	400–4500 V
Current	4500 A	2000 A Rev-800 A	400 A	1500 A	300 A	6000 A	300 A	4 KA	4 KA	250 A	65–250 A
Switching Time	100–400 μs	20–100 μs	10–50 μs	200–400 μs	200–400 μs	50–110 μs	5–10 μs	80–110 μs	80–110 μs	80–110 μs	50–110 μs
On state Resistance	0.48–0.72 mΩ	2.1 mΩ	2.2 mΩ	0.53 mΩ	3.6 mΩ	1.07 mΩ	5.6 mΩ	10.2 mΩ	0.5 mΩ	0.8 mΩ	10 mΩ – 28 mΩ.

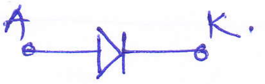
Limitation – high driver power snubber ckt, & dv/dt limitations (of GTO → MTO)

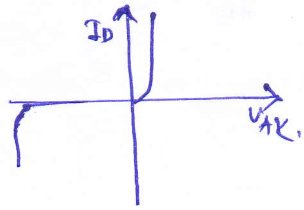
POWER TRANSISTERS.

	Power BJT	MOSFET	COOLMOS	IGBT	SIT
	Power BJT Bipolar Junction Transistor	MOSFET. Metal oxide semiconductor Field effect transistor.	COOLMOS.	IGBT Insulated gate bipolar transistor	SIT - static induction transistor - 1987, Tokin corporation
Symbol			* New techonology for high ~~power~~ voltage		
	• Current controlled • Fully controlled unidirectional. • Used in CE configuration.	• Voltage controlled • Fully controlled unidirectional • Used in common source configuration.	voltage controlled. • compensation in vertical drift region to improve on state resistance. • Less on state resistance • Conduction loss 5 times less • Power handling capacity 2-3 times more • Active chip are 5 times smaller.	• Voltage controlled. • 4 layer, 3 terminal, unidirectional, fully controlled device. • Combines advantage of quality MOSFET & transistor.	• Normally ON device • -ve voltage to turn off it. • like JFET but it is vertical device • low channel resistance & have low voltage drop. • It has low noise, low distortion, high freq^n capability. • Not used for general purpose.
Applications	Power converters below 10 KHz Washing m/c, AC, refrigerators, Robot, motor control.	Power converter upto several KHz freq^n. Microwave oven, Audio power supplies, VCR, Electric cars.	High voltage applications	High voltage & high current application - UPS Robots	High power, high freq^n audio amplifiers, eg. Audio ampl^n in VHF & UHF Microwave ampl^n.
Voltage	1200V	1000V	1500V	1700V	1200V
current	400A	100 A	400A	2400A	300 A
on state resistance	~~0.2 to~~ 0.4-30 mΩ	1Ω/100V, 5Ω/500V,	0.12mΩ - 2Ω	2.3mΩ -	1.2Ω
frequency	20 - 30 KHz	100 KHz	125 KHz	100 KHz	100 KHz
Switching Time	2 to 9 μs.	1.6 μs.	1 to 2 μs.	5-10 μs.	0.5μs. typically 0.25μs.

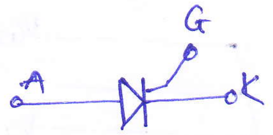
Symbol & VI charateristics of commonly used semiconductor devices :-

① Diode.

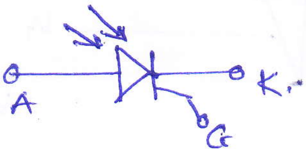


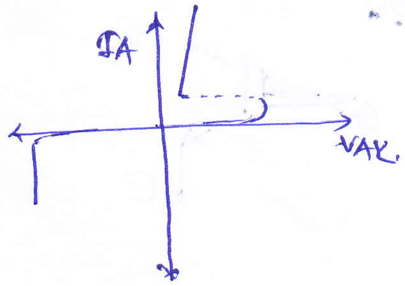


② Thyristor

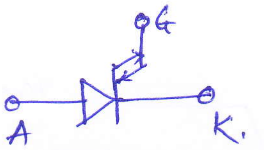


③ LASCR

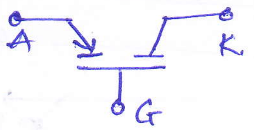




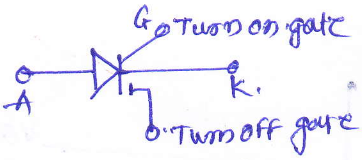
④ GTO.



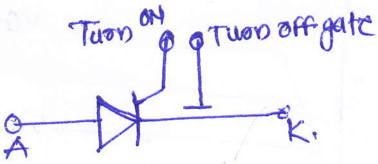
⑤ MCT



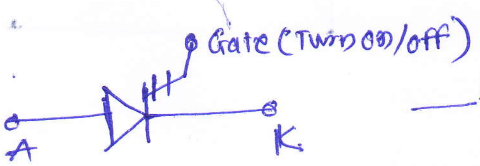
⑥ MTO



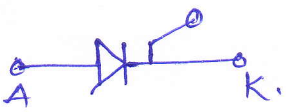
⑦ ETO

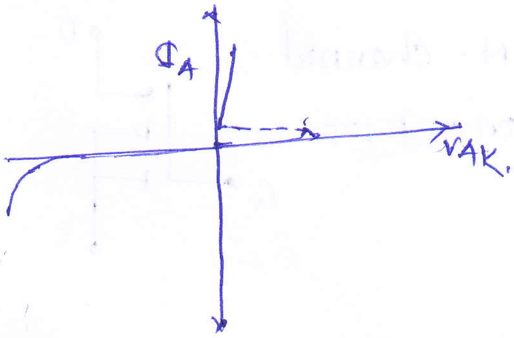


⑧ IGCT.

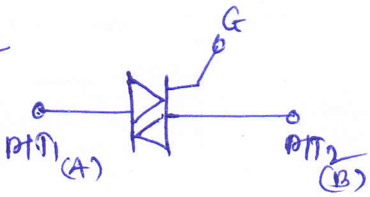


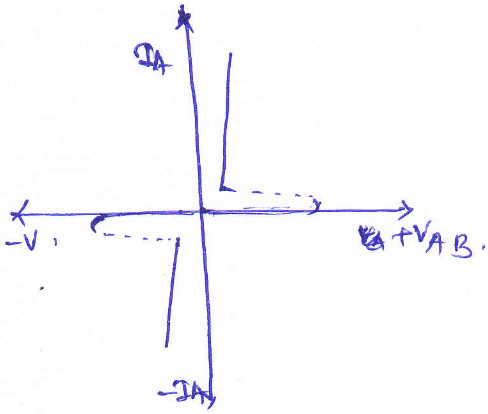
⑨ SITH



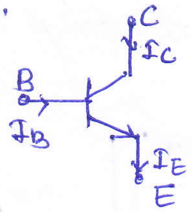


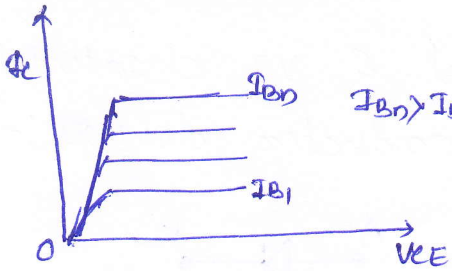
⑩ Triac





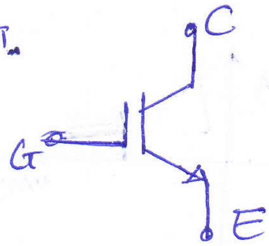
(11) NPN. BJT

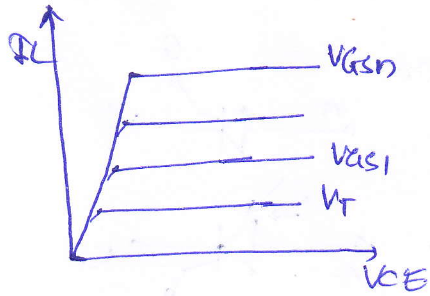




$I_{Bn} > I_{B1}$

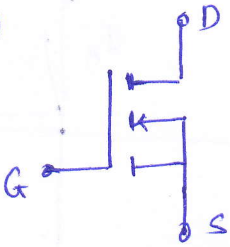
(12) IGBT.

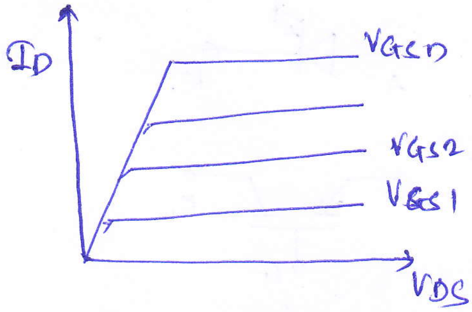




$V_{GSn} > V_{GS1}$

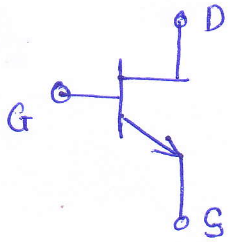
(13) N - channel MOSFET

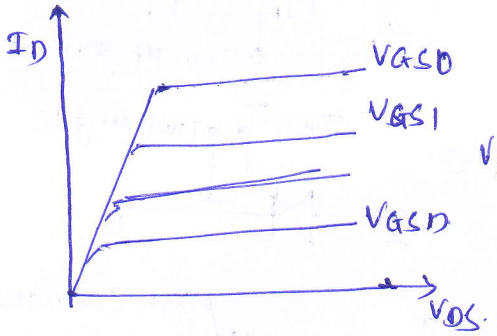




$V_{GSn} > V_{GS1}$

(14) SIT.





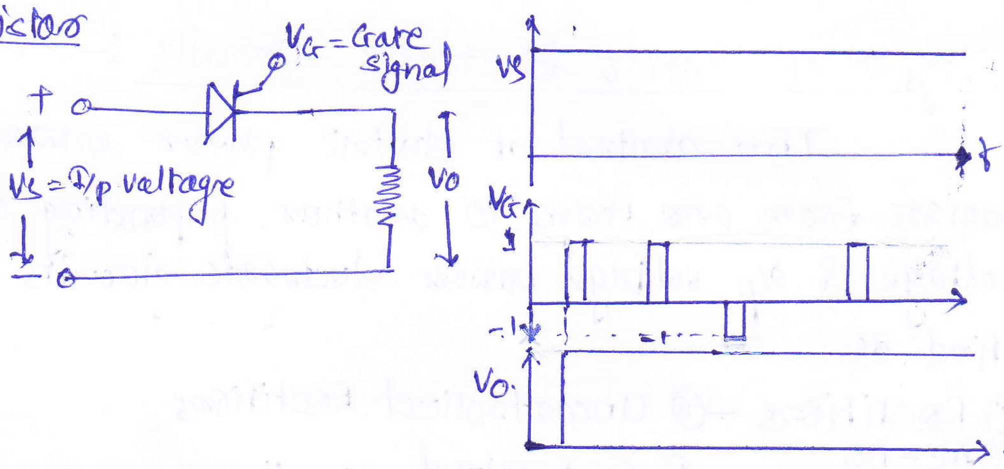
$V_{GSn} < V_{GS1}$

Control characteristics :-

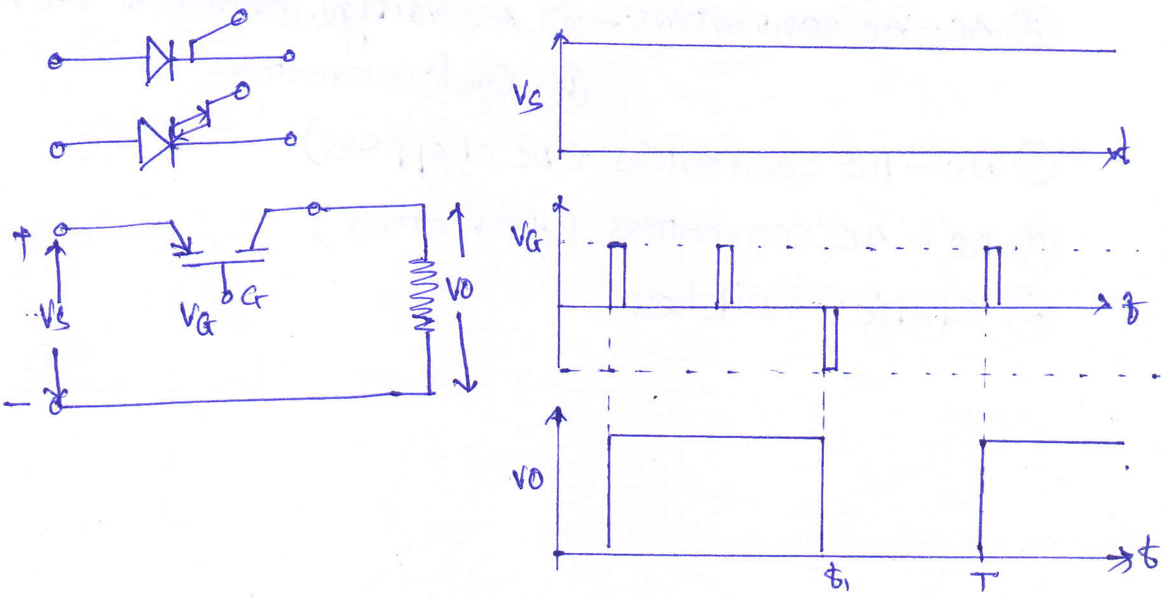
The power semiconductor devices can be used as switch by appling control signals at the gate / base terminal. The required o/p can be obtained, by using proper device & proper control signal at the control terminal. By varying conduction time of the device desired o/p can be obtained. Figure below shows the o/p voltages and control characteristics of commonly used power semiconductor devices.

When control signal is absent semiconductor devices are in off condition, i.e load current almost zero. Hence o/p voltage Vo is zero. When control signal of sufficient maginitude & pulse width the device will turn off & load current starts flowing. Load voltage is equal to supply voltage & drop access device is almost zero & hence it is neglected.

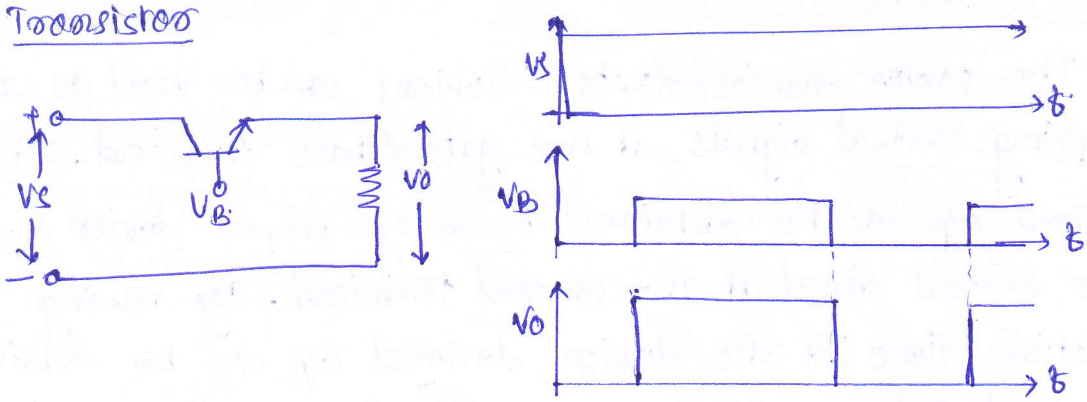
① Thyristor



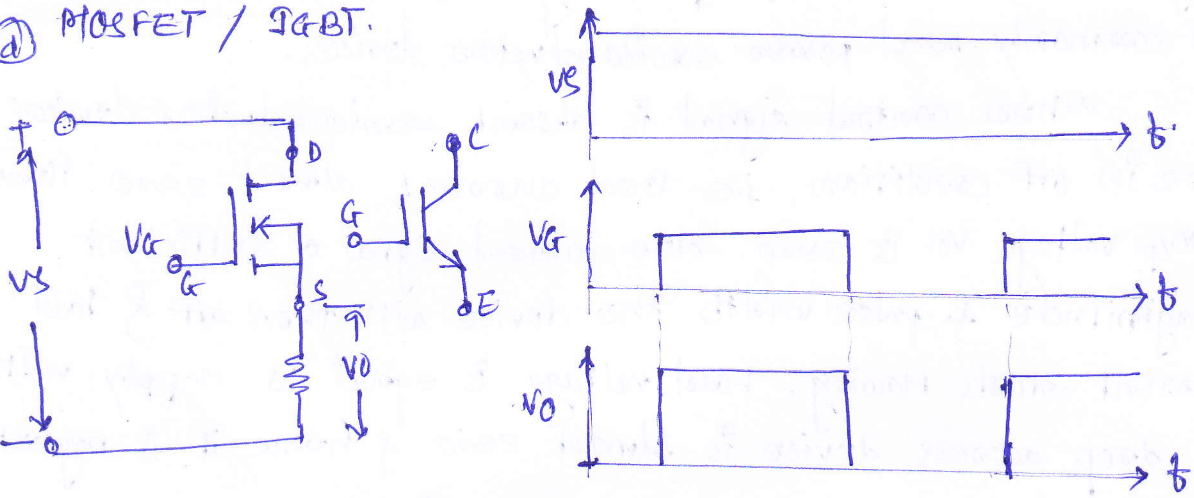
② GTO / MTO / ETO / IGCT / MCT / SITH



ⓒ Transistor



ⓓ MOSFET / IGBT.



Types of Power Electronic Circuits :-

The control of electric power means power conversion from one form to another. Depending upon i/p voltage & o/p voltage power electronic circuits are classified as.

① Rectifiers (AC-DC converters) — ⓐ Uncontrolled Rectifiers
ⓑ Controlled —"—

② AC-AC converters — ⓐ AC voltage controller (ACVC)
ⓑ Cycloconverter.

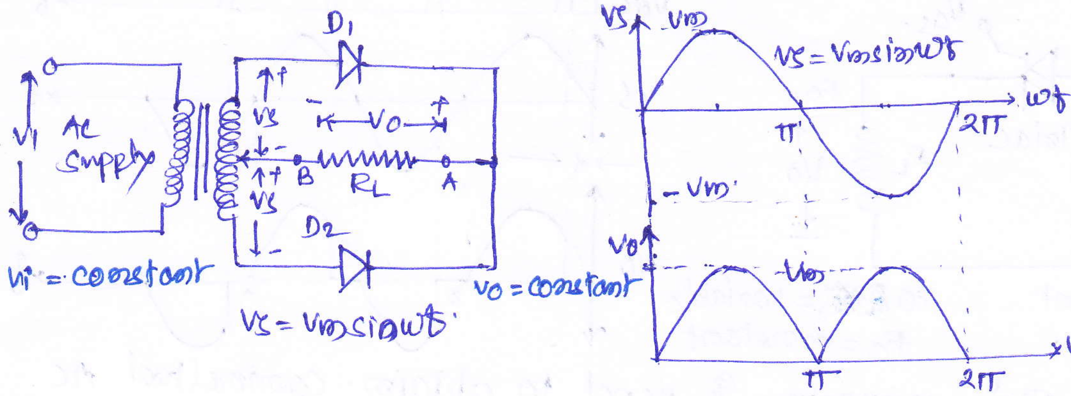
③ DC-DC converters (DC choppers).

④ DC-AC converters (Inverters)

⑤ Static switches

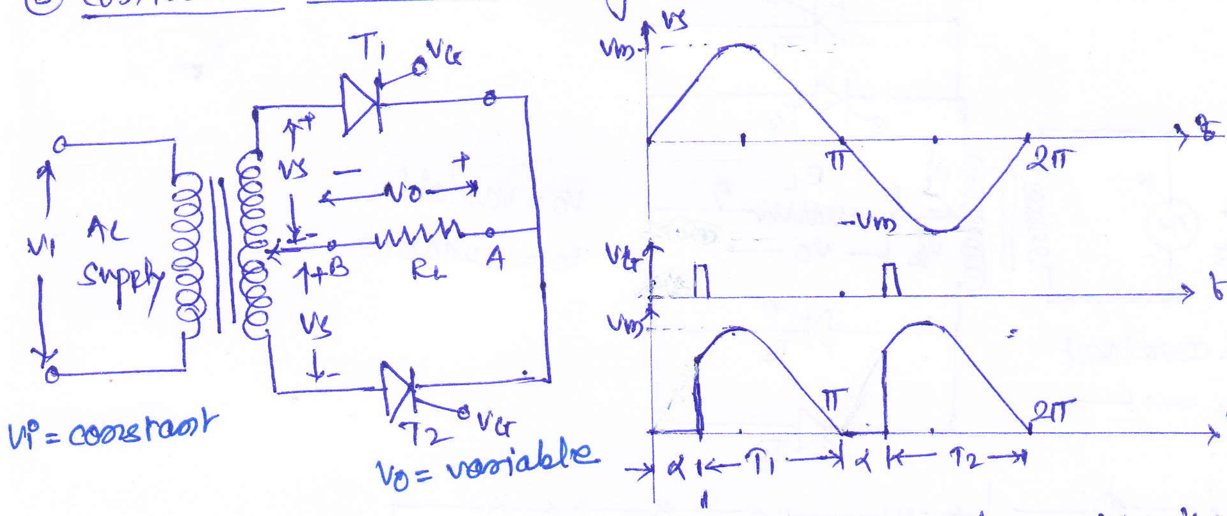
① AC-DC converters (Rectifiers)

ⓐ Uncontrolled Rectifiers (Diode Rectifiers) :-



AC I/p voltage is converted into unidirection voltage ie dc voltage. For given I/p voltage o/p voltage is fixed. Rectified o/p voltage is not able to change, hence it is uncontrolled rectifier.

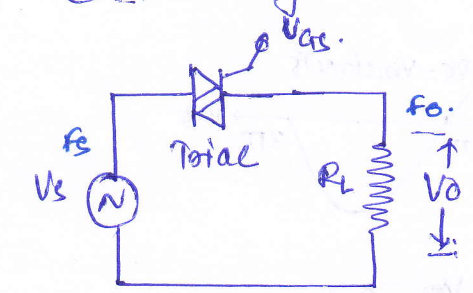
ⓑ Controlled Rectifiers (Thyristor Rectifier)

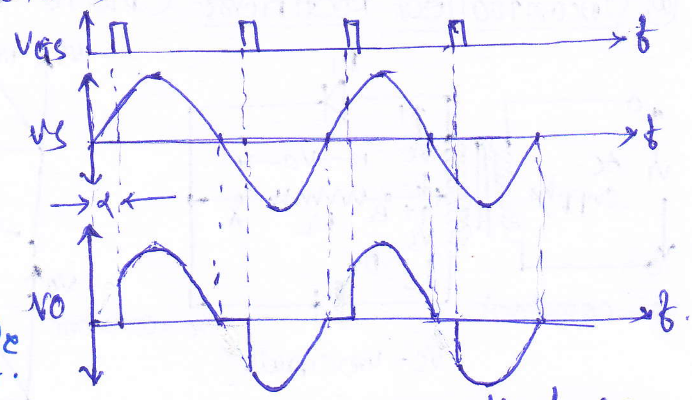


Diodes are replaced by thyristors in previous circuits for positive half cycle thyristor T_1 will conduct when trigger pulse is applied, & remaining cycle is passed to the load. In negative cycle T_1 will turn off due to natural commutation, T_2 will conduct when trigger pulse applied & remaining half cycle will be passed to load. T_2 will become off in positive half cycle due to natural commutation. Average o/p voltage is controlled by varying firing angle α. Firing angle α increases average o/p voltage decreases & vice versa. Hence these converter is called controlled rectifier.

(2) AC-AC converters :-

(a) AC voltage controller (ACVC)



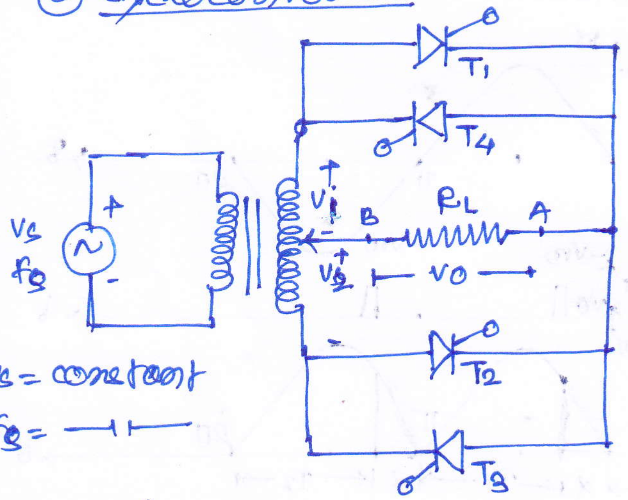


V_s = constant
f_s = — " —

V_o = variable
f_o = constant.

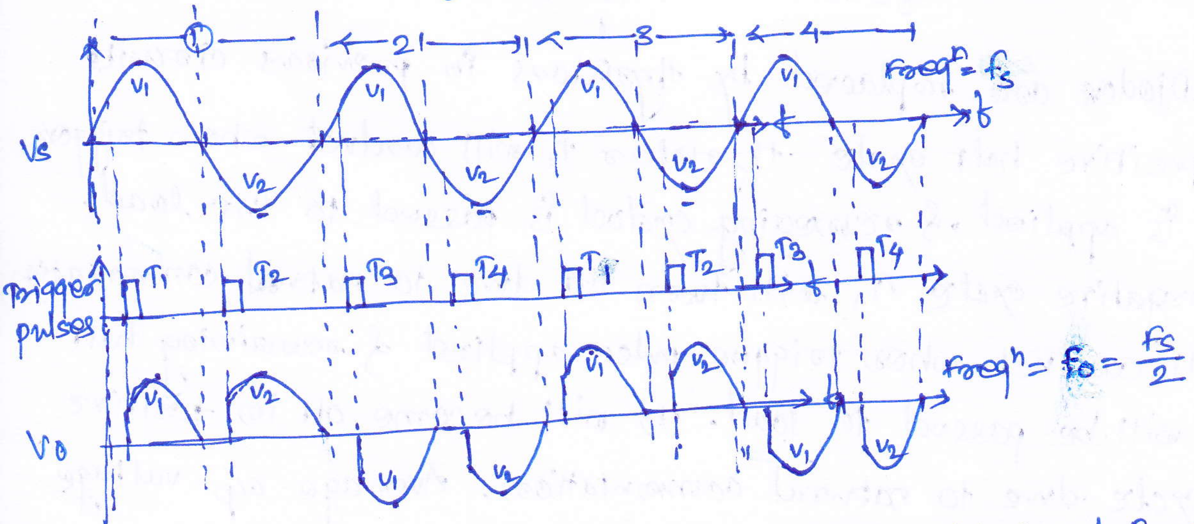
This converter is used to obtain controlled AC o/p voltage V_o from fixed AC voltage source V_s. The triac is used as control switch, Two antiparalled SCR's also can be ~~tool~~ used. Output voltage is controlled by varying the firing angle 'α'. This type of converter is ac voltage controller. This type of converter gives controlled o/p for fixed i/p freq^n.

(b) Cycloconverters:-



V_o = variable
f_o = variable

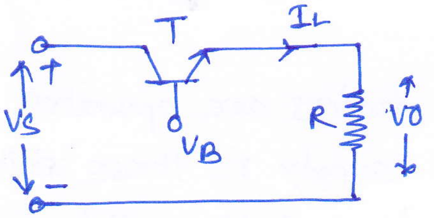
V_s = constant
f_s = — " —



Cycloconverter converts fixed voltage with fixed freq^n into variable o/p voltage at variable frequency. O/p freq^n can be step up or step down. Basic principle of cycloconvert can be understand with above fig. It is explained for step down freq^n.

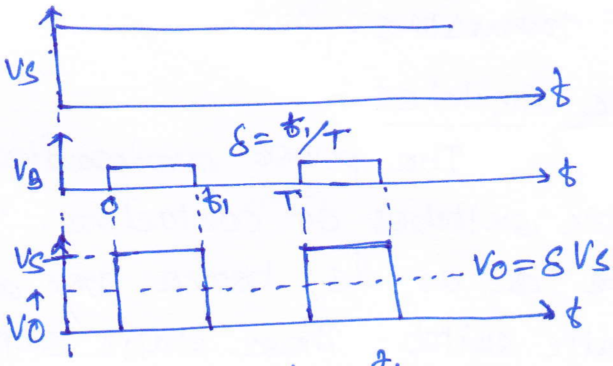
In this circuit T_1 T_2 T_3 & T_4 are SCRs, acting as switches. Each switch is turned on when it is forward biased & by appling trigger pulse to particular switch. For 1st positive half cycle T_1 & T_3 are forward bised but T_1 is fired by appling trigger pulse. For 1st negative half cycle T_2 & T_4 forward biased but T_2 is triggered. For second positive half cycle T_1 & T_3 forward biased but T_3 fired. For 2nd negative half cycle T_2 & T_4 forward but T_4 fired. Hence for 1st cycle we got positive o/p i.e current flowing from A to B and for 2nd cycle negative o/p i.e. current flowing from B to A. Thus we got one cycle at load for the two i/p cycles. Freqn of o/p is $f_0 = f_s/2$. By varying firing angle 'α' o/p voltage also varied.

(3) DC-DC converters (DC choppers)



V_s = constant DC voltage

V_0 = Variable DC voltage



δ = duty cycle $= \frac{t_1}{T}$.

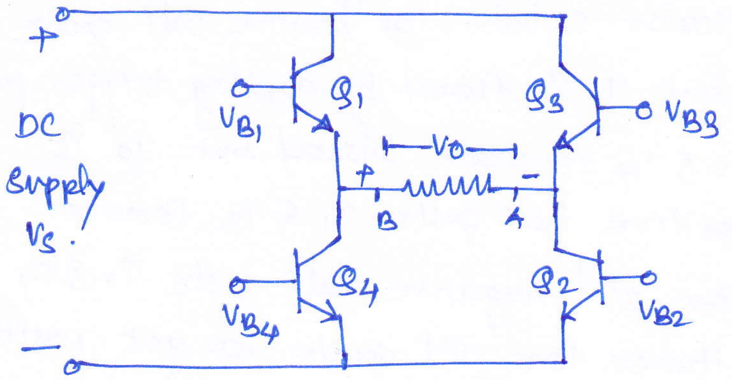
A dc-dc converter is also known as chopper. & a transistor chopper is as shown in above fig. The average o/p voltage is controlled by varying conduction time of transistor T. i.e by varying duty cycle δ. The duty cycle δ is given by

$$\delta = \frac{t_1}{T}$$

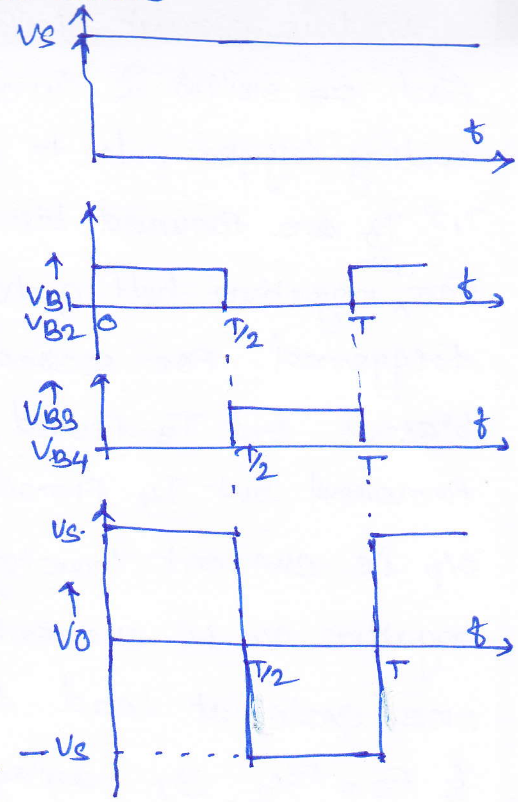
$$\therefore \text{Average o/p voltage} = \delta V_s = \frac{t_1}{T} V_s$$

4) DC – ac converters :- (Inverters)

Circuit Diagram :-



waveforms



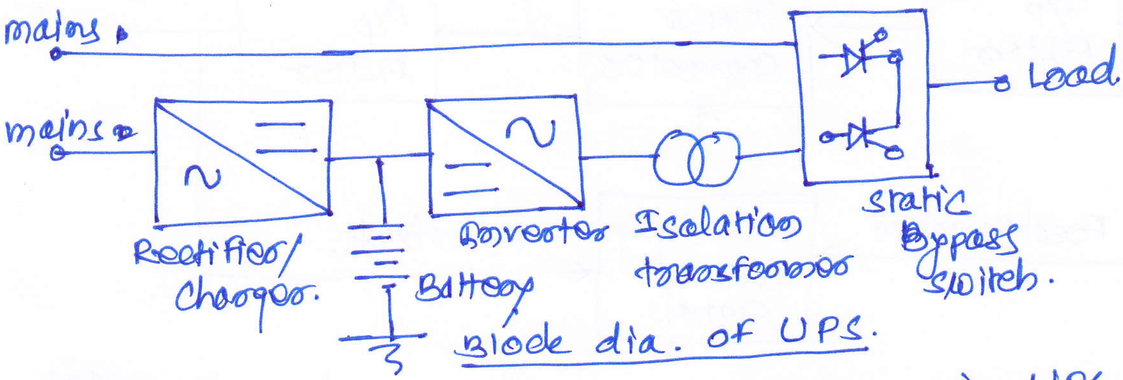
DC to ac converters is also known as an inverter. A single phase inverter is shown in above fig. The transistors Q_1 & Q_2 conducts for period 0 to $T/2$ & load current flows from B to A. The transistor Q_3 & Q_4 conducts for period $t_1 - T$ & load current flows from A to B. Thus o/p voltage is of alternating form. The o/p ac voltage can be controlled by varying the conduction time of transistors.

5) Static switches :-

The power semiconductor devices are operated as static switches or contactors. The supply to these switches could be ac or dc; hence they called ac static switch or dc static switch. These static switches are used to replace electromechanical switches. These electromechanical switches has moving parts. But the static switches does not have moving parts. And hence there is no wear & tear, no spark, no contact bounce, hence they are more efficient & reliable. Their switching frequency is more than electromechanical switches. Application of static switches are as follows.

1. Static switches are used to replace electromechanical switches like Relays, contactors & other mechanical switches.
2. Static switches are used in protection purpose because their operating speed is more.
3. They can be used to control active & reactive power.

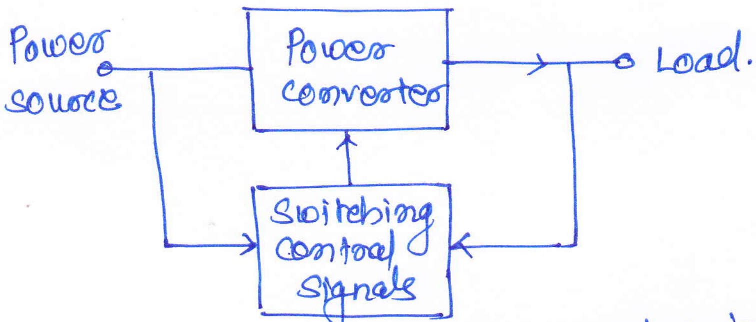
Application of static switch in UPS :-



Block dia. of UPS.

Above fig. shows the use of static s/w in UPS. Mains-1 supply provides normal supply to load. From mains standby batteries are charged. When mains supply fails the inverter o/p that is emergency power supply is connected to load through static switch. The static switch used here may be SCRs, transistors, MOSFET or IGBTs.

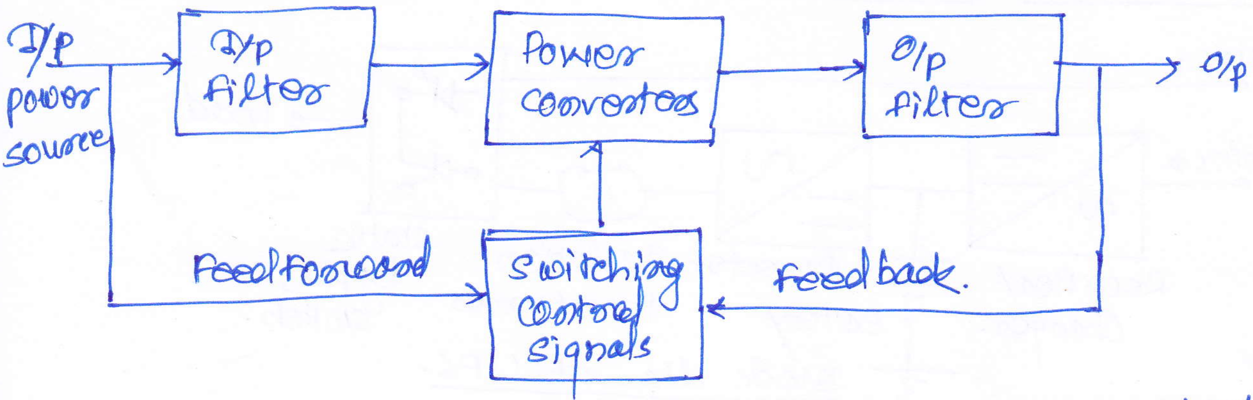
Peripheral Effects :-



Block dia of power electronics.

Operation of power converters based on the switching of power semiconductor devices. They are switched at high freq. As a result of converter produces current & voltage harmonics into the supply system & also on o/p of converter. This can cause problem of distortion of the o/p voltage, harmonic generation into the supply system, and interference with the communication system & signalling circuit.

To avoide this it is necessary to provide filters on i/p & o/p sides which reduces harmonics distortion to the acceptable level. Fig. below shows block dia of generalized power converter with i/p, o/p filter.



Controlling of power semiconductor plays important role in the harmonic generation & o/p waveform distortion. Power controlling will aims to minimize these problems. Putting I/p filter & O/p filter is one solution for it. Power converters also cause electromagnetic radiation causes radiofrequency interference. It also generates distortion to the gating signals. This interference is minimized by grounded shielding.