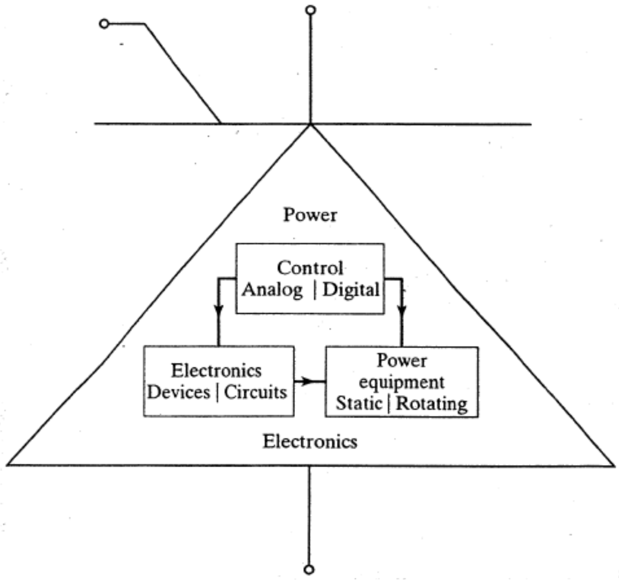
1. Define Power Electronics? Draw a neat block diagram of a generalized power converter system and explain. Explain how power, electronics and control are related in a power electronic system.

A.

Power electronics combines power, electronics and control. Power electronics may be defined as the applications of solid-state electronics for the control and conversion of electric power.



Power :- Power deals with the static and rotating power equipment for the generation, transmission and distribution of electric energy.

Electronics :- Electronics deal with the solid-state devices and circuits for signal processing to meet the desired control objectives.

Control :- The control deals with the stability and response (steady state & dynamic) characteristics of closed loop systems.

Block diagram of power electronic system :-

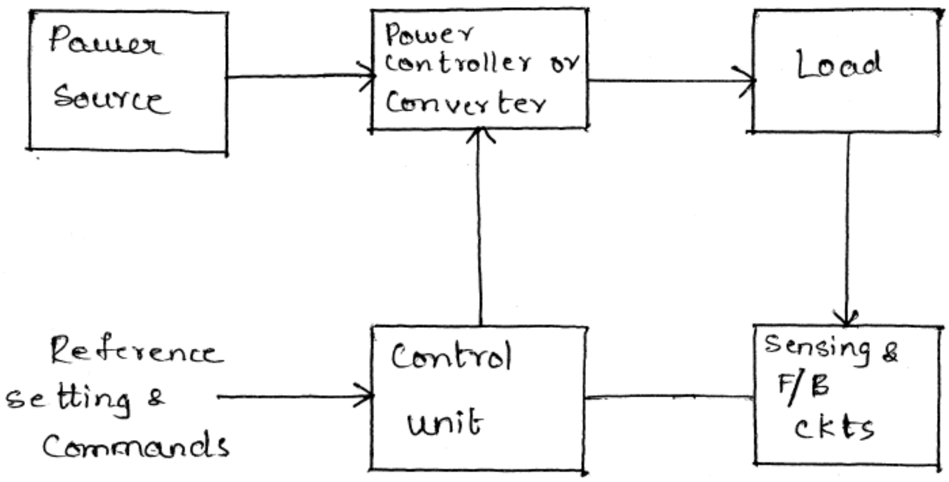


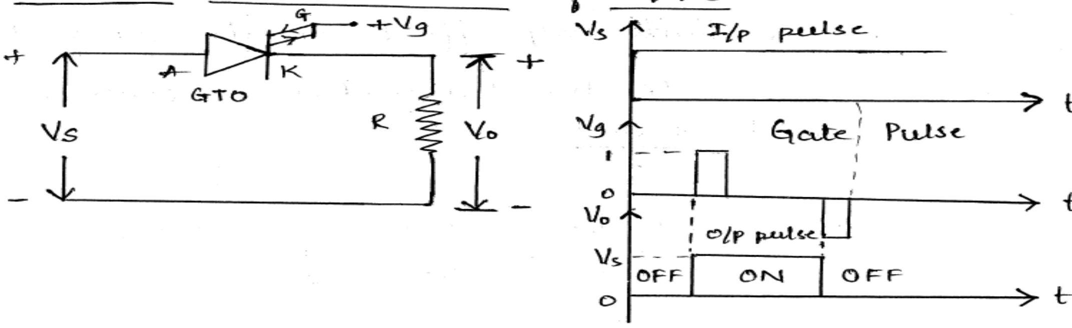
Figure shows the block diagram of the power system using a power converter or controller.

- The power controller or converter can use power devices such as thyristor (SCR), GTO, MOSFET, BJT or IGBT as a switch.
- The power source can be ac mains, generator or batteries. The power controller converts the input power which is suitable for the load. Let us take example of a speed control system for a dc motor. The power converter and controller is then a controlled rectifier which produces a variable dc voltage as its output.
- The sensing element is a speed sensor which senses the actual speed of the dc motor and produces a feedback signal proportional to actual speed of the motor.
- This feedback signal is compared with a reference signal which represents the desired speed. Based on the difference between these two signals, the control circuit will produce a control signal for the power converter and controller. This will change the dc output voltage of the converter so as to adjust the motor speed to the desired value.

2. With the circuit diagram, input and output waveforms, explain the control characteristics of a GTO and an SCR. Consider that an AC supply is given to a circuit which supplies a DC linear load. What is the circuit that can be used for this operation? Draw that circuit and explain its input and output waveforms.

A. GTO

Control characteristics of GTO



GTO is turned ON by applying a +ve gate pulse and is turned OFF by applying −ve pulse to the gate

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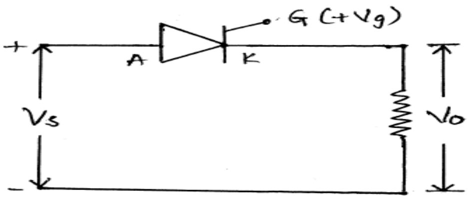
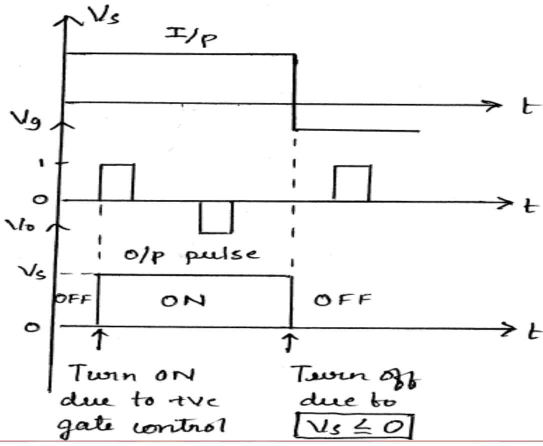
Whenever GTO is turned ON Vtg Vs appears across the load, when the device is OFF, the o/p Vtg is zero.

SCR

1> Control characteristics of SCR (Thyristor):-



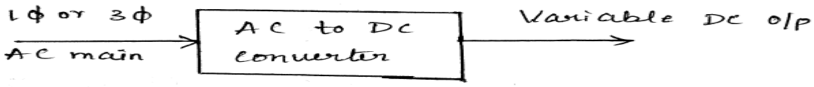


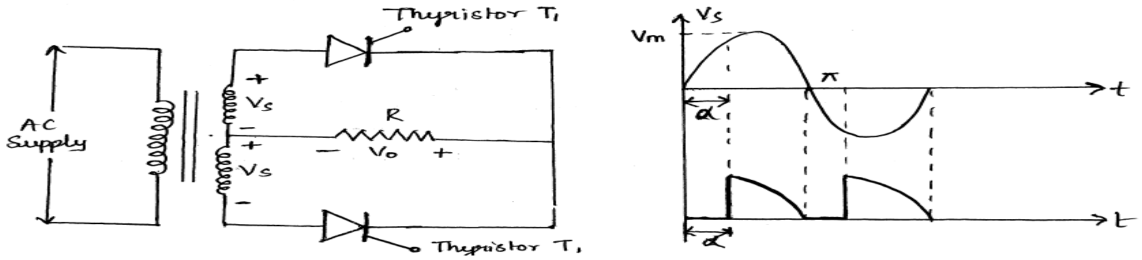
* A thyristor (SCR) can be made to conduct by applying a +ve pulse to its gate, when its anode vtg is more +ve than its cathode vtg

Once a thyristor starts conducting, it behaves like a closed switch & it becomes insensitive to gate signal ie when SCR is turned ON, the gate looses its control over the device (If gate looses its control over the device then gate is made either 0 or −ve, which will not have any effect on its conduction).

Due to this property the thyristor is considered as a "latched device"

AC – DC Converter [Controlled Rectifier]





* The input Voltage is available from the main source (Input Voltage is fixed AC voltage)

* The o/p of the converter is variable dc O/p ie o/p is controlled dc voltage & currents.

* The control rectifiers mainly use SCR's. The average value of the o/p voltage can be controlled by varying the firing angle 'α'.

* The SCR are turned off by natural commutation

Applications:

i> DC Motor drives
ii> Regulated DC power supplies
iii> Battery charger ckts etc

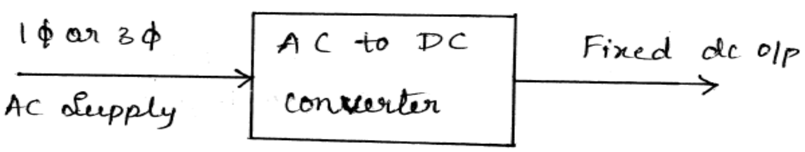
3. What is a power converter? List the different types of power converters and mention their conversion functions.

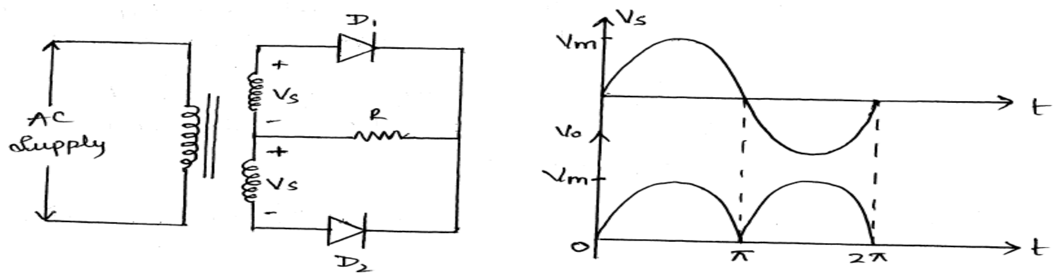
Types of power electronic circuits :-

The power electronic circuit can be classified into 6 types :

1> Diode Rectifiers (uncontrolled rectifiers)
2> AC – DC converter (controlled rectifiers)
3> AC – AC converter (AC Vtg converter)
4) DC – DC converter (DC choppers)
5> Static switches.

1> Diode Rectifiers

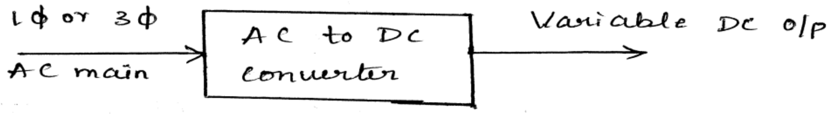


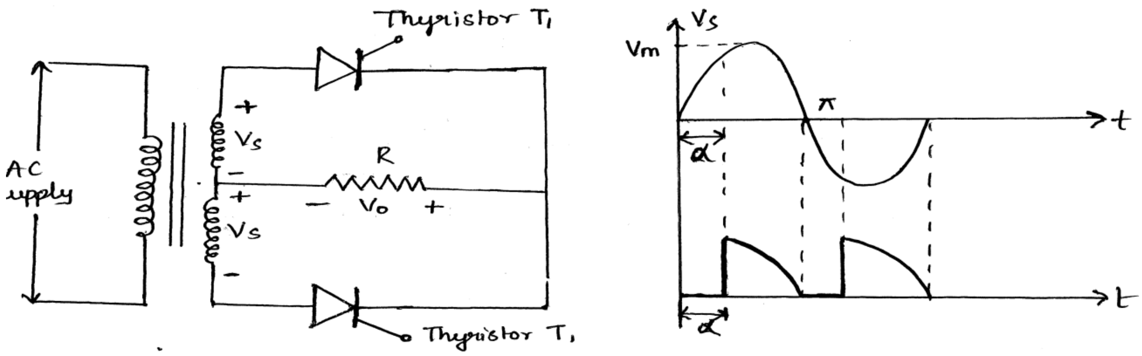


A diode Rectifier circuit converts AC voltage into fixed DC Voltage as shown in figure.

The I/P voltage to the Rectifier Vi could be either single phase or 3 phase.

AC - DC Converter [Controlled Rectifier]





The input Voltage is available from the main source (Input Voltage is fixed AC voltage).

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The SCR are turned off by natural commutation

Applications:

i> DC Motor drives

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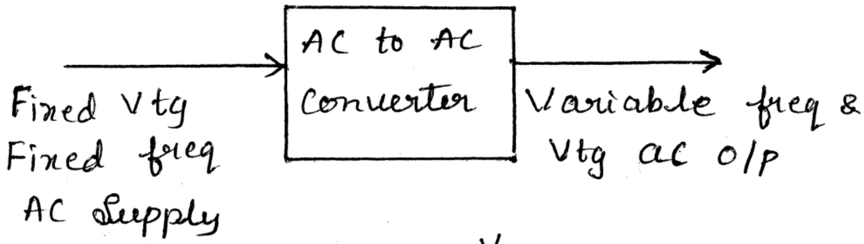
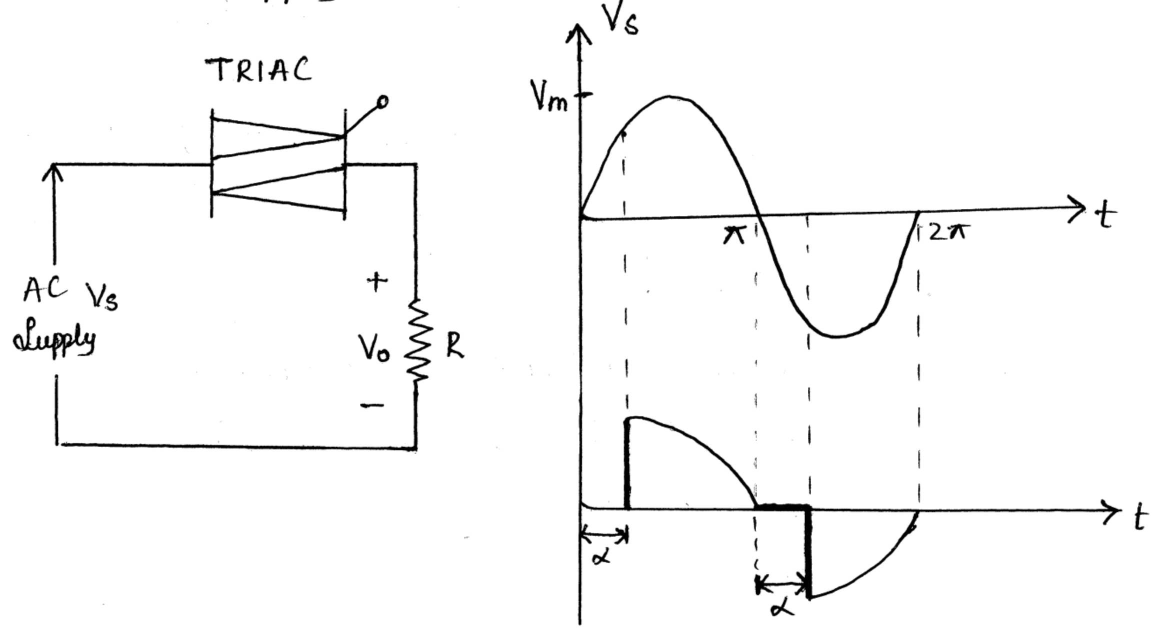
AC to AC converters :-

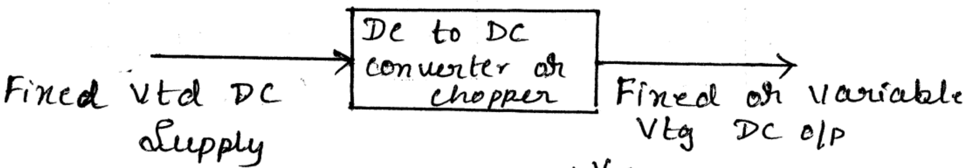


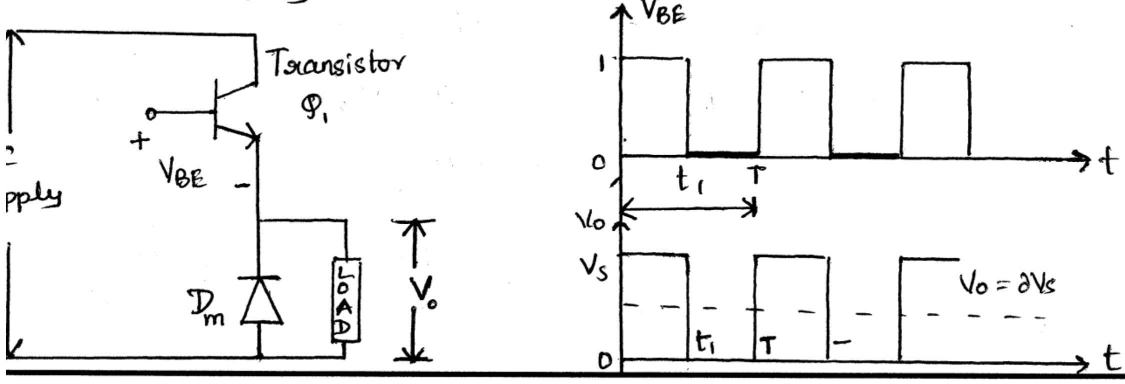


The I/p voltage to the converter is 1φ or 3φ fix
AC voltage.

The o/p is an variable ac vtg.

DC - DC Converters [Choppers] :-





A DC-DC converter is also known as a chopper or switching Regulator.

Fig shows transistor chopper.

The average o/p is controlled by varying the condution time 't_1' of transistor Q_1.

The duty cycle ∂ of the chopper is given by

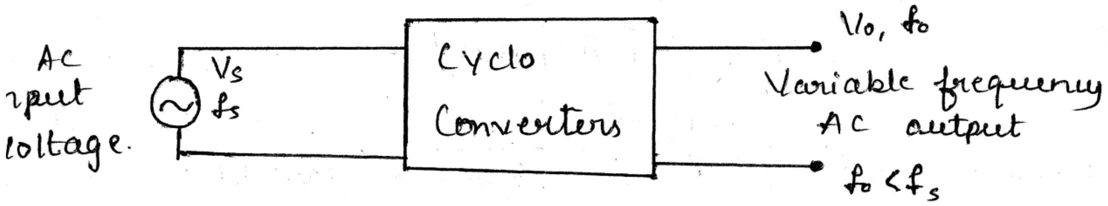
$$\partial = \frac{t_1}{T}$$

The converter use TRIAC as shown in the fig. The o/p Vtg is controlled by varying the firing angle of TRIAC ie 'α'.

Applications

Widely used for lighting control, speed control of fans, pumps etc.

CYCLO CONVERTERS :-



- These ckts converts Input power at one frequency to o/p power at a different frequency through one stage conversion

These are designed using Thyristors. The o/p frequency is lower than the source frequency.

Application

These are mainly used for slow speed, Very high power industrial drives

Application of DC - DC Converters

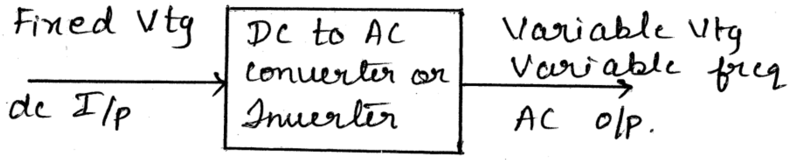
1) Battery driven Vehicles

2) SMPS

3) DC drives

4) Trolly trucks etc

> DC - AC converters :-



A DC - AC converter is also known as an Inverter

The I/p to the inverter is fixed DC Vtg usually Obtained from battery

The O/p of the inverter is the fixed or variable frequency ac voltage. Inverter are used Whenever mains are not available

Applications :-

1) Inverter

2) UPS

3) HVDC etc

Static Switches

Since the power devices can be used as static switches or contactors the supply to these switches could be either AC or DC and the switches are called as AC static switches or DC switches.

Applications:-

Static switches posses many advantages over mechanical & electromechanical circuit breakers.

4. What are the peripheral effects of power electronics circuit and what are the remedies for them?

A.

Due to the switching of power semiconductor devices, the power converter will introduce voltage & current harmonics into the supply system (ie I/p or source) & on the O/p of the converter (ie O/p)

* These harmonics will distort the O/p & causes interference with the communication & signalling ckts. Hence to reduce these harmonics levels the filters are used at both I/p & O/p of the converter.

These filters attenuate the harmonics and noise spike.

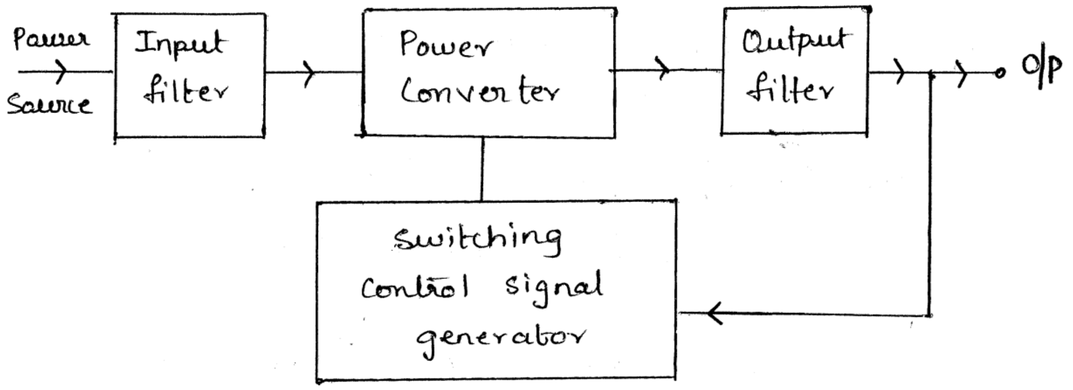


Fig ① shows the Block diagram of a generalized power converter

In order to resolve this problem (peripheral effects), it is required to know the quality of power & contents of harmonics

This can be analysed by calculating the Total harmonic distortion (THD),

Harmonic factor (HF)

I/p power factor (IPF)

These factors can be determined by analysing the voltage and current waveforms with the help of fourier series.

* The power converters can cause radio frequency interface due to electromagnetic radiation & the gating ckts may generate erraneous signals. This interference can be avoided by grounded shielding

Advantages or Merits of PE Systems

1) High efficiency due to low loss in power semiconductor devices.
2) High reliability of power-electronic converter systems
3) Fast dynamic response because static devices are used.
4) Low power loss as the device connected in the converter operate as switches & not in their active region.
5) Less maintenence and long life due to absence of any moving parts.
6) Compact or small size & light weight of the controller due to electronic devices.
7) Lower cost of the converter equipment.
8) Higher flexibility because converters use (μP) microprocessor based control unit.

Disadvantages or Demerits :-

1) Power electronic converter circuits generate Harmonics. These harmonics affect the performance of the system.
2) Some of the power converts have a very low power factor. So power factor correction techniques are required to be used
3) Due to abrupt switching of large currents, electromagnetic radiation takes place from the power

converters. This affect the neighbouring electronic circuits such as telephone networks.

4) Need of large heat sinks, large filters Inductors and Capacitors, the low frequency power converters become bulky & costly.

5) For very simple conversion requirements power electronic converters may be costly.

6) Power-electronic controllers have low overload Capacity.

7) Regeneration of power is difficult in power electronic converter System.

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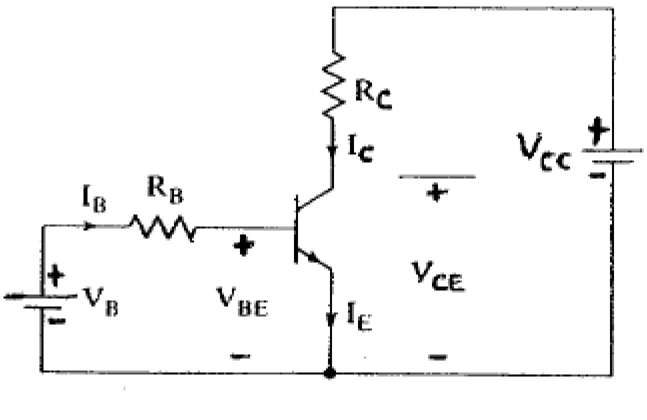
5. The BJT is specified to have β in the range of 8 to 40. The load resistance R_C= 11Ω . The dc supply voltage is V_{CC}=200V and the input voltage to the base circuit is V_B=10V. If $V_{CE(sat)}$=1.0V and $V_{BE(sat)}$=1.5V. Calculate

a. The value of R_B that results in saturation with an overdrive factor of 5.

b. The forced β_f

c. The power loss P_T in the transistor.



A.

<u>Given</u> :- $V_{cc} = 200V$ $\beta_{min} = 8$, $\beta_{max} = 40$, $R_c = 11\Omega$, $ODF = 5$

$V_B = 10V$, $V_{CE(sat)} = 1.0V$ & $V_{BE(sat)} = 1.5V$

<u>Soln</u> :-

$$I_B = \frac{V_B - V_{BE(sat)}}{R_B}$$

$$I_B = ?$$

$$I_{B(sat)} = \frac{I_{c(sat)}}{\beta_{min}}$$

$$* \; I_{c(sat)} = \frac{V_{cc} - V_{CE(sat)}}{R_c} = \frac{200V - 1V}{11\Omega}$$

$$\boxed{I_{c(sat)} = 18.09A}$$

$$* \; I_{B(sat)} = \frac{I_{c(sat)}}{\beta_{min}} = \frac{18.09}{8}$$

$$\boxed{I_{B(sat)} = 2.26A}$$

* WKT $ODF = \frac{I_B}{I_{B(sat)}}$

$$I_B = ODF \cdot I_{B(sat)}$$

$$= 5 \times 2.26A$$

$$\boxed{I_B = 11.33A}$$

* WKT $R_B = \frac{V_B - V_{BE(sat)}}{I_B} = \frac{10V - 1.5V}{11.33A}$

$$\boxed{R_B = 0.7522\Omega}$$

(b) Forced β factor :-

$$\beta_{forced} = \frac{I_{C(sat)}}{I_B} = \frac{18.09A}{11.33A}$$

$$\boxed{\beta_{forced} = 1.6}$$

(c) Power loss in the transistor

$$P_T = V_{BE} I_B + V_{CE(sat)} \cdot I_{C(sat)}$$

$$= 1.5 \times 11.33 + (1) \times 18.33$$

$$\boxed{P_T = 35W}$$

6. With a neat diagram explain the switching characteristics of an IGBT. Compare BJT and MOSFET

A.

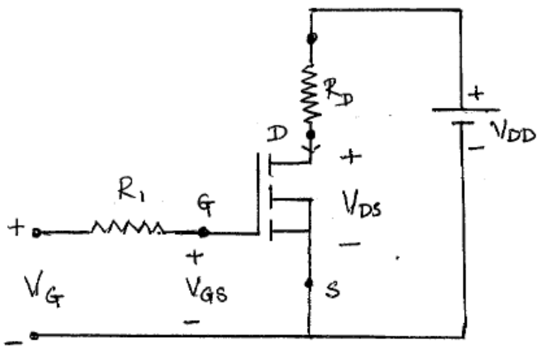


fig 1 (a) ckt diagram

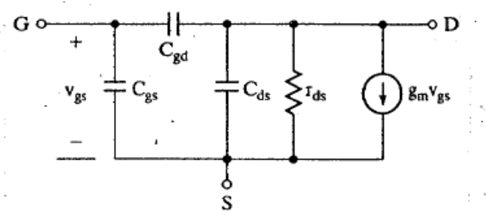
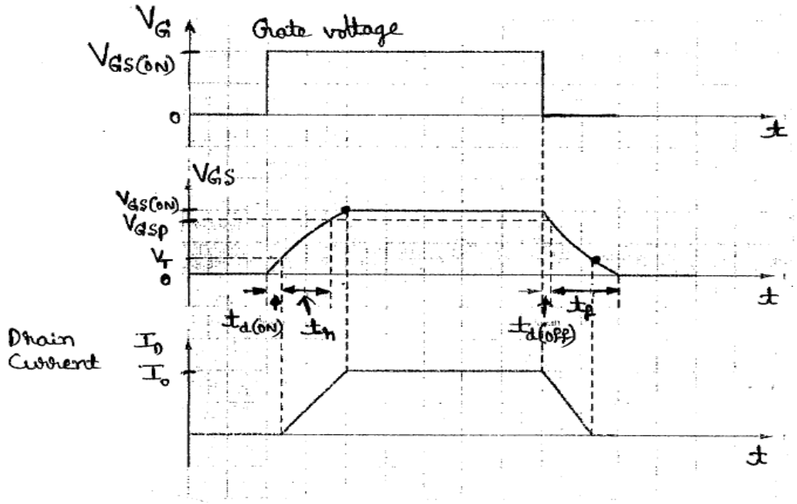


fig 1 (b) Switching model of MOSFET's



MOSFET can be turned ON by applying +ve gate voltage

- The internal capacitence of MOSFET affect the turn-ON & turn-OFF times of MOSFET.

Fig 1(b) show switching models of MOSFET.

- When the gate voltage is applied, the gate to source capacitence C_{gs} starts charging.

The turn-ON delay '$t_{d(ON)}$' is the time required to charge C_{gs} to the threshold voltage 'V_T'.

After this voltage, the drain current I_D starts rising

* The C_{gs} charges from V_T to full gate voltage 'V_{gsp}'

The time required for this charging is called rise time 't_r'

* When drain current raises to its full value ie I_D

The MOSFET is then said to have fully turned ON

$$\therefore t_{ON} = t_{d(ON)} + t_r$$

* To turn-OFF the MOSFET, the gate voltage is made -ve or zero. The V_{GS} the reduces from $V_{gs(ON)}$ to V_{GSP} ie C_{gs} discharges.

The time required for this discharge is called turn-OFF delay time $t_{d(OFF)}$.

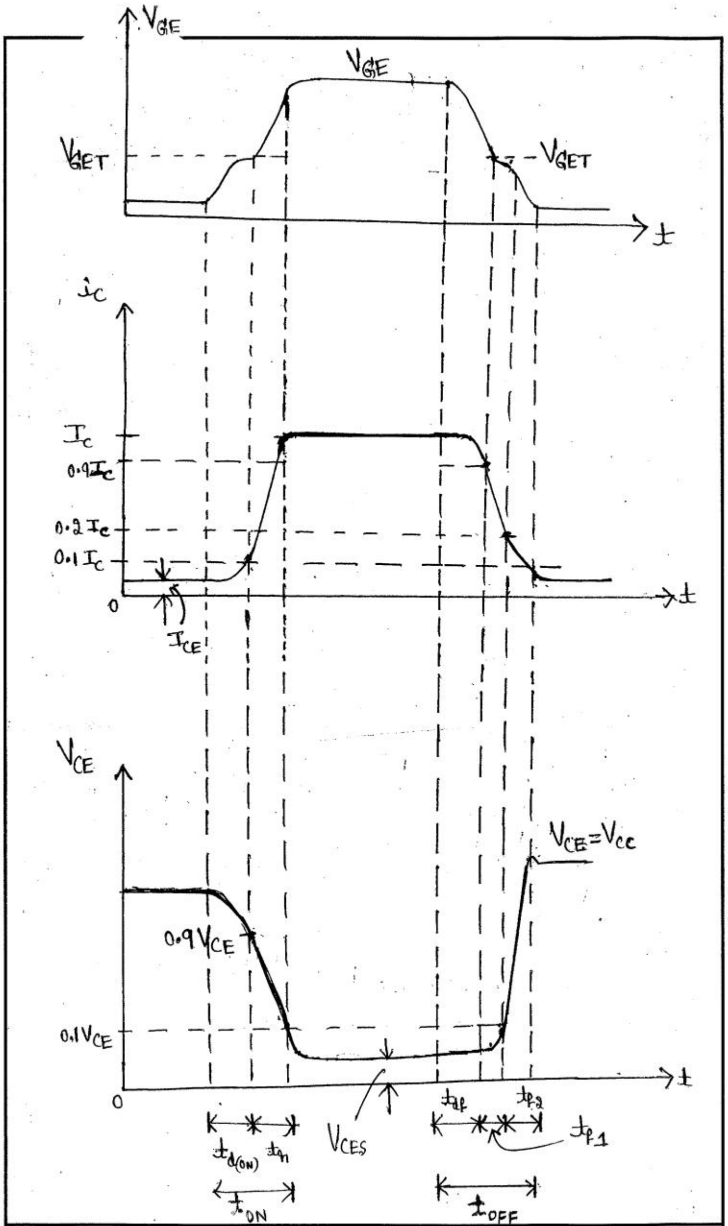
The drain current also start reducing. The C_{gs} keep on discharging & its voltage becomes equal to 'V_T'.

The ~~drain~~ time required to discharge C_{gs} from V_{GSP} to V_T is called fall time 't_f'.

When $V_{GS} < V_T$, then drain current becomes zero ie

∴ Turn off time of the MOSFET is

$$t_{OFF} = t_{d(OFF)} + t_f$$



* The turn - ON time is given by

$$t_{ON} = t_{d(ON)} + t_r$$

Where

Delay time '$t_{d(ON)}$':

i) The time for collector - emitter vtg to fall from V_{CE} to $0.9V_{CE}$

Rise time 't_r':

i) The time during which collector - emitter voltage falls from $0.9V_{CE}$ to $0.1V_{CE}$

ii) It is also defined as the time for the collector current to raise from $0.1I_c$ to its final value I_c.

Turn - OFF time is given by

$$t_{OFF} = t_{d(OFF)} + t_{f1} + t_{f2}.$$

First fall time 't_{f1}':-

i) The time during which collector current falls from 90% to 20% of its initial value of I_c

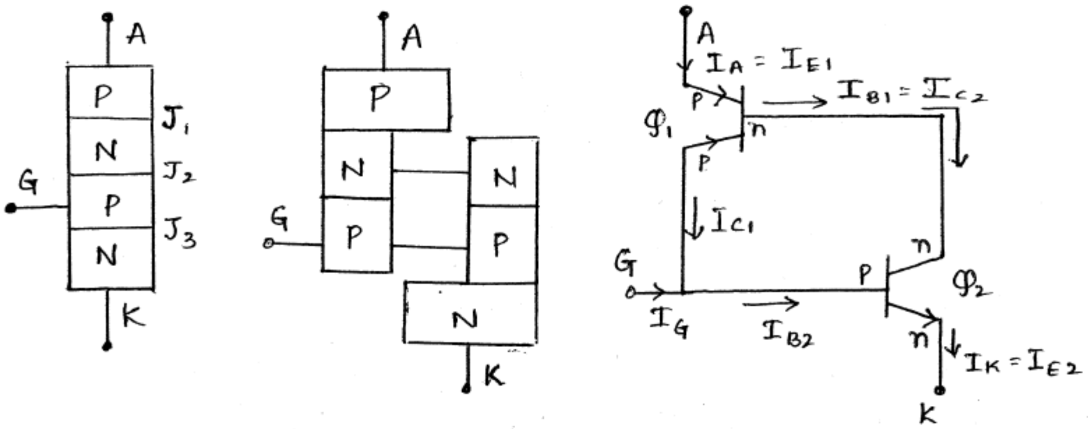
ii) The time during which collector - emitter voltage rises from V_{CES} to $0.1V_{CE}$

Final fall time 't_{f2}':-

i) The time during which collector current falls from 20% to 10% of I_c

7. Draw the two transistor model of a thyristor and derive an expression for the anode current in terms of common base current gain α1 and α2 of the transistors.

A.



a) Four layer structure of Thyristor

b) Two transistor model

c)

* The operation of the thyristor can be explained with the help of two transistor model as shown in fig b. The middle two layers are split into two seperate parts. Because of this the two transistors are formed. The transistor Q_1 is PNP & Q_2 is NPN.

* The Base of Q_1 is connected to collector of Q_2. Similarly base of Q_2 is connected to collector of Q_1.

* These transistors are in common base (CB) configuration. In general the relationship between collector current 'I_C', emitter current 'I_E' & leakage current I_{CBO} of a transistor is

$$I_C = \alpha I_E + I_{CBO} \longrightarrow (1)$$

Where $\alpha = \frac{I_C}{I_E}$, common base current gain

* For transistor Q_1

$$I_{C1} = \alpha I_{E1} + I_{CBO1} \longrightarrow (2)$$

from fig (c), $I_{E1} = I_A$

Substituting I_{E1} value in eqn (2), we get

$$I_{C1} = \alpha I_A + I_{CBO1} \longrightarrow (3)$$

Where α_1 is CB current gain of Q_1

I_{CBO} is CB leakage current of Q_1

* Similarly for transistor Q_2

$$\boxed{I_{C2} = \alpha_2 I_{E2} + I_{CBO2}} \longrightarrow (4)$$

from fig (C), $I_{E2} = I_K$

Substituting I_{E2} value in eq (4), we get

$$\boxed{I_{C2} = \alpha_2 I_K + I_{CBO2}} \longrightarrow (5)$$

Where α_2 is CB current gain of Q_2

I_{CBO2} is CB leakage current of Q_2

From fig (C), it is clear that

$$\boxed{I_A = I_{C1} + I_{C2}} \longrightarrow (6)$$

Substituting eqn (3) & (5) in eqn (6), we get

$$I_A = \alpha I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$$

from fig (C) $\boxed{I_K = I_A + I_G}$

$$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 [I_A + I_G] + I_{CBO2}$$

$$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_A + \alpha_2 I_G + I_{CBO2}$$

$$I_A - \alpha_1 I_A - \alpha_2 I_A = I_{CBO1} + I_{CBO2} + \alpha_2 I_G$$

$$I_A [1 - \alpha_1 - \alpha_2] = I_{CBO1} + I_{CBO2} + \alpha_2 I_G$$

$$I_A = \frac{I_{CBO1} + I_{CBO2} + \alpha_2 I_G}{1 - \alpha_1 - \alpha_2}$$

* The current gain α_1 varies with the emitter current $I_A = I_{E1}$ & α_2 varies with $I_K = I_A + I_G$

A typical variation of current gain α with the emitter current I_E is shown in fig ②

* If the gate current I_G is suddenly increased say (0 to 1mA) this immediately increases anode current I_A, which would further increase α_1 & α_2.

If $(\alpha_1+\alpha_2)$ tends to be unity, then denominator of eq ⑦ approaches zero, resulting in a large value of anode current I_A & the thyristor turns ON with a small gate current.