Gokaraju Rangaraju Institute of Engineering and Technology
(Autonomous)
Bachupally, Kukatpally, Hyderabad –500 090, A.P., India.

Department of Electrical and Electronics Engineering

Course File

Subject: Power Electronics

Subject Code: GR17A3018

Academic Year: 2022-23

Regulation: GR20A3013

Year: III Semester: I

Gokaraju Rangaraju Institute of Engineering and Technology

(Autonomous)

Department of Electrical and Electronics Engineering

Power Electronics

Vision of the Institute

To be among the best of the institutions for engineers and technologists with attitudes, skills and knowledge and to become an epicenter of creative solutions.

Mission of the Institute

To achieve and impart quality education with an emphasis on practical skills and social relevance

Vision of the Department

To impart technical knowledge and skills required to succeed in life, career and help society to achieve self sufficiency.

Mission of the Department

1. To become an internationally leading department for higher learning.
2. To build upon the culture and values of universal science and contemporary education.
3. To be a center of research and education generating knowledge and technologies which lay groundwork in shaping the future in the fields of electrical and electronics engineering.
4. To develop partnership with industrial, R&D and government agencies and actively participate in conferences, technical and community activities.

Gokaraju Rangaraju Institute of Engineering and Technology

(Autonomous)

Department of Electrical and Electronics Engineering

Power Electronics

Programme Educational Objectives

1. Graduates will have a successful technical or professional careers, including supportive and leadership roles on multidisciplinary teams.
2. Graduates will be able to acquire, use and develop skills as required for effective professional practices.
3. Graduates will be able to attain holistic education that is an essential prerequisite for being a responsible member of society.
4. Graduates will be engaged in life-long learning, to remain abreast in their profession and be leaders in our technologically vibrant society.

Program Outcomes

1. Ability to apply knowledge of mathematics, science, and engineering.
2. Ability to design and conduct experiments, as well as to analyze and interpret data.
3. Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. Ability to function on multi-disciplinary teams.
5. Ability to identify, formulates, and solves engineering problems.
6. Understanding of professional and ethical responsibility.
7. Ability to communicate effectively.
8. Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
9. Recognition of the need for, and an ability to engage in life-long learning.
10. Knowledge of contemporary issues.
11. Ability to utilize experimental, statistical and computational methods and tools necessary for engineering practice.
12. Graduates will demonstrate an ability to design electrical and electronic circuits, power electronics, power systems; electrical machines analyze and interpret data and also an ability to design digital and analog systems and programming them.

Programme Educational Objectives (PEO)	Program Outcomes (PO)												PSOs	
	1	2	3	4	5	6	7	8	9	10	11	12	1	2
1	H	M	H	M	M		M	H		M	M	H	M	H
2	M	M	H	H	M	M		M	H	H		H	M	H
3				H	H	H	H		M	H	H		M	H
4	M		H	H		M	H	H		M		H	M	H

* H: Strongly Correlating (3); M: Moderately Correlating (2);& L: Weakly Correlating (1);

Gokaraju Rangaraju Institute of Engineering and Technology

Department of Electrical and Electronics Engineering

GRIET/PRIN/06/G/01/22-23

BTech - EEE - A **I**

DAY/ HOUR	9:00 - 9:55	9:55- 10:50	10:50 - 11:45	11:45 -12:25	12:25-1:15	1:15 - 2:05	2:05 -2:55
MONDAY	PE	PE	EHV	BREAK	PE Lab (A1)/PS Lab (A2)		
TUESDAY	CC	MC	MC		PSA	PSA	Library
WEDNESDAY	MC	PSA	Mentoring		PS Lab (A1)/MC Lab (A2)		
THURSDAY	PSA	PSA	PE		MC Lab (A1)/PE Lab (A2)		
FRIDAY	EHV	EHV	CC		Library	MC	MC
SATURDAY	CC	PE	PE		Library	EHV	EHV

Theory/Tuto
Lab
Class Inchar

Subject Code	Subject Name	Faculty Code	Faculty Name	A
GR20A3012	Power Systems Analysis (PSA)	Dr JSD	Dr J. Sridevi	1st Spell of Instructions
GR20A3013	Power Electronics (PE)	Dr PB	Dr Pakkiraiah B	1st Mid-term Examinations
GR20A3014	Microprocessors and Microcontrollers (MC)	Dr DR	Dr D Raveendhra	2nd Spell of Instructions
GR20A3015	Electrical and Hybrid Vehicles (EHV)	Dr DGP	Dr D. G. Padhan	2nd Mid-term Examinations
	Cloud Computing (CC)	PRK	P. Ravikanth	Preparation
GR20A3020	Power Systems Lab (PS Lab)	Dr JSD/ VUR/UVL	Dr J. Sridevi/ V. Usharani/ U. Vijayalakshmi	End Semester Examinations (Theo Practicals) Regular / Supplementar
GR20A3021	Power Electronics Lab (PE Lab)	Dr PB/GSR/MRE	Dr. B. Pakkiraiah/G. Sandhya Rani/M Rekha	
GR20A3022	Microprocessors and Microcontrollers Lab (MC Lab)	Dr PSVD/MNSR	Dr. P. Srividya Devi/ M. N. Sandhya Rani	Commencement of Second Semest A.Y 2022-2023

Time Table Coordinator **HOD**

Gokaraju Rangaraju Institute of Engineering and Technology

Department of Electrical and Electronics Engineering

2022 -23 I sem Subject allocation sheet

II YEAR(GR20)	Section-A	
Electrical Circuit Analysis	G Sandhya Rani	
Principles of Analog Electronics	P Ravikanth	
DC Machines and Transformers	Dr Phaneedra Babu B	
Electromagnetic Fields	Dr T Suresh Kumar	
Power Generation and Transmission	V Vijaya Rama Raju	
Java Programming for Engine	CSE Dept. Staff	
Constitution of India	D Karuna Kumar	
Value Ethics and Gender Culture	M Prashanth	
Principles of Analog Electronics Lab	U Vijaya Lakshmi/ M Prashanth	
DC Machines and Transformers Lab	V Vijaya Rama Raju / M Rekha	
III YEAR (GR20)	**Section-A**	
Power System Analysis	Dr J Sridevi	
Power Electronics	Dr Pakkiraiah B	
Microproces sors and Microcontrol lers	Dr D Raveedhra	
Electrical and Hybrid Vehicles (PE-1)	Dr D G Padhan	
Cloud Computing (NPTEL)	P Ravikanth	
Power Systems Lab	Dr J Sridevi / V Usha Rani/ U Vijaya Lakshmi	
Power Electronics Lab	Dr Pakkiraiah B/ G Sandhya Rani	
Microproces sors and Microcontrol lers Lab	Dr P Srividya Devi/ M N Sandhya Rani	
IV YEAR(GR18)	**Section-A**	**Section-B**
Power Systems – III	Dr P Srividya Devi	P Prashanth Kumar
Electronics Design	Dr D S N M Rao	Dr D S N M Rao
Electrical and Hybrid Vehicles (PE-III)	D Srinivasa Rao	D Srinivasa Rao
High Voltage Engineering (PE-IV)	A Vinay Kumar	A Vinay Kumar
Robotics	Anitha (Mech)	
Database Management Systems	D Swathi (CSE)	
Electronics Design Lab	P Ravikanth /Dr DSNM Rao	D Karuna Kumar/ V Usha Rani

Project work - (PhaseI)	A Vinay Kumar/ D Srinivasa Rao	M N Sandhya Rani / G Sandhya Rani
I/I BEE(GR20)	Theory	LAB
EEE (1) BEE	R Anil Kumar/ P Praveen Kumar / P Prashanth Kumar/ K Sudha	
ECE (3) BEE		
IT (3) BEE		
CSBS (1) PEE		
Design Thinking	Dr D G Padhan	
Mech II/I (GR20)	A	
BEEE	M N Sandhya Rani	

Dr Phaneendra Babu B
HOD,EEE

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND CHNOLOGY

POWER ELECTRONICS

Course Code:GR22A3013 **L/T/P/C:3/0/0/3**

III year I semester

COURSE OBJECTIVES

1. Provide the students a deep insight into the working of different switching devices with respect to their characteristics.
2. Study advanced converters and switching techniques implemented in recent technology.
3. Analyze different converters and control with their applications.
4. Familiarize the students with the utilization aspects of power engineering, more specifically the techniques of solid-state power conversions and their applications.
5. Evaluate the steady-state and transient state analysis of all the power converters

COURSE OUTCOMES

1. Distinguish between signal level and power level devices and explain the characteristics of power electronic switching devices.
2. Illustrate the performance of controlled rectifiers and AC-DC converters
3. Analyze the operation of DC-DC choppers
4. Discuss the operation of voltage source inverters
5. Illustrate the performance of the AC-AC converters.

UNIT I

POWER SWITCHING DEVICES

Diode, Thyristor, MOSFET, IGBT: I-V Characteristics; R, RC, UJT firing circuits for thyristor; Line and forced commutation circuits of a thyristor; Gate drive circuits for MOSFET and IGBT.

UNIT II

AC-DC CONVERTERS

Single-phase half-wave and full-wave rectifiers, Single-phase full-bridge thyristor rectifier with R-load and highly inductive load; Three-phase full-bridge thyristor rectifier with R-load and highly inductive load; Input current wave shape and power factor.

UNIT III

DC-DC CONVERTERS

Elementary chopper with an active switch and diode, concepts of duty ratio and average voltage, power circuit of a buck converter, analysis and waveforms at steady state, duty ratio control of output voltage. Power circuit of a boost converter, analysis and waveforms at steady state, relation between duty ratio and average output voltage.

UNIT IV

SINGLE-PHASE & THREE-PHASE VOLTAGE SOURCE INVERTER(DC-AC CONVERTERS)

Power circuit of single-phase voltage source inverter, switch states and instantaneous output voltage, square wave operation of the inverter, concept of average voltage over a switching cycle, bipolar sinusoidal modulation and unipolar sinusoidal modulation, modulation index and output voltage.

Power circuit of a three-phase voltage source inverter: (180&120 degree mode), switch states, instantaneous output voltages, average output voltages over a sub-cycle.

UNIT V

AC-AC CONVERTERS

AC Voltage controller with R and RL loads with numerical problems. Cyclo-converters: step up cyclo converters; step down cyclo converters, numerical problems

TEXT BOOKS

1. M. H. Rashid, "Power Electronics: Circuits, Devices, and Applications", Pearson Education India, 2009.
2. P. S. Bimbhra, "Power Electronics", Khanna Publishers.

REFERENCES

1. R. W. Erickson and D. Maksimovic, "Fundamentals of Power Electronics", Springer Science & Business Media, 2007.
2. L. Umanand, "Power Electronics: Essentials and Applications", Wiley India, 2009.
3. B K.Bose "Modern power Electronics and AC Drives" Prentice Hall India Learning Private Limited, 2005.
4. N. Mohan and T. M. Undeland, "Power Electronics: Converters, applications and Design", John Wiley & Sons, 2007.

Gokaraju Rangaraju Institute of Engineering and Technology

(Autonomous)

Department of Electrical and Electronics Engineering

Power Electronics

CO-PO Mapping

Program Outcomes (PO)

1. Ability to apply knowledge of mathematics, science, and engineering.
2. Ability to design and conduct experiments, as well as to analyze and interpret data.
3. Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. Ability to function on multi-disciplinary teams.
5. Ability to identify, formulates, and solves engineering problems.
6. Understanding of professional and ethical responsibility.
7. Ability to communicate effectively.
8. Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
9. Recognition of the need for, and an ability to engage in life-long learning.
10. Knowledge of contemporary issues.
11. Ability to utilize experimental, statistical and computational methods and tools necessary for engineering practice.
12. Graduates will demonstrate an ability to design electrical and electronic circuits, power electronics, power systems; electrical machines analyze and interpret data and also an ability to design digital and analog systems and programming them.

Course Outcomes of Power Electronics:

1. Discuss the basics of power electronic devices.
2. Construct the design and control of rectifiers, inverters.
3. Discover of power electronic converters in power control applications.
4. Compare characteristics of SCR, BJT, MOSFET and IGBT.
5. Demonstrate communication methods.
6. Experiment the design of AC voltage controller and Cyclo Converter.
7. Construct the Chopper circuits.

CO-PO Mapping

Course Outcomes	Program Outcomes (PO)												PSOs	
	1	2	3	4	5	6	7	8	9	10	11	12	1	2
1	M				M	H	M	H	M	M	H	H	M	
2	M	M	M	M	M		H		H	M	H	H	M	H
3	H	H		H	M		M	M	H	H	H	H	M	H
4		M	M				M	H	M		H	H	M	
5			H		M		M	M	M	H	H	H	M	H

* H: Strongly Correlating (3); M: Moderately Correlating (2); & L: Weakly Correlating (1);

POWER ELECTRONICS

UNIT - I

INTRODUCTION.

* Power electronics combine the concepts of power, electronics and control
* Power deals with the static and rotating power equipme for generation, transmission and distribution of electric power.
* Electronics deals with the solid state devices and circuits for signal processing to meet the desired control objective
* It basically deals with power engineering ie, generation transmission and distribution and utilization of electrical energy at higher power levels.
* P.E combines the aspects of electronics engineering where efficiency is not that important but the principles of control thus play a major role in controlling power at higher levels.
* It is a subject that concerns the applications of electronic principles into situations that are rated at power level, rather than signal level.
* Power electronics is based primarily on the switchi of the power semiconductor devices

"A subject that deals with the apparatus and equipment working on the principle of electronics but rated at power level rather than signal level."

Some Applications of P.E

1. Aerospace: space shuttle power supplies, satellite power supplies, aircraft power systems.

2. Commercial: Advertising, heating, airconditioning, central refrigeration, computer and office equipment, uninterruptible power supplies, elevators, light dimmers and flashers.

3. Industrial: Arc and industrial furnaces, blowers and fans, pumps and compressors, industrial lasers, transformer tap changers, rolling mills, textile mills, excavators, cement mills, welding etc.

4. Residential: Airconditioning, lighting, space heating, refrigerators, electric door openers, dryers, fans, personal computers, vacuum cleaners, etc.

5. Tele Communication: Battery chargers, power supplies

6. Transportation: Battery chargers, traction control of electrical vehicles, electric locomotives, street cars, trolley buses, automotive electronics etc.

7. Utility systems:

High voltage dc transmission(HVDC), excitation systems VAR compensation, static circuit breakers, fans, supplementary energy systems (solar, wind).

Advantages of Power electronic converters:-

→ High efficiency due to low loss in power ~~electronic~~ semiconductor devices

→ High reliability of power electronic converter systems.

→ Long life & less maintainance due to absence of moving parts.

→ Fast dynamic response of the p.e systems as compared to electromechanical converter systems.

→ Small size and less weight result in less floor space and therefore lower installation cost

→ mass production of semiconductor devices has resulted in lower cost of the converter equipment.

Disadvantages:

→ They Power electronic converter circuits have a tendency to generate harmonics in the supply system as well as in the load circuit.

→ Ac to dc & ac to ac converters operate at a low input power factor under certain operating conditions

→ p.e controllers have low overload capacity

→ Regeneration of power is difficult in p.e converter systems.

The advantages possessed by them far outweigh their disadvantages mentioned above. As a consequence, semiconductor-based converters are being ~~extreme~~ extensively employed in systems where power flow is to be regulat

Based on turn-on & turn-off char, gate signal requirements, degree of controllability, the power semi conductor devices can be classified as under.

Diodes: These are uncontrolled rectifying devices. Their on & off states are controlled by power supply.

Thyristors: These have controlled turn-on by a gate signal. After thyristors are on they remain latched-in on-state due to internal regenerative action & gate loss control. These can be turned-off by power circuit.

Controllable switches: These devices are turned-on & turned-off by the application of control signals. eg: BJT, MOSFET, GTO, SITH, IGBT, SIT & MCT.

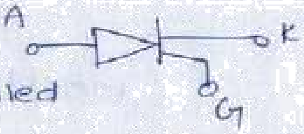
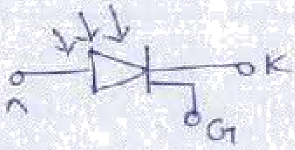
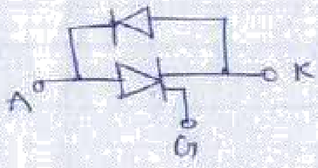
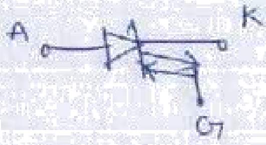
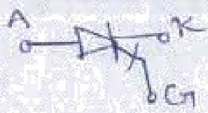
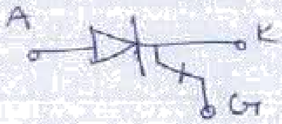
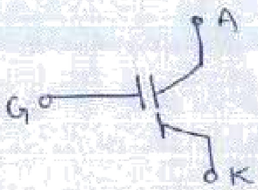
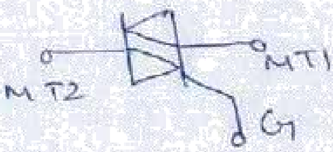
Triac & RCT possess bidirectional current capability whereas all other remaining devices (diode, SCR, GTO, BJT, MOSFET, IGBT, SITH, SIT & MCT) are unidirectional current devices.

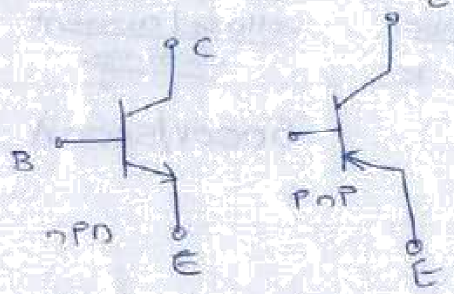
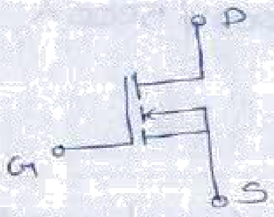
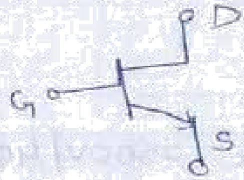
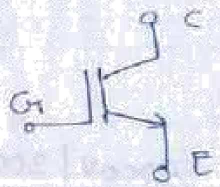
TYPES OF POWER ELECTRONIC CONVERTERS

→ A P.E system consists of one or more P.E converters.
→ A P.E converter is made up of some power semiconductor devices controlled by integrated circuits.
→ The P.E converters (or circuits) can be classified into six types.

1. Diode Rectifier: A diode rectifier circuit converts ac input voltage into a fixed dc voltage. The i/p voltage may be single phase or three phase.
They are used in electric traction, battery charging, electroplating, power supplies, UPS, welding etc.

Maximum ratings of Power semiconductor devices

Device	circuit symbol	voltage/current ratings	upper operating freq (kHz)
1. Diode		5000V/5000A	1.0
2. Thyristors			
(a) SCR Silicon controlled Rectifier		7000V/5000A	1.0
(b) LASCR Light Activated SCR		6000V/3000A	1.0
(c) ASCR/RCT Asymmetrical SCR/ Reverse conducting thyristor		2500V/400A	2.0
(d) GTO Gate turnoff thyristor	 or 	5000V/3000A	2.0
(e) SITH static induction thyristor		2500V/500A	100.0
(f) MCT MOS controlled thyristor		1200V/40A	20.0
(g) Triac		1200V/1000A	0.50

Device	circuit symbol	vatage / currentratings	upper operating freq (KHz)
3. Transistors			
(a) BJT Bipolor Junction Transistor		1400v/ 400 A	10'0
(b) MOSFET (n-channel)		1000V/50A	100'0
(c) SIT Static induction transistor		1200V/300A	100'0
(d) IGBT Insulated Gate bipolor transistor		1200V/500A	50'0

2. AC to dc converters (phase-controlled rectifiers) :- These convert constant ac voltage to variable dc output voltage. these are used in dc drives, chemical industries, excitation systems for synchronous machines

3. DC to DC Converters (DC choppers)

A dc chopper converts fixed dc input voltage to a controllable dc output voltage. The chopper ckt require forced, or load commutation to turnoff thyris
→ used in dc drives, battery driven vehicles, trolley trucks etc.

4. DC to ac Converters (inverters)

An inverter converts fixed dc voltage to a variable ac voltage. The o/p may be variable voltage or variable frequency. It requires line, load or forced commutation for turning-off the thyristors
→ use in induction-motor, synchronous motor drives, induction heating, UPS, HVDCT etc.

5. AC to ac converters : these convert fixed ac input voltag into variable ac output voltage. These are of two types as under.

(a) AC voltage controllers (AC voltage regulators) : converts fixed ac voltage directly to a variable ac voltage at the same frequency

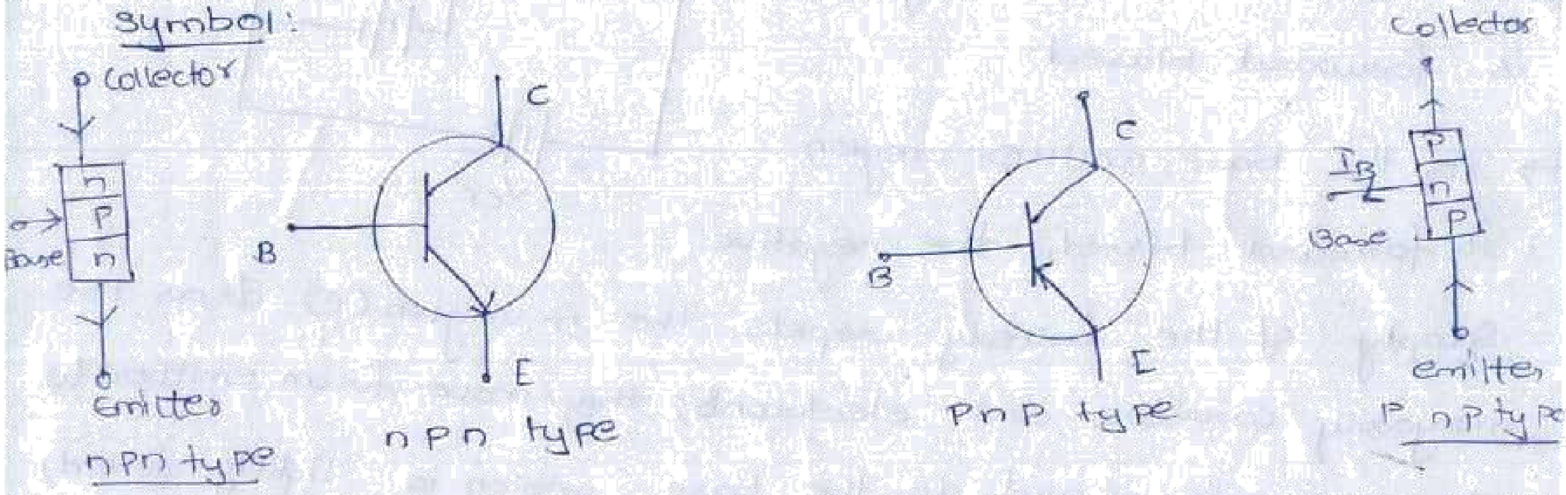
(b) cycloconverters : These circuits converts i/p power at one frequency to output power at a different frequency through one stage conversion

6. Static Switches: The power semiconductor devices can operate as static switches or contactors. Static switches possess many advantages over mechanical and electromechanical circuit Breakers.

POWER SEMICONDUCTOR DEVICES

* Bipolar Junction Transistors (BJTs)

Symbol:



→ Three layer, two junction npn or pnp semiconductor device.

→ with one p-region sandwiched by two n-regions, npn transistor is obtained

→ with two p-regions sandwiched one n-region, pnp transistor is obtained.

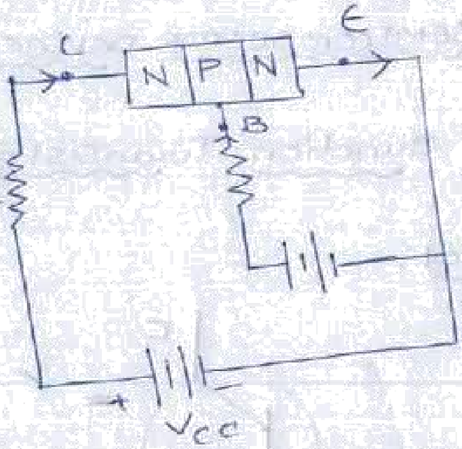
→ the term Bipolar denotes that the current flow in the device is due to the movement of both holes & electrons

→ A BJT has three terminals named collector(C), emitter(E) & Base(B).

→ use of power npn transistors is very wide in very wide in highvoltage and high current applications.

→ BJT is current controlled device.

→ PRINCIPLE OF OPERATION:



→ when the supply is given, the base emitter region is forward biased

→ As the base emitter region is forward biased, the negative supply of the battery repels the n-region (E) & as the majority carriers are electrons; they move from emitter to base region and as the base region is lightly doped, some of the electrons combine with holes and then remaining enter into the collector region as it is heavily doped and large amount of current flows in the collector region.

The Base current I_B is given by

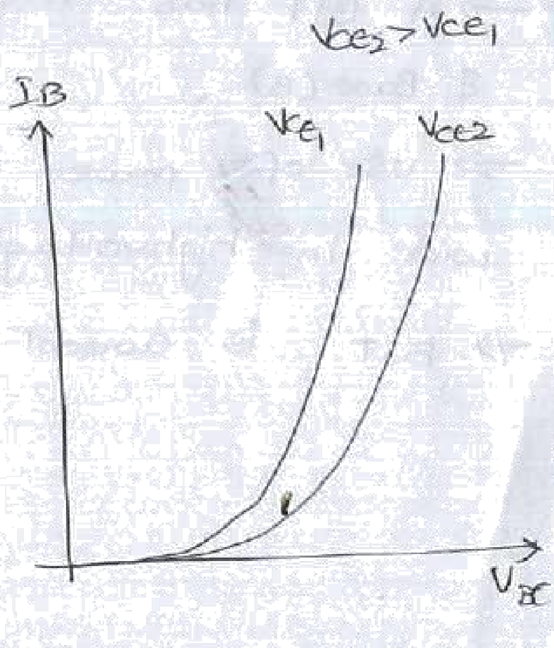
$$I_B = I_E - I_C$$

the currents I_E, I_B & I_C are assumed positive when the they enter into the transistor

CHARACTERISTICS

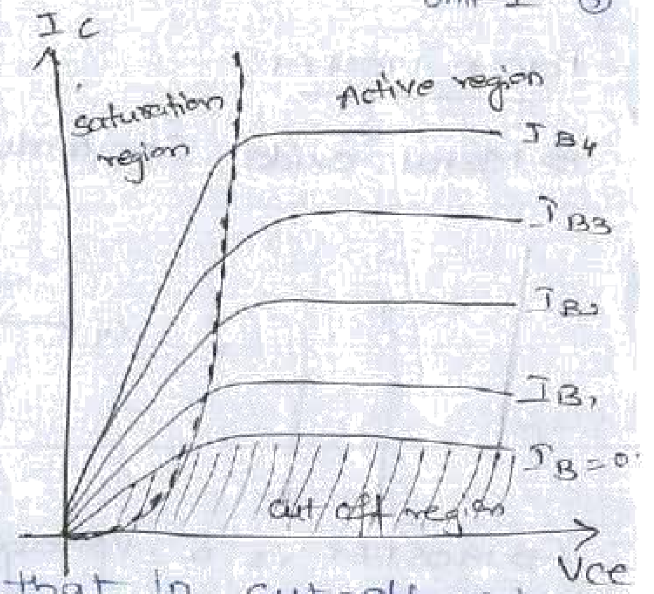
Steady state characteristics

Input characteristics:



The Input characteristics are drawn between the base emitter voltage and base current by keeping the value of the collector emitter voltage to a constant value.

Output characteristics:



$I_{B4} > I_{B3} > I_{B2} > I_{B1} > I_B$

The output characteristics are drawn between Vce and Ic keeping the base current to a constant value

From the graph, it is observed that in cut-off region the voltage is high and the current is less. and in the saturation region, the current is high and the voltag is less.

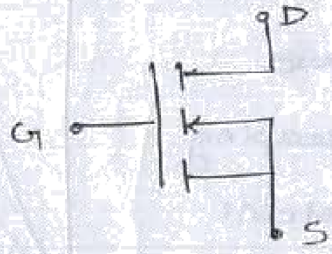
Switching characteristics

In transient condition the forward biased PN junction exhibits two parallel capacitances. A depletion layer capacitance and a diffusion capacitance & a reverse biased P-n junction has only depletion capacitance.

Under transient conditions, they influence the turn on & turn off behaviour of the transistor.

POWER MOSFET:

→ Metal Oxide Semiconductor Field Effecting transistor.



→ It has three terminals
(i) Drain (D)
(ii) Source (S)
(iii) Gate (G)

→ MOSFET is a voltage controlled device.

→ It is a unipolar device

→ The Gate circuit impedance in MOSFET is extremely high, of the order of $10^9 \Omega$, hence the base current or control signal required in MOSFET is much lesser than the control signal or base current required in BJT.

→ The large impedance permits the MOSFET gate to be driven directly from microelectronic circuits.

→ Power MOSFETS are now finding increasing applications in low power high frequency converters

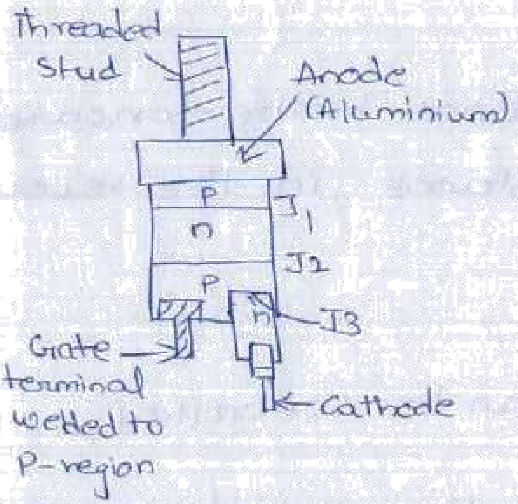
→ Two types
- n-channel MOSFET → more commonly used of higher mobility of electrons
- P-channel MOSFET

THYRISTORS

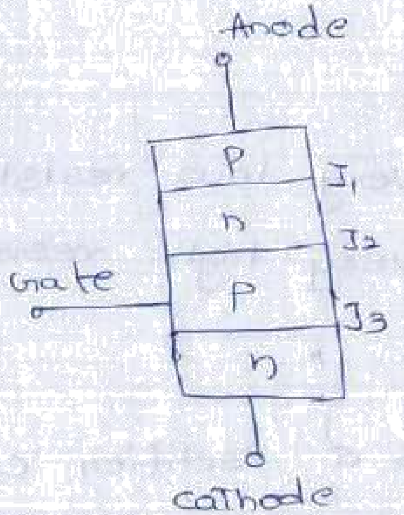
→ Bell laboratories were the first to fabricate a silicon-based semiconductor device called thyristor.

→ An oldest member of this thyristor family, called silicon-controlled Rectifier (SCR), is the most widely used device.

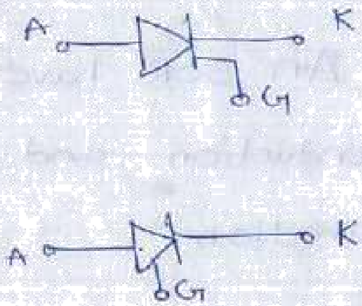
→ The word thyristor have become synonymous with SCR.



Constructional details (a)



Schematic diagram (b)



Circuit symbol (c)

→ Thyristor is a four layer, three junction, p-n-p-n semiconductor switching device.

→ It has three terminals: anode, cathode and gate.

→ The purpose of threaded stud in fig(a) is for the purpose of tightening the thyristor to the frame or heat sink.

→ The terminal connected to outer P region is called anode (A)

The terminal connected to outer n region is called Cathode(K) and that connected to inner p region is called Gate(G).

- For large current applications, thyristors need better cooling, by mounting them on to heat sinks.
- SCRs of voltage rating 10KV and an rms current rating of 3000A with corresponding power-handling capacity of 30MW are available.
- They are compact, possess high reliability and have low loss.
- An SCR have very low resistance in the forward conduction and very high resistance in the reverse direction.
- Its operation as a Rectifier can be controlled.
- It is a unidirectional device like the diode, that blocks the current flow from cathode to anode.
- Unlike the diode, a thyristor also blocks the current flow from anode to cathode until it is triggered into conduction by a proper gate signal between gate & cathode.

Principle of operation:

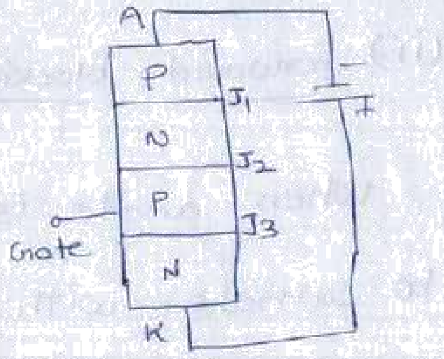
→ The thyristor operates in three modes

(i) Reverse blocking mode

(ii) Forward blocking mode

(iii) Forward conducting mode

(i) Reverse blocking mode:



→ when cathode is made positive with respect to anode the thyristor is reverse biased.

→ Junctions J_1, J_3 are reverse biased whereas J_2 is forward biased.

→ The device behaves as if two diodes are connected in series with reverse voltage applied across them

→ A small leakage current of the order of a few mA or uA flows. It

→ this is called reverse blocking mode, called off-state of the thyristor.

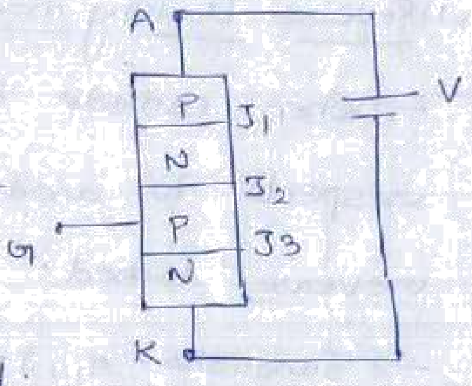
→ If the reverse voltage is increased, then at critical breakdown level, called reverse breakdown voltage V_{BR}, an avalanche occurs at J_1 & J_3 & the reverse current increase rapidly.

→ A large current associated with V_{BR} gives rise to more losses in the SCR.

This may lead to thyristor damage as the junction temperature is may exceed its permissible temperature rise.

→ Hence maximum working reverse voltage doesnot exceed V_{BR}.

(ii) Forward blocking mode:



When anode is positive with respect to cathode, with gate circuit open, thyristor is to be forward biased.

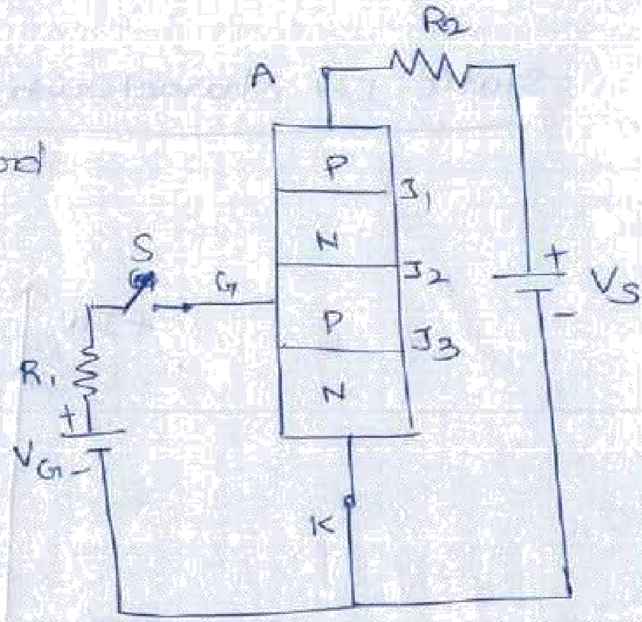
→ The junctions J_1 & J_3 are forward biased but Junction J_2 is reverse biased.

→ In this mode a small leakage current flows called forward leakage current, SCR offers high impedance

→ ∴ thyristor can be treated as an open switch even in the forward blocking mode.

→ [If we exceed the voltage beyond the forward break over voltage then it permanently damages the device].

(iii) Forward conduction mode:



→ When anode to cathode forward voltage is increased with gate open Gr. Circuit open, reverse biased junction J_2 will have an avalanche breakdown at a voltage called forward breakover voltage V_{BO}

→ After this breakdown, thyristor gets turned on with point M at once shift to N & then to a point b/w N & K. NK represents forward conducting mode.

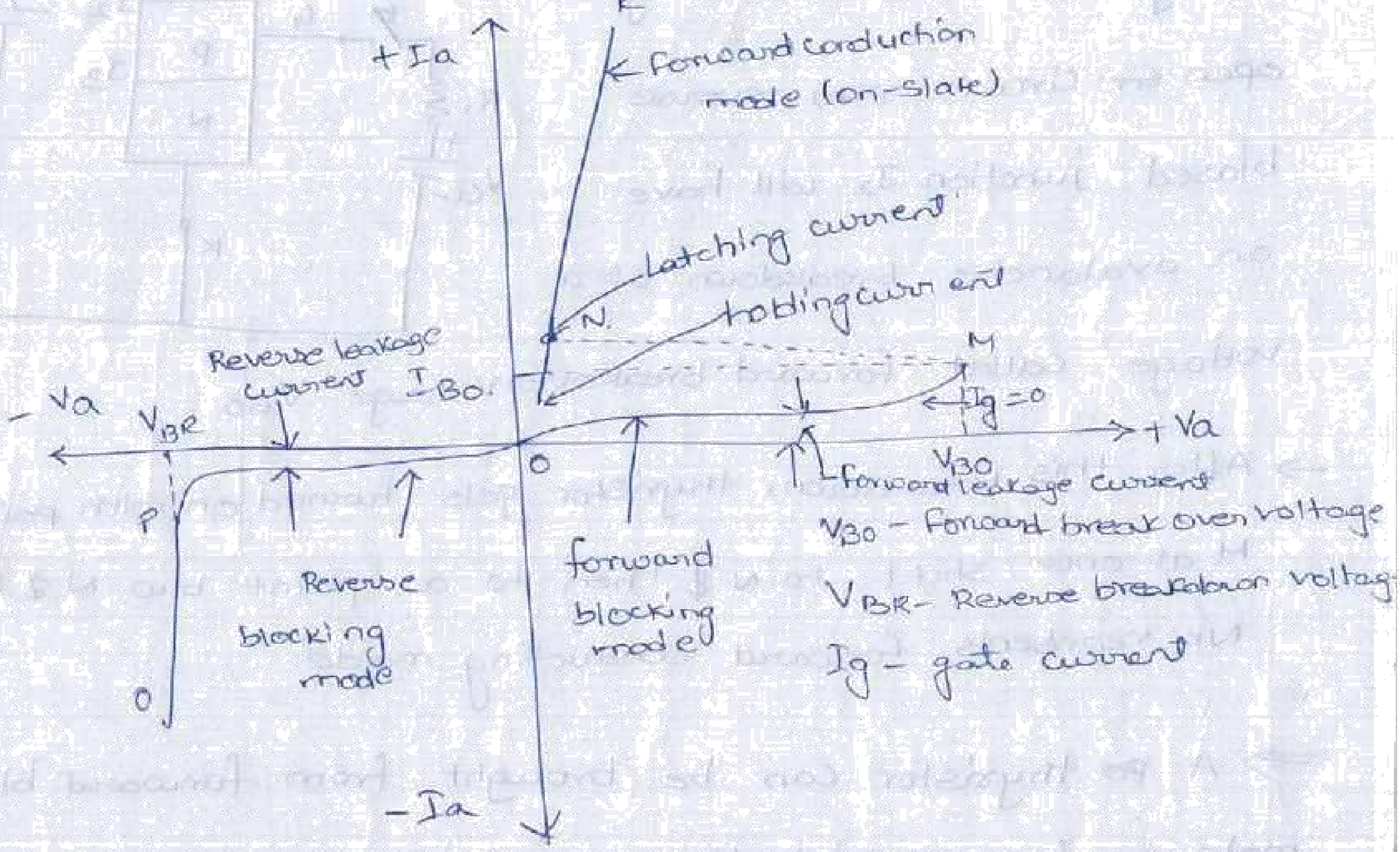
→ A thyristor can be brought from forward blocking mode to forward conduction mode by turning it on by applying (i) a positive gate pulse between gate and cathode

or (ii) a forward breakover voltage across anode and cathode.

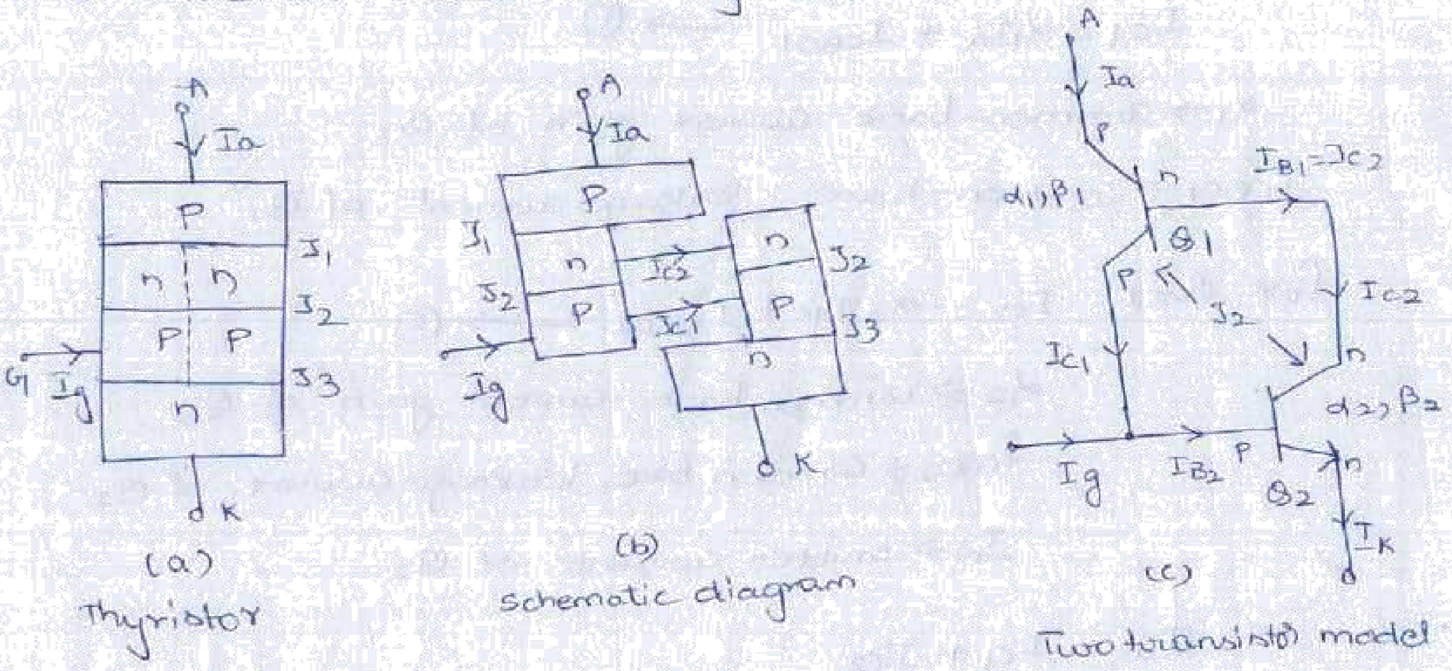
→ When we give +ve gate current w.r.t cathode then the device enters forward conducting mode. (when switch S is closed in fig)

→ In this mode, thyristor is treated as a closed switch.

Static I-V characteristics of a thyristor



Two transistor model of thyristor.



(a) Thyristor (b) schematic diagram (c) Two transistor model

→ The principle of thyristor operation can be explained with the use of its two-transistor model (or two transistor analogy).

→ The junctions $J_1 - J_2$ and $J_2 - J_3$ can be considered to constitute pnp and npn transistors seperately

→ The circuit representation of the two transistor model of a thyristor is shown in fig.

→ In off-state of a transistor, collector current I_C is related to emitter current I_E as

$$I_C = \alpha I_E + I_{CBO}$$

where α is common base current gain

I_{CBO} is the common base leakage current of collector-base junction of a transistor.

→ From fig, c, for Q_1 transistor, I_E = anode current I_a

$$I_C = I_{C1}$$

∴ for Q_1,

$$I_{C1} = \alpha_1 I_a + I_{CBO1} \longrightarrow (1)$$

$\alpha_1 \rightarrow$ common-base current gain of Q_1

$I_{CBO1} \rightarrow$ common-base leakage current of Q_1

for Q_2, $I_{C2} = \alpha_2 I_K + I_{CBO2} \longrightarrow (2)$

$\alpha_2 \rightarrow$ common base current gain of Q_2

$I_{CBO2} \rightarrow$ common base leakage current of Q_2

$I_K \rightarrow$ emitter current of Q_2

$$I_a = I_{C1} + I_{C2}$$

$$= \alpha_1 I_a + I_{CBO1} + \alpha_2 I_K + I_{CBO2} \longrightarrow (3)$$

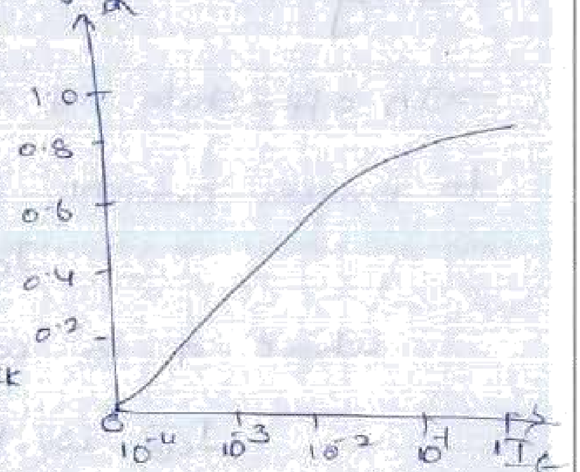
when gate current is applied, then $I_K = I_a + I_g$, substituting in eq (3) gives

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 (I_a + I_g) + I_{CBO2}$$

$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)} \longrightarrow (4)$$

$\alpha \simeq I_C / I_E$

current gain α_1 varies with emitter current $I_a = I_E$ and α_2 varies with $I_K = I_a + I_g$



→ If I_g is suddenly increased, then anode current I_a increases which would further increases α_1 & α_2

→ Increase in α_1 & α_2, further increases I_A (from (4))

∴ There is regenerative or positive feedback effect. If $(\alpha_1 + \alpha_2)$ tends to unity, eq (4) denominator approaches zero resulting in a large value of anode current I_A & thyristor turns on with a small gate current.

THYRISTOR TURN-ON METHODS:

→ With anode positive with respect to cathode, a thyristor can turned on by any one of the following techniques.

(a) Forward voltage triggering
(b) Gate triggering
(c) dv/dt triggering
(d) temperature triggering
(e) light triggering.

(a) Forward voltage triggering:

→ When forward voltage is applied between anode and cathode with gate circuit open, junction J_2 is reverse biased.

→ As a result, depletion layer is formed across junction J_2

→ The width of the layer decreases with an increase in anode-cathode voltage

→ If forward voltage across anode-cathode is gradually increased, a stage comes when the depletion layer across J_2 vanishes, J_2 is said to have avalanche breakdown and the voltage at which it occurs is called forward Breakover voltage V_{BO}.

→ As the junctions J_1, J_3 are already forward biased, breakdown of J_2 allows free movement of carriers across three junctions and as a result, large forward anode-current flows.

→ The forward current is limited by the load impedance.

→ In practice, the transition from off-state to on-state obtained by exceeding V_{BO} is never employed as it may destroy the device.

→ V_{BO} is taken as final voltage rating of the device during the design of SCR applications.

→ After avalanche breakdown, J_2 loses its reverse blocking capability ∴ if anode voltage is reduced below V_{BO}, SCR will continue conduction of the current.

→ The SCR can now be turned off only by reducing anode current below a certain value called 'holding current'

(b) Gate triggering:-

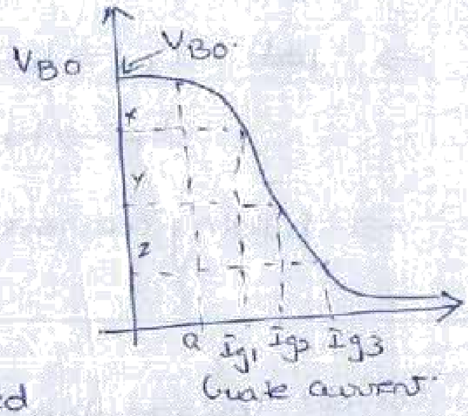
→ This Turning on of thyristors by gate triggering is simple, reliable and efficient, most usual method.

→ A positive gate voltage between gate and cathode is applied.

→ With gate current, a ~~posi~~ charges are injected into the inner P layer and voltage at which the forward breakover occurs is reduced.

→ The forward voltage at which the device switches to on-state depends upon the magnitude of gate current

→ Higher the gate current, lower is the forward breakover voltage



→ once the SCR is conducting a forward current, reverse biased junction J_2 no longer exists.

→ As such, no gate current is required for the device to remain in on-state.

if the gate current is removed, the conduction of current from anode to cathode remains unaffected.

→ If gate current is reduced to zero before the rising anode current attains a value, called the latching current, the thyristor will turn-off again.

→ The gate pulse width should therefore be judiciously chosen to ensure that anode current rises above the latching current.

→ Latching current:- may be defined as the minimum value of anode current which it must attain during turn-on process to maintain conduction when gate signal is removed.

→ The thyristor can be turned-off only if the forward current falls below a low-level current called the holding current.

→ Holding current: may be defined as the minimum value of anode current below which it must fall for turning-off the thyristor.

→ $I_L > I_H$

→ ~~let~~ I_L → turn on

I_H → turn off

→ holding current in industrial applications is almost taken as zero.

(c) $\frac{dv}{dt}$ triggering.

→ with forward voltage across the anode and cathode of a thyristor, the two outer junction J_1, J_3 are forward biased. J_2 is reverse biased.

→ J_2 has the characteristics of a capacitor due to charges existing across the junction.

→ the space charges exist in the depletion region near junction J_2 & ∴ J_2 behaves like a capacitance.

→ If forward voltage suddenly applied, a charging current through junction capacitance C_j may turn on SCR ~~on the~~

→ Almost the entire suddenly applied forward voltage V_a appears across junction J_2

the charging current $i_c = \frac{dQ}{dt} = \frac{d}{dt}(C_j V_a)$

$$= C_j \frac{dV_a}{dt} + V_a \frac{dC_j}{dt}$$

As the junction capacitance is constant, $\frac{dC_j}{dt} = 0$.

$$\therefore i_c = C_j \frac{dV_a}{dt}$$

∴ if rate of rise of forward voltage dV_a/dt is high, I_c would be more

→ This changing current I_c play the role of gate current & turns on the SCR even though gate signal is zero.

→ Note: even if V_a is small, it is the rate of change of V_a that plays the role of turning-on the device.

(d) Temperature triggering:-

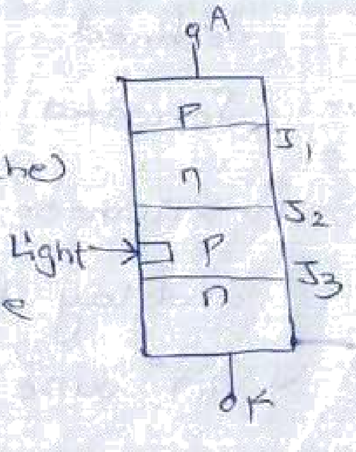
→ During F.B mode, most of applied voltage appears across reverse biased junction J_2.

→ This voltage across J_2, associated with leakage current, would rise the temperature of this junction

→ With increase in temperature, width of depletion layer decreases. This further leads to more leakage current and there-fore, more junction temperature.

→ With cumulative process, at some high temperature (within safe limits), depletion layer of reverse biased junction vanishes and the device gets turned on.

(e) Light triggering:-



→ For light triggered SCRs, a recess (or niche) is made in the inner p-layer.

→ If this recess is irradiated, free charge carriers are generated.

→ If the intensity of this light thrown on the receiver exceeds a certain value, forward biased SCR is turned on.

used in HVDCT. (advantage of electrical isolation between power and control circuits)

Turn off:

→ Commutation is defined as the process of turning-off a thyristor.

Dynamic or switching characteristics of thyristor

→ During turn-on & turn-off processes, a thyristor is subjected to different voltages across it & different currents through it

→ The time variations of the voltage across a thyristor & the current through it during turn-on & turn-off processes give the dynamic or switching characteristic of a thyristor.

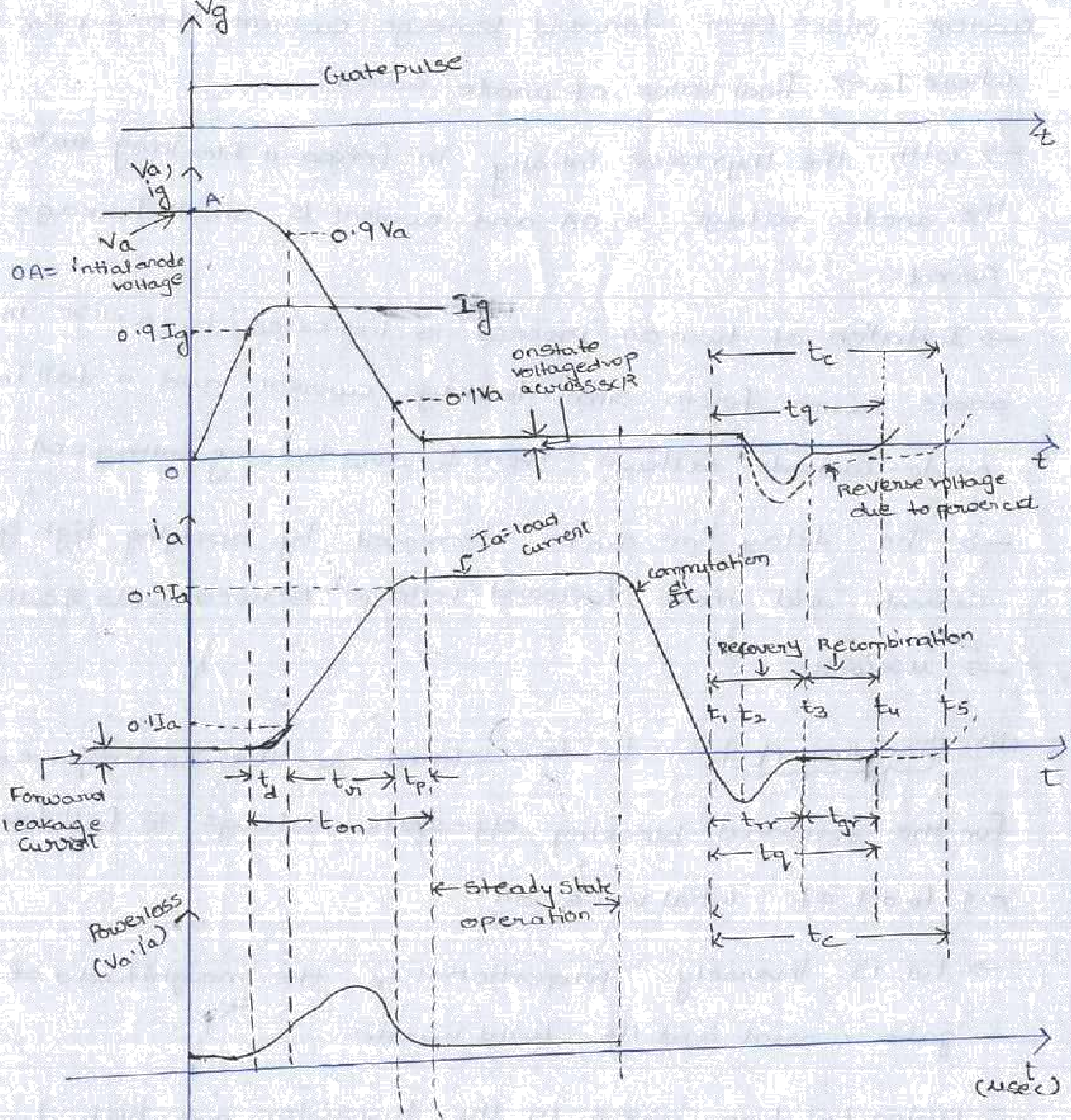
(a) switching characteristics during turn-on:-

~~Ton~~ A transition time from forward off-state to forward on-state called thyristor turn-on time, is defined as the time during which it changes from forward blocking state to final on-state.

→ Turn-on time can be divided into three intervals.

(i) delay time t_d

(ii) rise time t_r and (iii) spread time t_p



Thyristor voltage and current waveforms during turn-on and turn-off processes

<u>Turn on</u>

(i) <u>Delay time</u> t_d: t_d is defined as the time during which anode voltage falls from Va to 0.9Va where $V_a \rightarrow$ intial value of anode voltage. (or)

t_d is defined as the time during which anode current rises from forward leakage current to 0.1 I_a

where $I_a \rightarrow$ final value of anode current.

→ with the thyristor initially in forward blocking state, the anode voltage is OA and current is small leakage current.

→ Initiation of turn-on process is indicated by a rise in anode current from small leakage current and a fall in anode-cathode voltage from forward blocking voltage OA

→ The delay time can be decreased by applying high gate current and more forward voltage between anode & cathode.

→ μseconds.

(ii) Rise time (t_r):- t_r is defined as the time required for the forward blocking off-state voltage to fall from 0.9 to 0.1 of initial value OA.

→ t_r is inversely proportional to the magnitude of gate current and its build uprate.

→ During t_r, turn losses in the thyristor are high due to high V_a & high I_a occurring together in thyristor

(iii) Spread time (t_p):- t_p is the time taken by the anode current to rise from 0.9 to I_a.

(or) It is the time for the forward blocking voltage to fall from 0.1 to its initial value to on-state drop.

→ After the spread time, anode current attains steady state value and the voltage drop across SCR is equal to the on-state voltage drop of the order of 1 to 1.5V.

→ Turn on time of an SCR is equal to sum of delay time, risetime and spread time.

→ Total turn on time depends upon anode ckt parameters & the gate signal waveshapes.

→ Turn on time can be reduced by using higher values of gate currents.

Switching characteristics during Turn-off:-

→ The dynamic process of the SCR from conduction state to forward blocking state is called commutation process or turn-off process.

→ once the thyristor is on, gate loses control.

→ SCR can be turned off by reducing the anode current below holding current.

→ the turn-off time t_q of a thyristor defined as the time between the instant anode current becomes zero and the instant SCR regains forward blocking capability.

→ turn off time is divided into two intervals, reverse recovery time t_{rr} and the gate recovery time t_{gr}.

i.e., $t_q = t_{rr} + t_{gr}$

At instant t_1, anode current becomes zero.

→ After t_1, anode current builds up in the reverse direction with same di/dt slope as before t_1 because of the presence of carriers stored in four layers.

→ The reverse recovery current removes excess carriers from J_1 & J_3 between the instants t_1 & t_3.

→ Reverse recovery current flows due to the sweeping out of holes from top p-layer and electrons from bottom n-layer.

→ At t_2, when about 60% of the stored charges are removed from the outer two layers, carrier density across J_1 & J_3 begins to decrease and reverse recovery current also starts decaying.

→ It decays fast in beginning but gradual thereafter.

→ The fast decay of recovery current causes a reverse voltage across the device due to the circuit inductance.

→ This reverse voltage surge appears across the thyristor terminals & may therefore damage it.

→ At t_3 when reverse recovery current falls nearly zero, J_1 & J_3 recover & SCR is able to block the reverse voltage.

→ At end of reverse recovery period ($t_3 - t_1$), the middle Junction J_2 still has trapped charges, ∴ the Thyristor is not able to block the forward voltage at t_3.

→ The trapped charges must decay only by recombination.

→ Recombination is possible if a reverse voltage is maintained across SCR.

→ The time for recombination ~~is possible if a re.~~ of charges between t_3 & t_4 is called gate recovery time t_{gr}.

→ At t_4, J_2 recovers & the forward voltage can be reapplied between anode and cathode

→ t_q (turn-off time) is in range of 3 to 100 µs.

→ t_q is influenced by magnitude of forward current, $\frac{di}{dt}$ at the time of commutation and junction temperature. Turn-off time increases with increase in above 3 factors.

→ If forward current is high before commutation, trapped charges around junction J_2 are more

→ the time required for their recombination is more and therefore turn off time is increased.

→ The turn off time decreases with an increase in the magnitude of reverse voltage because, it sucks out the carriers out of J_1 & J_3.

→ The turn-off time provided ~~to~~ the transistor by ~~the~~ the practical circuits is called circuit turn-off time t_c.

→ t_c is defined as time between the instant anode current becomes zero and the instant reverse voltage due to practical circuit reaches zero.

$t_c > t_q$ for reliable turn-off. Otherwise the device may turn-on at an undesired instant, a process called commutation failure.

→ Thyristors with slow turn-off time (50-100 μsec) are called converter grade SCRs & ~~for~~ with fast turn-off time (3-50 μs) are called inverter grade SCRs.

Gate triggering methods:

→ Gate triggering is most common method to turn-on the SCR because this method lends itself accurately for turning on the SCR at the desired instant of time.

→ It is an efficient & reliable method.

→ By means of gate voltage control, the turning on of the SCR can be controlled.

→ The gate circuit is also called firing or triggering circuit.

(1) Resistance firing circuit:-

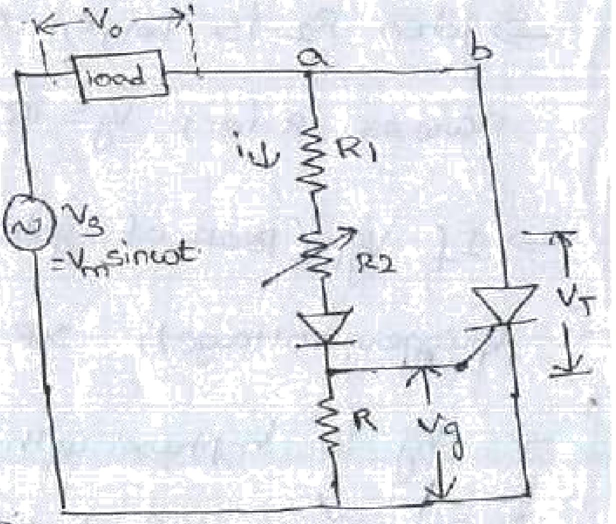
→ It is simple & most economical.

→ Limited range of firing angle control (0° to 90°), greatest dependence on temperature & difference in performance between individual SCRs are drawbacks ~~which they sol~~

→ R_2 is variable resistance.

→ If R_2 is zero, gate current may flow from source, through load, R_1, D and gate to cathode.

→ This current should not exceed maximum permissible gate current I_{gm}.



R-firing circuit.

R_1 can be found from

$$\frac{V_m}{R_1} \leq I_{gm} \Rightarrow R_1 \geq \frac{V_m}{I_{gm}}$$

V_m → maximum value of source voltage.

The function of R_1 is to limit the gate current to a safe value as R_2 is varied.

→ R should have such a value that maximum voltage drop across it does not exceed maximum permissible gate voltage V_{gm}

This can happen only when R_2 is zero.

under this condition,
$$\frac{V_m}{R_1+R} \cdot R \leq V_{gm}$$

$$R \leq \frac{V_{gm} \cdot R_1}{V_m - V_{gm}}$$

→ As resistances R_1 & R_2 are large, gate trigger circuit draws small current.

→ Diode D allows flow of current during positive half cycle only. ie., V_g is half-wave dc pulse. The amplitude of this dc pulse can be controlled by varying R_2

→ Potentiometer setting R_2 determines the gate voltage amplitude.

→ when R_2 is large, current i is small and the voltage across R ie.) $V_g = iR$ is also small.

→ If V_{gp} (peak of gate voltage V_g) is less than V_{gt} (gate trigger voltage), SCR will not turn on. (ie., $V_{gp} < V_{gt}$ → SCR does not turn-on)

→ V_g is in phase with V_s.

→ If R_2 is adjusted such that $V_{gp} = V_{gt}$, gives $\alpha = 90^\circ$ firing angle

→ If $V_{gp} > V_{gt}$, as soon as V_g becomes equal to V_{gt} for first time SCR turns on, gate loses control and V_g is reduced to zero (almost zero about 1V).

→ The firing angle never be equal to zero but nearer $2^\circ - 4^\circ$.

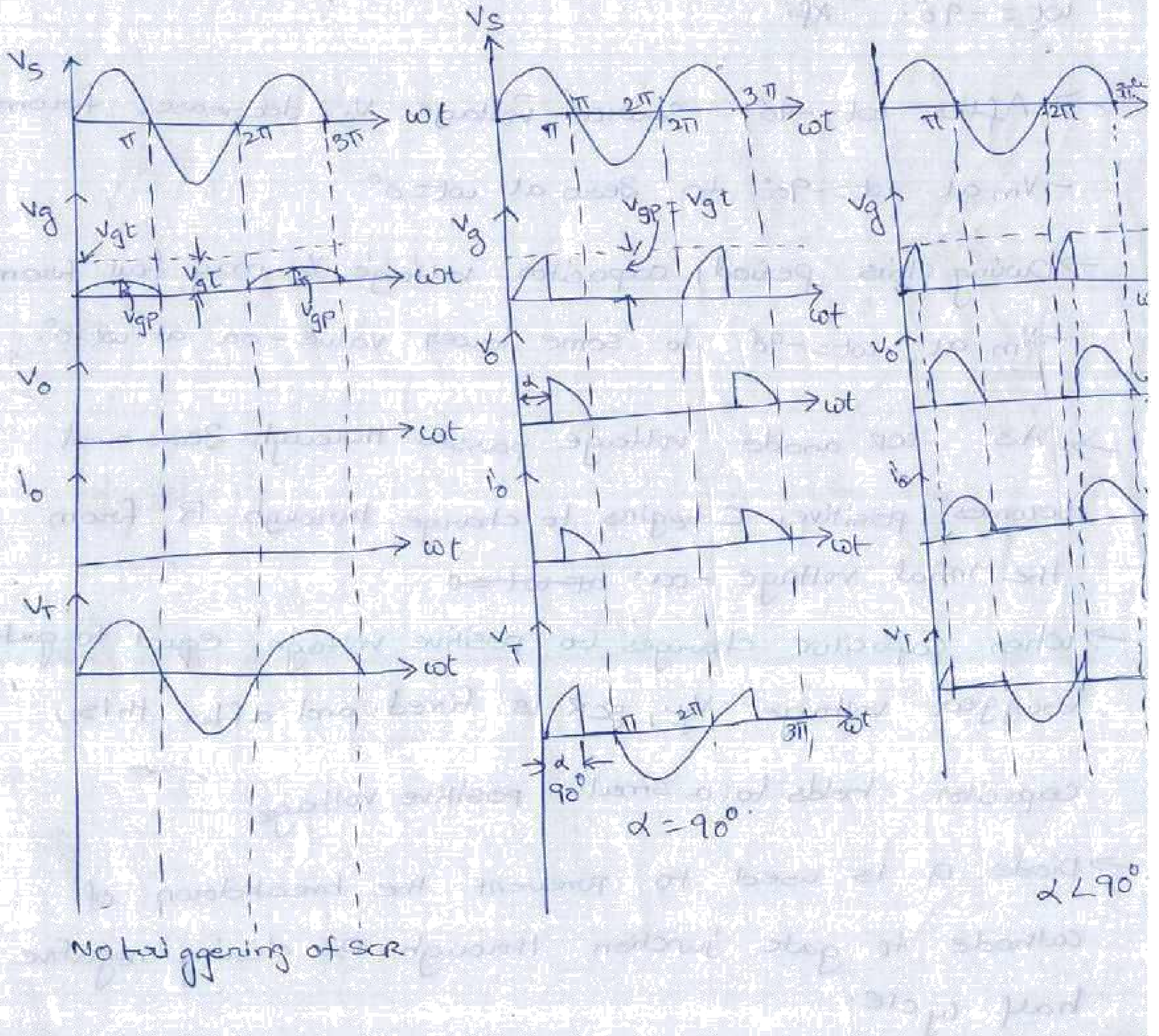
$$V_{gp} \sin\alpha = V_{gt}$$

$$\Rightarrow \alpha = \sin^{-1}(V_{gt}/V_{gp})$$

Since $V_{gp} = \frac{V_m R}{R_1 + R_2 + R}$

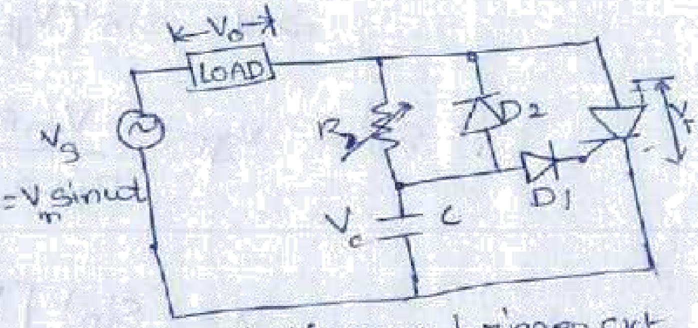
$$\alpha = \sin^{-1}\left[\frac{V_{gt} \cdot (R_1 + R_2 + R)}{V_m R}\right]$$

As V_{gt}, R_1, R and V_m are fixed, $\alpha = \sin^{-1}(R_2)$ or $\alpha = R_2$



Rc firing circuit:-

→ By varying the value of R, firing angle can be controlled from 0° to 180°.



Rc half wave trigger ckt

→ In the negative half cycle, capacitor C charges through D2 with lower plate positive to the peak supply voltage V_m at $\omega t = -90°$. Af

→ After $\omega t = -90°$, source voltage V_s decreases from $-V_m$ at $\omega t = -90°$ to zero at $\omega t = 0°$

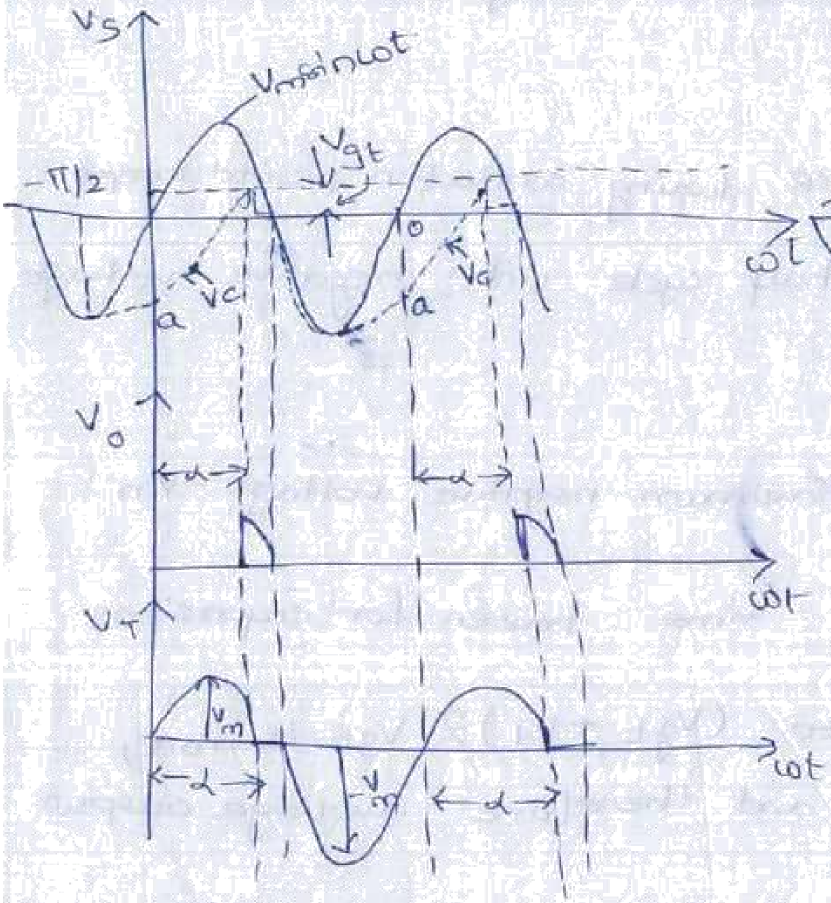
→ During this period, capacitor voltage V_c may fall from $-V_m$ at $\omega t = -90°$ to some lower value $-oa$ at $\omega t = 0°$.

→ As SCR anode voltage passes through zero and becomes positive, C begins to charge through R from the initial voltage $-oa$. ~~at ωt = 0~~

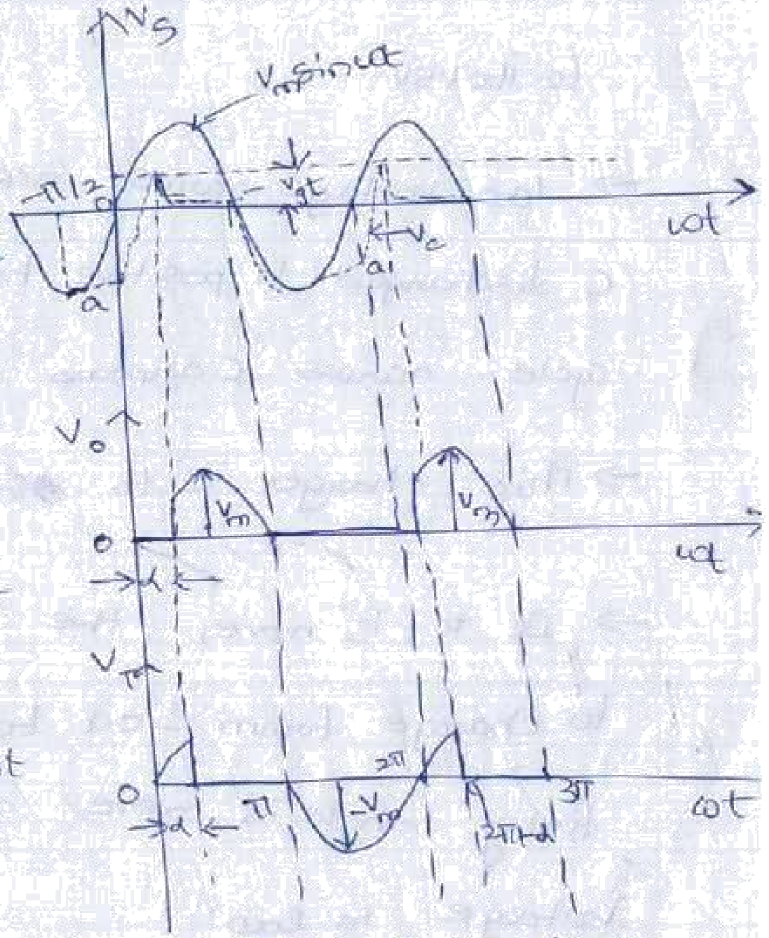
→ When capacitor charges to positive voltage equal to gate trigger voltage V_{gt}, SCR is fired and after this, capacitor holds to a small positive voltage.

→ Diode D1 is used to prevent the breakdown of cathode to gate junction through D2 during negative half cycle.

→ the firing angle can never be zero & 180°.



high value of R.



low value of R

SCR will trigger when $v_c = V_{gt} + V_d$

where V_d is the voltage drop across diode D1

At instant of triggering, if v_c is assumed constant, the current I_{gt} must be supplied by voltage source through R, D1 & gate to cathode circuit.

max. value of R, is given by

$$V_s \geq R I_{gt} + V_c$$

$$V_s \geq R I_{gt} + V_{gt} + V_d$$

$$R \leq \frac{V_s - V_{gt} - V_d}{I_{gt}}$$

→ when SCR triggers, Voltage drop across it falls to 1 to 1.5V. This in turn, lowers the voltage across R & C to 1 to 1.5V.

→ low voltage across SCR during conduction period keeps C discharged in positive half cycle until negative voltage cycle across C appears

→ This charges C to maximum negative voltage $-V_m$

→ If R is more, the time taken for capacitor to charge from $-oa$ to $(V_{gt} + V_d) \simeq V_{gt}$ is more, firing angle is more and therefore average output voltage is low.

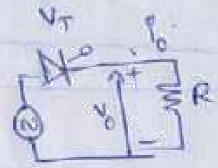
→ If R is less, firing angle is low, average output voltage is more

Class F Line commutation or natural commutation:

→ only when source is ac.

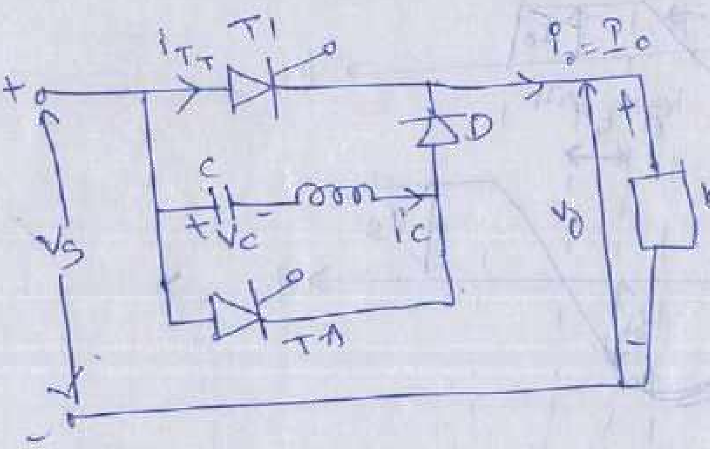
→ current has to pass through its natural zero at the end of every positive half cycle

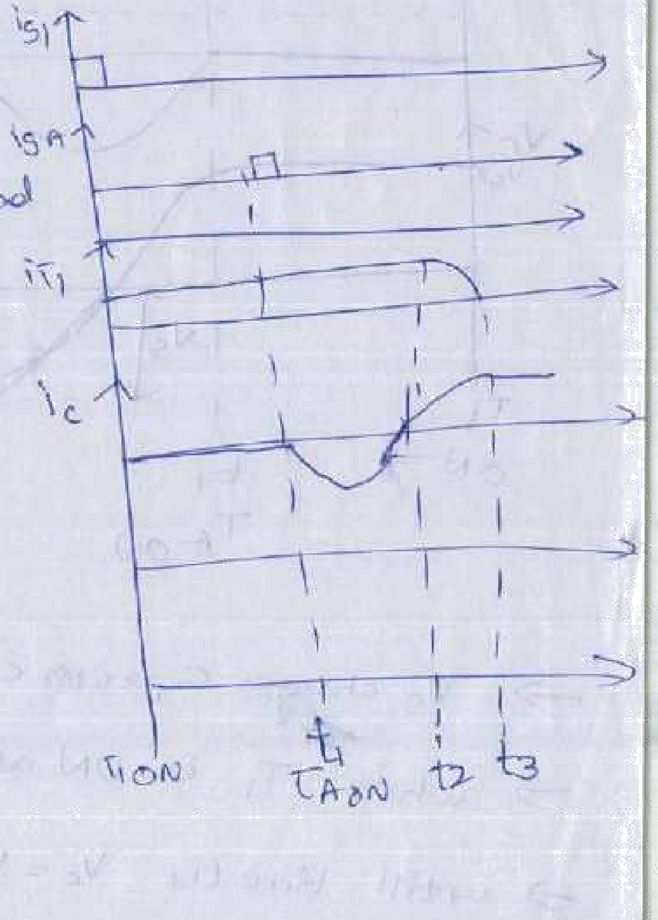
→ Then ac source applies a reverse bias across SCR

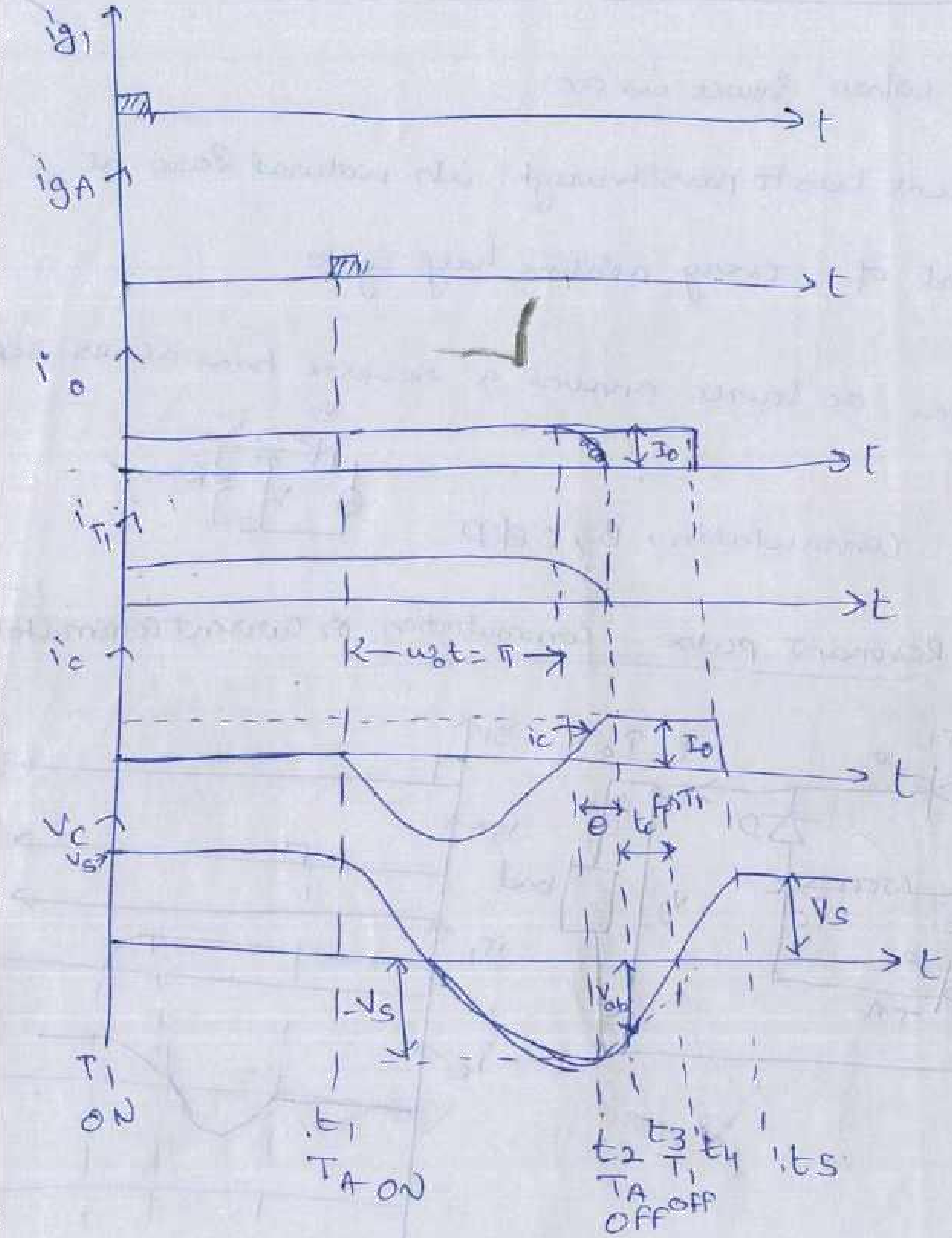


Forced commutation, B, C & D

Class B Resonant pulse commutation or current commutation







→ V_S charges capacitor C to voltage V_S; T_1 & T_A are off.

→ when T_1 is ON at $t=0$, I_0 is established.

→ uptill time t_1, $V_c = V_S$, $i_c = 0$, $i_0 = I_0$ and $i_{T1} = I_0$.

→ For initiating commutation of T_1, T_A is gated at $t = t_1$

→ i_c begins to flow from C, T_A, L & C.

t_1, $i_c = -V_S\sqrt{\frac{C}{L}} \sin\omega_0 t = -I_p \sin\omega_0 t$

$V_c(t) = \frac{1}{C}\int i_c \, dt$

$= V_s \cos\omega_0 t'$

→ After half cycle of i_c from t_1, $i_c = 0$, $V_c = -V_s$ & $i_{T_1} = I_0$

→ after π radians from t_1, i.e., just after instant t_2, i_c tends to reverse, TA is OFF at t_2.

with $V_c = -V_s$, right hand has +ve polarity.

i_c now flows C, L, D & T_1.

→ As i_c grows opp to forward thyristor current T_1,

$i_{T_1} = I_0 - i_c$ begins to decrease.

→ finally when i_c in reverse direction equal I_0,

$i_{T_1} = I_0 - I_0 = 0$ & T_1 is turned off at t_3.

→ After T_1 is off, t_3, I_0 flows from V_s to load through C, L & D.

C begins charging linearly from $-V_{ab}$ to zero at t_4

then to V_s at t_5.

at t_5, $V_c = V_s$, $i_0 = i_c = I_0$ to zero.

i_c when T_1 is off: $V_s\sqrt{\frac{C}{L}} \sin\omega_0 (t_3 - t_2) = I_0$

$$\omega_0(t_3 - t_2) = \sin^{-1}\left[\frac{I_0}{I_P}\right]$$

$I_P = V_s\sqrt{\frac{C}{L}}$ Peak resonant current.

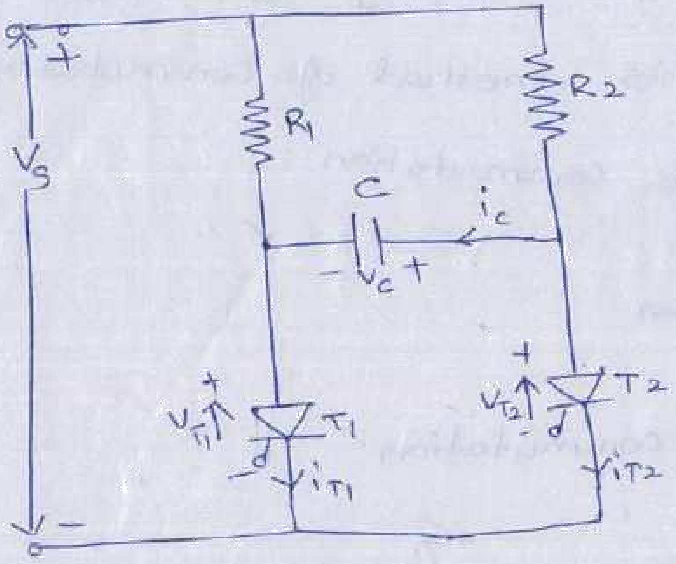
$t_c = t_4 - t_3 = C\frac{V_{ab}}{I_0}$

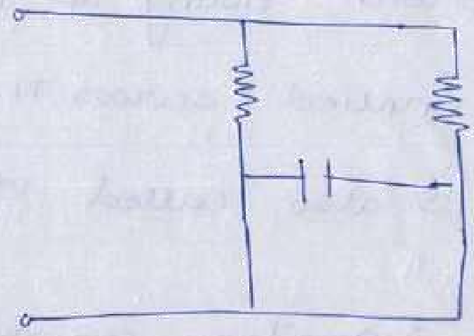
t_c dependent on load current.

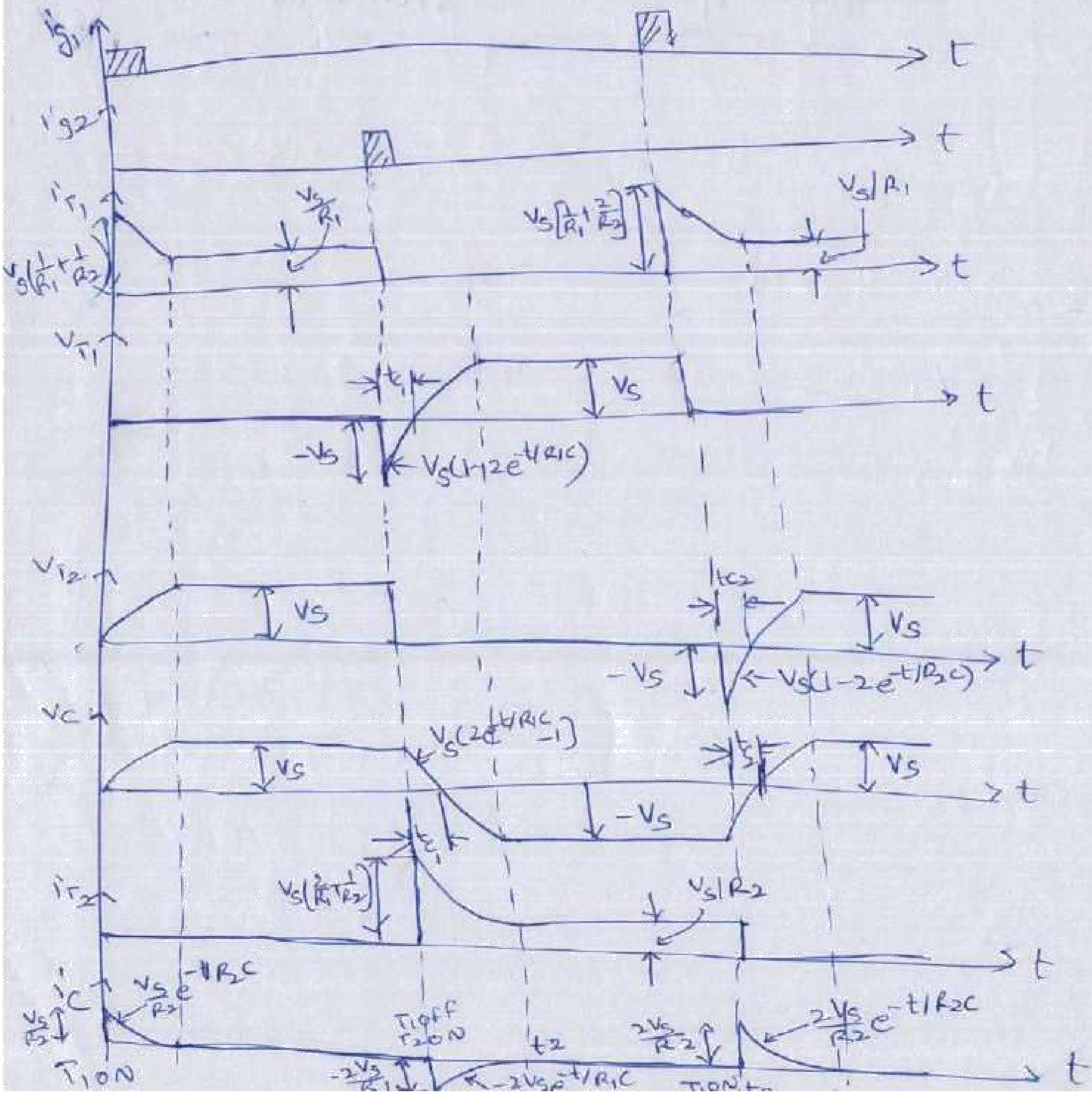
$V_{ab} = V_s \cos\omega_0(t_3 - t_2)$ V across T_1 at time of commutation

Class C Commutation:

Complementary commutation:







→ again capacitor charges from +Vs to +Vs

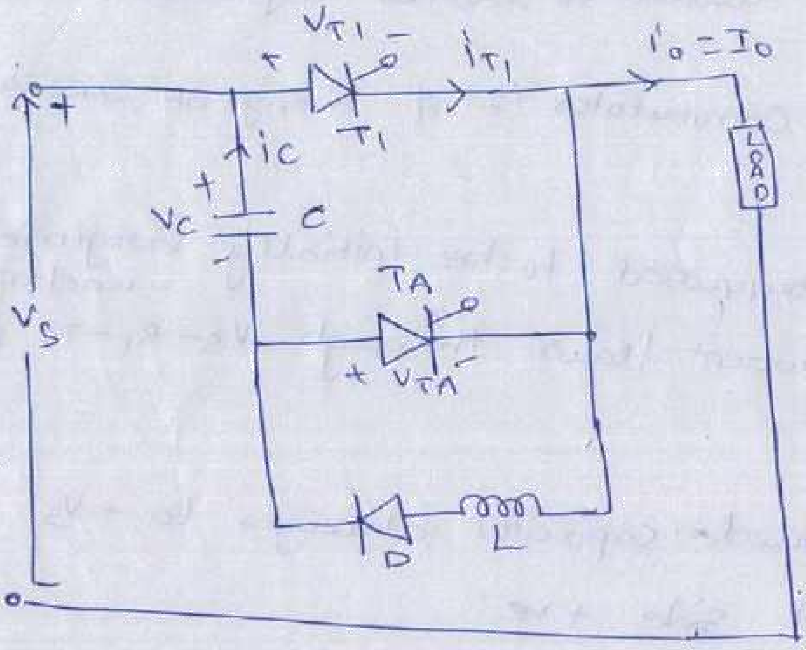
→ with firing of TA, reverse voltage Vs is suddenly applied across T1. this method of commutation is also called voltage commutation.

→ auxilary commutation

→ parallel capacitor commutation.

Waveforms of Derivations from text

class D Commutation: or Impulse Commutation



→ Initially T_1 & T_A are off

→ capacitor is assumed to charged to voltage V_S with upper plate +ve.

→ when T1 is turned on, Vs is applied across load & load current I_o begins to flow.

→ Another oscillator circuit consisting of C, T_1, L & D is formed.

where $i_c = V_S\sqrt{\frac{C}{L}}\sin\omega t = I_p\sin\omega t$.

→ The capacitor discharges from +Vs to Vs & lower plate becomes +ve.

→ when TA is turned on, capacitor voltage Vs applies a reverse voltage across main thyristor T1 so that $V_{T1} = -V_S$ & T_1 is turned OFF.

→ A thyristor carrying load current is commutated by transferring its load current to another thyristor

→ firing of scr T1 commutates T2 & firing of scr T2 would turn off T1

→ The capacitor is supposed to be initially virgin ie, uncharged.

→ when T_1 is on, current flows through $V_S - R_1 - T_1$ & $V_S - R_2 - C - T_1$.

→ During this period capacitor charges to $+V_S$ with right hand side +ve.

→ To commutate the main thyristor, T2 is turned on.

→ At this instant, the capacitor voltage V_C applies a reverse voltage V_S across scr T1 and turns it off

→ The capacitor discharges through $R_1 - C - T_2$ the capacitor voltage changes from V_S to $-V_S$

derivation part in P.S bimbra text

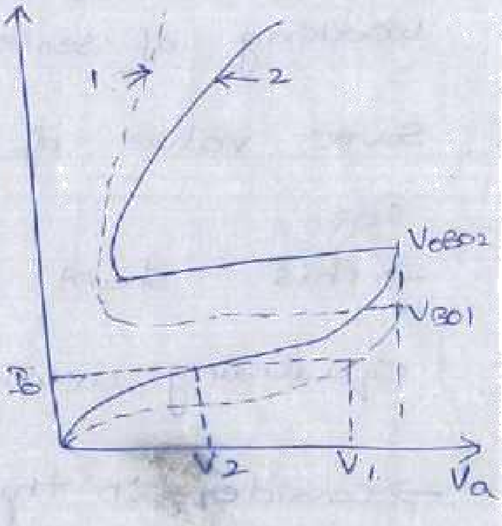
Series operation of SCR

→ When system voltage is more than voltage rating of a single thyristor, SCRs are connected in series in string

→ SCRs should have their I-V characteristics as close as possible

→ On account of inherent variations in their characteristics the voltage shared by each SCR may not be equal

SCR1 leakage resistance $= \frac{V_1}{I_0}$ is high whereas for SCR2, it is low (V_2/I_0)



~~String~~

$$\text{String efficiency} = \frac{\text{Actual voltage/current rating of the whole string}}{[\text{Individual voltage/current rating of one SCR}][\text{number of SCRs in the string}]}$$

Derating factor DRF = 1 − string efficiency

$$\text{string efficiency} = \frac{V_1+V_2}{2V_1};$$

→ The two SCRs can support a max voltage of V_1+V_2 and not the rated blocking voltage $2V_1$

→ A uniform voltage distribution in steady state can be achieved by connecting a suitable resistance across each SCR such that each parallel combination has the same resistance.

→ This will require different value of Resistance for each SCR which is a difficult proposition.

→ A more practical way of obtaining a reasonably uniform voltage distribution during steady state working of series-connected SCRs is to connect the same value of shunt resistance R across each SCR.

→ This shunt resistance R is called the static equalizing circuit.

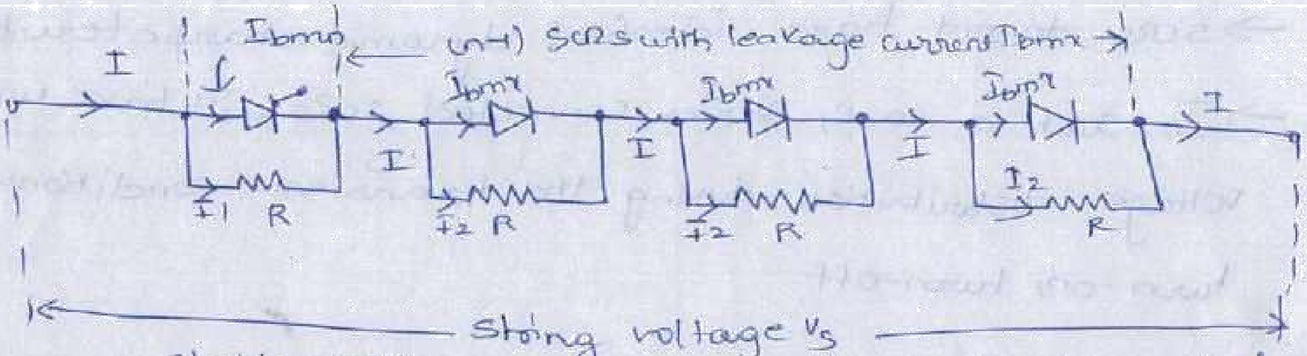
→ Consider 'n' thyristors connected in series.

→ Let SCR1 has minimum leakage current I_{bmn} and each of the remaining (n-1) SCRs have same leakage current $I_{bmn} > I_{bm}$.

→ SCRs with lower leakage current blocks more voltage.

→ As SCR1 has lower leakage current, it will block voltage V_{bm} (say) which is more than that shared by each of the other (n-1) SCRs.

Here V_{bm} is maximum permissible blocking voltage of SCR 1.



Static-voltage equalization for series connected String

$$I_1 = I - I_{bmn}$$

$$I_2 = I - I_{bmx}$$

I = total string current

$$V_{bm} = I_1 R$$

voltage across (n-1) SCRs = $(n-1) I_2 R$

$$V_s = I_1 R + (n-1) R I_2$$

$$= V_{bm} + (n-1) R (I - I_{bmx})$$

$$= V_{bm} + (n-1) R [I_1 - (I_{bmx} - I_{bmn})]$$

$$= V_{bm} + (n-1) R I_1 - (n-1) R \cdot \Delta I_b$$

$$\Delta I_b = I_{bmx} - I_{bmn}$$

$$R I_1 = V_{bm}$$

$$V_s = n V_{bm} - (n-1) R \cdot \Delta I_b$$

$$\therefore R = \frac{n V_{bm} - V_s}{(n-1) \Delta I_b}$$

SCR data sheet → I_{bmx}, rarely ΔI_b

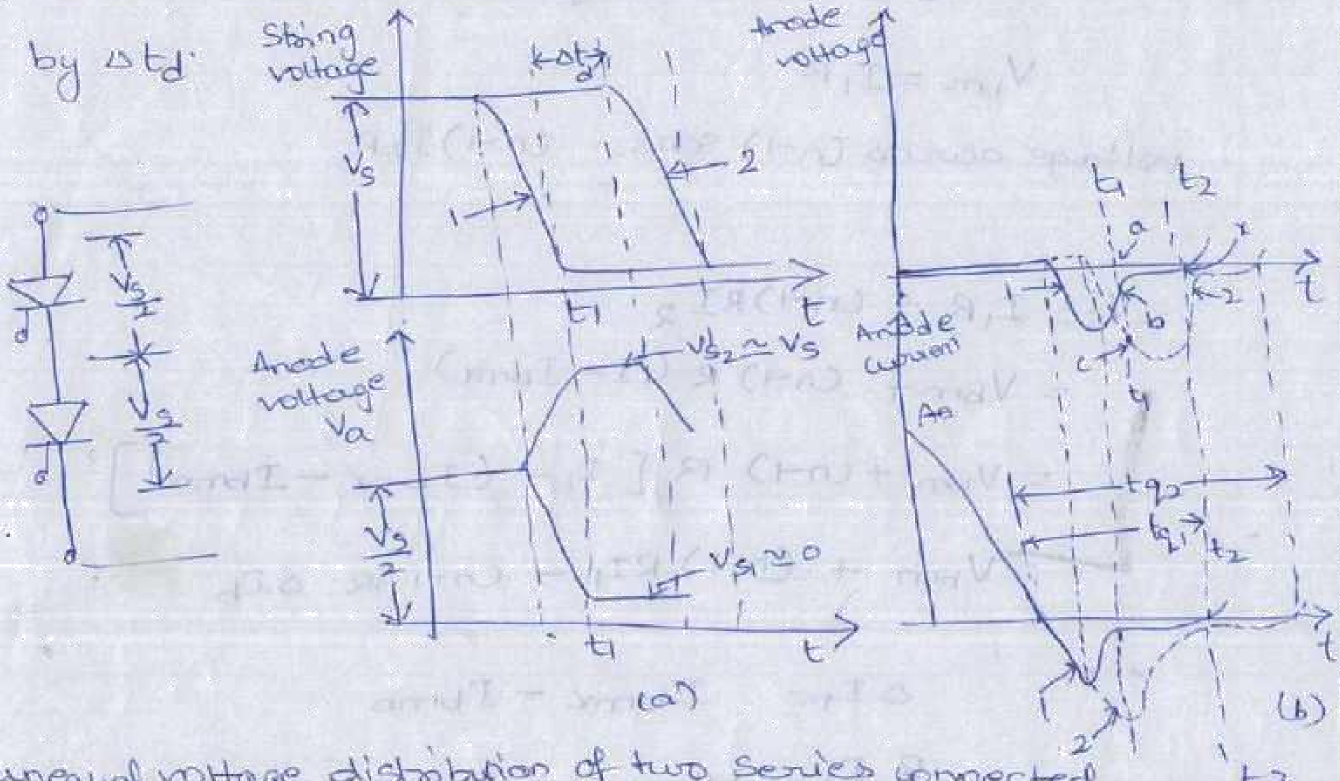
In such case $\Delta I_b = I_{bmx}$ with $I_{bmn} = 0$

Power rating $P_R = \frac{V_r^2}{R}$ V_r → rms voltage across R

→ SCRs do not have identical dynamic characteristics.

→ In such a case, series connected SCRs will have unequal voltage distribution during the transient conditions of turn-on, turn-off

→ The dynamic characteristics of two SCRs during turn-on are shown, where it is assumed that turn-on time of SCR2 is more than that of SCR1 by Δt_d.



unequal voltage distribution of two series connected SCRs during (a) turn-on and (b) turn-off

→ Before both SCRs are gated, string voltage V_s is shared as $V_s/2$ by each thyristor.

→ If both SCRs are gated at the same time, As SCR1 has less turn-on time, it gets turned-on at instant t_1, whereas SCR2 is yet off

→ voltage across SCR1 drops from $\frac{V_s}{2}$ to almost zero

→ At t_1, voltage across off SCR2 will boost from $\frac{V_s}{2}$ to V_s.

→ Thus voltage shared by two SCRS are unequal

→ After t_1, voltage V_s across SCR2 may turn it on in case V_s is greater than its breakover voltage

→ SCR2 will get turned on at time $(t_1 + \Delta t_d)$.

→ During turn-off, SCR1 is assumed to have less turn-off time t_{q1} than that of SCR2 i.e., $t_{q1} < t_{q2}$

→ At instant t_2, SCR1 has recovered and is passing through zero voltage whereas SCR2 is developing reverse voltage xy.

→ At t_3 fig(b) both SCRS are developing different reverse recovery voltages given by ab for SCR1 & ac for SCR2.

→ So two SCRS have unequal voltages across them at t_3

→ Thus it is seen that SCRS with different characteristics during turn-off time suffer from unequal voltage distribution during their turn-off process

& turn-off process.

→ A simple resistor for static voltage equalization cannot maintain equal voltage distribution under transient condition.

→ During turn-on & turn-off, the capacitance of reverse biased junctions determines the voltage distribution across SCRs in a series connected string.

→ As reverse biased junctions are likely to have different capacitances called self capacitances, the voltage distribution during turn-on & turn-off periods would be unequal.

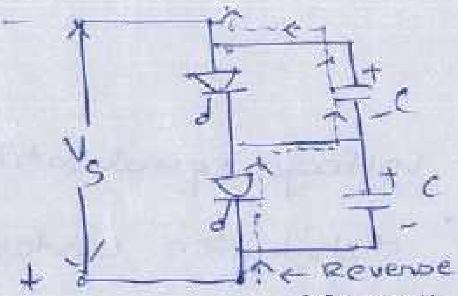
→ Voltage equilization under these conditions can be achieved by employing shunt capacitors.

→ This capacitance has the effect of removing the inequalities in thyristor self capacitances.

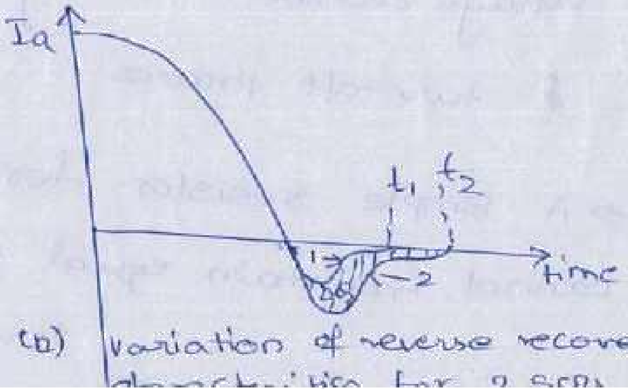
→ In otherwords, during turn-on and turn-off periods, the resultant of shunt capacitance & self capacitance of each SCR tend to be equal for each of the series connected SCRs

→ The choice of capacitor C is based on the reverse recovery characteristics of SCRs

→ Consider 2 SCRs connected in series



a) Flow of R.R current



(b) Variation of reverse recovery characteristics for 2 SCRs

→ SCR1 is assumed to have short reverse recovery time as compared to SCR2.

→ $\Delta Q \propto \Delta I \cdot \Delta t$ is difference in reverse recovery charges of two SCRs 1 & 2

→ under this assumption SCR1 recovers first; it therefore goes into blocking state & doesnot allow passage of excess charge ΔQ left on SCR2.

→ this ΔQ, pass through C as shown in fig

→ voltage induced by ΔQ in C, connected across SCR1 is $\frac{\Delta Q}{C}$. where as no voltage is Induced by $\Delta Q\ (= Q_2 - Q_1)$ in C Connected across SCR2.

→ ∴ differences in voltages, equal to $\frac{Q_2 - Q_1}{C} = \frac{\Delta Q}{C}$ to which the two shunt Capacitors are charged.

→ SCR1 with least recovery time will share highest transient voltage V_{bm}

→ Transient voltage shared by slow SCR2 must be $V_{bm} - \frac{\Delta Q}{C}$ (less than V_{bm} shared by fast SCR1)

∴ voltage across $SCR_1 V_1 = V_{bm}$

" " $SCR2,\ V_2 = V_{bm} - \frac{\Delta Q}{C}$

∴ string voltage $= V_s = V_1 + V_2 = V_{bm} + V_{bm} - \frac{\Delta Q}{C} = 2V_{bm} - \frac{\Delta Q}{C}$

$\Rightarrow V_s = 2V_{bm} - \frac{\Delta Q}{C} \Rightarrow V_{bm} = \frac{1}{2}\left(V_s + \frac{\Delta Q}{C}\right)$

and $V_2 = V_{bm} - \frac{\Delta Q}{C} = \frac{1}{2}\left[V_s - \frac{\Delta Q}{C}\right]$

the string voltage reverses in polarity in order to aid the R.R process of SCRs in string

→ now consider for n-series-connected SCRs in a string

if top SCR1 has characteristics similar to SCR1 & remaining (n-1) SCRs have characteristics similar to SCR2, then SCR1 would recover first & support voltage V_{bm}

→ the charge $(n-1)\Delta Q$ from (n-1) SCRs would pass through 'C' connected across top SCR1 & as result, a voltage

→ $\frac{(n-1)\Delta Q}{C}$ would be induced in C

→ excess charge contributed by each one of the (n-1) SCRs is ΔQ

∴ voltage across each one of slow thyristors is $\left[V_{bm}-\frac{\Delta Q}{C}\right]$

Thus for n connected SCRs,

voltage across fast top SCR1, $V_1 = V_{bm}$

voltage across each one of slow SCR2, $V_2 = V_{bm}-\frac{\Delta Q}{C}$

" " (n-1) slow thyristors $= (n-1)V_2$

$= (n-1)\left[V_{bm}-\frac{\Delta Q}{C}\right]$

∴ string voltage $V_s = V_1 + (n-1)V_2$

$$= V_{bm} + (n-1)\left[V_{bm}-\frac{\Delta Q}{C}\right]$$

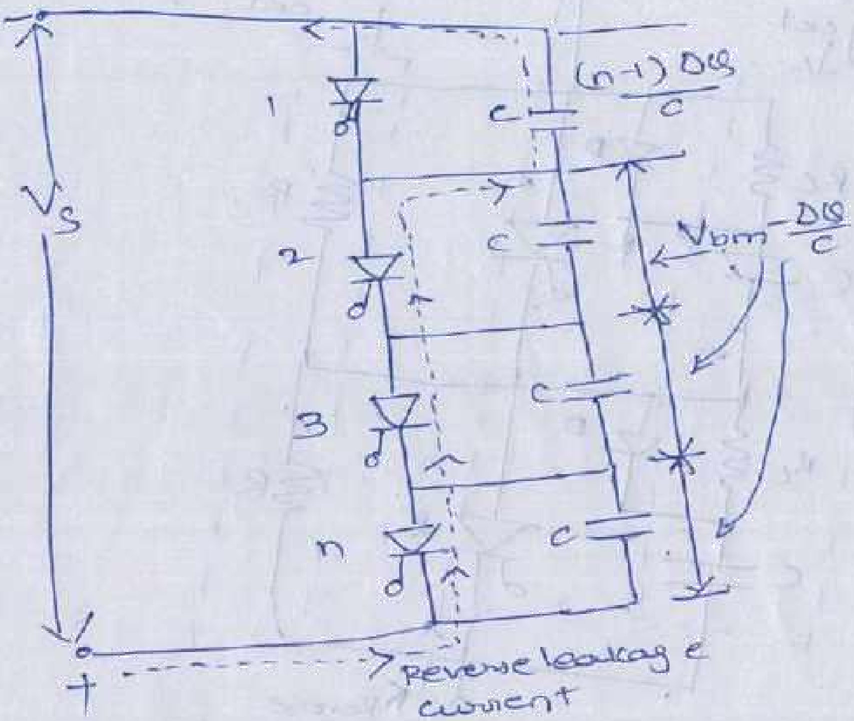
$$V_{bm} = \frac{1}{n}\left[V_s + \frac{(n-1)\cdot\Delta Q}{C}\right]$$

$$C = \frac{(n-1)\Delta Q}{nV_{bm}-V_s}$$

voltage across each one of slow SCRs, in terms of V_s is

$$V_2 = \left[V_{bm}-\frac{\Delta Q}{C}\right] = \frac{V_s}{n}+\frac{(n-1)\Delta Q}{nC}-\frac{\Delta Q}{C}$$

$$\therefore V_2 = \frac{V_s-\frac{\Delta Q}{C}}{n}$$



String having n-series connected thyristors

→ During turn-off, V_s (source voltage) must reverse to aid the reverse recovery current

→ The transient voltage which each scr must be able to withstand is V_{bm}

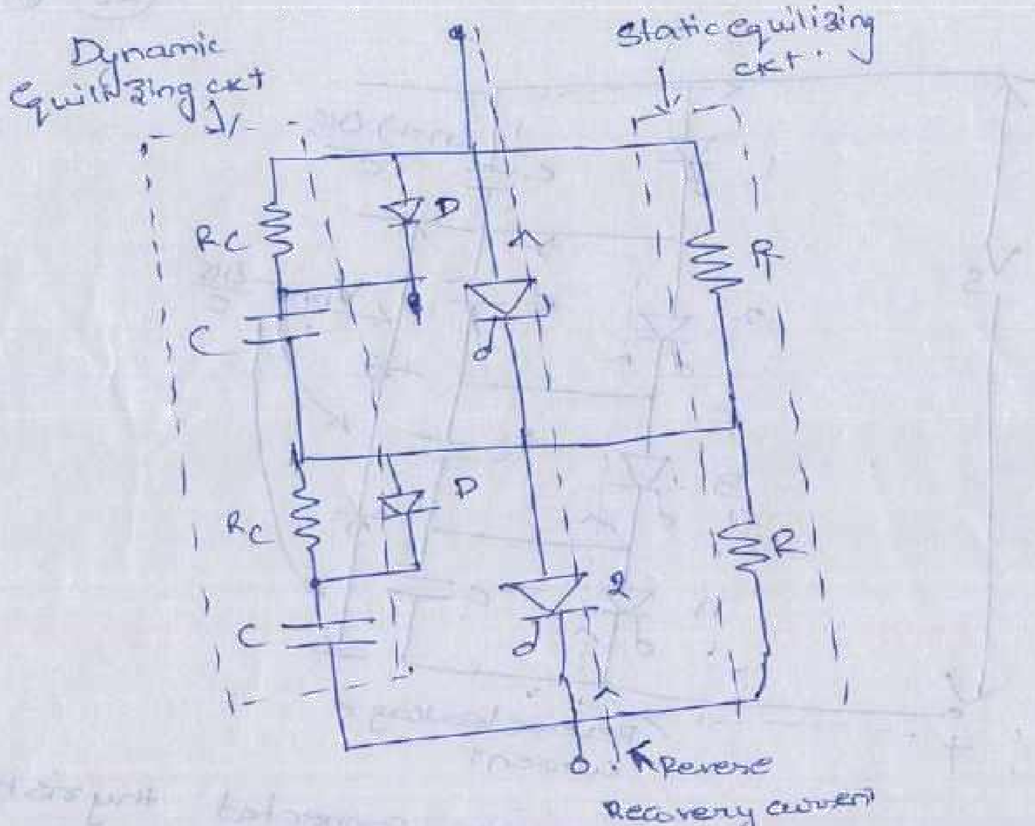
→ The total voltage acting across ckt consisting of V_s, SCRs n, 3, 2, & top C & per KVL is $V_s + \frac{(n-1)\Delta Q}{C}$ & this must be supported by all SCRs which is equal to $n \cdot V_{bm}$.

$$\therefore nV_{bm} = V_s + \frac{(n-1)\cdot \Delta Q}{C}$$

$$\Rightarrow V_{bm} = \frac{1}{n}\left[V_s + \frac{(n-1)\cdot \Delta Q}{C}\right]$$

$$\Rightarrow C = \frac{(n-1)\Delta Q}{nV_{bm} - V_s}$$

35



→ when any scr1 is F.B. state, capacitor connected across it gets change to voltage existing across that scr.

→ when this scr is turned on, c discharges heavy current through this scr. for limiting this current spike, a damping resistor Rc is used in series with c. R_C also damps out high frequency oscillations that may arise due to Rc, shunt capacitor & ckt inductance.

→ combination of Rc & c is called dynamic equilizing circuit.

→ Rc & c used is to equalize the voltage during dynamic (or transient) conditions & to protect scrs against high dv/dt

→ when forward voltage appears, diode D bypasses Rc during charging time of capacitor c, makes capacitor more effective in voltage equalization & for limiting $\frac{dv}{dt}$ across scr.

→ During capacitor discharge Rc comes into play for limiting current spike & di/dt.

Thyristor protection:

→ For Reliable operation of a thyristor, its specified ratings must not exceed.

→ In practice, a thyristor may be subjected to overvoltage and overcurrents.

→ During SCR turn-on, $\frac{di}{dt}$ may be very large.

→ There may be false triggering of SCR by high value of $\frac{dv}{dt}$

→ A spurious signal across gate-cathode terminals may lead to unwanted turn-on.

→ SCRs are very delicate devices, their protection against abnormal operating conditions is, therefore, essential.

(a) $\frac{di}{dt}$ protection:-

→ When a thyristor is forward biased and is turned on by a gate pulse, conduction of anode current begins in the neighbourhood of the gate-cathode junction.

→ Thereafter current spreads across the whole area of junction.

→ If the rate of rise of anode current, i.e., $\frac{di}{dt}$ is large as compared to the spread velocity of carriers, local hot spots will be formed near the gate connection on account of high current density. This localised heating may destroy the thyristor.

∴ $\frac{di}{dt}$ at the time of turn-on must be kept below the specified limiting value.

→ $\frac{di}{dt}$ can be maintained below acceptable limit by using a small inductor, called $\frac{di}{dt}$ inductor, in series with anode circuit.

→ Typical di/dt limit values of SCRs are 20–500 A/µsec.

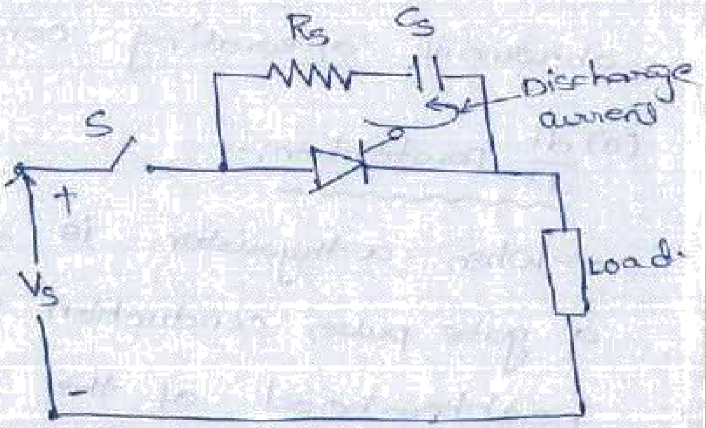
(b) dv/dt protection: W.K.T if rate of rise of suddenly applied voltage across thyristor is high, the device may get turned on. $\frac{dv}{dt}$ turn-on must be avoided as it leads to false operation of thyristor circuit.

→ dv/dt (rate of rise of forward anode to cathode voltage) dV_a/dt must be kept below specified rated limit. Typical values of dv/dt are 20–500 V/µsec.

→ False turn-on by large dv/dt can be prevented by using a snubber circuit in parallel with the device.

Design of Snubber circuit:

→ A snubber circuit consists of a series combination of resistance R_s and capacitance C_s in parallel with thyristor.



Snubber circuit across SCR

→ Capacitor C_s in parallel with device is sufficient to prevent unwanted dv/dt triggering of SCR.

→ When switch S is closed, a sudden voltage appears across circuit. C_s behaves like a short circuit, therefore across C_s builds up at a slow rate such that dv/dt across C_s & therefore across SCR is less than specified maximum dv/dt rating of the device.

→ Before SCR is fired by gate pulse, C_s charges to full voltage V_s. When SCR is turned on, capacitor

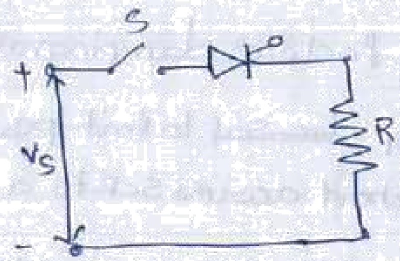
Capacitor discharges through the SCR & sends a current equal to Vs/(resistance of local path formed by Cs and SCR).

→ As this resistance is quite low, the turn-on di/dt will tend to be excessive and as a result, SCR may be destroyed.

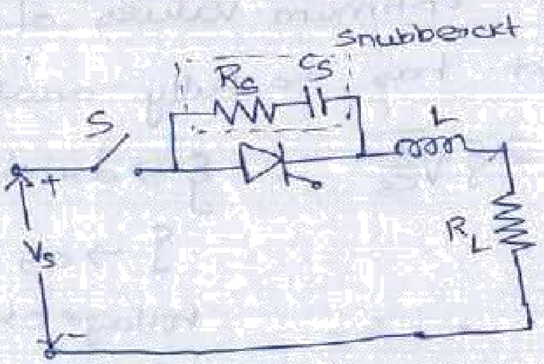
→ Inorder to limit the magnitude of discharge current a resistance Rs is inserted in series with Cs & turn on di/dt is reduced.

→ Rs, Cs & load circuit parameters should be such that dv/dt across Cs during its charging is less than the specified dv/dt rating of the SCR & discharge current at the turn-on of SCR is within ~~reasonable~~ reasonable limits.

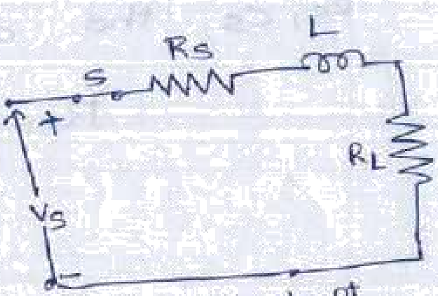
→ Normally, Rs, Cs & load circuit parameters form an underdamped circuit so that dv/dt is limited to acceptable values.



SCR in series with RL (a)



Thyristor protection with L & Rs, Cs (b)



eq. ckt at instant when S is closed (c)

→ when S is closed, Cs behaves like a short ckt and SCR in the forward blocking state offers a high resistance then eq ckt is shown in fig (c).

For ckt (c), $V_S = (R_S + R_L)i + L\frac{di}{dt}$

$$\Rightarrow i = I(1 - e^{-t/\tau}), \quad I = \frac{V_S}{R_S + R_L} \ \& \ \tau = \frac{L}{R_S + R_L} \quad \text{—(1)}$$

$$\frac{di}{dt} = \frac{d}{dt}\left(I(1 - e^{-t/\tau})\right) = I \cdot e^{-t/\tau} \cdot \frac{1}{\tau} = \frac{V_S}{R_S + R_L} \cdot \frac{R_S + R_L}{L} e^{-t/\tau}$$

$$= \frac{V_S}{L} e^{-t/\tau}$$

Value of di/dt is maximum when t=0.

$$\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L} \longrightarrow (2)$$

$$L = \frac{V_s}{\left(\frac{di}{dt}\right)_{max}}$$

Voltage across SCR, $V_a = R_s \cdot i$

$$\frac{dV_a}{dt} = R_s \cdot \frac{di}{dt}$$

$$\left[\frac{dV_a}{dt}\right]_{max} = R_s \cdot \left[\frac{di}{dt}\right]_{max} \longrightarrow (3)$$

From (2) & (3),

$$\left[\frac{dV_a}{dt}\right]_{max} = \frac{R_s V_s}{L}$$

$$R_s = \frac{L}{V_s}\left[\frac{dV_a}{dt}\right]_{max}$$

To determine optimum values of snubber ckt parameters R_s, C_s the ckt has to fully analysed.

$$R_s = 2\xi\sqrt{\frac{L}{C_s}}$$

$\xi \rightarrow$ damping factor or damping ratio

$\xi \rightarrow$ 0.5 to 1 ~~for saf~~ to limit peak voltage overshoot across SCR to a safe value.

When SCR is turned on, C_s will discharge a max. current of V_s/R_s & total current through thyristor will be $(V_s/R_s + V_s/R_L)$ this should be less than (I_{TRM}) of SCR. Thus if R_s is small, current spike contributed by C_s is small. Inorder reduce spike, R_s is greater than what is required to dv/dt, value of C_s is also reduced so that energy stored in C_s is small.

→ over current protection

→ over voltage protection

→ di/dt protection

→ dv/dt protection

→ Gate protection → against overvoltages & overcurrents which causes false triggering of SCR & damages

→ ~~Zenore~~ Zener diode is connected across gate ckt.

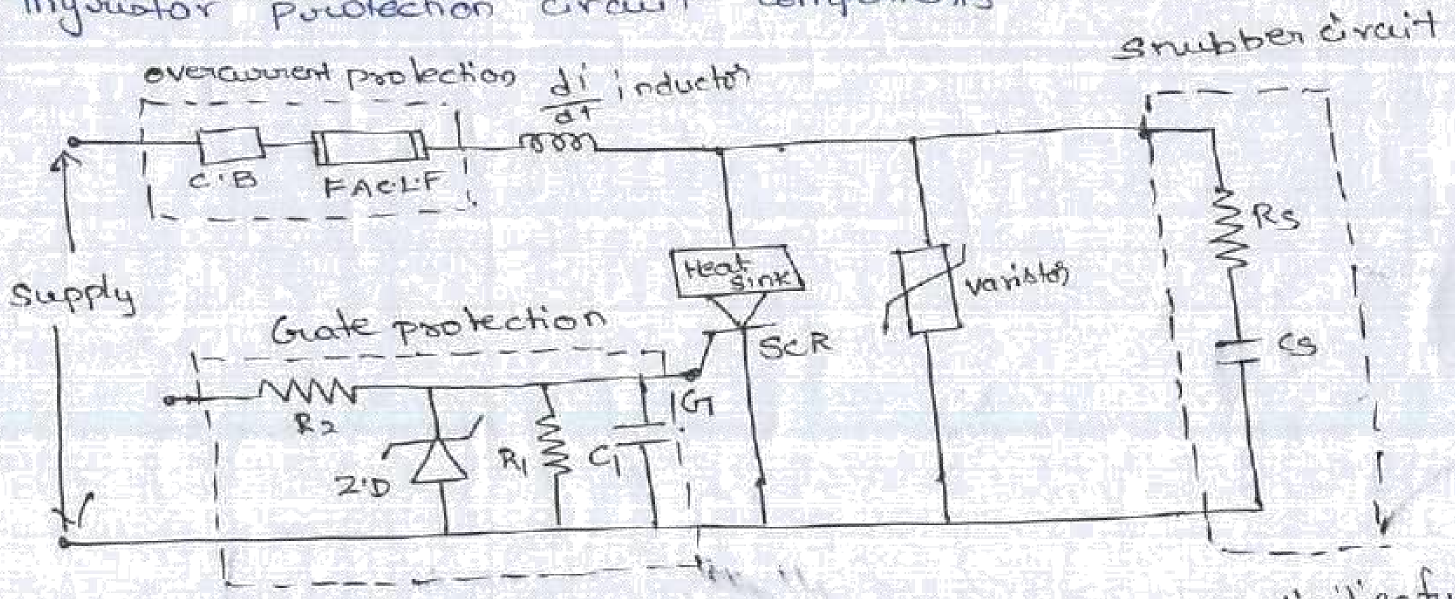
→ Resistor connected in series with gate ckt provides protection against over currents.

→ noise can reduced by shielded cables

→ Resistor & Capacitor are also connected across gate to cathode to bypass noise signals.

→ C must be less than 0.1uF & must not deteriorate wave shape of gate pulse

Thyristor protection circuit components



C.B → circuit Breaker, FACLF → fast acting current limiting fu[se]

Z.D → Zener diode

Thyristors

STATIC I-V characteristics of a Thyristor:

→ When During forward bias

J1 & J3 → forward biased,

J2 → Reverse biased

→ Presence of depletion layer at J2, does not allow any current to flow through the device

→ only leakage current, negligibly small in magnitude, flow through the device due to the drift of the mobile charges this current is insufficient to make the device conduct.

→ The depletion layer, mostly of immobile charges do not constitute any flow of current

→ This is forward blocking state or off state of the device.

→ The width of the depletion layer at the junction J2 decreases with the increase in anode to cathode voltage (Since the width is inversely proportional to voltage)

→ If the voltage b/w anode & Cathode ~~increases~~ is kept on increasing, a stage comes (corresponding to forward breakover voltage) when the depletion layer at J2 vanishes

→ The reverse biased junction J2 will breakdown due to the large voltage gradient across its depletion layer

This phenomenon is known as the Avalanche Breakdown

→ Since J1 & J3 are already forward biased, there will be a free Carrier movement across all the three junctions resulting in a large amount of current flowing from anode to cathode.

→ Due to the flow of this forward current, the device starts conducting & it is then said to be in forward conducting state or on state.

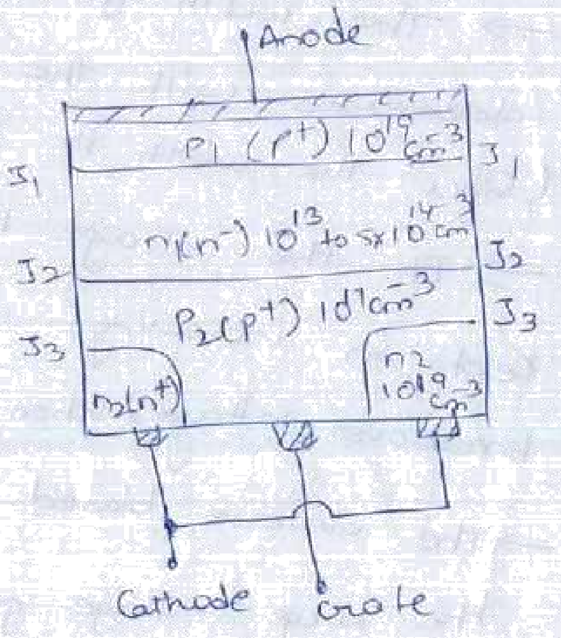
Reverse blocking state

→ when Cathode is made positive w.r. to end p layer, J_2 becomes F.b, J_1 & J_3 becomes R.B.

→ J_1 & J_2 do not allow any current to flow through device.

→ only a very small amount of leakage current may flow because of the drift of the charges.

→ The leakage current is insufficient to make the device conduct.



UNIT-II

Converters

→ Many industrial applications make use of controllable dc power.

examples:-

→ steel rolling mills, paper mills, printing presses, textiles mills employing dc motor drives

→ Traction systems working on dc

→ Electrochemical & electrometallurgical processes

→ magnet power supplies

→ Portable hand tool drives

→ HVDCT.

→ phase controlled rectifiers (ac to dc converters) employing thyristors are extensively used for changing constant ac input voltage to controlled dc output voltage.

→ In phase-controlled rectifiers, a thyristor is turned off as ac supply voltage reverse biases it, provide anode current has fallen to a level below the holding current

→ The turning-off, or commutation of a thyristor by supply voltage itself is called "natural or line commutation".

→ In study of thyristor systems SCRs and Diodes are assumed ideal switches which means that

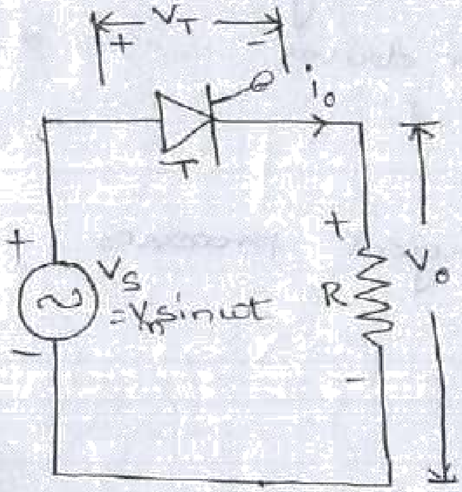
(i) there is no voltage drop across them

(ii) no reverse current exists under reverse voltage conditions

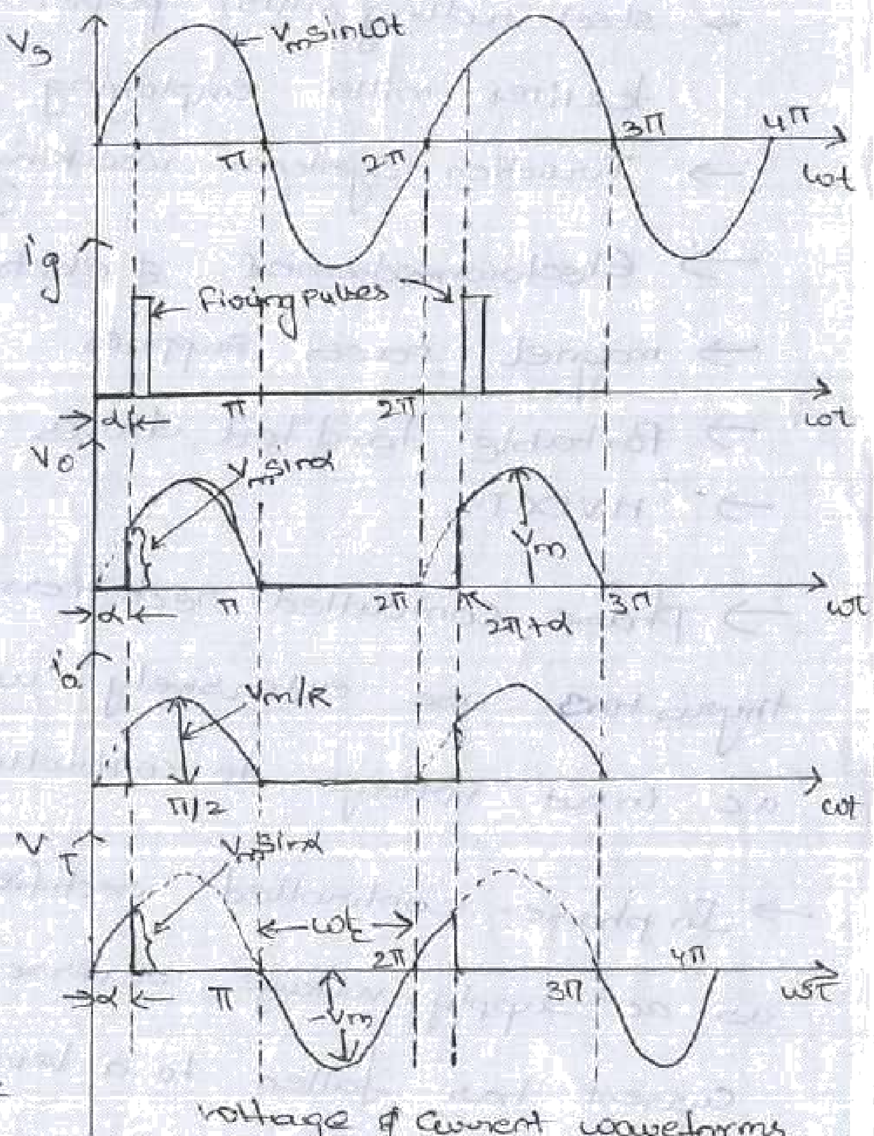
(iii) holding current is zero.

Trigger circuits are not shown in SCR circuit for convenience

Single phase halfwave controlled converter



circuit diagram



voltage & current waveforms

→ circuit consist of single thyristor feeding dc power to a resistive load R.

→ Source voltage $V_s = V_m \sin\omega t$

→ An SCR conduct only when anode voltage is positive and a gating signal is applied.

→ a thyristor blocks the flow of load current i_0 until it is triggered

→ At some delay angle α, a positive gate signal applied between gate and cathode turns on the SCR

→ Immediately, full supply voltage is applied to load as V_0

→ At the instant of delay angle α, V_0 rises from zero to $V_m \sin\alpha$.

→ For resistive load, current I_0 is in phase with V_0.

→ Firing angle of a thyristor is measured from the instant it would start conducting if it were replaced by a diode

→ A firing angle may thus be defined as the angle between the instant thyristor would conduct if it were a diode and the instant it is triggered

→ firing angle may be defined as the angle measured from the instant SCR gets forward biased to the instant it is triggered

→ once SCR is on, load current flows, until it is turned-off by reversal of voltage at $\omega t = \pi$, 3π etc.

→ At these angles of π, 3π, 5π etc. load current falls to zero and soon after the supply voltage reverses biases the SCR, the device is therefore turned off.

→ By varying the firing angle α, the phase relation-ship between the start of the load current and the supply voltage can be controlled. Hence the term 'phase control' is used for such a method of controlling the load currents.

→ A single phase half-wave circuit is one which produc only one pulse of load current during one cycle of source voltage.

→ Thyristor conducts from $\omega t = \alpha$ to π, $(2\pi + \alpha)$ to 3π, $(4\pi + \alpha)$ to 5π and so on.

→ over the firing angle delay α, load voltage $V_0 = 0$ but during conduction angle $(\pi - \alpha)$, $V_0 = V_s$

→ As firing angle is increased from zero to π, the average load voltage decreases from the largest value to zero.

→ During on intervals, $\omega t = \alpha$ to π, $(2\pi + \alpha)$ to 3π etc, $V_T = 0$ (1 to 1.5V)

→ During off intervals, $\omega t = \pi$ to $(2\pi + \alpha)$, 3π to $(4\pi + \alpha)$ etc; V_T has the waveshape of supply voltage V_s.

$V_s = V_0 + V_T$

The circuit turn off time $t_c = \frac{\pi}{\omega}$ sec; As SCR is reverse biased for π radians

where $\omega = 2\pi f$ & f is supply frequency in Hz.

→ The circuit turn-off time t_c must be more than SCR turn-off time t_q as specified by manufacturers.

Average voltage V_0

$$V_0 = \frac{1}{T}\int_0^T v(t)\,dt = \frac{1}{2\pi}\int_0^{2\pi} V_0\,d(\omega t)$$

$$\therefore V_0 = \frac{1}{2\pi}\int_0^{\alpha}(0)\,dt + \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t\, d(\omega t) + \frac{1}{2\pi}\int_{\pi}^{2\pi}(0)\,dt$$

$$= 0 + \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d\omega t + 0$$

$$= \frac{V_m}{2\pi}\int_{\alpha}^{\pi} \sin\omega t \, d\omega t$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi}$$

$$= \frac{V_m}{2\pi}\left[-\cos\pi - (-\cos\alpha)\right]$$

$$V_{o(avg)} = \frac{V_m}{2\pi}\left[1+\cos\alpha\right] \text{ ; Av.}$$

$$V_{o(rms)} = \sqrt{\frac{1}{T}\int_{0}^{T} V_0^2 \, d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \cdot d\omega t}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d\omega t}$$

$$= \frac{V_m}{2\sqrt{\pi}}\sqrt{\int_{\alpha}^{\pi}(1-\cos 2\omega t)\, d\omega t}$$

$$= \frac{V_m}{2\sqrt{\pi}}\sqrt{[(\pi-\alpha) - \left[\frac{\sin 2\omega t}{2}\right]_{\alpha}^{\pi}}$$

$$= \frac{V_m}{2\sqrt{\pi}}\sqrt{\pi - \alpha - \left[\frac{\sin 2\pi}{2} - \frac{\sin 2\alpha}{2}\right]}$$

$$V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}}\sqrt{\pi - \alpha + \frac{\sin 2\alpha}{2}}$$

Average load current, $I_o = \frac{V_o}{R} = \frac{V_m}{2\pi R}(1+\cos\alpha)$

RMS value of load current $I_{o(rms)} = \frac{V_{o\,rms}}{R} = \frac{V_m}{2R\sqrt{\pi}}\sqrt{\pi - \alpha + \frac{\sin 2\alpha}{2}}$

$$P_o = (V_{o(rms)})(I_{o(rms)}) = \frac{V_{o(rms)}^2}{R} = I_{o(rms)}^2 R$$

Input voltamperes = (rms source voltage) (total rms line current)

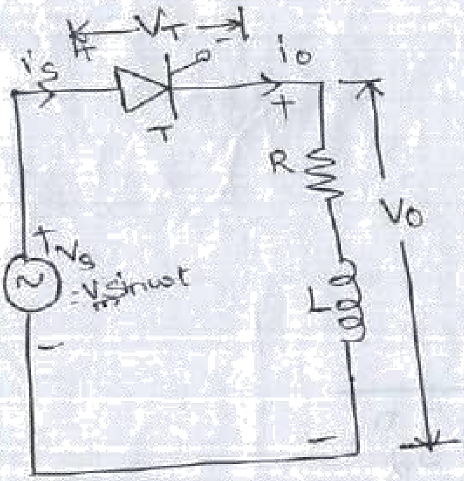
Input VA $= V_S I_{orms}$ $\quad V_{max} = \sqrt{2} V_{S_{rms}}$

$$= \frac{\sqrt{2} V_S^2}{2R\sqrt{\pi}} \left[(\pi - \alpha) + \frac{\sin 2\alpha}{2} \right]^{1/2}$$

Input powerfactor = ~~$\frac{1}{\sqrt{2}\pi}\left[(\pi-\alpha)+\right.$~~ $\dfrac{\text{Power delivered to load}}{\text{Input VA}}$

$$\text{Input pf} = \frac{V_{orms} I_{orms}}{V_S I_{orms}} = \frac{V_{orms}}{V_S} = \frac{1}{\sqrt{2\pi}} \left[(\pi-\alpha) + \frac{\sin 2\alpha}{2} \right]^{1/2}$$

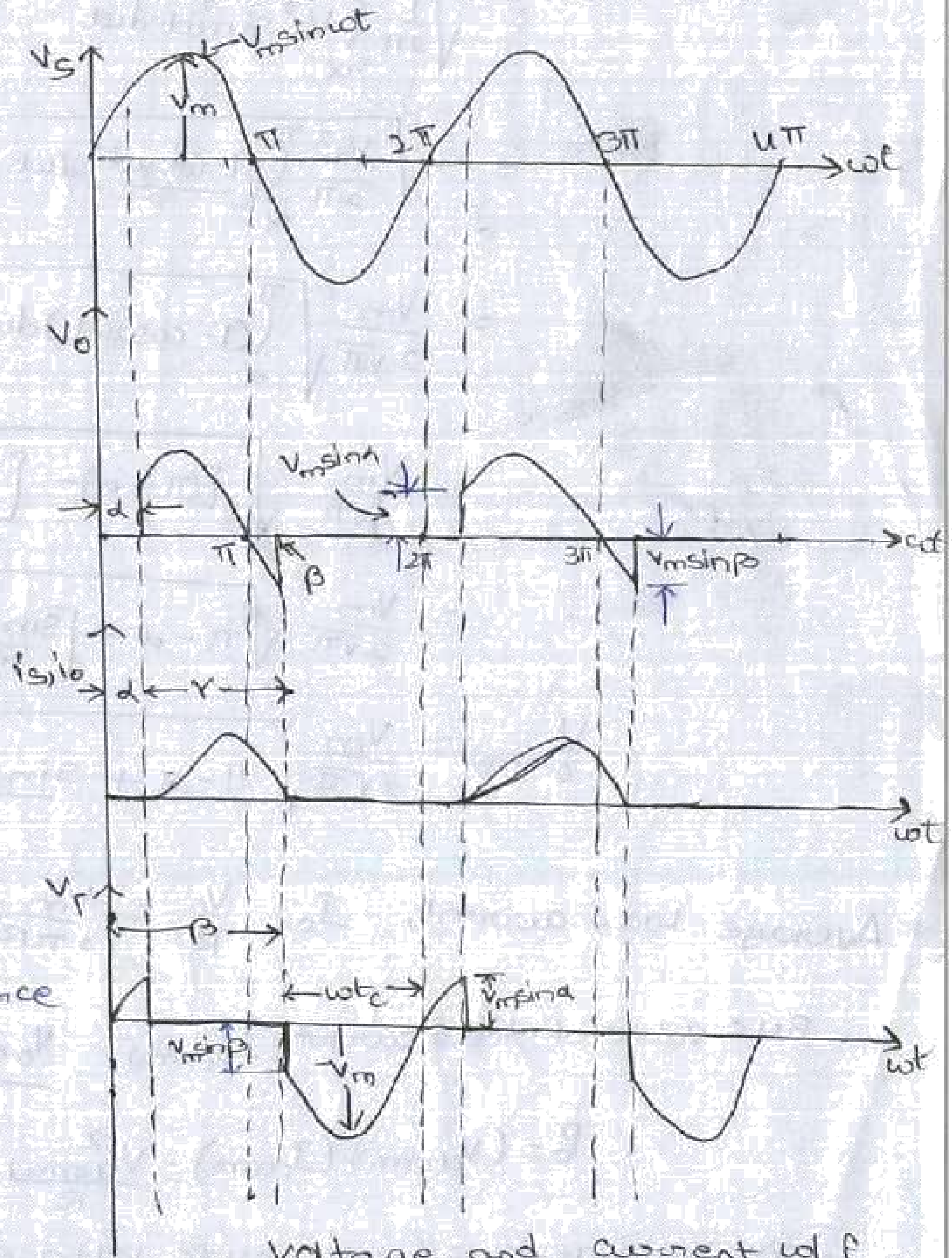
Single phase Half wave rectifier with RL Load.



Circuit diagram

→ At $\omega t = \alpha$, thyristor is turned on by gating signal

→ The load voltage V_0 at once becomes equal to source voltage V_S as shown



Voltage and current w/f

→ But the inductance L forces the load, or output current i_o to rise gradually

→ After some time i_o reaches maximum value and then begins to decrease.

→ At $\omega t = \pi$, V_o is zero but i_o is not zero because of the load inductance L.

→ After $\omega t = \pi$, SCR is subjected to reverse anode voltage but it will not be turned off as load current I_o is not less than its holding current.

→ At some angle $\beta > \pi$, i_o reduces to zero and SCR is turned off as its is already reverse biased.

→ After $\omega t = \beta$, $V_o = 0$ and $i_o = 0$.

→ At $\omega t = 2\pi + \alpha$ SCR is triggered again, V_o is applied to load current develops as before.

→ Angle 'β' is called extinction angle and $(\beta - \alpha) = \gamma$ is called conduction angle.

→ At $\omega t = \alpha$, $V_T = V_m \sin\alpha$, from $\omega t = \alpha$ to β, $V_T = 0$ and at $\omega t = \beta$, $V_T = V_m \sin\beta$.

As $\beta > \pi$, V_T is negative at $\omega t = \beta$.

Thus circuit turn-off time $t_c = \frac{2\pi - \beta}{\omega}$ sec.

$t_c > t_q$

Voltage equation for the circuit when T is on, is

$$V_m \sin\omega t = R i_o + L\frac{di_o}{dt}$$

The load current i_o consists of two components, one steady state component i_s and the other transient component i_t.

Here i_s is given by

$$i_s = \frac{V_m}{\sqrt{R^2+X^2}} \sin(\omega t - \phi)$$

$\phi = \tan^{-1}\left(\frac{X}{R}\right)$ & $X = \omega L$ — ϕ is angle by which rms current I_s lags V_s.

Transient component i_t can be obtained from force-free equation

$$R i_t + L\frac{di_t}{dt} = 0$$

$$i_t = A e^{-(R/L)t}$$

$$\therefore\ i_o = i_s + i_t = \frac{V_m}{Z}\sin(\omega t - \phi) + A e^{-(R/L)t} \longrightarrow (1)$$

Constant A can be obtained from the boundary condition at $\omega t = \alpha$.

At this time $t = \frac{\alpha}{\omega}$, $i_o = 0$.

Thus from eq (1),

$$0 = \frac{V_m}{Z}\sin(\alpha - \phi) + A e^{-R\alpha/L\omega}$$

$$A = \frac{-V_m}{Z}\sin(\alpha - \phi)\, e^{R\alpha/\omega L}$$

Substitution of A in eq (1) gives

$$i_o = \frac{V_m}{Z}\sin(\omega t - \phi) - \frac{V_m}{Z}\sin(\alpha - \phi)\exp\left[-\frac{R}{\omega L}(\omega t - \alpha)\right] \rightarrow (2)$$

for $\alpha < \omega t < \beta$

It is also seen from the waveform of i_0 that when $\omega t = \beta$, load current $i_0 = 0$ substituting this in eq ② gives

$$\sin(\beta - \phi) = \sin(\alpha - \phi) \exp\left[-\frac{R}{\omega L}(\beta - \alpha)\right]$$

This transcendental eqn can be solved to obtain the value of extinction angle β. In case β is known, average load voltage V_0 is given by

$$V_{0(avg)} = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\beta}$$

$$= \frac{V_m}{2\pi}\left[-\cos\beta - (-\cos\alpha)\right]$$

average load voltage $V_0 = \frac{V_m}{2\pi}[\cos\alpha - \cos\beta]$

average load current $I_0 = \frac{V_m}{2\pi R}[\cos\alpha - \cos\beta]$

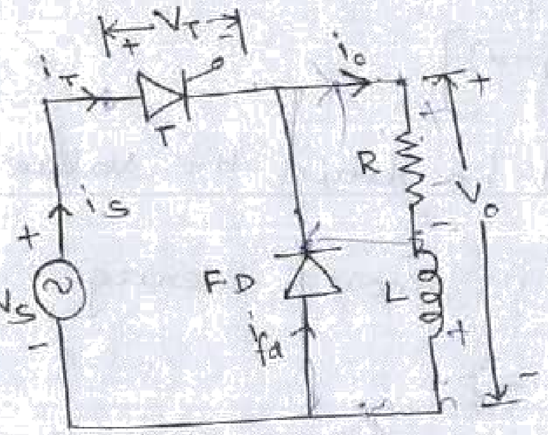
RMS load voltage $V_{0(rms)} = \left[\frac{1}{2\pi}\int_{\alpha}^{\beta} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$

$$= \frac{V_m}{2\sqrt{\pi}}\left[\int_{\alpha}^{\beta}(1 - \cos 2\omega t)\right]^{1/2}$$

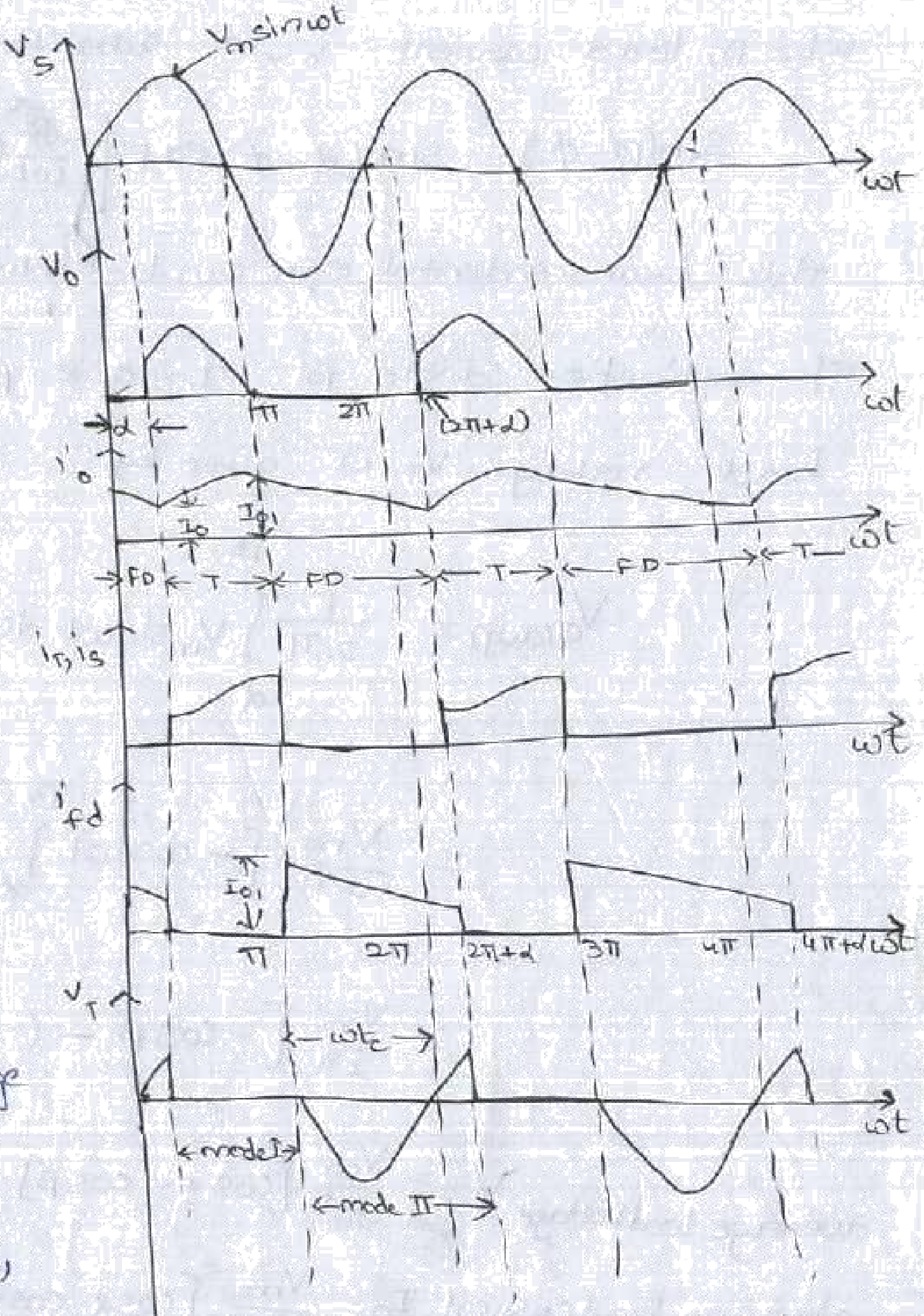
$$= \frac{V_m}{2\sqrt{\pi}}\sqrt{(\beta - \alpha) - \frac{1}{2}[\sin 2\beta - \sin 2\alpha]}$$

Rms load current can be found from eq ②.

Single phase Halfwave circuit with RL Load and Freewheeling Diode



Circuit Diagram



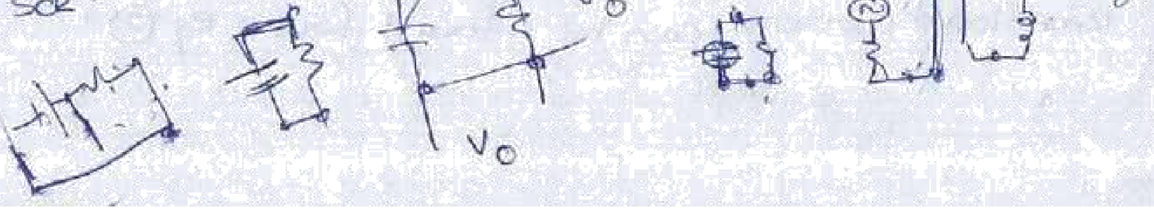
A free wheeling (or fly-wheeling) diode is also called by-pass or commutating diode.

→ At $\omega t = 0$, source voltage is becoming positive.

→ At some delay angle α, forward biased SCR is triggered and source voltage V_s appears across load as V_0

Voltage & current wave forms

→ At $\omega t = \pi$, source voltage V_s is zero and just after this instant, as V_s ~~appears across load~~ as ve tends to reverse, free wheeling diode FD is forward biased through the conducting SCR



→ As a result, load current i_o is immediately transferred from SCR to FD as V_s tends to reverse.

→ At the same time, SCR is subjected to reverse ~~bias~~ voltage and zero current, it is therefore turned off at $\omega t = \pi$.

→ It is assumed that during freewheeling(FW)period, load current does not decay to zero until the SCR is triggered again at $(2\pi + \alpha)$

→ Voltage drop across FD is taken as almost zero, the load voltage V_o is therefore, zero during the FW period

→ The circuit turn off time is $t_c = \frac{\pi}{\omega}$ sec

→ The ~~sc~~ source current i_s and thyristor current i_T have same wave form.

→ operation of circuit can be explained in two modes

Mode I : This mode also called conduction mode, SCR conducts from α to π, $2\pi + \alpha$ to 3π and so on & FD is reverse biased. Duration of this mode is for $\frac{\pi - \alpha}{\omega}$ sec.

→ Let the load current at the beginning of mode I be I_o

→ voltage equation is $V_m \sin\omega t = R i_o + L\frac{di_o}{dt}$

$$\Rightarrow i_o = \frac{V_m}{Z}\sin(\omega t - \phi) + Ae^{-\left(\frac{R}{L}\right)t}$$

At $\omega t = \alpha$, $i_o = I_o$, ie, at $t = \frac{\alpha}{\omega}$, $i_o = I_o$

$$\therefore A = \left[I_o - \frac{V_m}{Z}\sin(\alpha - \phi)\right]e^{R\alpha/\omega L}$$

$$i_o = \frac{V_m}{Z}\sin(\omega t - \phi) + \left[I_o - \frac{V_m}{Z}\sin(\alpha - \phi)\right]\exp\left[-\frac{R}{L}\left(t - \frac{\alpha}{\omega}\right)\right]$$

for mode I, $\alpha \le \omega t \le \pi$

Mode II: called freewheeling mode, extends from π to $2\pi+\alpha$, 3π to $4\pi+\alpha$ and so on.

In this mode, SCR is reverse biased from π to 2π, 3π to 4π ...

→ As the load current is assumed continuous, FD conducts from π to $(2\pi+\alpha)$, 3π to $(4\pi+\alpha)$ & so on

→ Let the current at the beginning of mode II be I_{01} as shown.

As load current is passing through FD, voltage equation for mode II is

$$0 = Ri_0 + L\frac{di_0}{dt}$$

its solution is $i_0 = Ae^{-\left(\frac{R}{L}\right)t}$

At $\omega t = \pi$, $i_0 = I_{01}$

$$\Rightarrow A = I_{01}e^{R\pi/\omega L}$$

$$\therefore i_0 = I_{01}\exp\left[-\frac{R}{L}\left(t-\frac{\pi}{\omega}\right)\right]$$

For mode II, $\pi < \omega t \le (2\pi+\alpha)$

Average load voltage $V_0 = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t)$

$$\therefore V_0 = \frac{V_m}{2\pi}(1+\cos\alpha)$$

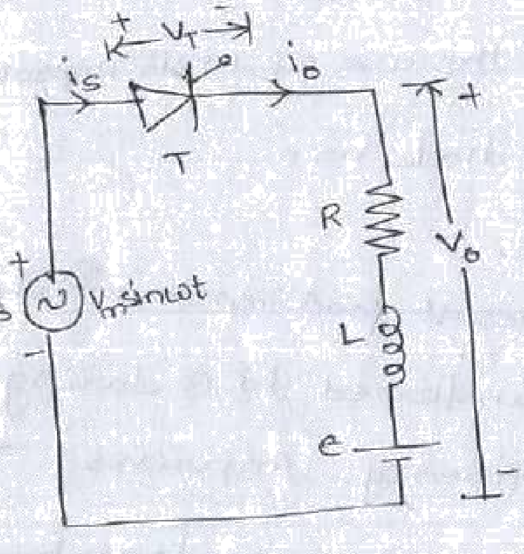
Average load current, $I_0 = \frac{V_0}{R} = \frac{V_m}{2\pi R}(1+\cos\alpha)$

→ Load current i_0 is contributed by SCR from α to π, $(2\pi+\alpha)$ to 3π ...
& " " " " " by FD from 0 to α, π to $(2\pi+\alpha)$ & so on

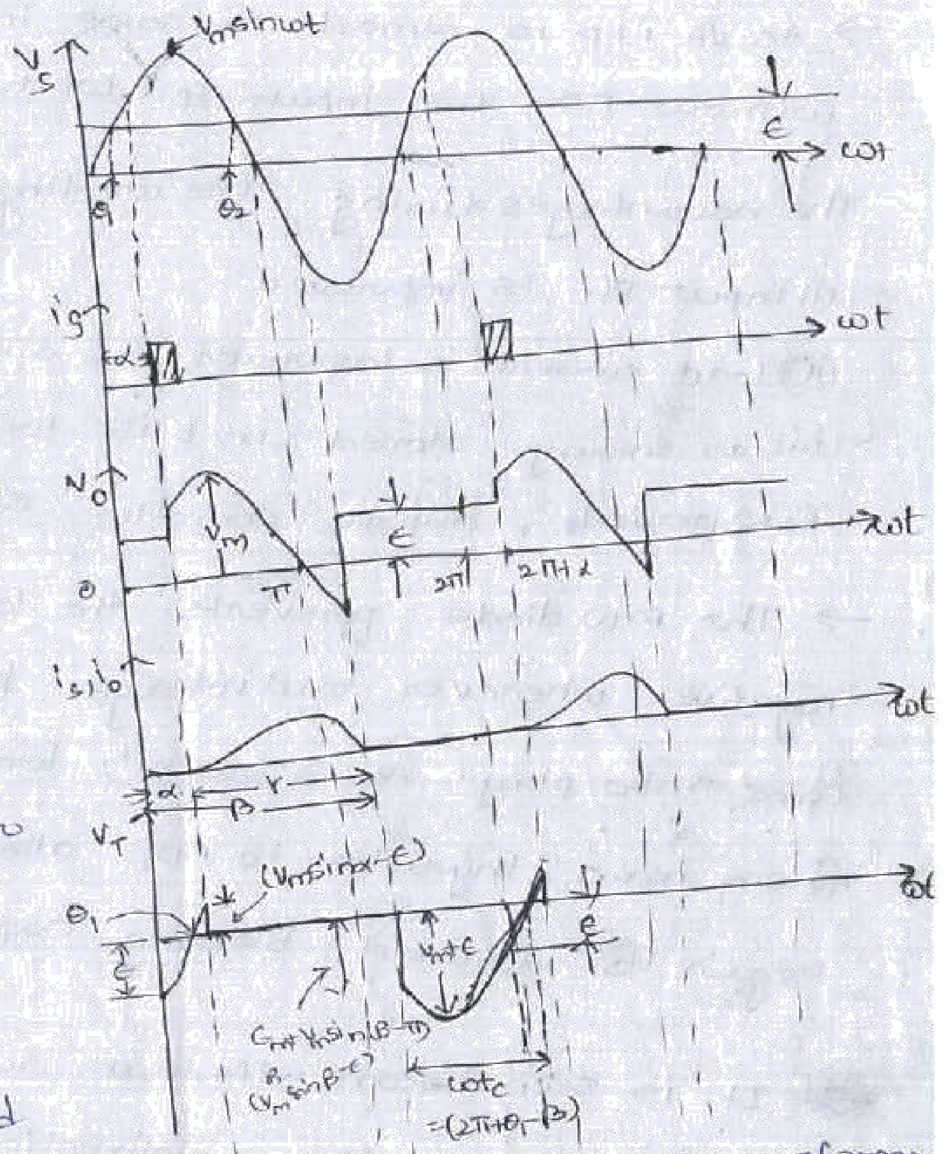
Thus wave shape of thyristor current i_T is identical with wave shape of i_0 for $\omega t = \alpha$ to π, $(2\pi+\alpha)$ to 3π & so on.

IIIly, wave shape of FD current i_{fd} is identical with w/f of i_0 for $\omega t = 0°$ to α, π to $(2\pi+\alpha)$ and so on.

Single phase Half wave circuit with RLE load:



circuit diagram



voltage and current waveforms

→ the counter emf E in the load may be due to battery or a dc motor

→ The minimum value of firing angle is obtained from the relation $V_m \sin\omega t = E$ at an angle θ_1, $\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$

→ In case Thyristor T is fired at an angle $\alpha < \theta_1$ then $E > V_S$, SCR is reverse biased and it will not turn on.

→ Similarly, maximum value of firing angle is $\theta_2 = \pi - \theta_1$

→ During the interval load current i_o is zero, load voltage $V_o = E$ and during the time i_o is not zero, V_o follows V_s curve

with SCR T on, KVL gives the voltage differential equation as $V_m \sin\omega t = Ri_o + L\frac{di_o}{dt} + E$

→ Power consumed by load is more when FD is connected.

→ As VA i/p is almost is same in both circuits with FD & without FD, the input pf with the use of FD is improved.

The advantages of using Free wheeling diode are

(i) input pf is improved.

(ii) load current is improved, as a result load impedance is better.

(iii) as energy stored in L is transferred to R during f.w periods, overall converter efficiency improves.

→ The F.W diode prevents the load voltage V_0 from becoming negative. whenever load voltage tends to go negative, FD come into play. As a result, load current is transferred from main thyristor to FD, allowing the thyristor to regain its forward blocking capability.

→ It is seen from w/fs, that supply current is taken from source is unidirection & is in form of dc pulses

→ single phase Halfwave rectifier thus introduces a dc component into the supply line. This is undesirable as it leads to saturation of supply Hf, Harmonics etc

The solution of the equation have steady state current component i_s and the transient current component i_t.

i_s is sum of i_{s1} (steady state current due to ac source voltage acting alone) and i_{s2} (due to dc counter emf E acting alone).

i_{s1} due to source voltage $V_m \sin\omega t$ is given by

$$i_{s1} = \frac{V_m}{Z}\sin(\omega t - \phi)$$

If only E were present,

$$i_{s2} = -\frac{E}{R}$$

transient current i_t is given by $i_t = Ae^{-\frac{R}{L}t}$

Total current i_0 is given by $i_0 = i_{s1} + i_{s2} + i_t = \frac{V_m}{Z}\sin(\omega t - \phi) - \frac{E}{R} + Ae^{-\frac{R}{L}t}$

At $\omega t = \alpha$, $i_0 = 0$ ie, at $t = \frac{\alpha}{\omega}$, $i_0 = 0 \Rightarrow A = \left[\frac{E}{R} - \frac{V_m \sin(\alpha - \phi)}{Z}\right] e^{\frac{R\alpha}{L\omega}}$

$$\therefore i_0 = \frac{V_m}{Z}\left[\sin(\omega t - \phi) - \sin(\alpha - \phi)\exp\left\{-\frac{R}{\omega L}(\omega t - \alpha)\right\}\right] - \frac{E}{R}\left[1 - \exp\left\{-\frac{R}{\omega L}(\omega t - \alpha)\right\}\right] \rightarrow ①$$

eq ① is applicable for $\alpha < \omega t < \beta$. The extinction angle β depends upon load emf E, firing angle α & load impedance angle ϕ $\quad \phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

Average voltage across inductor is zero.

$$\text{Average load current } I_0 = \frac{1}{2\pi R}\left[\int_{\alpha}^{\beta}(V_m \sin\omega t - E)\,d(\omega t)\right]$$

$$= \frac{1}{2\pi R}\left[V_m(\cos\alpha - \cos\beta) - E(\beta - \alpha)\right] \rightarrow ②$$

Here conduction angle $\gamma = \beta - \alpha$. Putting $\beta = \gamma + \alpha$ in eq ②

$$I_0 = \frac{1}{2\pi R}\left[V_m \{\cos\alpha - \cos(\gamma+\alpha)\} - E\cdot\gamma\right]$$

$$I_0 = \frac{1}{2\pi R}\left[2V_m \sin\left[\alpha+\frac{\gamma}{2}\right]\sin\left[\frac{\gamma}{2}\right] - E\cdot\gamma\right] \quad \left[\cos x - \cos y = 2\sin\frac{x+y}{2}\sin\frac{y-x}{2}\right]$$

Average load voltage $V_0 = E + I_0 R$

$$= E + \frac{1}{2\pi}\left[2V_m \sin\left[\alpha+\frac{\gamma}{2}\right]\sin\frac{\gamma}{2} - \gamma E\right]$$

$$\therefore V_0 = E\left[1-\frac{\gamma}{2\pi}\right] + \frac{V_m}{\pi}\sin\left(\alpha+\frac{\gamma}{2}\right)\sin\frac{\gamma}{2} \quad \text{— eq (3)}$$

Average voltage V_0 can also be obtained as

for periodicity 2π, extending from α to $2\pi+\alpha$

$$V_0 = \frac{1}{2\pi}\left[\int_\alpha^\beta V_m \sin\omega t \cdot d\omega t + E(2\pi+\alpha-\beta)\right]$$

$$= \frac{1}{2\pi}\left[V_m(\cos\alpha - \cos\beta) + E(2\pi+\alpha-\beta)\right]$$

$$V_0 = \frac{1}{2\pi}\left[\int_\alpha^\beta V_m \sin\omega t\, d\omega t + \int_\beta^{2\pi+\alpha} E\, d\omega t\right]$$

In case β is made equal to $(\gamma+\alpha)$ in above expression, eq (3) is obtained.

If load inductance L is zero, the extinction angle β would be equal to $\theta_2 = \pi - \theta_1$ i.e. now β would be less than π.

Average value of load current can still be obtained from eq (2) by substituting $\beta = \pi - \theta_1$

$\therefore$ average load current I_0, with $L=0$, is

$$I_0 = \frac{1}{2\pi R}\{V_m(\cos\alpha - \cos(\pi-\theta_1)) - E(\pi-\theta_1-\alpha)]$$

$$= \frac{1}{2\pi R}\left[V_m(\cos\alpha + \cos\theta_1) - E(\pi-(\theta_1+\alpha))\right]$$

RMS value of load current with $L=0$ is given by

$$I_{or}^2 = \frac{1}{2\pi}\int_\alpha^\beta \left(\frac{V_m \sin\omega t - E}{R}\right)^2 d(\omega t)$$

$$I_{or}^2 = \frac{1}{2\pi R^2}\int_{\alpha}^{\beta} (V_m^2 \sin^2\omega t + E^2 - 2V_m E \sin\omega t)\, d(\omega t)$$

$$I_{or} = \left[\frac{1}{2\pi R^2}\left\{(V_s^2 + E^2)(\beta-\alpha) - \frac{V_s^2}{2}(\sin 2\beta - 2\sin 2\alpha) - 2V_m E(\cos\alpha - \cos\beta)\right\}\right]^{1/2}$$

Power delivered to load, $P = I_{or}^2 R + I_o E$

Supply powerfactor $= \dfrac{I_{or}^2 R + I_o E}{V_s I_{or}}$

At $\omega t = 0$, $V_s = 0$ and therefore $V_T = -E$

At $\omega t = \theta$, $V_s = E$ $\therefore V_t = 0$

At $\omega t = \alpha$, $V_s = V_m \sin\alpha$ $\therefore V_t = V_m \sin\alpha - E$

During the conduction angle $\gamma = (\beta - \alpha)$, $V_T = 0$

At $\omega t = \beta$, V_s has reverse polarity

$\therefore$ Just after thyristor is turned off at $\omega t = \beta$, $V_T = -[V_m \sin(\beta - \pi) + E]$

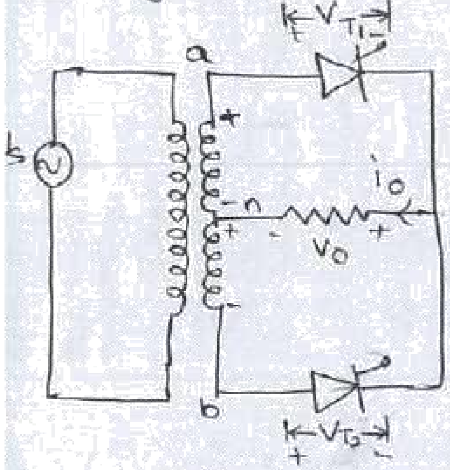
$V_T = V_m \sin\beta - E$ at $\omega t = \beta$, $\because V_m \sin\beta$ is $-$ve for $\beta > \pi$

The magnitude of maximum reverse voltage is $V_m + E$

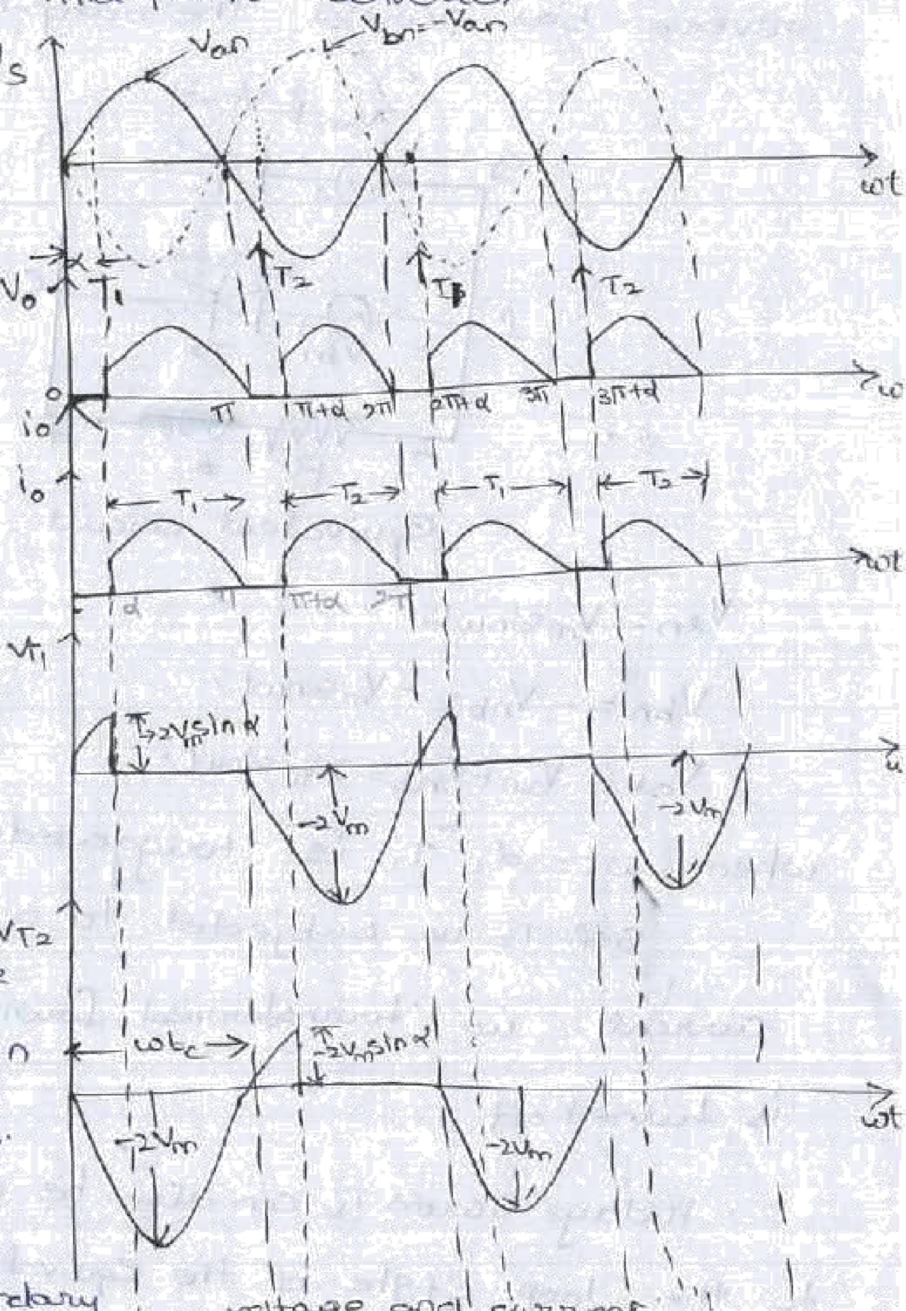
circuit turn-off time is $\dfrac{2\pi + \theta_1 - \beta}{\omega}$ sec

Single phase Full wave Converters:

→ Single phase fullwave mid-point converter



circuit diagram



voltage and current waveforms

→ The ckt diagram of a single phase fullwave converter using a centre-tapped T/f is shown

→ when terminal a is positive with respect to n, terminal n is positive with respect to b.

∴ $V_{an} = V_{nb}$ or $V_{an} = -V_{bn}$

as n is midpoint of secondary winding.

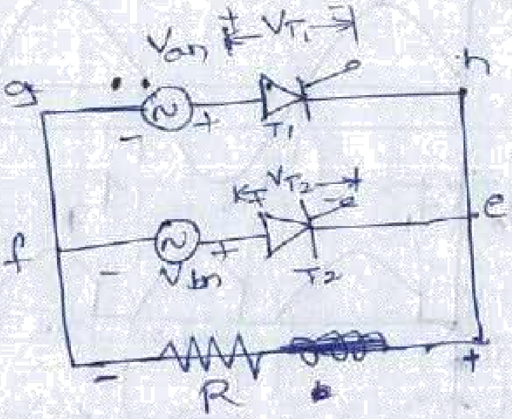
→ Thyristor T_1 is forward biased during positive half cycle and thyristor T_2 is forward " " negative " . these are therefore triggered accordingly.

→ At $\omega t = 0$, V_{an} is positive, T_1 is ∴ forward biased and triggered at delay angle α, T_1 gets turned on.

→ At this firing angle α, supply voltage $2V_m \sin\alpha$ reverse biases T_2, this SCR is ∴ turned off

Here T_1 is called incoming thyristor & T_2 is outgoing thyristor

→ As incoming SCR T_1 is triggered, ac supply voltage applies reverse bias across the outgoing thyristor and turns it off.



Equivalent circuit

$V_{an} = V_m \sin \omega t$

$V_{bn} = -V_{nb} = -V_m \sin \omega t$

$V_{ab} = V_{an} + V_{nb} = 2V_m \sin \omega t$

when $\omega t = \alpha$, T_1 is triggered.

SCR T_2 is subjected to a reverse voltage $V_{ab} = 2V_m \sin \alpha$

current is transferred from T_2 to T_1 and as a result T_2 is turned off.

. voltage across T_2 can also be obtained by applying KVL to the loop efghe of the equivalent circuit at the instant T_1 is triggered.

$V_{T2} - V_{bn} + V_{an} - V_{T1} = 0$

$\Rightarrow V_{T2} = V_{T1} - V_{an} + V_{bn}$

$\Rightarrow V_{T1} = 0$ when T_1 is conducting

$V_{T2} = 0 - V_m \sin \alpha + (-V_m \sin \alpha)$

$\Rightarrow V_{T2} = -2V_m \sin \alpha$

|||ly At $\omega t = \pi + \alpha$, T_2 is triggered, T_1 is reverse biased by voltage magnitude $2V_m \sin \alpha$

(1) T_1 conducts from α to $\pi+\alpha$

At $\omega t = \pi$, T_1 is reverse biased by voltage $2V_m \sin\alpha$.

At $\omega t = \pi+\alpha$, T_2 is triggered

At $\omega t = 0$ T_2 is turned off & it remains reverse biased

from $\omega t = 0$ to π

$\therefore$ For T_2, $t_c = \frac{\pi}{\omega}$ sec

III'ly for T_2, $t_c = \frac{2\pi - \pi}{\omega} = \frac{\pi}{\omega}$ sec

$$V_{o(avg)} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi}(-\cos\omega t)_{\alpha}^{\pi}$$

$$= \frac{V_m}{\pi}(-\cos\pi - \cos\alpha)$$

$$\therefore V_{o(avg)} = \frac{V_m}{\pi}(1+\cos\alpha)$$

$$I_{o(avg)} = \frac{V_{o(avg)}}{R} = \frac{V_m}{\pi R}(1+\cos\alpha]$$

$$V_{o(r.m.s)} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{V_m^2}{\pi}\int_{\alpha}^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)\right]^{1/2}$$

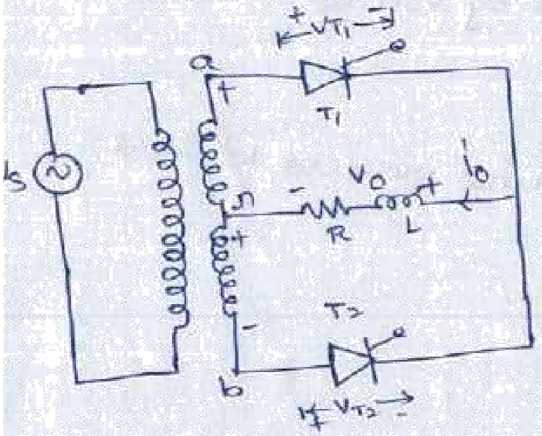
$$= V_m\left[\frac{1}{2\pi}\left[(\pi-\alpha) + \frac{\sin 2\alpha - \sin 2\pi}{2}\right]\right]^{1/2}$$

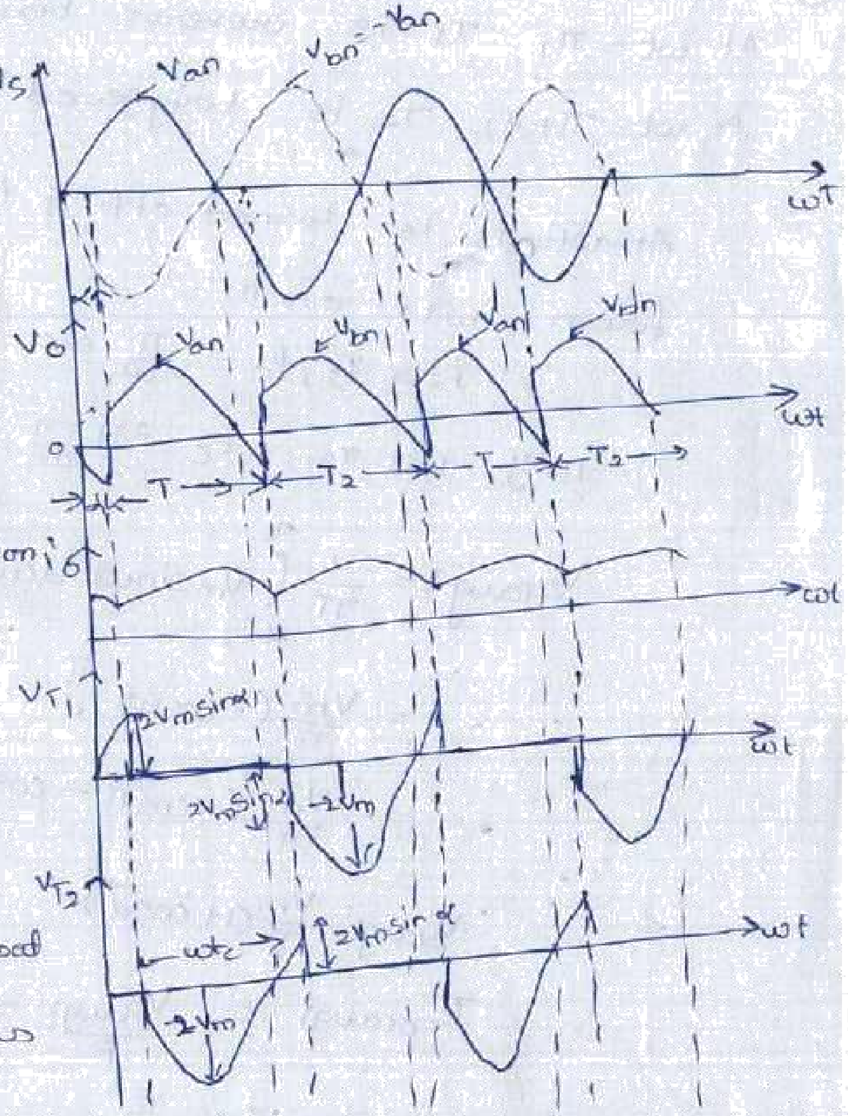
$$\therefore V_{o(rms)} = V_m\left[\frac{1}{2\pi}\left(\pi-\alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

→ SCR is subjected to a peak voltage of $2V_m$

→ $t_c > t_q$

Single phase full wave Mid point converter with RL load





→ At $\omega t = 0$, V_{an} is +ve.

T_1 → F.B & at α, It gets turned on & T_2 reverse biases by $2V_m \sin\alpha$ & turned off

→ After $\omega t = \alpha$, T_1 conducts from α to $\pi + \alpha$

→ At $\omega t = \pi$, T_1 reverse biased but will continue conducting as T_2 is not get gated.

→ At $\omega t = \pi + \alpha$, T_2 is triggered, T_1 is reverse biased voltage magnitude $2V_m \sin\alpha$, current is transferred from T_1 to T_2. T_1 is ∴ turned off

→ At $\omega t = \alpha$, T_2 is off, $t_c = \frac{\pi - \alpha}{\omega}$

→ At $\omega t = \pi + \alpha$ T_1 is off, $t_c = \frac{2\pi - (\pi + \alpha)}{\omega} = \frac{\pi - \alpha}{\omega}$

$$V_{o(avg)} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t) = \frac{V_m}{\pi}\left(-\cos\omega t\right)_{\alpha}^{\pi+\alpha}$$

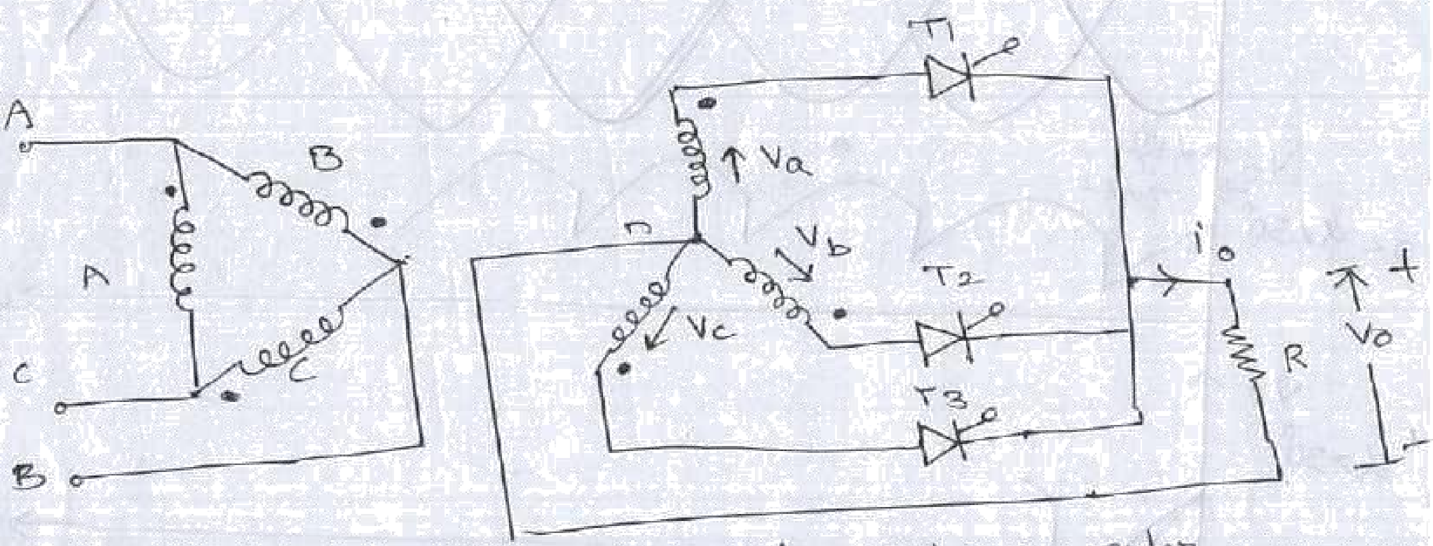
$$= \frac{V_m}{\pi}\left(-\cos(\pi + \alpha) + \cos\alpha\right)$$

$$\boxed{V_{o(avg)} = \frac{2V_m}{\pi}\cos\alpha}$$

Three phase Half wave controlled converter.

(or) 3-ϕ, 3-pulse converter or 3-phase M-3 converter.

→ Three phase M-3 converter with R Load:



3-ϕ half wave thyristor converter feeding R load.

→ If firing angle α is 0°, SCR T1 would begin conducting from ωt = 30° to 150°.

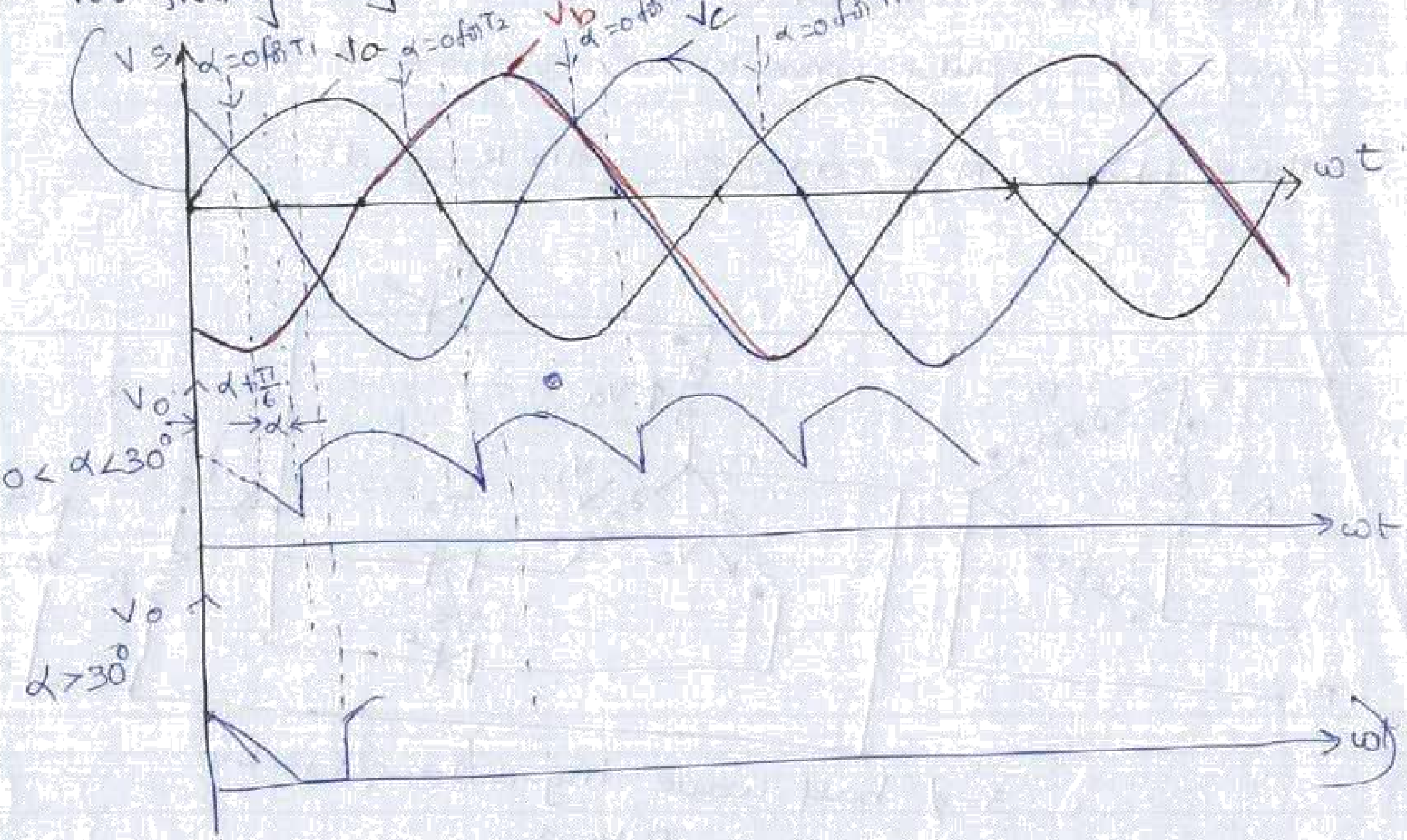
T_2 from ωt = 150° to 270°.

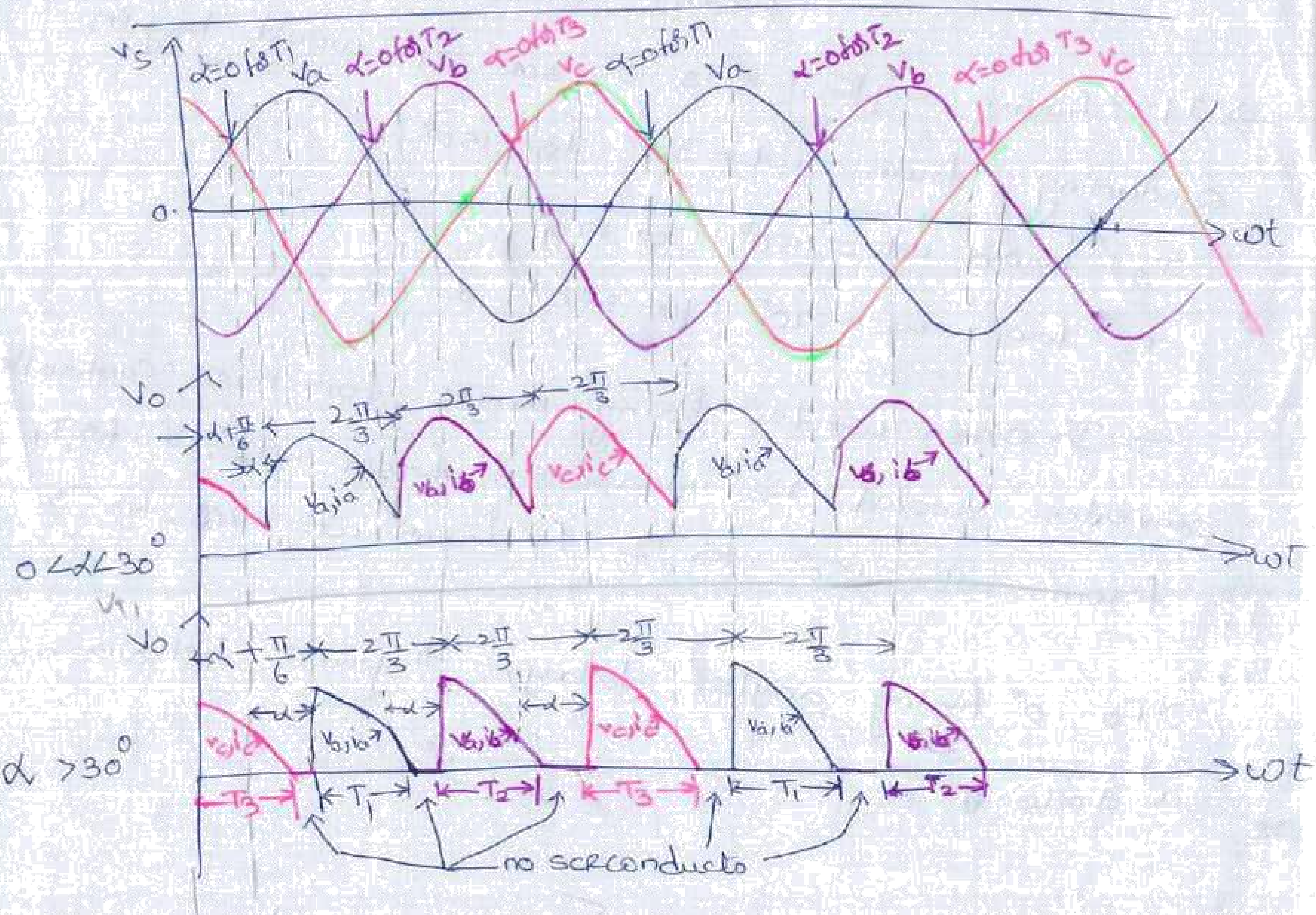
T_3 from ωt = 270° to 390° & so on.

→ In other words, firing angle for this controlled converter would be measured from ωt = 30° for T_1 from ωt = 150° for T_2 & from ωt = 270° for T_3.

→ For 0° firing angle delay, thyristor behaves as a diode.

For firing angle < 30°





Firing angle $< 30°$:-

The o/p voltage V_0 for $\alpha < 30°$ (i.e., around $15°$) is shown in fig where T_1 conducts from $\omega t = 30° + \alpha$ to $\omega t = 150° + \alpha$,

T_2 " " $\omega t = 150° + \alpha$ to $\omega t = 270° + \alpha$ & so on

T_3 " " $\omega t = 270° + \alpha$ to $\omega t = 390° + \alpha$.

Each SCR conducts for $120°$.

w/f of load current i_0 would be identical with voltage waveform is

$$V_0 = \frac{3}{2\pi}\int_{\alpha+\frac{\pi}{6}}^{\alpha+\frac{5\pi}{6}} V_{mp}\sin\omega t\, d(\omega t)$$

$V_{ml} = \sqrt{3}\, V_{mp}$

$$= \frac{3\sqrt{3}}{2\pi} V_{mp}\cos\alpha$$

$$= \frac{3V_{ml}}{2\pi}\cos\alpha$$

$V_{mp} \rightarrow$ max. value of phase (line to neutral) voltage

$V_{ml} \rightarrow$ " " line voltage $= \sqrt{3}\, V_{mp}$

$\alpha \rightarrow$ firing angle delay.

Average load current, $I_0 = \frac{V_0}{R} = \frac{3V_{ml}}{2\pi R}\cos\alpha$

RMS value of o/p or load voltage is

$$V_{orms} = \left[\frac{3}{2\pi}\int_{\alpha+\pi/6}^{\alpha+\frac{5\pi}{6}} V_{mp}^2 \sin^2\omega t\, d(\omega t)\right]^{1/2}$$

$$V_{orms}^2 = \frac{3V_{mp}^2}{4\pi}\left[(\omega t)_{\alpha+\frac{\pi}{6}}^{\alpha+\frac{5\pi}{6}} - \left[\frac{\sin 2\omega t}{2}\right]_{\alpha+\pi/6}^{\alpha+5\pi/6}\right]$$

$$= \frac{3V_{mp}^2}{4\pi}\left[\frac{2\pi}{3} + \frac{\sqrt{3}}{2}\cos 2\alpha\right]$$

$$V_{orms}\; V_{mp}\left[\frac{1}{2} + \frac{3\sqrt{3}}{8\pi}\cos 2\alpha\right]^{1/2}$$

$$= \sqrt{3}\, V_{mp}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\pi}\cos 2\alpha\right]^{1/2}$$

$$V_{orms} = V_{ml}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\pi}\cos 2\alpha\right]^{1/2}.$$

$$I_{or} = \frac{V_{orms}}{R} = \frac{V_{ml}}{R}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\pi}\cos 2\alpha\right]^{1/2}.$$

for firing angle > $30°$:

→ when firing angle is more than $30°$, T_1 would conduct from $30° + \alpha$ to $180°$, T_2 from $150° + \alpha$ to $300°$ & so on.

→ for R load, when phase voltage V_a reaches zero at $\omega t = 180°$, current $i_0 = 0$, T_1 is ∴ turned off.

Thus T_1 would conduct from $30° + \alpha$ to $180°$.

Each SCR, for firing value of > $30°$, conducts for $(150° - \alpha)$ only.

this also implies that for R load, maximum possible value of firing angle is $150°$.

$$\therefore V_0 = \frac{3}{2\pi} \int_{\alpha+\pi/6}^{\pi} V_{mp} \sin\omega t \, d(\omega t)$$

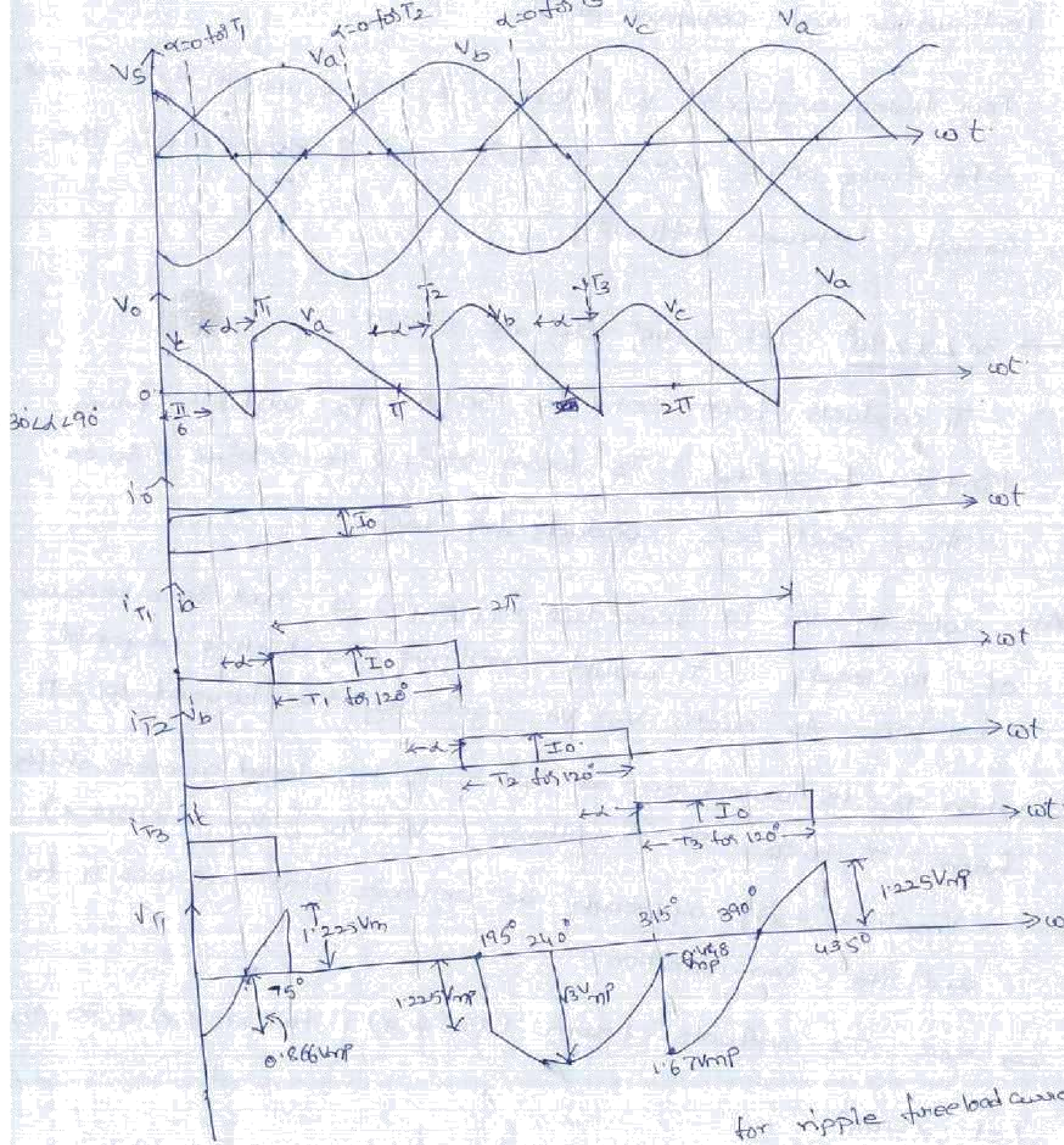
$$= \frac{3 V_{mp}}{2\pi} \left[1 + \cos(\alpha + 30°)\right]$$

$$\therefore V_{o\,rms} = \left[\frac{3}{2\pi} \int_{\alpha+\pi/6}^{\pi} V_{mp}^2 \sin^2\omega t \cdot d(\omega t)\right]^{1/2}$$

$$V_{o\,rms} = \frac{\sqrt{3} \cdot V_{mp}}{2\sqrt{\pi}} \left[\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2}\sin(2\alpha + \pi/3)\right]^{1/2}$$

$$= \frac{V_{ml}}{2\sqrt{\pi}} \left[\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2}\sin(2\alpha + \pi/3)\right]^{1/2}$$

3 - ϕ M-3 Converter with RL load:-



for ripple free load current

→ The load inductance L is large so that load current is continuous and constant as I_0.

For firing angle $< 30°$, V_0 & V_{orms} is same as for R-load $< 30°$.

→ for firing angle range of $30° < \alpha < 90°$ & $90° < \alpha < 180°$, the converter behaves differently.

→ <u>$30° < \alpha < 90°$:</u> let $\alpha = 45°$, w/f are shown.

T_1 conducts from $30 + \alpha$ to $150 + \alpha$, T_2 conducts from $150 + \alpha$ to $270° + \alpha$, T_3 from $270° + \alpha$ to $390° + \alpha$ & so on.

Thus each SCR conducts for $120°$.

At $\omega t = \pi$, V_a is zero but i_{T_1} (or i_a) is not zero because of RL load. ∴ T_1 would continue conducting beyond $\omega t = \pi$. As such, $V_0 = V_a$ goes negative beyond $\omega t = \pi$.

→ when T_2 is turned on at $\omega t = 150° + \alpha$, load current shifts from T_1 to T_2 & a voltage $V_a - V_b$ [$= V_m \sin(150 + \alpha)$ to $-V_m \sin(30° + \alpha)$] appears as reverse bias across T_1 to aid its commutation.

→ SCR T_2 conducts from $(150° + \alpha)$ to $(270° + \alpha)$ & so on.

Let $\alpha = 45°$.

when T_1 is on, $V_{T_1} = V_a - V_a = 0$ from $\omega t = 75°$ to $195°$

when T_2 is on, $V_{T_1} = V_a - V_b$ from $\omega t = 195°$ to $315°$ and

when T_3 is on, $V_{T_1} = V_a - V_c$ from $\omega t = 315°$ to $435°$ & so on.

when T_2 is turned on at $\omega t = 195^\circ$,

$V_{T_1} = V_a - V_b = -V_{mp}\sin(15^\circ) - V_{mp}\sin 75^\circ = -1.225 V_{mp}$;

at $\omega t = 210^\circ$; $V_{T_1} = -1.5\ V_{mp}$.

$\omega t = 240^\circ$, $V_{T_1} = \sqrt{3} V_{mp}$

$\omega t = 270^\circ$, $V_{T_1} = -1.5 V_{mp}$

$\omega t = 300^\circ$, $V_{T_1} = -V_{mp}\sin 60 - 0 = -0.866 V_{mp}$

$\omega t = 315^\circ$, $V_{T_1} = -V_{mp}\sin 45^\circ + V_{mp}\sin 15^\circ = -0.448 V_{mp}$

$V_{T_1} = V_a - V_b$ At $\omega t = 315^\circ$, T_2 gets turned-off whereas T_3 is turned on

$\therefore V_{T_1} = V_a - V_c = -V_{mp}\sin 45^\circ + V_{mp}\sin 75^\circ = -1.673 V_{mp}$

so at $\omega t = 315^\circ$, V_{T_1} changes from $-0.448 V_{mp}$ to $-1.673 V_{mp}$

At $\omega t = 330^\circ$, $V_{T_1} = -V_{mp}\sin 30^\circ - V_{mp} = 1.5 V_{mp}$

At $\omega t = 360^\circ$, $V_{T_1} = 0 - 0.866 V_{mp} = -0.866 V_{mp}$

At $\omega t = 390^\circ$, $V_{T_1} = 0.5 V_{mp} - 0.5 V_{mp} = 0$

At $\omega t = 420^\circ$, $V_{T_1} = 0.866 V_{mp} - 0 = 0.866 V_{mp}$

At $\omega t = 435^\circ$, $V_{T_1} = V_{mp}\sin 75^\circ + V_{mp}\sin 15^\circ = 1.225 V_{mp}$

& $V_{T_1} = V_a - V_a = 0$ & so on

$$V_0 = \frac{3V_{mp}}{2\pi}\cos\alpha$$

$$V_{0rms} = V_{mp}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\pi}\cos 2\alpha\right]^{1/2}$$

<u>$90^\circ < \alpha < 180^\circ$:</u> Let $\alpha = 165^\circ$

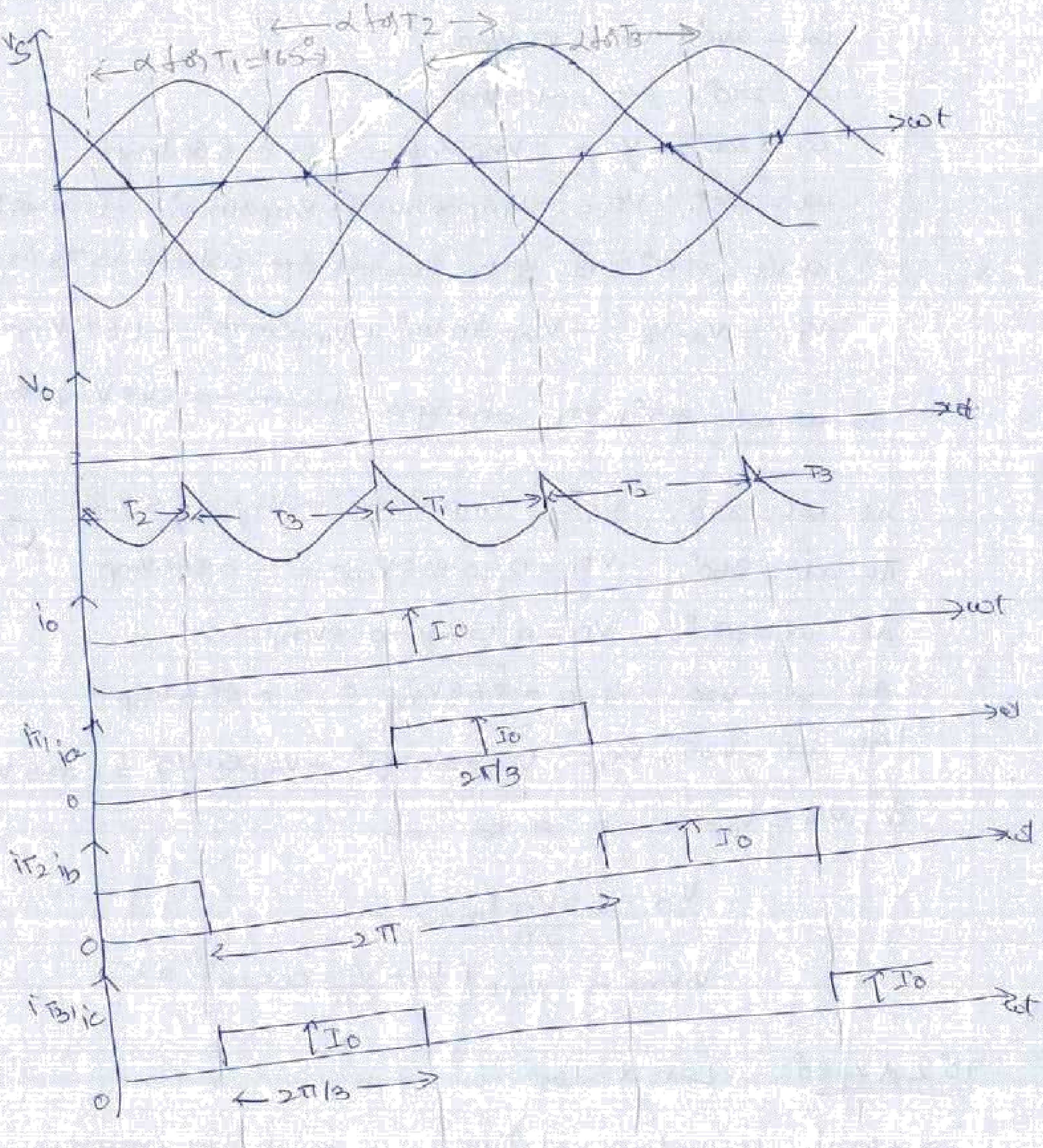
→ o/p V_0 is below ref line, V_0 must be negative.

→ ∴ $V_0 = \left(\frac{3V_{mp}}{2\pi}\right)\cos\alpha$ when α is more than 90°, V_0 is -ve.

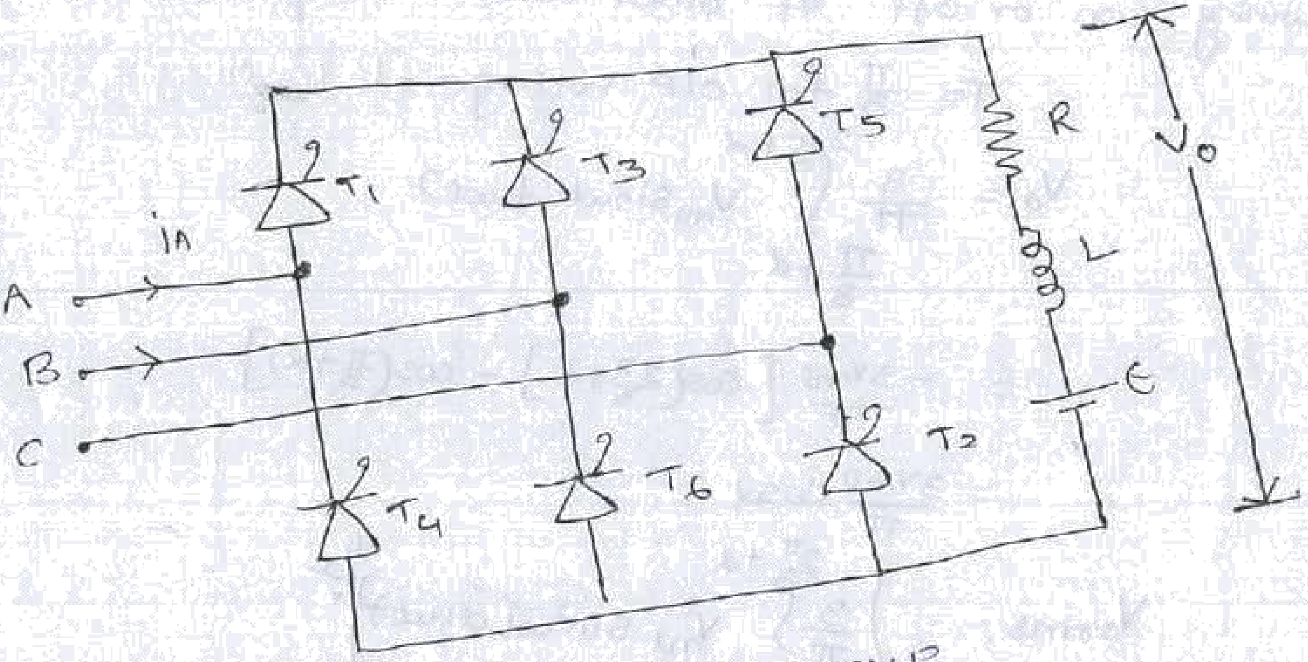
for $\alpha > 90^\circ$, 3-ϕ 3 pulse converter operates as a line-commutated inverter which is possible only if load ckt has dc voltage source of reverse polarity.

I_{TA} = avg value of source current, $I_{sn} = \frac{I_0 \times 120}{360} = \frac{I_0}{3}$

rms value, $I_{Tr} = I_{sr} = \left[\frac{I_0^2 \times 120}{360}\right]^{1/2} = \frac{I_0}{\sqrt{3}}$



Three phase full converter with RLE.



→ SCRS 1, 3, 5 form positive group
" " 4, 6, 2 form negative group

→ For $\alpha = 0°$, $T_1, T_2 \ldots T_6$ behaves like diodes

If $\alpha = 0°$, T_1 is triggered at $\omega t = 30°$, T_2 at $150°$,
T_3 at $300°$ ...

→ For $\alpha = 60°$, T_1 is turned at $60° + 60° = 120°$.
T_2 is turned at $60° + 120° = 180°$
T_3 at $60 + 240° = 300°$
T_4 at $60 + 360 = 420°$ & so on . .

Each SCR conducts for $120°$.

→ When T_1 is turned on at $\omega t = 120°$, T_5 is turned off,
T_6 is already conducting

→ As T_1 & T_6 are connected to A and B resp, load voltage must be V_{ab}

→ When T_2 is turned on, T_6 will be turned off & T_1 is already conducting
as T_1 & T_2 are connected to A & C resp, load voltage must be V_{AC}

→ In this manner, load voltage o/p can be drawn with turning on or off of other SCRS in sequence.

$T = \frac{\pi}{3}$ for o/p voltage (for 60°, o/p cycle is repeating)

$$\therefore V_0 = \frac{3}{\pi}\int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} V_{ml}\sin\omega t \, d(\omega t)$$

$$= -\frac{3V_{ml}}{\pi}\left[\cos\left(\frac{2\pi}{3}+\alpha\right) - \cos\left(\frac{\pi}{3}+\alpha\right)\right]$$

$$= \frac{3V_{ml}}{\pi}\cos\alpha$$

$$V_{0rms} = \left[\frac{3}{\pi}\int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} V_{ml}^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$V_{0rms} = V_{ml}\sqrt{\frac{3}{2\pi}}\left[\frac{\pi}{3}+\frac{\sqrt{3}}{2}\cos 2\alpha\right]^{1/2}$$

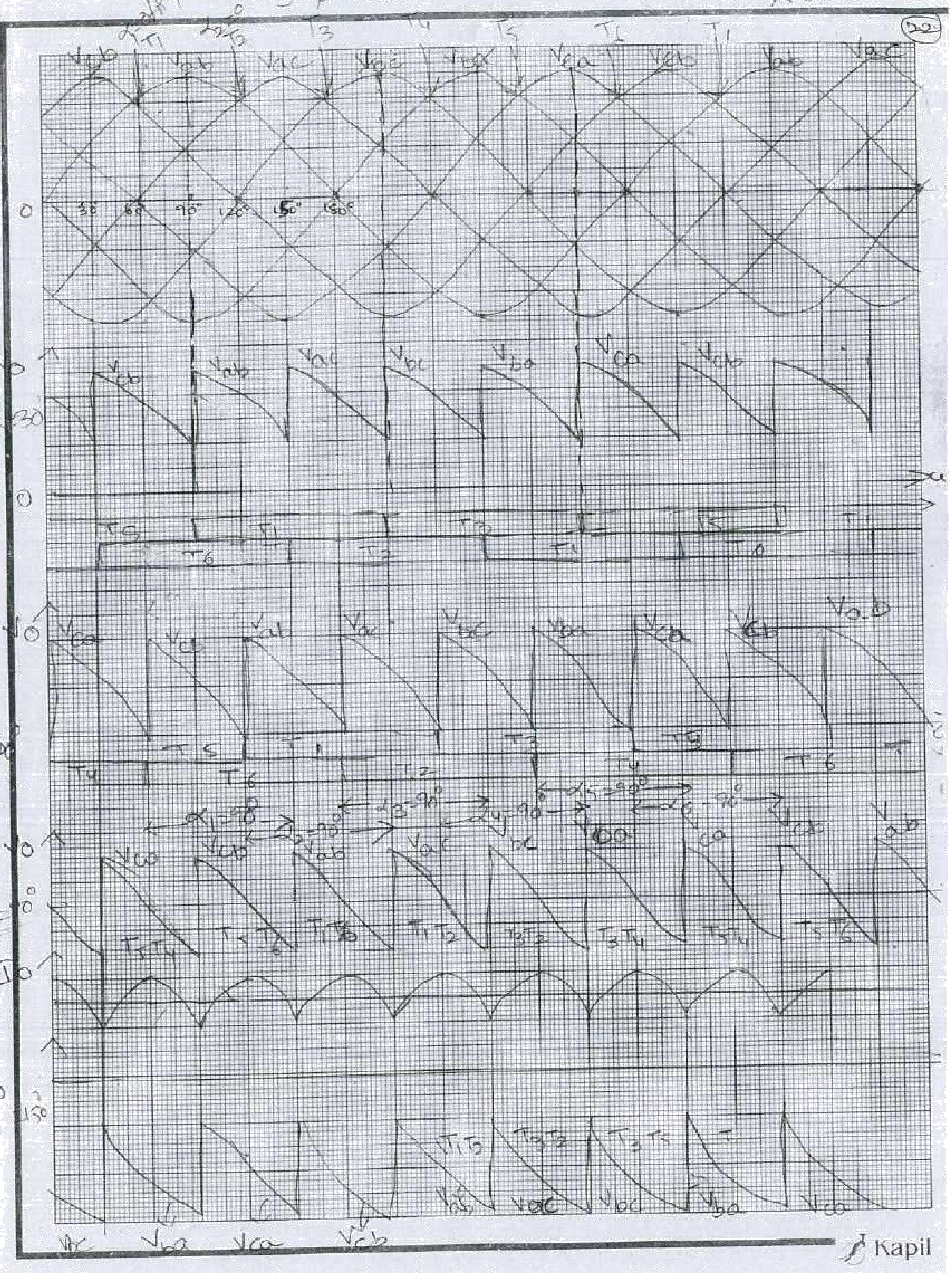
Source current for phase A, i.e., i_A flows for 120° for every 180°.
$\because$ o/p current is assumed constant,
$\therefore$ I_{rms} for source current $I_S = \sqrt{I_0^2 \times \frac{2\pi}{3} \times \frac{1}{\pi}} = I_0\sqrt{\frac{2}{3}}$

Each SCR conduct for 120°
and for upper to lower the difference will be 180°.

i.e., If T_1 is on at α
T_3 is at $\alpha + 120°$
T_5 " " $\alpha + 240°$
T_4 is at $\alpha + 180°$
IIIly
T_6 is at $\alpha + 120° + 180° = \alpha + 300°$
T_2 is at $\alpha + 240° + 180° = \alpha + 420$

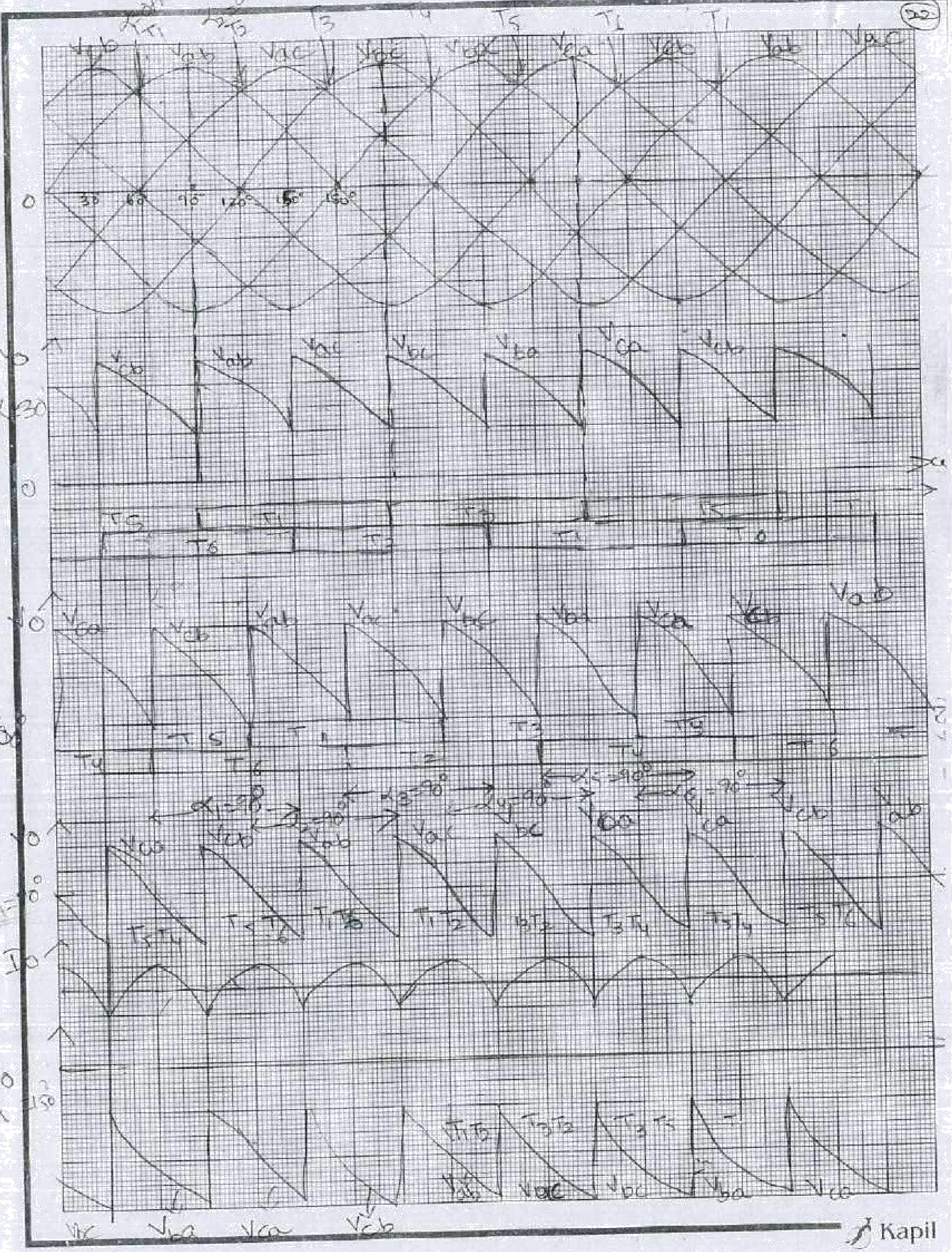
i.e., if $\alpha = 30°$, $T_1 \to 30°$ $T_4 \to 210°$
$T_3 \to 150°$ $T_6 \to 330°$
$T_5 \to 270°$ $T_2 \to 450°$ or $(360° + 90°)$
(or 90°)

3-Φ Full W-R with RLE Load X-axis→1unit=



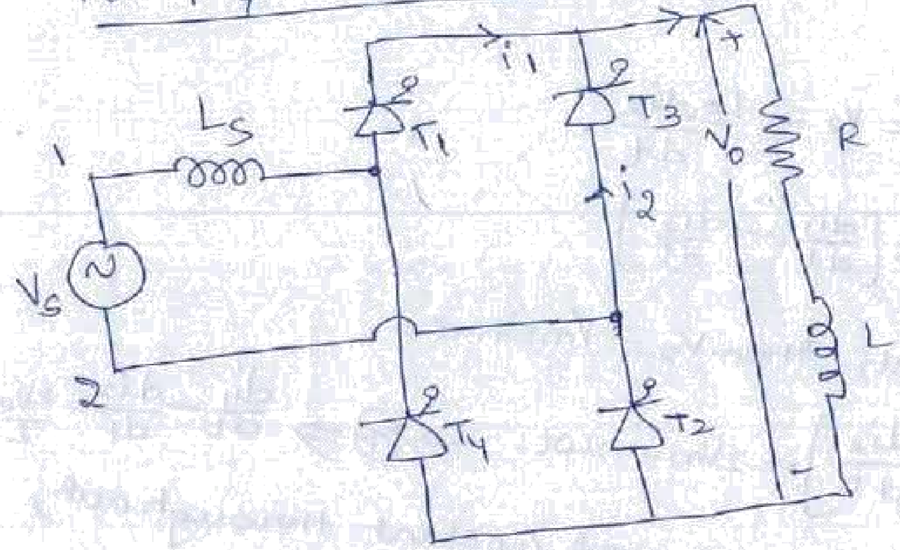
Kapil

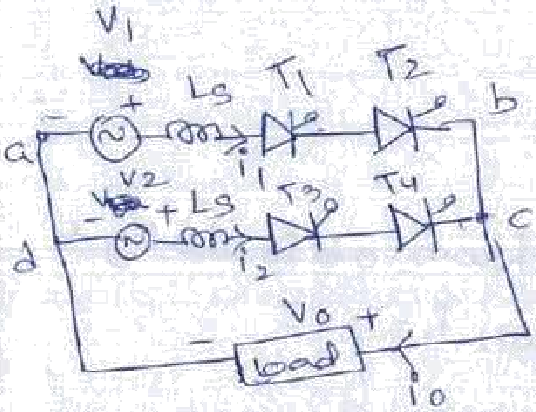
3-φ Full W.R with RLE Load X-axis→1unit=

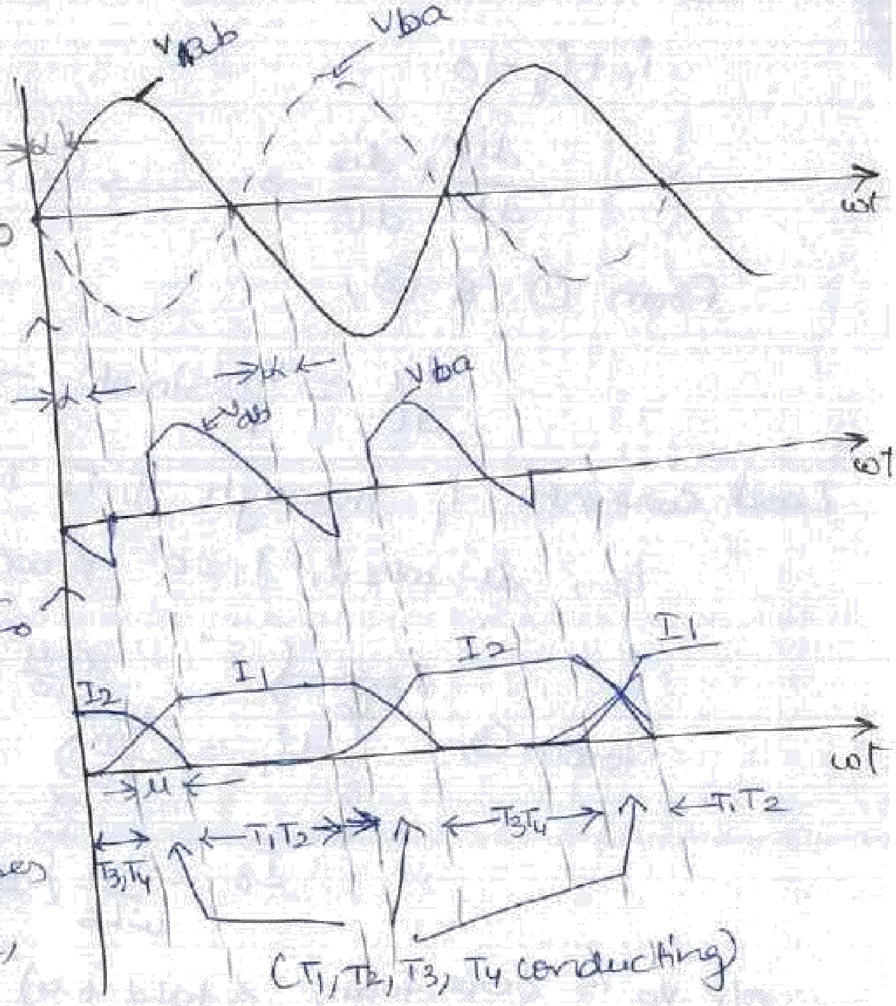


Effect of Source Impedance

For 1-φ Full converter







when T_1 & T_2 are triggered, T_3 & T_4 already conducting

~~KVL for loop abcd~~

due to presence of L_S, i_2 decreases gradually to zero, where for $T_1 T_2$, current builds up gradually from zero to full value of load current I_0

$\mu \rightarrow$ overlap angle.

During the overlap angle μ,

~~Three phase full converters with RLE~~

KVL for loop abcda gives

$$V_1 - L_s\frac{di_1}{dt} = V_2 - L_s\frac{di_2}{dt}$$

$$\therefore V_1 - V_2 = L_s\left[\frac{di_1}{dt} - \frac{di_2}{dt}\right]$$

if $V_1 = V_m \sin\omega t$, then $V_2 = -V_m \sin\omega t$

$$\therefore L_s\left[\frac{di_1}{dt} - \frac{di_2}{dt}\right] = 2V_m \sin\omega t \longrightarrow (1) \Rightarrow \frac{di_1}{dt} - \frac{di_2}{dt} = \frac{2V_m \sin(\omega t)}{L}$$

As load current is assumed constant throughout,

$$i_1 + i_2 = 0.$$

$$\frac{di_1}{dt} + \frac{di_2}{dt} = 0 \longrightarrow (2)$$

from (1) & (2),

$$\frac{di_1}{dt} = \frac{V_m}{L}\sin\omega t \longrightarrow (3)$$

Load current i_1 through $T_1 T_2$ builds from 0 to I_0 during μ

i.e., at $\omega t = \alpha$, $i_1 = 0$ & $\omega t = (\alpha + \mu)$, $i_1 = I_0$

$$\therefore \text{from (3)}, \int_0^{I_0} di_1 = \frac{V_m}{L_s}\int_{\alpha/\omega}^{\frac{\alpha+\mu}{\omega}} \sin\omega t\, dt$$

$$\therefore I_0 = \frac{V_m}{\omega L_s}\left[\cos\alpha - \cos(\alpha+\mu)\right]$$

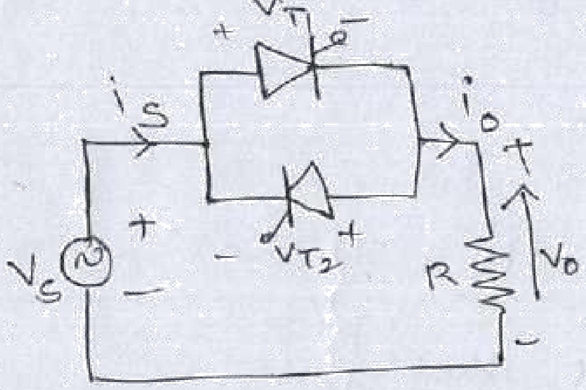
o/p V_0 is zero from α to $(\alpha + \mu)$

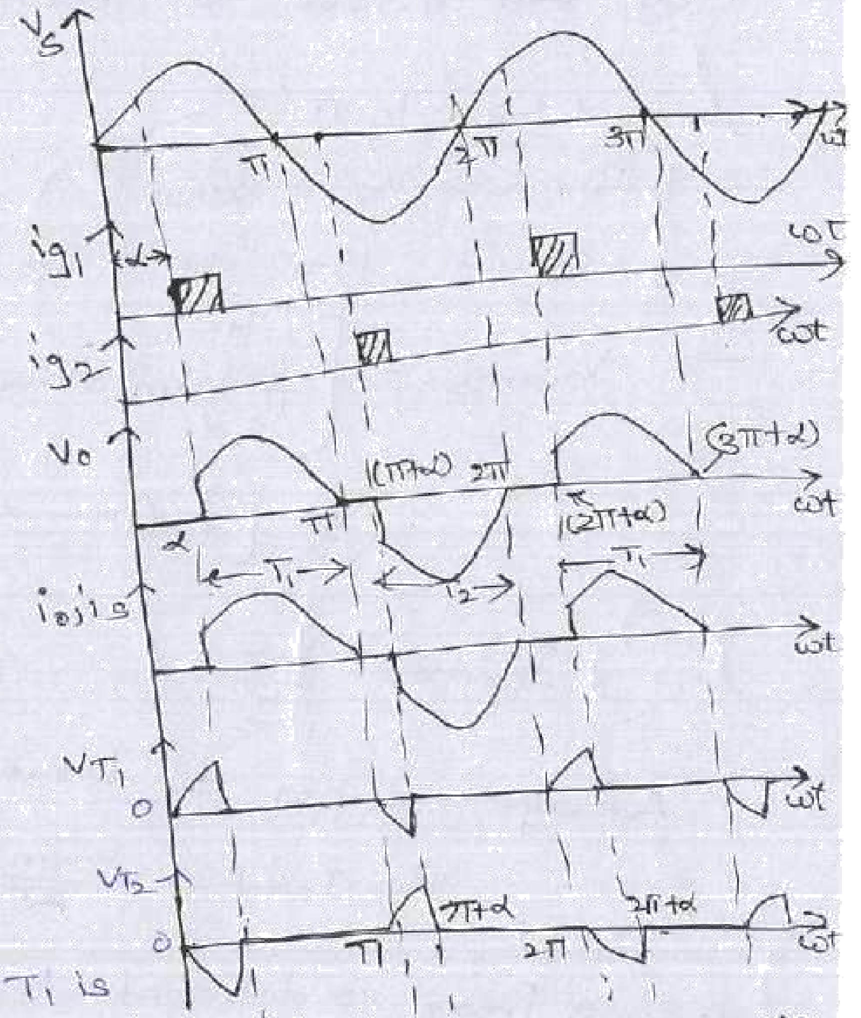
$$\therefore V_{0x} = \frac{V_m}{\pi}\int_{\alpha+\mu}^{\alpha+\pi} \sin\omega t\, d\omega t = \frac{V_m}{\pi}\left[\cos\alpha + \cos(\alpha+\mu)\right]$$

UNIT-II

1-ϕ AC voltage controllers:

Single phase AC voltage controller with R-load:-





voltage & current waveform

→ Two thyristors connected in antiparallel.

→ T_1 → forward biased during positive half cycle

→ T_2 → F.B during negative half cycle

→ During positive half cycle, T_1 is triggered at a firing angle α

→ T_1 starts conducting and source voltage is supplied to load from α to π.

→ At π, both V_o, i_o fall to zero. Just after π, T_1 is subjected to reverse bias, it is turned off.

→ During negative half cycle, T_2 is triggered at negative cycle, T_2 conducts from π+α to 2π

→ Soon after 2π, T_2 is subjected to reverse bias it is therefore commutated.

→ Load & Source has same waveforms.

→ From 0 to α, T_1 is forward blocking mode, $V_{T_1} = V_s$.

→ & $V_{T1} = V_s$ from π to $\pi+\alpha$ because T_1 is reverse bias

→ from $\pi+\alpha$ to 2π, T_2 conducts, T_1 is reverse biased by VD across T_2 which is about 1 to 1.5V (here zero)

→ α → 0 to π.

& V_{rms} → V_s to zero

circuit turn-off time $t_c = \frac{\pi}{\omega}$ sec.

→ $$V_{orms} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \; d(\omega t)\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2}}\left[\frac{1}{\pi}(\pi-\alpha) + \frac{1}{2}\sin 2\alpha\right]^{1/2}$$

$$I_{orms} = \frac{V_{or}}{R}$$

Average power P delivered to load resistance R is

$$P = I_{orms}^2 R = \frac{V_{orms}^2}{R} = \frac{V_m^2}{2\pi R}\left[(\pi-\alpha) + \frac{1}{2}\sin 2\alpha\right].$$

Max. power P_{max} is delivered to load when $\alpha = 0$.

$$P_{max} = \frac{V_s^2}{R}.$$

$$\text{Power factor} = \frac{\text{Real power}}{\text{Apparent power}} = \frac{V_s I_1 \cos\phi_1}{V_s \cdot I_{rms}} = \frac{I_1 \cos\phi_1}{I_{rms}}$$

$I_1 = \frac{I_m}{\sqrt{2}}$ = rms value of fundamental component of load or source current

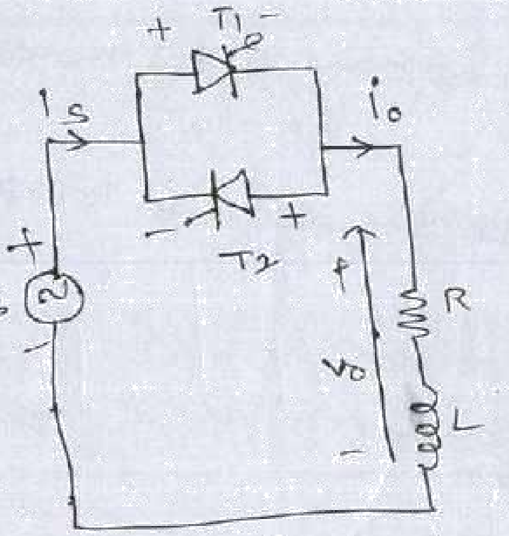
I_{orms} = rms value of load or source current

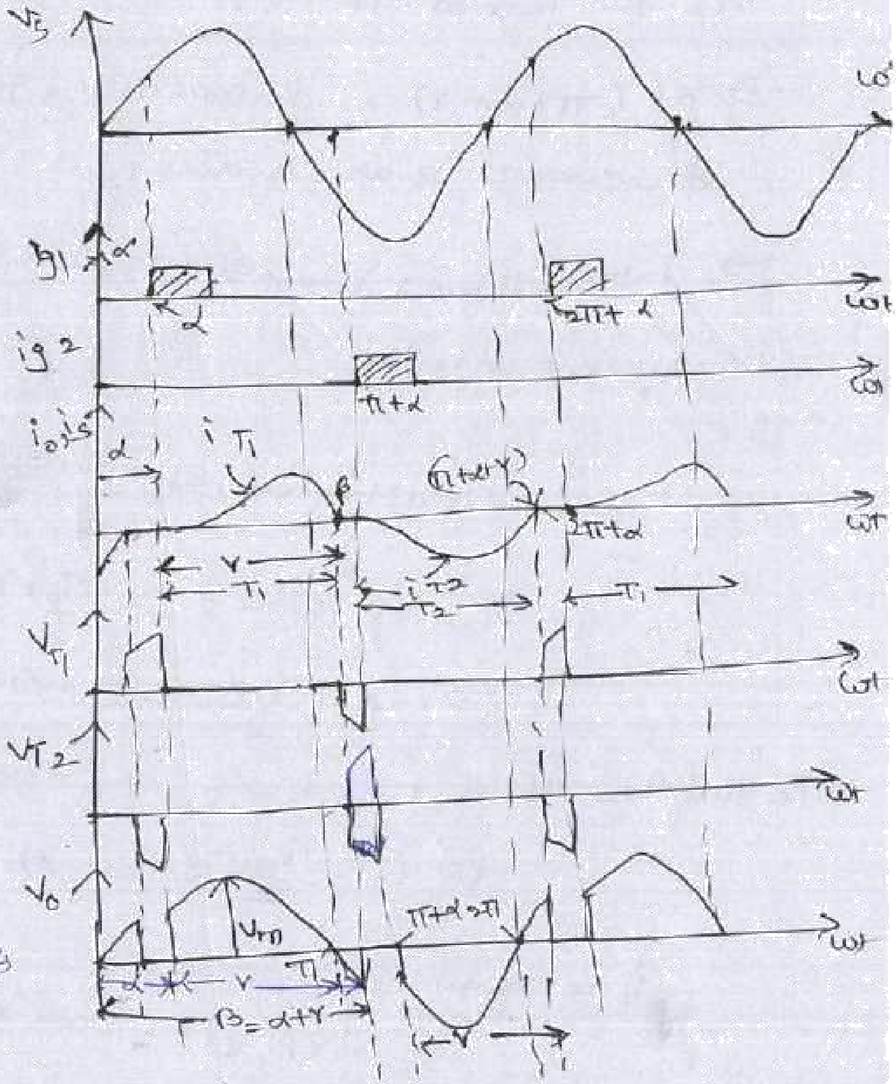
ϕ_1 = phase angle b/w V_s & I_1

or $$P.f = \frac{V_{or}^2}{R} \Big/ V_s \cdot I_{rms} = \frac{V_{orms}^2/R}{V_s \cdot V_{orms}/R} = \frac{V_{orms}}{V_s}$$

$$\therefore \boxed{P.f = \frac{V_{orms}}{V_s}} = \left[\frac{1}{\pi}\left[(\pi-\alpha) + \frac{1}{2}\sin 2\alpha\right]\right]^{1/2}$$

AC voltage controller with RL load:





α > φ

→ During 0 to π, T_1 is F.B.
At $\omega t = \alpha$, T_1 is triggered & $i_o = i_{T_1}$ starts building up through load.

→ At π, load & source voltage are zero but the current is not zero because of inductance in load ckt.

→ At β > π, load current reduces to zero. β → extinction angle

→ After π, T_1 is reverse biased but does not turn off because i_o is not zero. At β only, when i_o is zero.

→ T_1 is turned off as it is already reverse biased.

→ After commutation of T_1 at β, $V_m \sin\beta$ appears at once as a R.B across T_1 & as a F.B across T_2.

→ From β to π+α, no current exists in power circuit, $V_o = 0$, $V_{T_1} = -V_s$, $V_{T_2} = V_s$.

→ When T_2 is turned on at $(\pi+\alpha) > \beta$, current $i_o = i_{T_2}$ starts building up in reverse direction through load.

At 2π, v_s & v_0 are zero but $i_{T2} = i_0$ is zero At $(\pi+\alpha+\gamma)$, $i_{T2}=0$ &

T_2 is turned off because it is already reverse biased.

→ At $(\pi+\alpha+\gamma)$, $V_m \sin(\pi+\alpha+\gamma)$ appears as F.B across T_1 & reverse Bias across T_2.

→ from $(\pi+\alpha+\gamma)$, ~~$V_m \sin(\pi+\alpha+\gamma)$ appears as a F.B~~ to $(2\pi+\alpha)$ no current exists.

Circuit turn off time $t_c = \frac{\pi}{\omega}$ sec

$$V_S = V_m \sin\omega t = Ri_0 + L\frac{di_0}{dt}$$

$$\Rightarrow i_0 = \frac{V_m}{Z}\sin(\omega t-\phi) + Ae^{-(R/L)t}$$

To find A, At $\omega t = \alpha$, $i_0 = 0$, $t = \alpha/\omega$

$$\therefore i_0 = \frac{V_m}{Z}\left[\sin(\omega t-\phi) - \sin(\alpha-\phi)\exp\left[\frac{R}{L}\left(\frac{\alpha}{\omega}-t\right)\right]\right]$$

$i_0 = 0$ again at $\omega t = \beta$

$$\therefore \sin(\beta-\phi) = \sin(\alpha-\phi)\exp\left[\frac{R}{L}\left(\frac{\alpha-\beta}{\omega}\right)\right]$$

Operation with $\alpha < \phi$

1. If $\alpha = \phi$, $\sin(\beta-\phi) = \sin(\beta-\phi) = 0$

   & $\beta - \alpha = \pi = \gamma$

2. → Because conduction angle γ cannot exceeds π & load current must pass through zero, the delay angle α may not less than ϕ & control range of α is

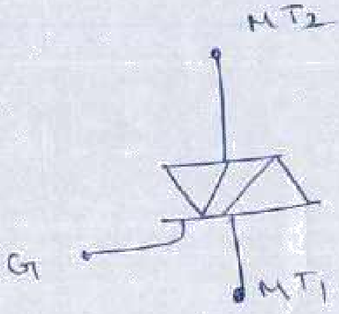
$$\phi \le \alpha \le \pi$$

3. If $\alpha \le \phi$, load current would not change with α, but both SCRs conduct for π. T_1 would turn on at $\omega t = \phi$ & T_2 at $\pi + \phi$

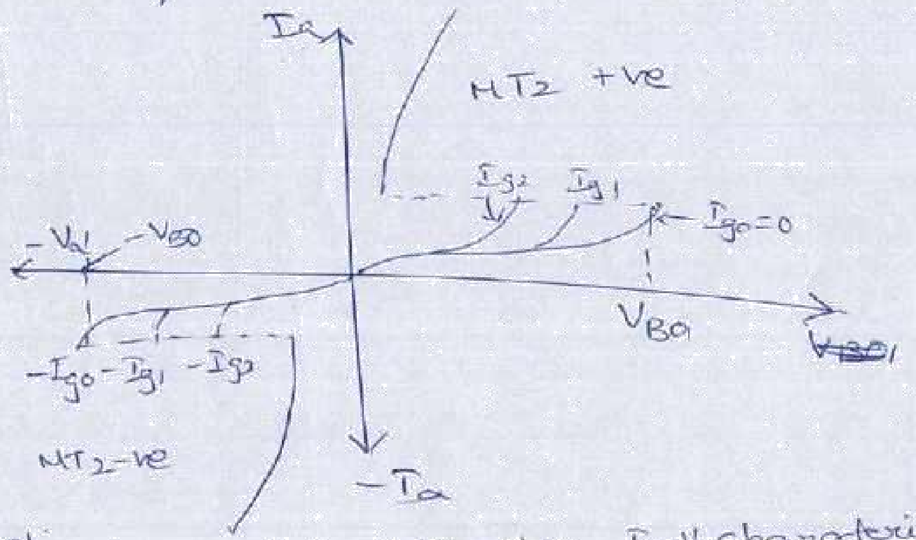
→ **TRIAC** → conducts in both directions

→ It is a bidirectional thyristor with 3 terminals

→ operation is equivalent to two SCRs connected in antiparallel.



Circuit symbol



Static I-V characteristics

→ It can conduct in both directions,

→ when gate signal is not given, triac will block both half cycles of ac voltage (applied) incase of this voltage is less than V_{BO1} or V_{BO2}

→ It can be turned on in each cycle of applied voltage by applying a +ve or -ve voltage to gate with r.t terminal MT1.

Cycloconverter

→ A device which converts input power at one frequency to output power at a different frequency with one-stage conversion is called a cycloconverter.

→ It is one-stage frequency changer. Two types,

(1) step-down cycloconverter (if o/p freq. $f_o < f_s$ (supply freq.))

(2) step-up " [if o/p freq. $f_o > f_s$]

Applications → speed control of high power ac drives

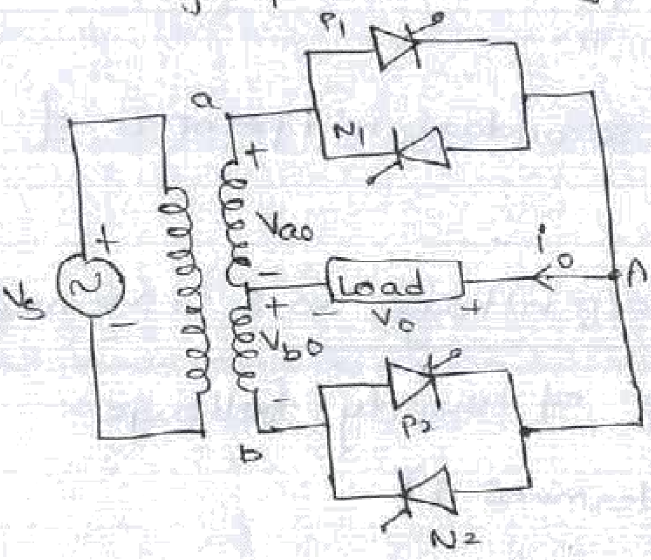
→ Induction heating

→ static VAR compensation

→ for converting variable speed alternator voltage to constant freq. o/p voltage

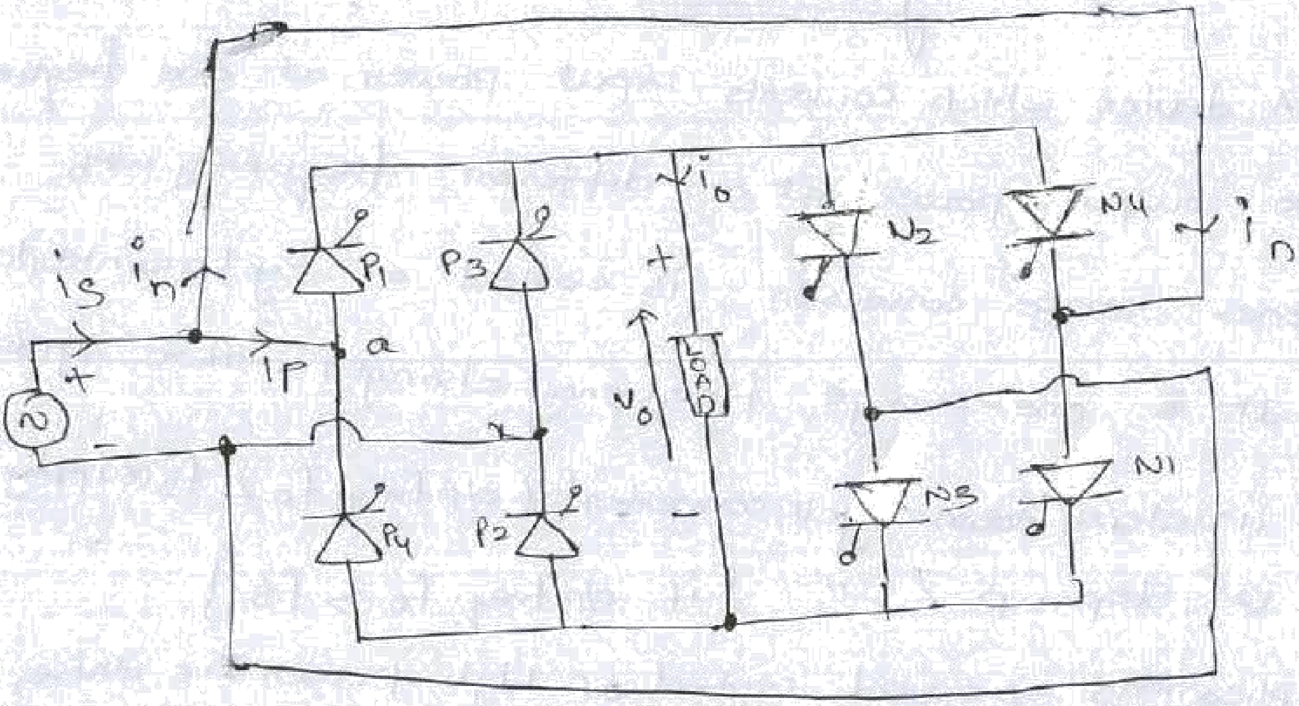
Principle of cycloconverter operation:

(single phase to single phase cycloconverter)



Midpoint type

(1)



Bridge type cycloconverter.

1. ~~Single phase~~ Step-up cycloconverter requires forced commutation.

1. Step-up cyclo converter : Mid point cycloconverter

→ P_1, P_2 are for positive group

→ N_1, N_2 " " negative ".

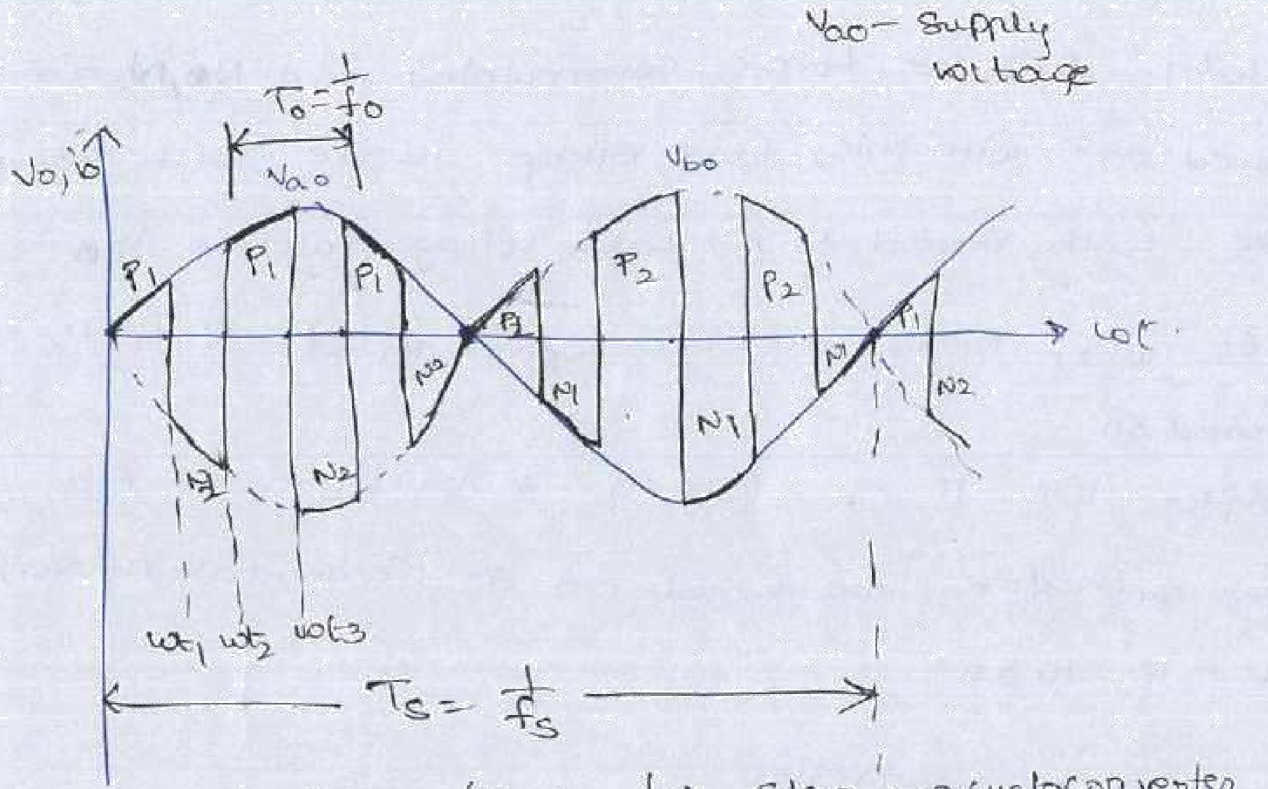
→ Load is connected b/w secondary mid point o & terminal A.

→ positive directions for o/p voltage V_0 & i_0 are marked

→ During positive half cycle of supply voltage, terminal a is +ve w.r.t terminal b.

→ ∴ P_1 & N2 are F.B from $\omega t=0$ to $\omega t=\pi$.

→ As such SCR P1 is turned on at $\omega t=0°$ so that load voltage is +ve with terminal A +ve & o negative



wave forms for step-up cycloconverter

→ the load voltage now follows supply voltage

→ At ωt_1, P_1 is force commutated & N_2 is triggered.

→ The o/p voltage follows V_{bo}.

→ At ωt_2, N_2 is force commutated & P_1 is turned on.

→ After $\omega t = \pi$, SCRs P_2 & N_1 F·B from π to 2π.

→ N2 is force commutated & F·B SCR P2 is turned on.

→ P_2 is force commutated & N1 is turned on at $\omega t = \frac{1}{2f_s} + \frac{1}{2f_0}$

→ For Bridge-type cycloconverter:

→ P_1 to P_4 → +ve group
P_5 to P_6 → −ve group.

→ when supply voltage is +ve, P_1 P_2 & N_1 N_2 are F·B from $\omega t = 0°$ to $\omega t = \pi$.

→ when F·B thyristors P_1 P_2 are turned on together at $\omega t = 0°$, load voltage is +ve w.r.t. x

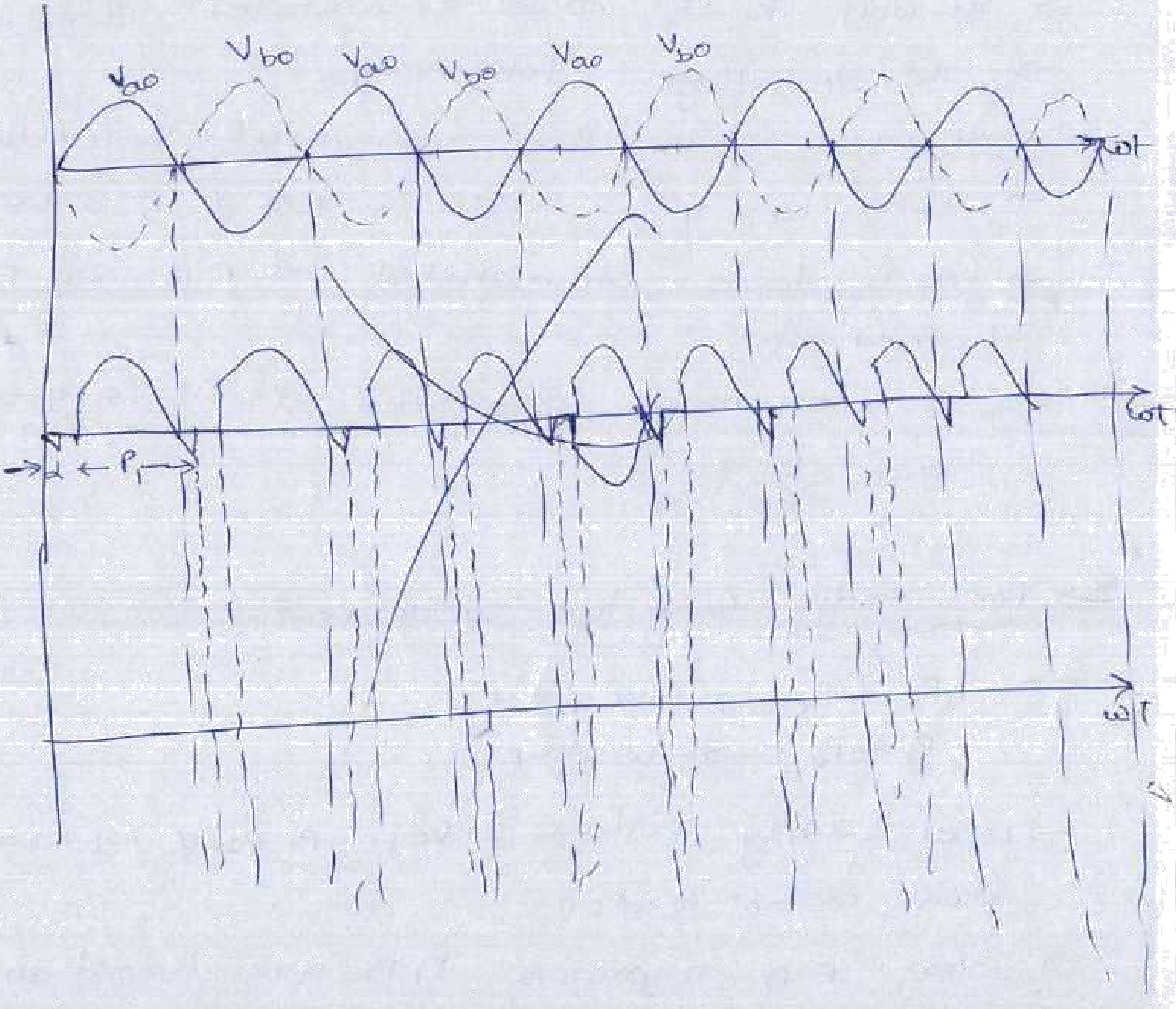
→ At ωt_1, P_1, P_2 are force commutated and N_1, N_2 are turned on. With this, load voltage is -ve with terminal O +ve with respect to A; load voltage follows V_{bo}.

→ At ωt_2, N_1 N_2 are force commutated & P_1, P_2 are turned on.

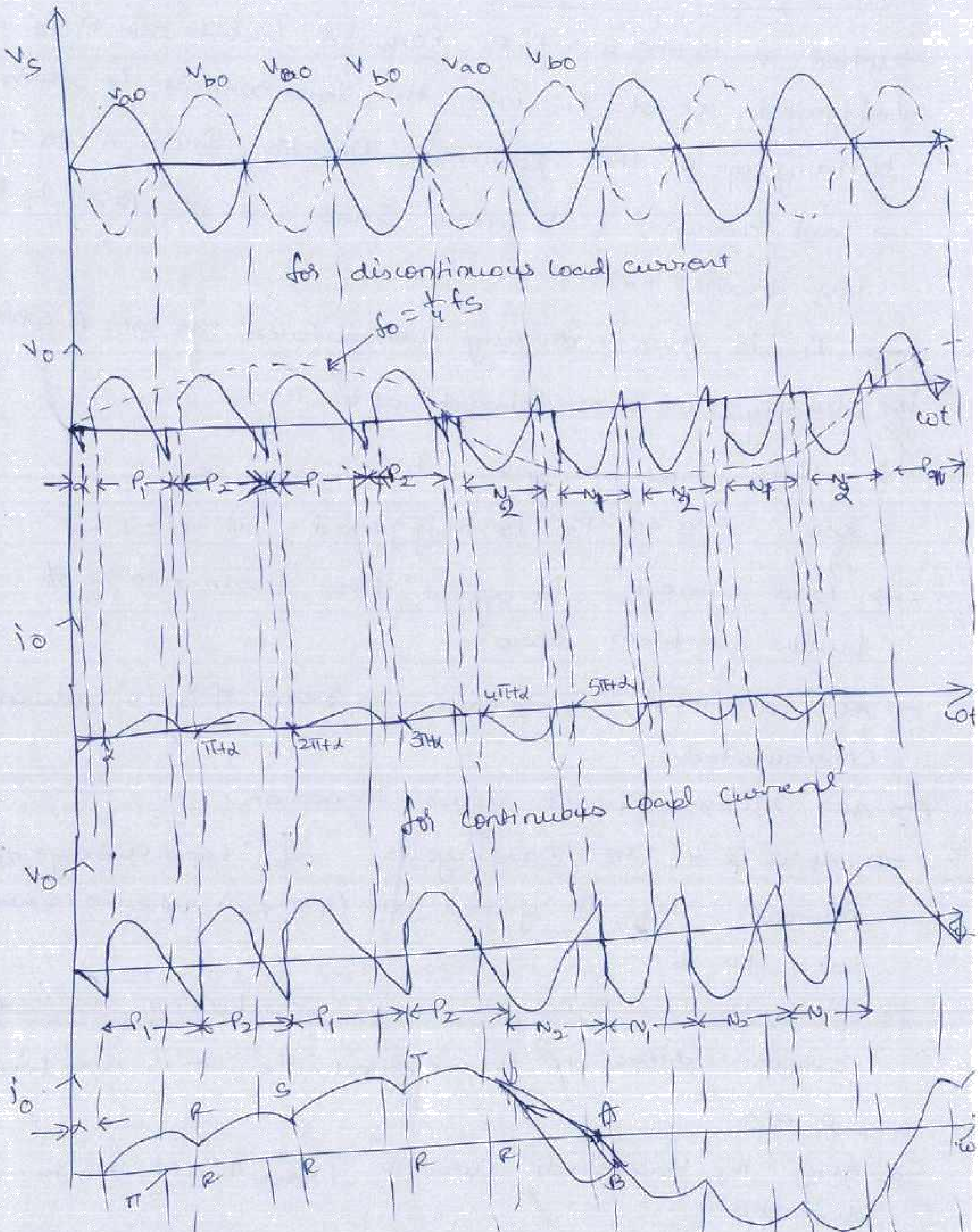
→ After $\omega t = \pi$, P_3, P_4 & N_3, N_4 are F.B these can therefore be turned on & commutated from $\omega t = \pi$ to 2π.

Step-down cyclo converter:

(i) Mid point cycloconverter:



$f_0 = \frac{1}{4} f_s$ ⑥



(a) Discontinuous load current:

→ when a is +ve w.r.t. O, forward biased SCR P_1 is triggered at $\omega t = \alpha$, with this load current i_0 starts building up in the positive direction from A to O.

→ load current i_0 becomes zero at $\omega t = \beta > \pi$ but less than $(\pi + \alpha)$.

→ P_1 is thus naturally commutated at $\omega t = \beta$ which is already reverse biased after π.

→ After half a cycle, b is +ve w.r.t. O

→ now F.B SCR P_2 is triggered at $\omega t = \pi + \alpha$.

→ Load current is again +ve from A to O & builds up from zero.

→ At $\omega t = \pi + \beta$, i_0 decays to zero & P_2 is naturally commutated.

→ At $2\pi + \alpha$, P_1 is again turned on.

→ After 4 +ve half cycles of load voltage of current, N_2 is gated at $(4\pi + \alpha)$ when O is +ve w.r.t. to b.

→ As N_2 is F.B it starts conducting but load current direction is reversed, i.e., it is now from O to A.

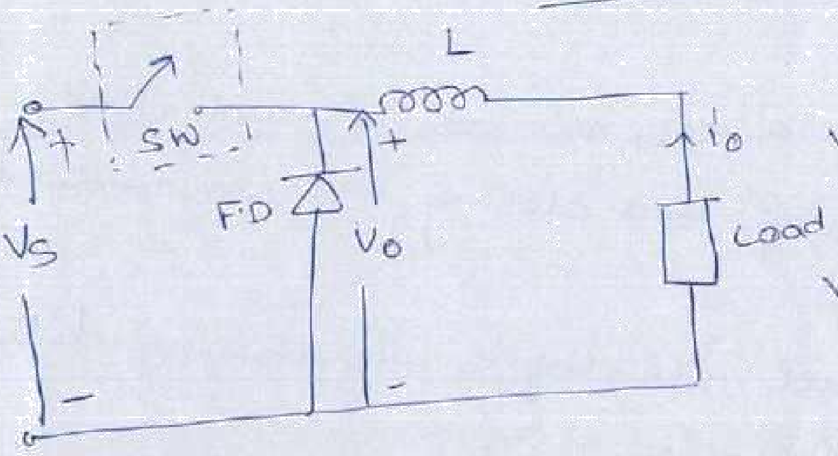
→ After N_2 triggered, Current ~~flows~~ builds up in -ve direction.

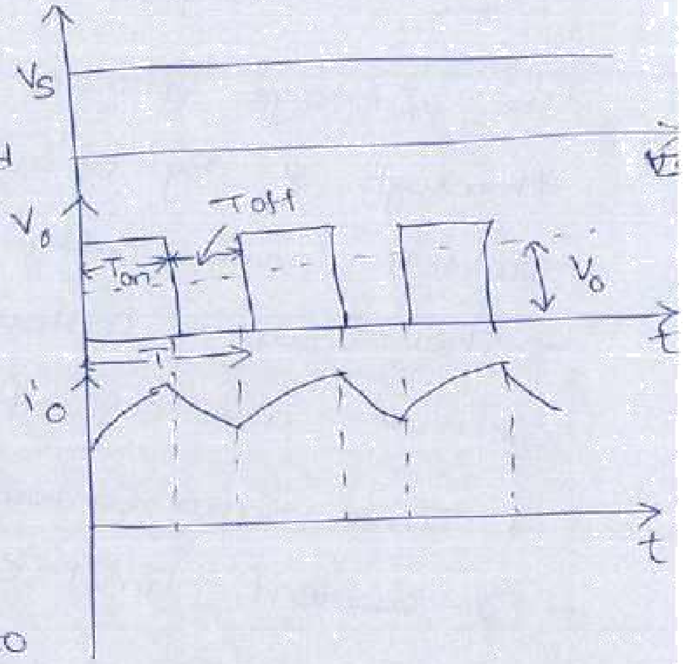
→ In next half cycle O is +ve w.r.t to a but before N_1 is fired i_0 decays to zero & N_2 is naturally commutated.

→ Now when N1 is gated at $(5\pi+\alpha)$, i_0 again builds up but it decays to zero before N2 in sequence is again gated.

Continuous load.

Stepdown chopper (or) class A or Type A chopper





mode I when SW is closed, i.e., during Ton, chopper is on & load voltage is equal to source voltage Vs.

→ During turnoff interval Toff, chopper is off, load current flows through freewheeling diode FD

→ As a result, load terminals are short circuited by FD and load voltage is therefore zero during Toff.

→ In this manner, the chopped dc voltage is produced at the load terminals.

→ During Ton, load current rises whereas during Toff, load current decays

Average voltage $V_o = \frac{T_{on}}{T_{on}+T_{off}} V_s = \frac{T_{on}}{T} V = \alpha V_s$

$\alpha = \frac{T_{on}}{T}$ → duty cycle

$T = T_{on} + T_{off}$ = chopping period

$V_o = f \cdot T_{on} \cdot V_s$

$f = \frac{1}{T}$ = chopping frequency

Control strategies:

The average voltage of o/p, V_0 can be controlled through α by opening and closing the semiconductor switch periodically.

→ The various control strategies for varying duty cycle α are as follows

1. Time ratio Control (TRC)
2. current-limit control.

1. Time ratio control (TRC).

→ Time ratio $\frac{T_{on}}{T}$ is varied.

→ this is realized in two different strategies called constant frequency system & variable frequency system.

(i) Constant frequency system:

→ The on-time T_{on} is varied but chopping frequency f (or chopping period T) is kept constant. Varion of T_{on} means adjustment of pulse width, as such this scheme is also called pulse-width modulation

$\alpha \rightarrow 0$ to 1

$V_0 \rightarrow 0$ to V_s.

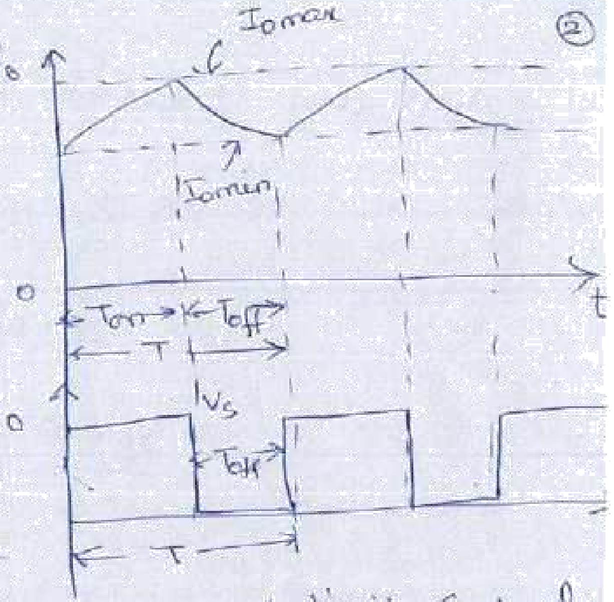
(ii) Variable frequency system:

→ The chopping frequency f (or chopping period T) is ~~kept constant variation~~ is varied and either (i) on-time T_{on} is kept constant or

(ii) Off-time T_{off} is kept constant.

This is called frequency modulation

Current-limit control:



Current-limit control for choppers

→ The on & off of chopper circuit guided by the previous set value of load current

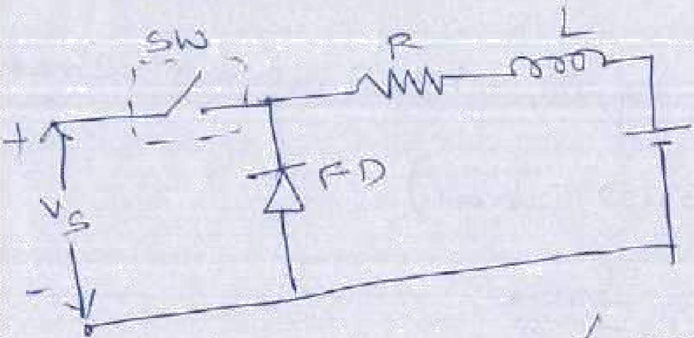
→ These two set values are max. load current Iomax & minimum load current Iomin

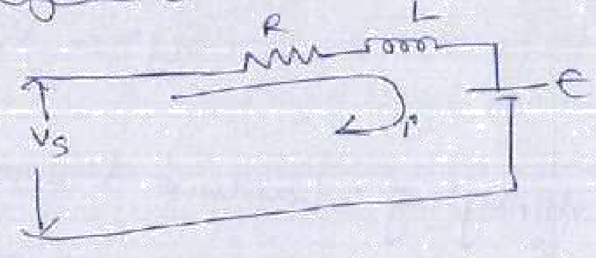
→ when load current reaches the upper limit Iomax, chopper is switched off

→ now load current freewheels and begins to decay exponentially

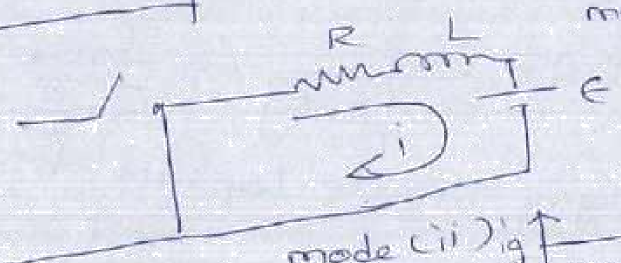
→ when it falls to lower limit Iomin, chopper is switched on & load current begins to rise

Steady state time domain analysis of Stepdown chopper

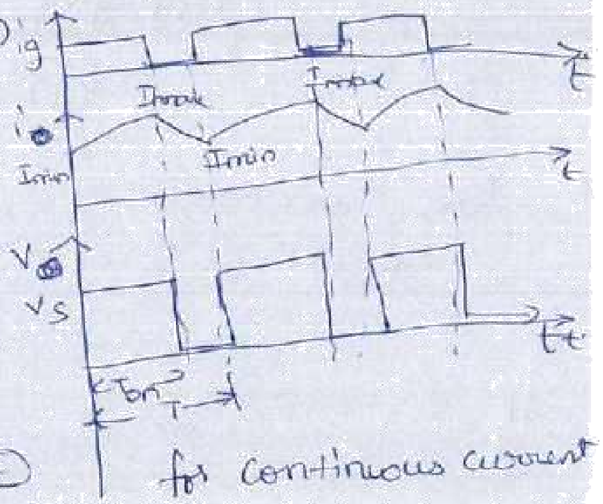




mode (i)



mode (ii)



for continuous current

mode (i) when switch is on, the equivalent is shown in fig. $0 \leq t \leq T_{on}$

$$V_s = Ri + L\frac{di}{dt} + E \rightarrow ①$$

mode (ii) when switch is off,

$$0 = Ri + L\frac{di}{dt} + E \rightarrow ②$$

$T_{on} \leq t \leq T$

Applying Laplace transform to eq ①, initial current = I_{min}

$$\frac{V_s - E}{S} = R\,I(S) + L(S\,I(S) - I_{min})$$

$$\Rightarrow I(S) = \frac{\frac{V_s - E}{S} - L(S\,I(S) - I_{min})}{R}$$

$$\Rightarrow \frac{V_s - E}{S} = I(S)\,[R + LS] - L\,I_{min}$$

$$\Rightarrow I(S) = \frac{V_s - E}{S(R+LS)} + \frac{L\,I_{min}}{(R+LS)}$$

$$I(S) = \frac{V_s - E}{L\,S\left[S+\frac{R}{L}\right]} + \frac{L\,I_{min}}{L\left(S+\frac{R}{L}\right)}$$

$$I(S) = \frac{V_s - E}{S \cdot L\left[S+\frac{R}{L}\right]} + \frac{I_{min}}{S+\frac{R}{L}}$$

Taking inverse Laplace to above equation,

$$i(t) = \frac{V_s - E}{R}\left(1 - e^{-\frac{R}{L}t}\right) + I_{min}\,e^{-\frac{R}{L}t} \longrightarrow ③$$

Applying Laplace transform to eq ②, initial current = I_{max}

$$-\frac{E}{S} = R\,I(S) + L(S\,I(S) - I_{max})$$

$$\Rightarrow I(S) = \frac{-E}{S \cdot L\left[S+\frac{R}{L}\right]} - \frac{I_{max}}{S+\frac{R}{L}}$$

Applying inverse Laplace to above equation,

$$i(t) = -\frac{E}{R}\left(1 - e^{-\frac{R}{L}t'}\right) + I_{max}\,e^{-\frac{R}{L}t'} \longrightarrow ④$$

for $T_{on} < t \leq T$,

where $t' = t - T_{on}$, when $t = T_{on}$, $t' = 0$

when $t = T$, $t' = T - T_{on} = T_{off}$

eq (3) at $t = T_{on}$, $i(t) = I_{max}$

$$\Rightarrow I_{max} = \frac{V_s - E}{R}\left[1 - e^{-\frac{T_{on}}{T_a}}\right] + I_{min} e^{-\frac{T_{on}}{T_a}} \rightarrow (5)$$

where $T_a = \frac{L}{R}$

eq (4) at $t' = T_{off} = T - T_{on}$, $i(t') = I_{min}$

$$\Rightarrow I_{min} = -\frac{E}{R}\left[1 - e^{-\frac{(T - T_{on})}{T_a}}\right] + I_{max} e^{-\left(\frac{T - T_{on}}{T_a}\right)} \longrightarrow (6)$$

sub eq (6) in eq (5),

$$I_{max} = \frac{V_s - E}{R}\left[1 - e^{-\frac{T_{on}}{T_a}}\right] + \left[-\frac{E}{R}\left(1 - e^{-\left(\frac{T - T_{on}}{T_a}\right)}\right) + I_{max} e^{-\left(\frac{T - T_{on}}{T_a}\right)}\right] e^{-\frac{T_{on}}{T_a}}$$

$$\Rightarrow I_{max} = \frac{V_s}{R}\left[\frac{1 - e^{-\frac{T_{on}}{T_a}}}{1 - e^{-\frac{T}{T_a}}}\right] - \frac{E}{R} \longrightarrow (7)$$

III'ly eq (5) in eq (6),

$$I_{min} = \frac{V_s}{R}\left[\frac{1 - e^{-\frac{T_{on}}{T_a}}}{1 - e^{-\frac{T}{T_a}}}\right] \frac{e^{\frac{T_{on}}{T_a}}}{e^{\frac{T}{T_a}}} - \frac{E}{R}$$

$$I_{min} = \frac{V_s}{R}\left[\frac{e^{\frac{T_{on}}{T_a}} - 1}{e^{\frac{T}{T_a}} - 1}\right] - \frac{E}{R} \longrightarrow (8)$$

In case CH conducts continuously then $T_{on} = T$

from eqns (7) & eq (8)

$$I_{max} = I_{min} = \frac{V_s - E}{R}$$

steady state ripple

→ the current pulsates b/w I_{max} & I_{min}

→ The ripple current ($I_{max} - I_{min}$) can be obtained

from ⑦ & ⑧

$$I_{max} - I_{min} = \frac{V_s}{R}\left[\frac{1-e^{-\frac{T_{on}}{T_a}}}{1-e^{-\frac{T}{T_a}}} - \frac{e^{\frac{T_{on}}{T_a}}-1}{e^{\frac{T}{T_a}}-1}\right]$$

$$= \frac{V_s}{R}\left[\frac{1-e^{-\frac{T_{on}}{T_a}}}{1-e^{-\frac{T}{T_a}}} - \frac{\left(1-e^{-\frac{T_{on}}{T_a}}\right)e^{\frac{T_{on}}{T_a}}}{\left(1-e^{-\frac{T}{T_a}}\right)e^{\frac{T}{T_a}}}\right]$$

$$= \frac{V_s}{R}\left[\frac{\left(1-e^{-\frac{T_{on}}{T_a}}\right)-\left(1-e^{-\frac{T_{on}}{T_a}}\right)e^{\frac{(T_{on}-T)}{T_a}}}{1-e^{-\frac{T}{T_a}}}\right]$$

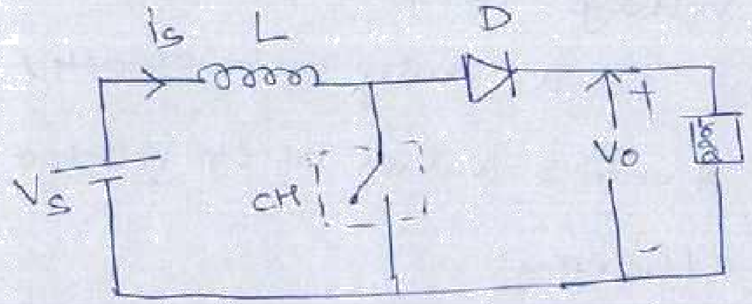
$$= \frac{V_s}{R}\left[\frac{\left(1-e^{-\frac{T_{on}}{T_a}}\right)\left(1-e^{-\frac{(T-T_{on})}{T_a}}\right)}{1-e^{-\frac{T}{T_a}}}\right]$$

∴ the ripple current is independent of E.

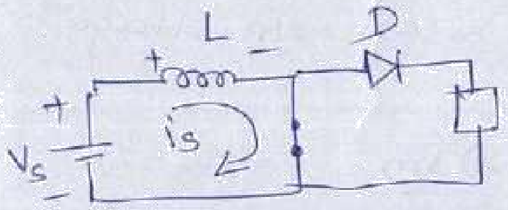
with $T_{on} = \alpha T$ & $T - T_{on} = (1-\alpha)T$,

$$I_{max} - I_{min} = \frac{V_s}{R}\left[\frac{\left(1-e^{-\frac{\alpha T}{T_a}}\right)\left(1-e^{-\frac{(1-\alpha)T}{T_a}}\right)}{1-e^{-\frac{T}{T_a}}}\right]$$

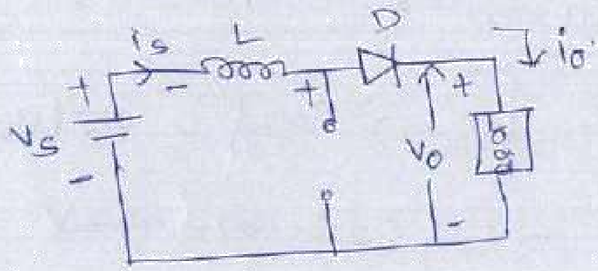
Step-up chopper:



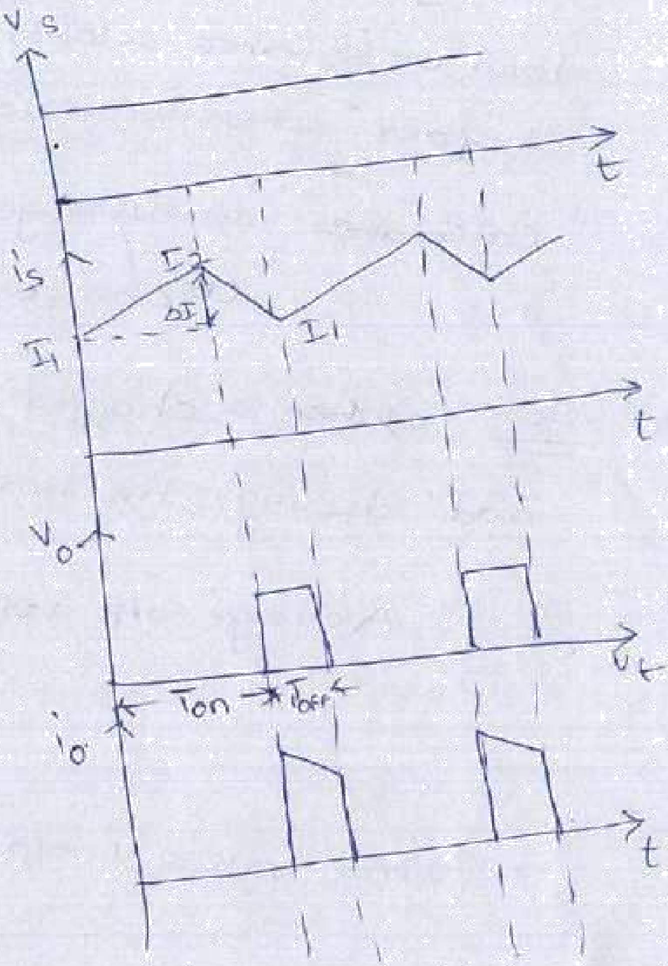
Step up chopper



L stores energy



$L\frac{di}{dt}$ is added to Vs



during Ton,

energy i/p to inductor from source

W_{in} = (Voltage across L)(average current through L) Ton

$$= V_s \left[\frac{I_1 + I_2}{2}\right] T_{on}$$

when Toff, = voltage across L × avg current through L) Toff

$$W_{off} = (V_o - V_s) \left[\frac{I_1 + I_2}{2}\right] T_{off}.$$

$$V_s \left[\frac{I_1 + I_2}{2}\right] T_{on} = (V_o - V_s) \left[\frac{I_1 + I_2}{2}\right] T_{off}$$

$$\Rightarrow V_s \cdot T_{on} = (V_o - V_s) T_{off}$$

$$\Rightarrow V_o T_{off} = V_s (T_{on} + T_{off}) = V_s \cdot T$$

$$\therefore V_o = \frac{T}{T_{off}} \cdot V_s = \frac{V_s \cdot T_{on}}{T - T_{on}} = V_s \cdot \frac{1}{1 - \alpha}$$

→ For type-A chopper, dc source voltage = 230 V, load resistance = 10 Ω, Take a voltage drop of 2V across chopper when it is on. For a duty cycle of 0.4, calculate (a) average & r.m.s values of o/p voltage

(b) chopper efficiency

Sol:- a) when a chopper is on, o/p voltage is $(V_s - 2)$ volts and during the time chopper is off, o/p voltage is zero

$\therefore$ Average o/p voltage $= \frac{(V_s - 2) T_{on}}{T} = \alpha(V_s - 2)$

$= 0.4(230 - 2) = 91.2\,V$

R.m.s value of o/p voltage $= \left[(V_s - 2)^2 \frac{T_{on}}{T}\right]^{1/2} = \sqrt{\alpha}(V_s - 2)$

$= \sqrt{0.4}(230 - 2) =$ ~~91.2V~~

$= 144.2\,V$

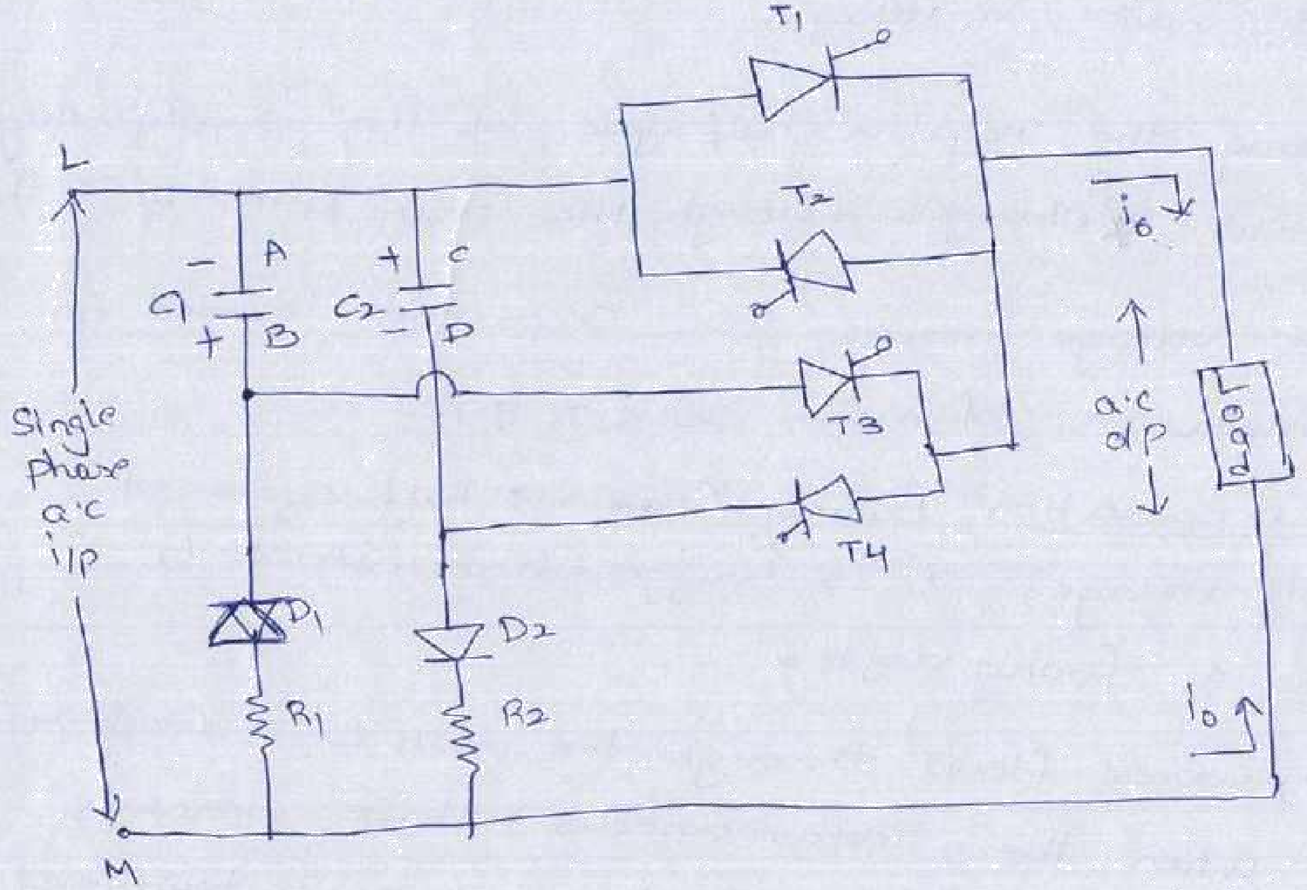
(b) power o/p or power delivered to load,

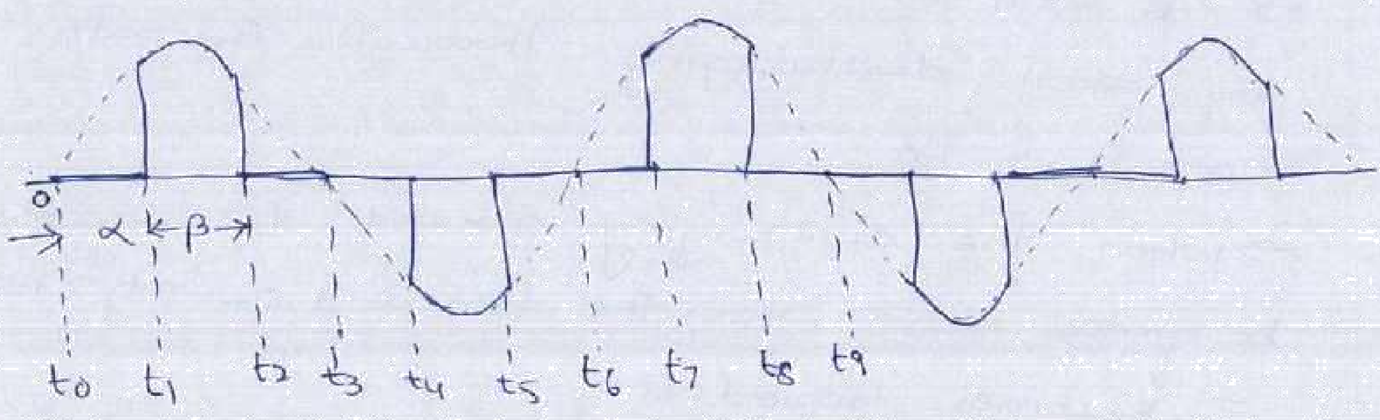
$P_o = \frac{V_{or}^2}{R} = \frac{(144.2)^2}{10} = 2079.364\,W$

Power i/p to chopper $P_i = V_s I_o = 230 \times \frac{91.2}{10} = 2097.6\,W$

chopper efficiency $= \frac{P_o}{P_i} = 99.13\%$

AC chopper – voltage changing circuits employing semiconductor devices as a static switch are known as a.c. chopper.





Load voltage w/f

→ T_1 & T_2 are main SCR

T_3 & T_4 are auxilary SCRs

C_1 & C_2 are commutating Capacitors

D_1 & D_2 provide charging path ~~of~~ for the Capacitors

Thyristors T_1 and T_3 forms the first pair for producing the positive alternation, and T_2 & T_4 constitute the second pair for producing the negative alternation of the input a.c voltage.

→ During the negative half cycle of the supply voltage capacitor C_1 charges through the path $M-R_1-D_1-C_1-L$

→ The voltage across these capacitors is used for commutation of main SCRs T_1 & T_2.

Mode 1 operation: During 1st positive half cycle of supply voltage, T_1 is triggered at instance t_1 with a firing angle α.

→ current flows through the path $L-T_1-$ Load $-M$.

→ when the instantaneous voltage reaches the instant T_2, auxilary thyristor T_3 is triggered.

→ As soon as T_3 is triggered, capacitor C_1 will start discharging through the path $C_B - T_3 - T_1 - C_A$

→ when the discharging current of capacitor C_1 becomes more than the forward current of SCR T_1, T_1 becomes turned off.

→ auxilary T_3 will be automatically turned off at instant t_3 because of the zero current at this instant.

→ Hence, SCRs T_1 & T_3 forms the first pair for producing the positive alternation of i/p a.c voltage

Mode II operation For the formation of the negative alternation, second pair of thyristors T_2 & T_4 are used

→ Main SCR T_2 is triggered at the instant t_4 during

→ first negative half-cycle of i/p voltage.

→ The current flows through the path M-load-T_2-1

→ when the Instantaneous voltage reaches the instant t_5, SCR T_4 is triggered.

→ As soon as thyristor T_4 is triggered, capacit C_2 will start discharging through the path

$C_2 - T_2 - T_{4(A-K)} - C_D$.

→ when this discharging current is more than the load current, SCR T_2 becomes turned off.

→ At Instant t_6, SCR T_4 is automatically turned off as the current passing through it becomes zero.

→ Again at instant t_7, SCR T_1 is triggered to produce the ~~neo~~ next positive alternation

→ The load power can be changed simply by varying the pulse-width (or conduction angle) β.

→ The fundamental i/p p.f is always unity

→ This ckt is generally used for obtaining a regulated a.c o/p voltage

→ A step up chopper has i/p voltage of 220V & o/p voltage of 660V. If the conducting time of thyristor-chopper is 100μs, compute the pulse width of o/p voltage.

In case o/p voltage pulse width is halved for constant frequency operation, find the avg value of new o/p voltage.

$$V_0 = V_S \cdot \frac{1}{1-\alpha}$$

$$\Rightarrow 660 = 220 \frac{1}{1-\alpha} \Rightarrow \alpha = \frac{2}{3} = \frac{T_{on}}{T}.$$

$$T_{on} = \frac{2}{3}T = 100\mu s.$$

$$\therefore \text{chopping period } T = 100 \times \frac{3}{2} = 150\mu s.$$

$$\therefore \text{Pulse width of o/p voltage} = T_{off} = T - T_{on}$$

$$= 150 - 100 = 50\mu s.$$

when pulse width of o/p voltage is halved,

$$T_{off} = \frac{50}{2} = 25\mu s$$

for constant frequency operation, $T = 150\mu s$

$T_{on} = 150 - 25 = 125\mu s$

$$\alpha = \frac{T_{on}}{T} = \frac{125}{150} = \frac{5}{6}.$$

$$\therefore V_0 = 220 \times \frac{1}{1-\frac{5}{6}} = 1320V$$

When CH_1 is turned OFF, the load current follows the same path by reversing the polarities of the inductor through the conducting diode D_2. The load current path when chopper CH_1 is in turned OFF state is

$$L^+ - E - CH_4 - D_2 - L^-$$

For the second quadrant operation chopper CH_2 is operated while CH_1, CH_3, CH_4 are in the OFF state. Here, $E > \frac{Ldi}{dt}$, hence reverse current flows whenever CH_2 is in the on state. It's path may be given as

$$E^+ - L - CH_2 - D_4 - E^-$$

During this period, the inductor gets charged. When CH_2 is in the OFF state, the load current flows in the same direction by following the path as shown.

$$L^+ - D_1 - E_{dc}^+ - E_{dc}^- - D_4 - E - L^-$$

In this second Quadrant operation of chopper, power is fed back from load to source as the voltage $E + \frac{Ldi}{dt} > E_{dc}$

For third Quadrant operation, chopper CH_3 is operated while CH_1, CH_4 are in the OFF state and CH_2 is in the ON state. In order to operate the chopper in this quadrant, the polarity of E must be changed. When CH_3 is in the on state the load voltage is negative and the load current is also negative whose path may be given as follows

$$E_{dc}^+ - CH_3 - E - L - CH_2 - E_{dc}^-$$

When CH_4 is turned off, the load current follows the path as shown below through CH_2 and diode D_4.

$$L^+ - CH_2 - D_4 - L^-$$

For fourth quadrant operation, chopper CH_4 is operated by keeping the other choppers in the OFF state. Here also, the chopper operates only when polarity of E is reversed. The load current follows the path as shown

$$E^+ - CH_4 - D_2 - L - E^-$$

The current direction is positive, whereas load voltage is negative whenever CH_4 gets turned OFF, and the load current follows the path as shown by conducting diods D_2 and D_3.

$$L^+ - E - D_3 - E_{dc}^+ - E_{dc}^- - D_2 - L^-$$

Here also, the power is fed back to source from load.

4.14 DC Jones Chopper

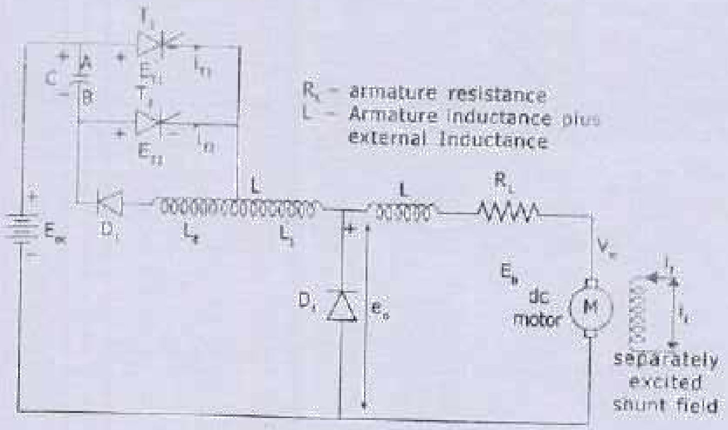


Figure 4.21(a)

Circuit description

It consists of main thyristor T_1, auxiliary thyristor T_2. Commutating circuit for main thyristor consists of capacitor C, diode D_1, T_2, autotransformer. The main advantage of using autotransformer is that, it eliminates the commutation failure, since the energy stored in LL_2 slightly enhances the capacitor voltage to a value greater than E_{dc} from which the definite commutation process occur as L_1 and L_2 are closely coupled. In this chopper, type 'D' commutation process occurs.

The operating principle may be explained in different modes

Mode I: Initially, the capacitor 'C' is assumed to be charged to a voltage E_{dc} with the polarity as shown. When SCR T_1 is triggered at the instant $t = t_a$, the current follows the path as shown in fig. 4.21(b). Its path is given as

$$C_A - T_1 - LL_2 - D_1 - C_B$$

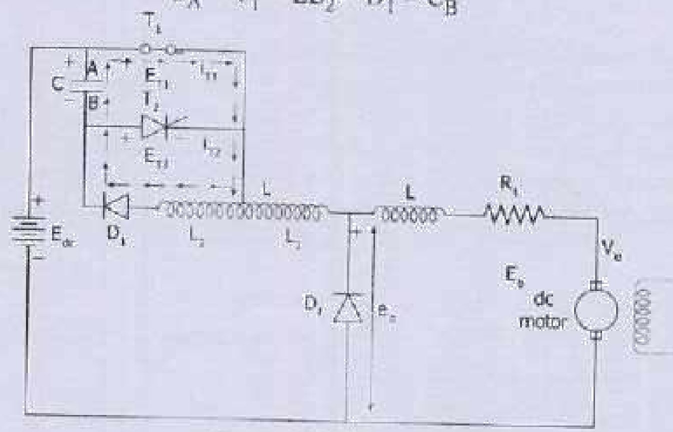


Figure 4.21(b)

Now, the capacitor 'C' gets charged to the opposite polarity i.e., plate B becomes positive and plate A becomes negative. Diode D_1 prevents further oscillation of L_2C circuit. Thus capacitor retains its charge till the thyristor T_2 gets triggered. When the thyristor T_1 is in the on state for a long duration of time then the motor reaches the steady state speed determined by the battery voltage, the motor and the mechanical load characteristics.

Mode 2: At the instant $t = t_c$ SCR T_2 is turned on. Now, the current follows the path as shown in Fig. 4.21(c)

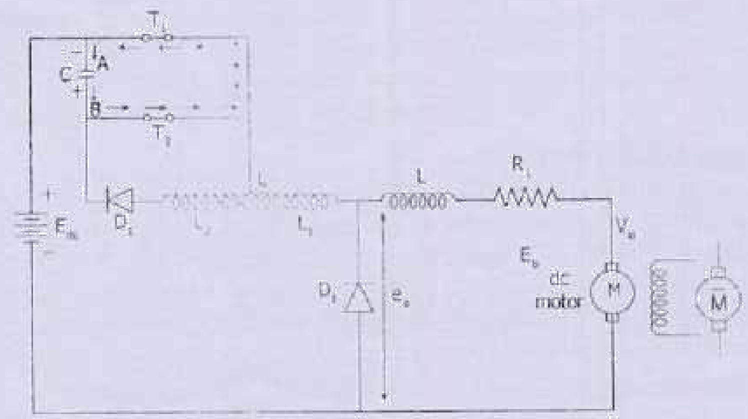


Figure 4.21(c)

Its path is given as,

$$C_B - T_2 - T_1 - C_A$$

Hence, the capacitor discharge reverse biases the thyristor T_1 and it gets turned off. Whenever capacitor 'C' is recharged, SCR T_2 gets turned off because the current through it falls below that of the holding current value. When SCR does not conduct, inductance L maintains the load current through diode D_f. Thus, the motor torque proportional to load current becomes smooth instead of pulsating in nature. At the instant $t = t_e$, bottom plate of capacitor 'C' reaches a peak value greater than E_{dc}. The time duration t_c to t_d is known as circuit turn off time.

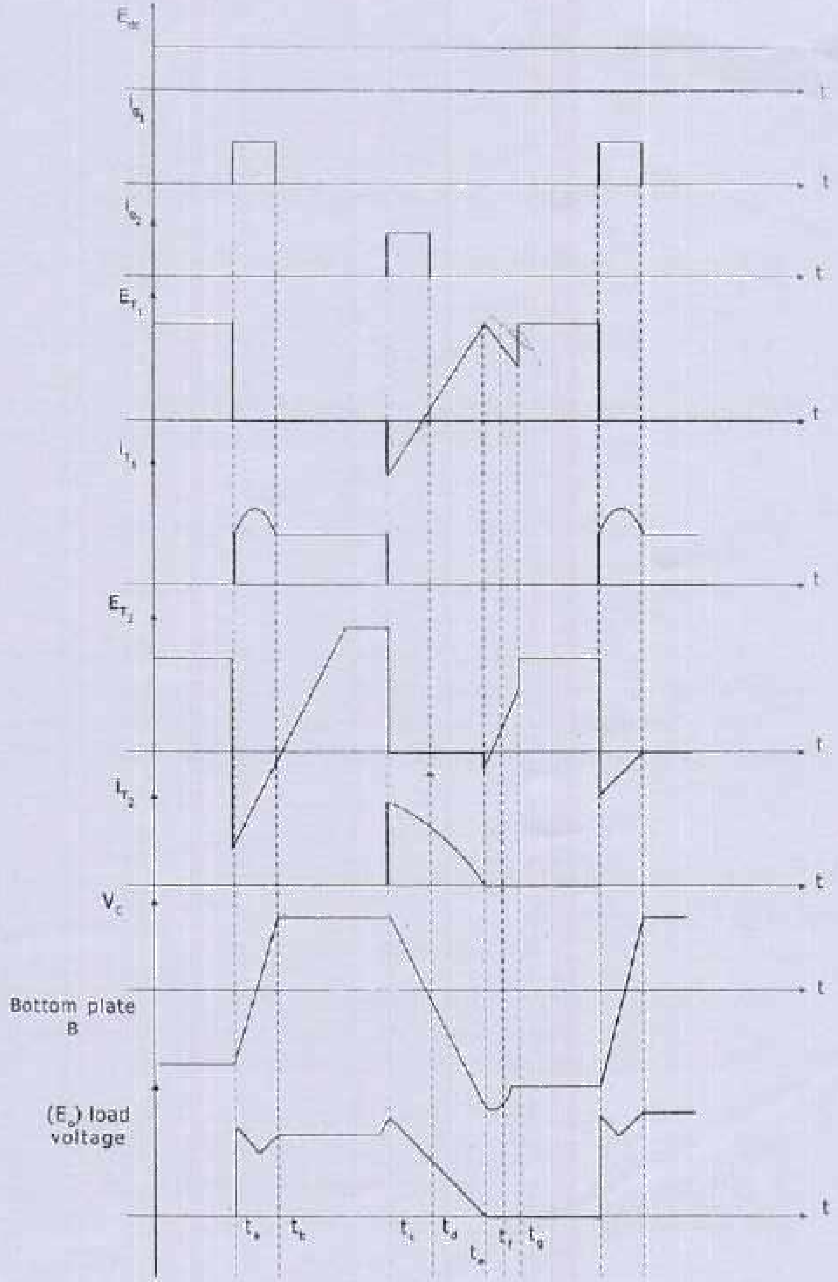


Figure 4.21(d) Voltage and current waveforms in D.C Jones Chopper

Design consideration

Proper selection of commutating capacitor 'C' and auto transformer 'T' is essential for the design of Jones chopper circuit. Initially, maximum current I_{omax} flows through L_1. During the turn off time of SCR T_1, the energy stored in inductance L_1 is transferred to capacitor 'C'

Hence, $$\frac{1}{2} L_1 I_{omax}^2 = \frac{1}{2} C V_c^2$$

or $$\frac{V_c^2}{I_{omax}^2} = \frac{L_1}{C}$$

or $$V_c = I_{omax} \sqrt{\frac{L_1}{C}} \qquad (1)$$

During turn off time of the SCR,

capacitor voltage gets changed from V_c to 0

$$\therefore \quad t_q = \frac{V_c C}{I_{omax}}$$

By substituting the value of V_c in the above equation, we get

$$t_q = \frac{I_{omax} \sqrt{\frac{L_1}{C}} C}{I_{omax}}$$

$$= \sqrt{L_1 C}$$

Dividing Equation (1) by E_{dc} results

$$\frac{V_c}{E_{dc}} = \frac{I_{omax}}{E_{dc}} \sqrt{\frac{L_1}{C}} \qquad (2)$$

Let us assume,

$$\frac{V_c}{E_{dc}} = g; \quad R_m = \frac{E_{dc}}{I_{omax}}$$

By substituting these values in equation (2), we get

$$g = \frac{1}{R_m} \sqrt{\frac{L_1}{C}}$$

Voltage across SCRs T_1 and T_2 may be given as

$$V_c = g.E_{dc}$$

Thus, as the value of g increases, the requirements of increase in voltage rating of SCR results.

Efficiency of circuit: As dissipative elements used in this chopper circuit are winding resistance and forward conducting resistance of SCRs and diodes the efficiency of the circuit increases.

Problem 12

The Jones chopper controls the speed of separately excited dc motor. If the i/p voltage E_{dc} = 60v, turnoff time = 10μ sec and the current flowing through main SCR is 100 Amps, conductance = 4mho. Calculate the value of the commutating capacitor 'C' and transformer inductances L_1 and L_2 for the given data

Solution: Given

E_{dc} = 60v

turn off time (t_q) = 10 μ sec.

$I_o = I_{T1}$ = 100A

g = 4 *mho*

$$g = \frac{1}{R_m} \sqrt{\frac{L_1}{C}}$$

$$R_m = \frac{E_{dc}}{I_o} = \frac{60}{100} = 0.6\Omega$$

or $$\sqrt{\frac{L_1}{C}} = 4(0.6) = 2.4 \qquad (1)$$

But we know that,

$$t_q = \sqrt{L_1 C} \text{ or } \sqrt{L_1 C} = 10 \times 10^{-6} \qquad (2)$$

from (1) and (2)

$$\sqrt{\frac{L_1}{C}} \sqrt{L_1 C} = (2.4)\, 10 \times 10^{-6}$$

$$L_1 = 24 \times 10^{-6} = 24\mu H$$

Substutitute L_1 value in equation (2) gives

$$\sqrt{24 \times 10^{-6}} \times \sqrt{C} = 10 \times 10^{-6}$$

$$24 \times 10^{-6} \times C = (10)^2 \times (10^{-6})^2$$

$$C = \frac{100\times10^{-12}}{24\times10^{-6}} = 4.16\,\mu F$$

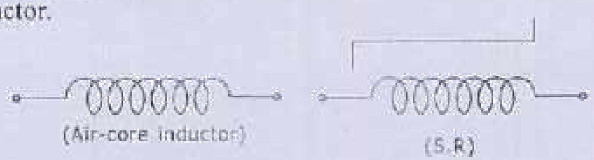
$\because$ $L_1 = L_2$

$L_2 = 24\mu H$

4.15 Morgan Chopper

Circuit description

Morgan chopper consists of one S.C.R known as main thyristor. The advantage of using this circuit is, the cost is very low because of the presence of single SCR. The commutating elements in this circuit are capacitor 'C', saturable Reactor (SR), and diode (D). There exists a difference between air core inductor and saturable reactor.



As air can take any amount of flux, the aircore inductor never saturates. The inductance offered by the air core inductor is very large. In the case of S.R, it can saturate for a low value of exciting current. The inductance offered by the S.R is very low.

Mode 0: (Charging of the capacitor). When the S.C.R T_1 is in OFF state, the capacitor 'C' will charge to the supply voltage (E_{dc}). The charging path will be $E_{dc+} - C_+ - C_- - SR - L - Load - E_{dc-}$ as shown in Fig. 4.22(a). The inductance offered by the S.R is very low. When the capacitor charges to E_{dc}, the charging will be stopped. The saturable reactor is placed in positive saturation condition.

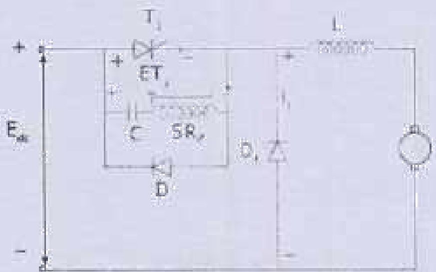


Figure 4.22(a) Morgans chopper

Mode 1: Give the gate signal to the chopper at the instant $t = t_1$. When the chopper is turned ON, the voltage across the capacitor is applied to the saturable reactor. The core flux direction is driven from positive saturation to negative saturation. When the S.R changes completely from positive saturation to the negative saturation. The capacitor 'C' discharges through the path. (C_+ – S.C.R (T_1) – S.R – C_-). LC circuit forms a resonating circuit with a discharging time of $T_1\sqrt{L_s C}$ sec where L_s is the post saturation reactance. Since the discharging time is very small, the capacitor 'C' will reverse the charge very quickly. The capacitor voltage $-E_{dc}$, is applied on the saturable reactor in the reverse direction. The core is driven from negative saturation towards positive saturation. After some time, the core flux reaches the positive saturation, the capacitor will discharge the charge in opposite direction to the Main S.C.R (T_1). So the S.C.R (T_1) is turned off.

Mode 2: The free wheeling Diode (D_1) gets forward biased because of the stored energy in the inductor. The load current flows but the Load output voltage is zero.

The time required to saturate the core is constant which depends on the volt–time integral. The conduction period for the S.C.R is fixed, and is function of the L_s and 'C'. The average output voltage can be altered by changing the operating frequency. The total ontime for the S.C.R (T_1) is determined by the time required for the reactor to move from positive saturation to the negative saturation and back to positive saturation only. The associated Waveforms of morgan's chopper is as shown in Fig. 4.22(b)

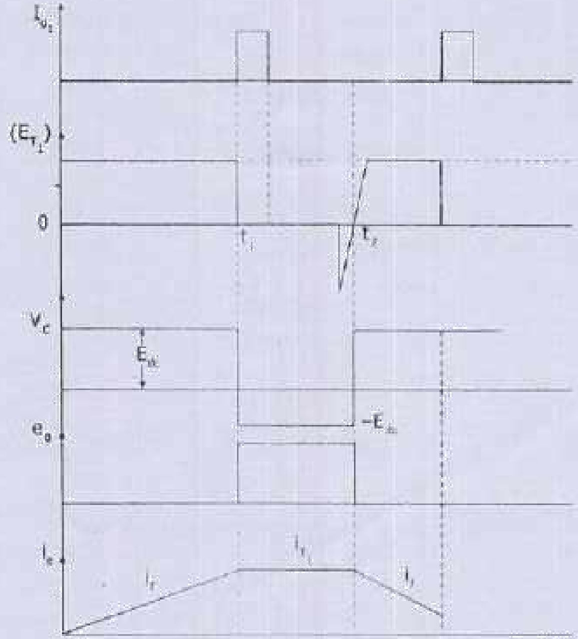


Figure 4.22(b) Voltage and current waveforms in a Morgan chopper

4.16 Oscillation Chopper

Oscillation chopper is also known as Henneman's chopper.

Circuit description: Its circuit diagram is as shown in Fig. 4.23(a).

It consists of a main thyristor T_1. The commutating circuit elements of thyristor T_1 are the auxiliary thyristor T_2, capacitor 'C' inductor L_1 and diode D. At the time of charging, the capacitor 'C', resistor 'R' is placed in series with the switch which are connected across the dc supply. It consists of a freewheeling diode D_f. Its operation may be explained in different modes as follows:

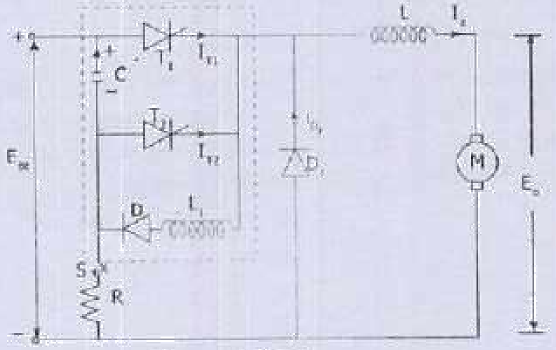


Figure 4.23(a)

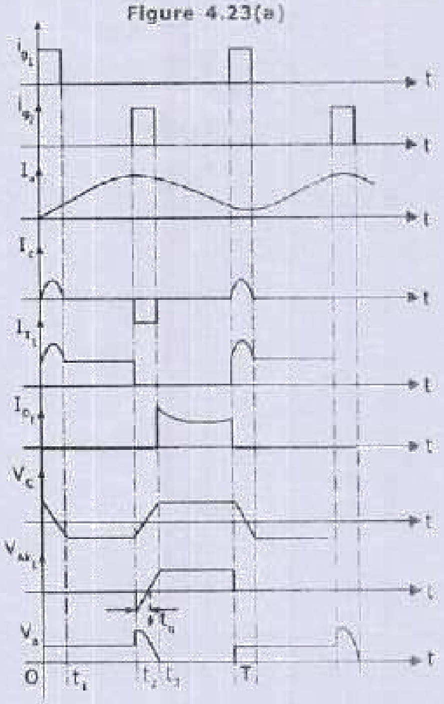


Figure 4.23(b)

Mode 1: During this mode, the capacitor 'C' gets charged to a voltage of E_{dc} by closing the switch 'S'. It's charging path may be given as

$$E_{dc}^{+} - C^{+} - C^{-} - S - R - E_{dc}^{-}$$

whenever the capacitor gets charged to a voltage of E_{dc} with upper plate positive and lower plate negative as shown in figure, current through the resistance is zero. Hence, the switch 'S' may be opened.

Mode 2: Whenever thyristor 'T_1' is triggered, it comes into the conduction state from forward blocking state. During this mode, two currents flow through the thyristor T_1. One is the load current (I_0), and the other is the capacitor discharging current (I_c). Load current path may be given as

$$E_{dc}^{+} - T_1 - L - \text{load} - E_{dc}^{-}$$

capacitor discharging current (I_c) follows the path as shown

$$C^{+} - T_1 - L_1 - D - C^{-}$$

Mode 3: During this mode, the capacitor 'C' gets charged with the reverse polarity i.e., with lower plate positive and upper plate negative. Now, the auxiliary thyristor 'T_2' gets into the forward biased condition.

Mode 4: During this mode, auxiliary thyristor T_2 is triggered in order to commutate the main thyristor 'T_1'. As the thyristor 'T_2' gets into the forward biased condition, as seen in the previous mode it gets into the conduction state when it is triggered. Now, the capacitor discharging current flows through the auxiliary thyristor (T_2). It's path may be given as

$$C^{+} - T_2 - T_1 - C^{-}$$

whenever, the cathode potential of thyristor T_1 becomes more with respect to anode potential, thyristor T_1 gets turned off.

During the off state of the thyristor 'T_1', due to the presence of stored energy in the inductor, current flows through the load whose path may be given as

$$L^{+} - \text{load} - D_f - L^{-}$$

Diode 'D' is known as blocking diode. The associated waveforms are as shown in fig. 4.23(b).

4.17 AC Choppers

The desired ac voltage magnitudes may be obtained by two methods:

1. By using stepup and stepdown transformers, in which the change in voltage depends upon the transformation ratio (k) of the transformer.
2. By using Ac choppers

Ac choppers are those voltage changing or voltage varying circuits which

Circuit description: Its circuit diagram is shown in fig. 4.24(a).

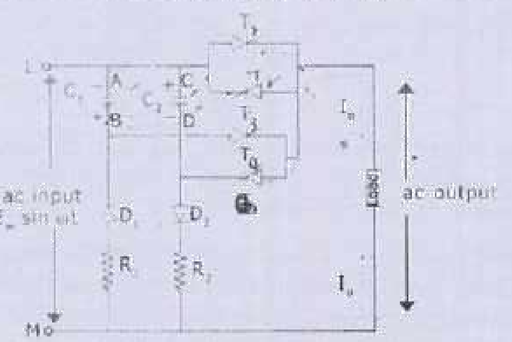


Figure 4.24(a) A.C chopper circuit diagram

It consists of two main thyristors T_1, T_2 and two auxiliary thyristors T_3 and T_4. C_1 and C_2 are the commutating capacitors where as diodes D_1 and D_2 provides the charging path for these capacitors. Thyristors T_1 and T_3 may be used for producing the positive alternation and thyristors T_2 and T_4 for negative alternation of input ac voltage.

Principle of operation may be explained in different modes

Mode 0: In this mode, during positive half cycle of ac supply voltage, capacitor C_2 gets charged whose path may be given as

$$L - C_2 - D_2 - R_2 - M$$

During negative half cycle, the capacitor C_1 **gets charged** through the path

$$M - R_1 - D_1 - C_1 - L$$

with the polarities as shown in circuit diagram.

For commutation of the main SCRs T_1 and T_2, the voltage across these capacitors may be used.

Mode 1: During the positive half cycle of the supply voltage, thyristor T_1 is forward biased which may be triggered at the instant T_1 with a firing angle α. The current flows through the path as shown.

$$L - T_1 - \text{load} - M$$

At the instant t_2, the auxiliary thyristor T_3 may be turned on so that the capacitor C_1 gets discharged through it. It's path may be given as

$$C_B - T_3 - T_1 - C_A.$$

Whenever the discharging current becomes more than the forward current of T_1, thyristor T_1 gets commutated. The auxiliary thyristor T_3 may be turned off naturally at the instant t_3 as the current passes through natural zero.

Hence, SCRs T_1 and T_3 forms the first pair for producing the positive alternation of the input ac voltage.

Mode 2 operation: During negative half cycle of the supply voltage, thyristor T_2 is forward biased which may be triggered at the instant t_4. The load current follows the path

$$M - \text{load} - T_2 - L$$

when the instantaneous voltage reaches the instant t_5, auxiliary thyristor T_4 may be triggered. As soon as the auxiliary thyristor gets turned on the capacitor C_2 gets discharged whose discharging current path may be given as

$$C_C - T_2 - T_4 - C_D.$$

When this discharging current becomes more than the load current, SCR T_2 becomes turned off. At the instant t_6, SCR T_4 gets automatically turned off due to natural zero. Again at instant t_7, SCR T_1 gets triggered and the above process repeats. Its associated waveform is as shown in Fig.4.24(b).

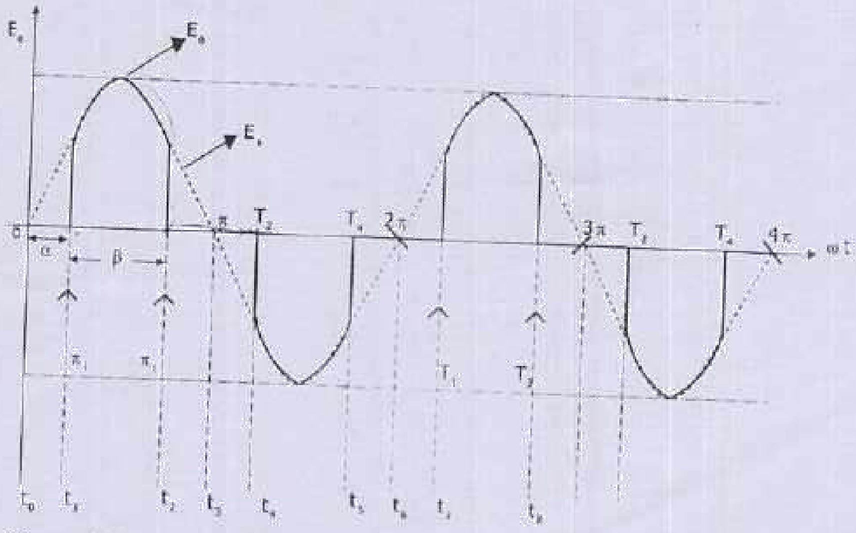


Figure 4.24(b) Supply voltage and output voltage waveforms in an A.C Chopper

Exercise

1. Explain the operating principle of both stepup and stepdown choppers involving different modes with the neat circuit diagrams.
2. Derive an expression for output voltage in terms of duty cycle for a stepup, stepdown and step down/up chopper.
3. Discuss the methods of controlling the output voltage of a chopper.
4. What type of commutation process does D.C chopper undergoes? Explain different type of commutation processes involved in chopper with suitable waveforms.
5. Describe different types of chopper circuit.
6. Explain the working of first quadrant or type A chopper with suitable voltage and current waveforms. Give the complete time domain analysis of type A chopper.
7. Obtain the expressions for I_{omax} and I_{omin} for type A chopper and also derive expression for per unit ripple current.
8. Describe the continuous and discontinuous modes of operation involved in type A chopper and get the average load current expression for this type of chopper.
9. With a neat sketch, explain the working principle of type B and type C choppers.
10. Give the detailed analysis of type D chopper.
11. Explain the working principle of type E chopper with a neat sketch.
12. With the circuit diagram and waveforms, explain the working of Jones chopper.
13. Give the design consideration of D.C Jones chopper and mention the advantages of it over other chopper circuits.
14. Write short notes on

    a. Morgan's chopper b. AC chopper

Problems

1. The input voltage of a step down chopper being 220v, the load voltage is 100v. Assuming a chopping frequency of 5kHz, find the ON and OFF intervals of the thyristors in each cycle.

   Ans: $T_{on} = 90.9\ \mu$ sec

   $T_{off} = 109.1\ \mu$sec

2. A stepup chopper has a supply voltage of 100v while output voltage is 250v. If the off period of chopper is 150μsec determine the pulse width of the output voltage. If pulse width is reduced to 1/2 for constant frequency operation, find the output voltage.

   Ans: $T_{on} = 375\ \mu$ sec;

   $E_{o(new)} = 155.55$v

3. For the basic chopper circuit, $E_{dc} = 50$volts, $R = 80\Omega$, duty cycle $\alpha = 30\%$. Find out

   i. the average output voltage and current
   ii. output current at the instant of commutation
   iii. freewheeling diode average and rms currents.
   iv. rms values of output voltage and current
   v. Average and Rms value of thyristor currents

   Ans: (i) 15v, 0.1875A (ii) 0.625A (iii) 0 (iv) 27.38V, 0.342A, (v) 0.1875A, 0.342A.

4. A stepup chopper supplies a load of 500v from 400vdc supply. If the period of nonconduction is 100μ sec. Find the on time of thyristor.

   Ans: $T_{on} = 25\mu$ sec.

5. For a type A chopper, if the constant supply voltage is 300v and the load being 50Ω, find the average, rms values of the output voltage and chopper 'η' by assuming a voltage drop of 1volt across the chopper circuit during on time. Assume duty cycle $\alpha = 0.6$

   Ans: $E_{o(avg)} = 179.4$ V, $E_{orms} = 231.60$v; $\eta = 99.66\%$

6. A chopping circuit is operating on TRC principle at a frequency of 4kHz on a 440v dc supply. If the load voltage is 200v, Compute the conduction and non conduction period of thyristor in each cycle, and the duty cycle.

   Ans: $T_{ON} = 0.113$ m sec

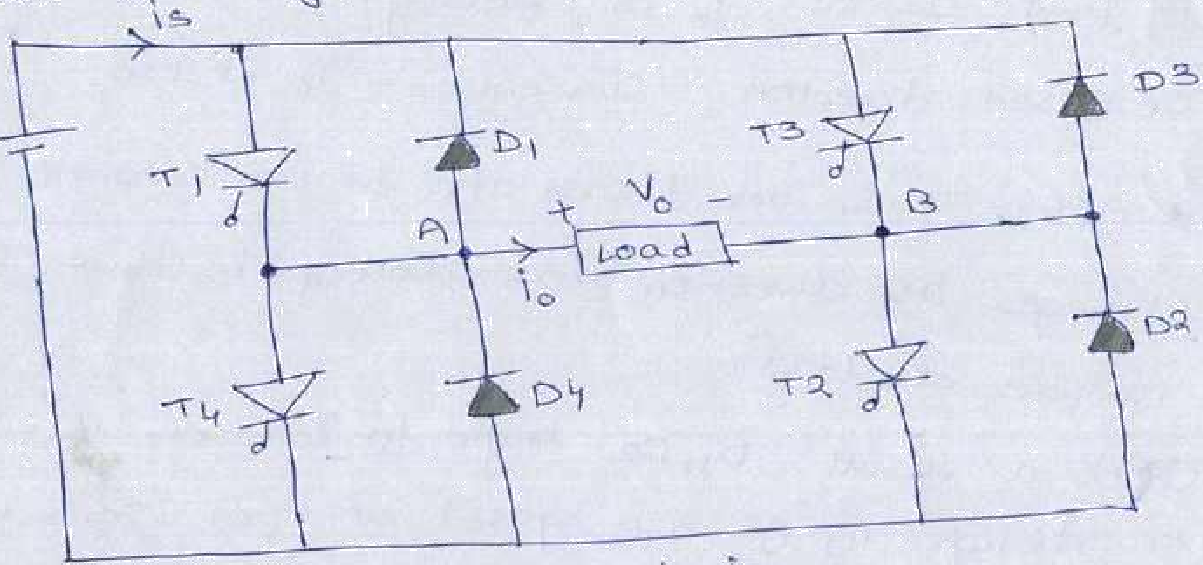
   $T_{OFF} = 0.137$ m sec

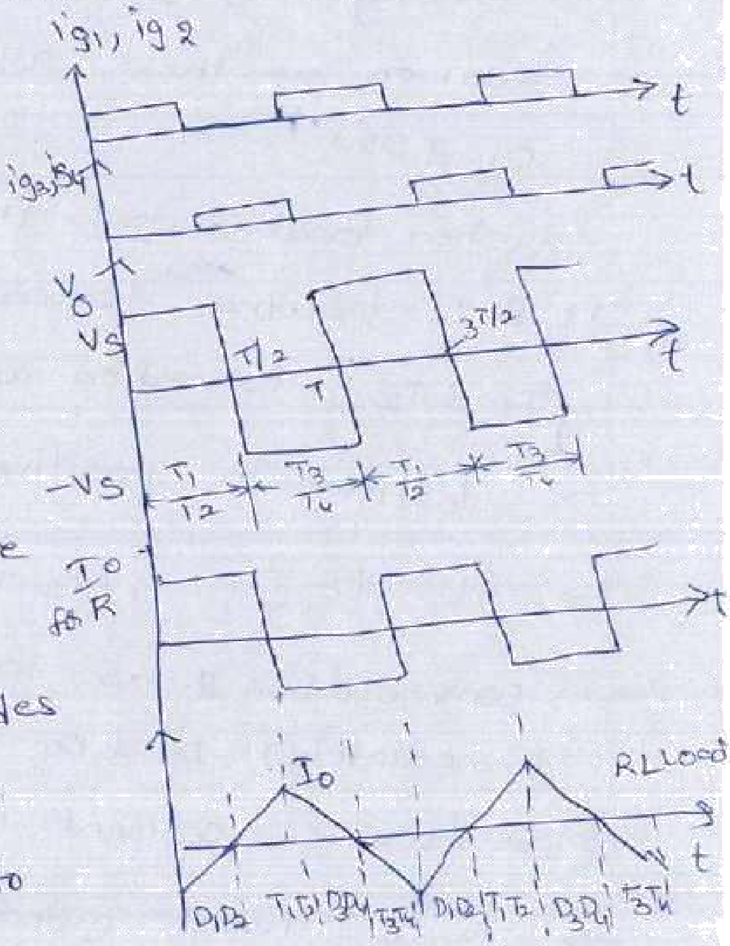
   $\alpha = 0.45$

UNIT - V

INVERTERS

Single phase full bridge inverter :-





→ For ~~load~~ Resistive load, ~~four~~ SCRs would suffice because load current i_o & V_o would always be in phase with each other.

→ For other than the resistive loads, current i_o will not be inphase with voltage V_o & diodes connected in antiparallel with SCRs will allow the current to flow when the main thyristors are turned off.

→ As the energy is fed back to the dc source when these diodes conduct, these are called feedback diodes (D1, D2, D3, D4)

For RL load: Before $t=0$, SCRs T_3 & T_4 are conducting & load current i_0 is flowing from B to A i.e. in reversed direction. current $= -I_0$ at $t=0$.

→ After T_3, T_4 are turned off at $t=0$, current i_0 cannot change its direction immedialtely because of the nature of load.

→ As a result D_1, D_2 begin to conduct, $V_0 = V_S$.

→ Though T_1, T_2 are gated at $t=0$, SCRs will not turn on as these are reverse biased by V.D across D1 & D2.

→ when load current through D_1, D_2 falls to zero, T1 & T2 become forward biased by source voltage V_s.

T_1 & T_2 ∴ turned on as these are gated for a period $T/2$ s.

→ i_0 flows in positive direction from A to B

→ At $t = \frac{T}{2}$; T_1, T_2 are turned off by forced commutation & as load current cannot reverse immediately) D3 & D4 come into conduction to allow flow of current i_0 after $T/2$.

→ T_3, T_4 though gated, will not turn on as these are reverse biased by the voltage drop in diodes D3, D4

→ when current in diodes D_3, D_4 drops to zero, T_3, T_4 are turned on as these are already gated

UNIT – I
POWER SEMI CONDUCTOR DEVICES

Objective:

To study the different types of power semiconductor devises and their switching characteristics

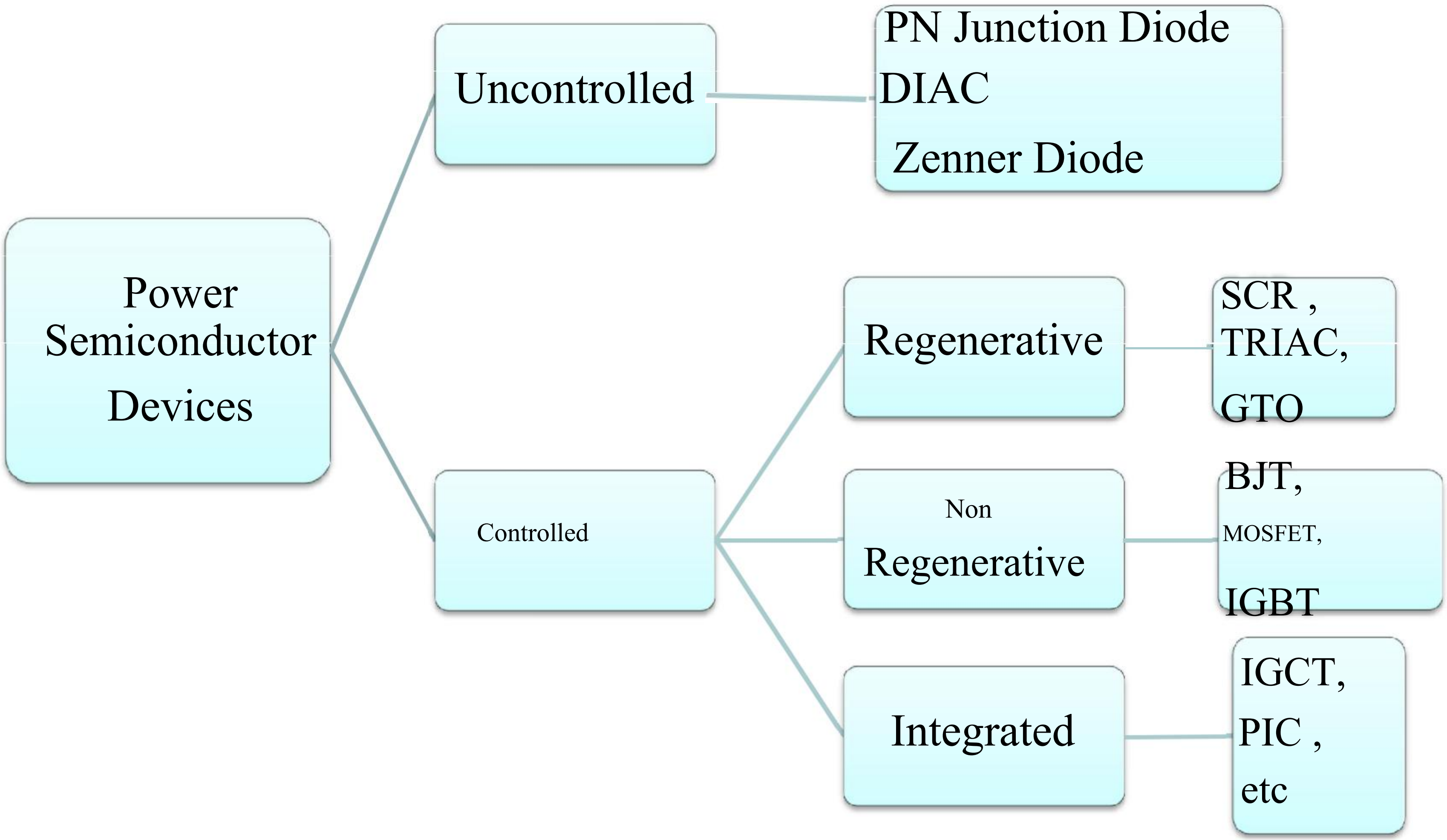
Topics to be covered:

- Introduction on power semiconductor devises
- Power diode static and dynamic characteristics
- Basic theory of operation thyristor (SCR)
- SCR Static (steady state) characteristics
- TRIAC, GTO characteristics
- Dynamic characteristics of SCR
- Power BJT steady state and switching characteristics
- Power MOSFET steady state and switching characteristics
- Power IGBT steady state and switching characteristics

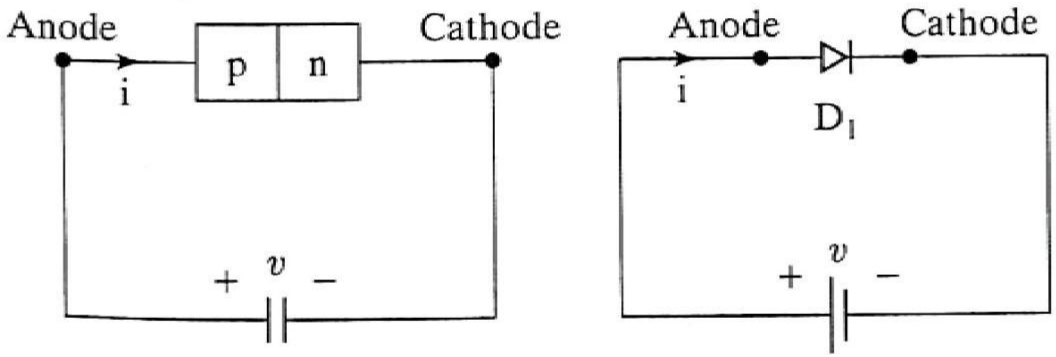
POWER DEVICES

- Voltage, current and power ratings are much higher than the conventional devises.
- Switching speed is also much higher than the conventional devices.

CLASSIFICATION



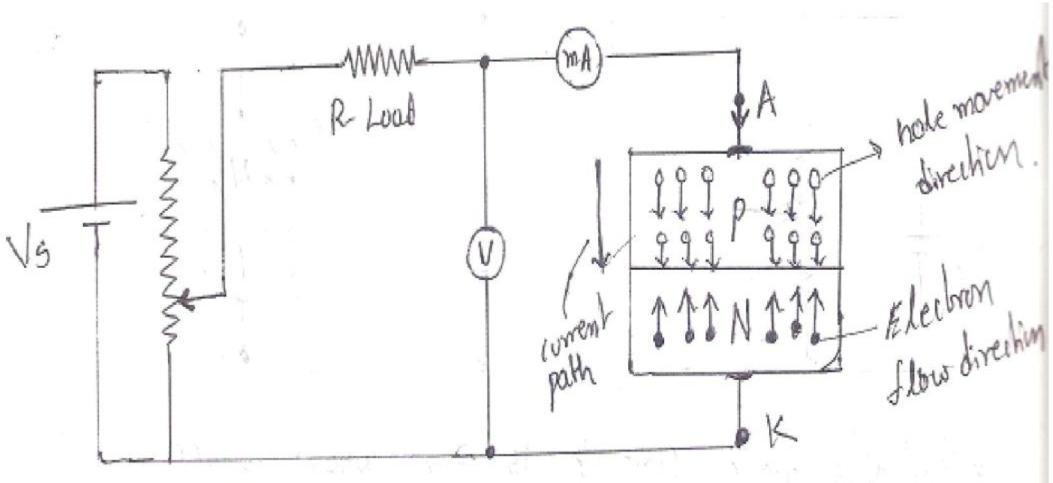
PN-JUNCTION DIODE

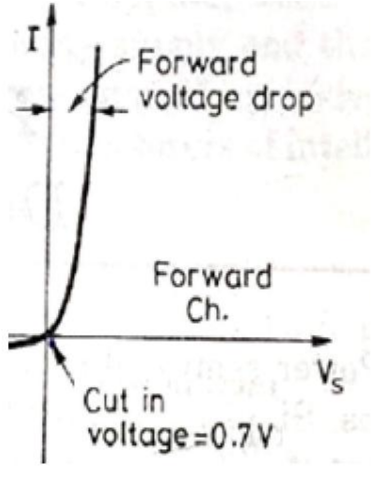


❖Forward Bias :- Diode Anode terminal is connected to more positive than the cathode terminal.

❖Reverse Bias :- Diode cathode terminal is connected to more positive than the anode terminal.

PN-JUNCTION DIODE V-I CHARACTERISTICS(FORWARD BIASED)





➢When source voltage greater than cut in or threshold or turn on voltage

diode current rises rapidly .

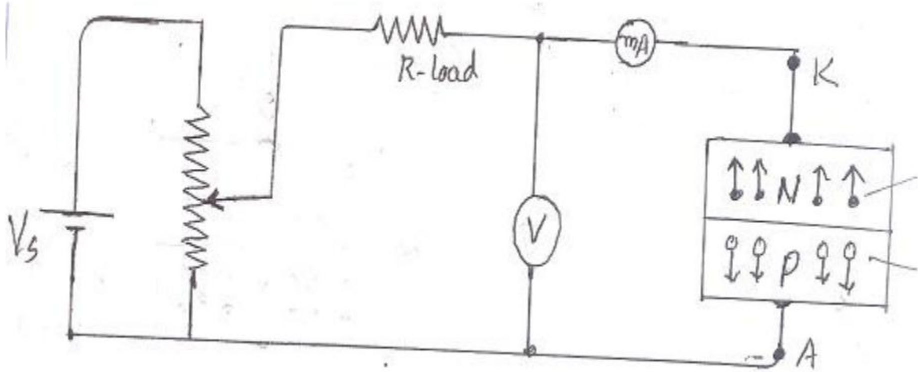
➢Diode offers less impedance in forward

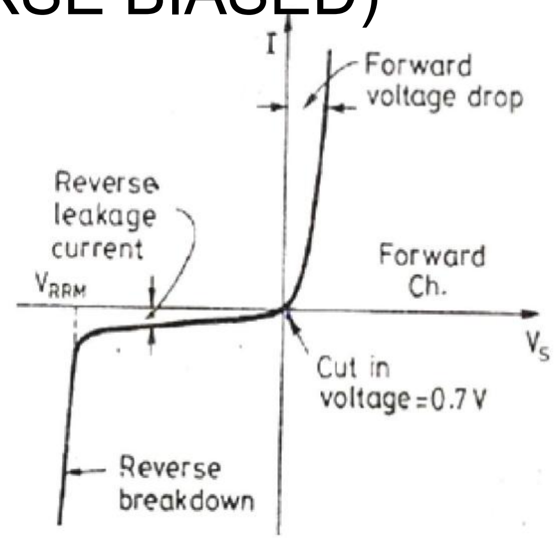
bias ➢Diode act as closed switch during forward

bias.

- Forward voltage drop across diode is typically 0.8v to 1v

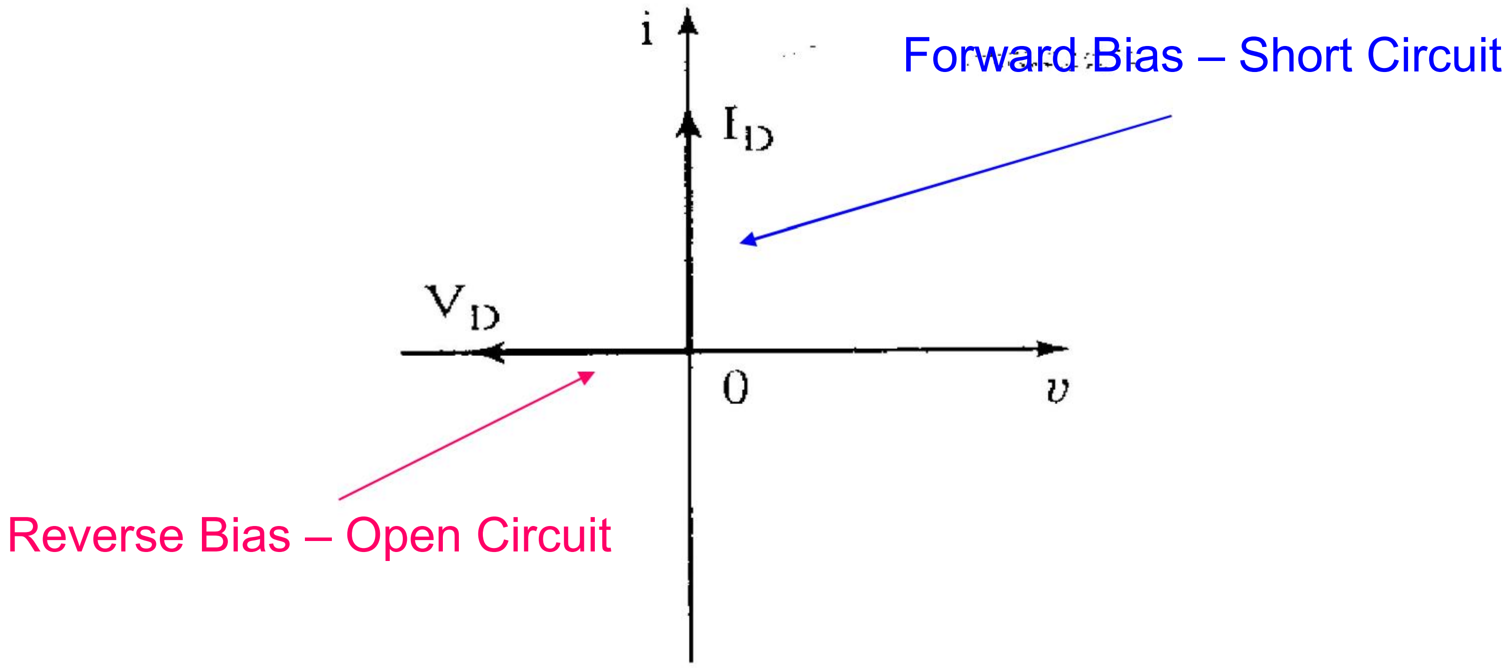
PN-JUNCTION DIODE V-I CHARACTERISTICS(REVERSE BIASED)





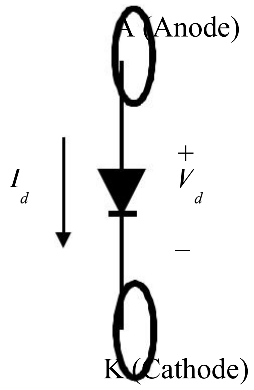
- By increasing reverse voltage across diode small amount of leakage current will flow from cathode to anode terminal.
- By keep on increasing reverse voltage at particular instant diode junction will break down and starts conduction and diode get damage.
- Diode offers high impedance in reverse bias ($V<V_{RRM}$)
- Diode act as open switch during reverse bias
- Diodes are available up to 3000A and 5KV

IDEAL DIODE V-I CHARACTERISTIC

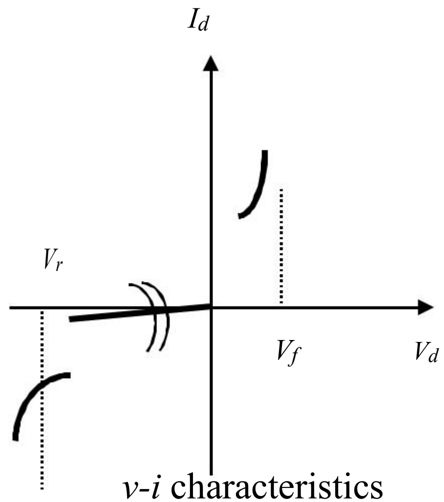


(b) Ideal

Power Diode



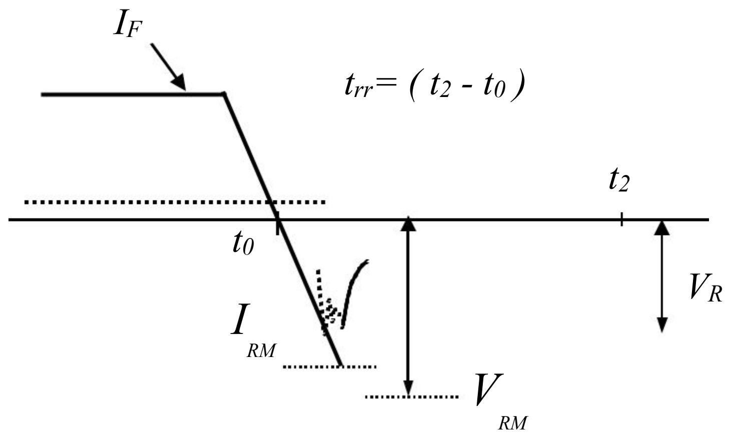
Diode: Symbol



v-*i* characteristics

- When diode is forward biased, it conducts current with a small forward voltage (V_f) across it (0.2-3V)
- When reversed (or blocking state), a negligibly small leakage current (uA to mA) flows until the reverse breakdown occurs.
- Diode should not be operated at reverse voltage greater than V_r

Reverse Recovery



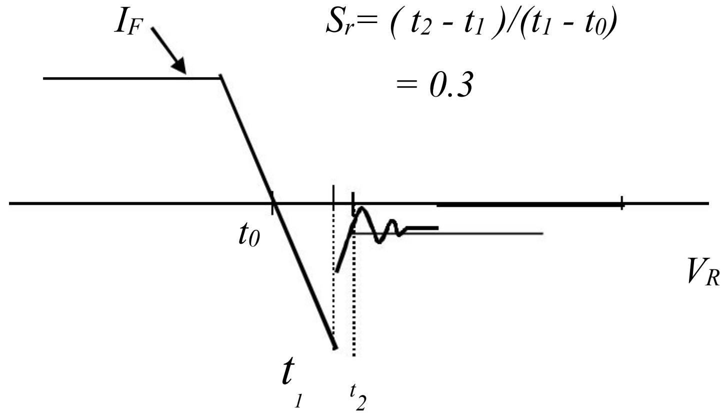
- When a diode is switched quickly from forward to reverse bias, it continues to conduct due to the *minority carriers* which remains in the p-n junction.

- The minority carriers require finite time, i.e, t_{rr} (reverse recovery time) to recombine with opposite charge and neutralise.

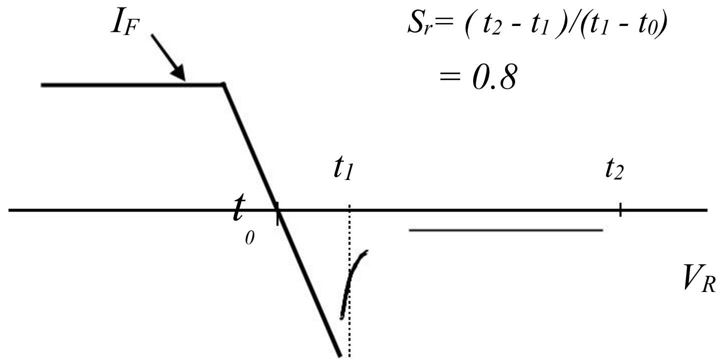
- Effects of reverse recovery are increase in switching losses, increase in voltage rating, over-voltage (spikes) in inductive loads

Softness factor, S_r

Snap-off



Soft-recovery



Types of Power Diodes

- Line frequency (general purpose):
  - On state voltage: very low (below 1V)
  - Large t_{rr} (about 25us) (very slow response)
  - Very high current ratings (up to 5kA)
  - Very high voltage ratings(5kV)
  - Used in line-frequency (50/60Hz) applications such as rectifiers

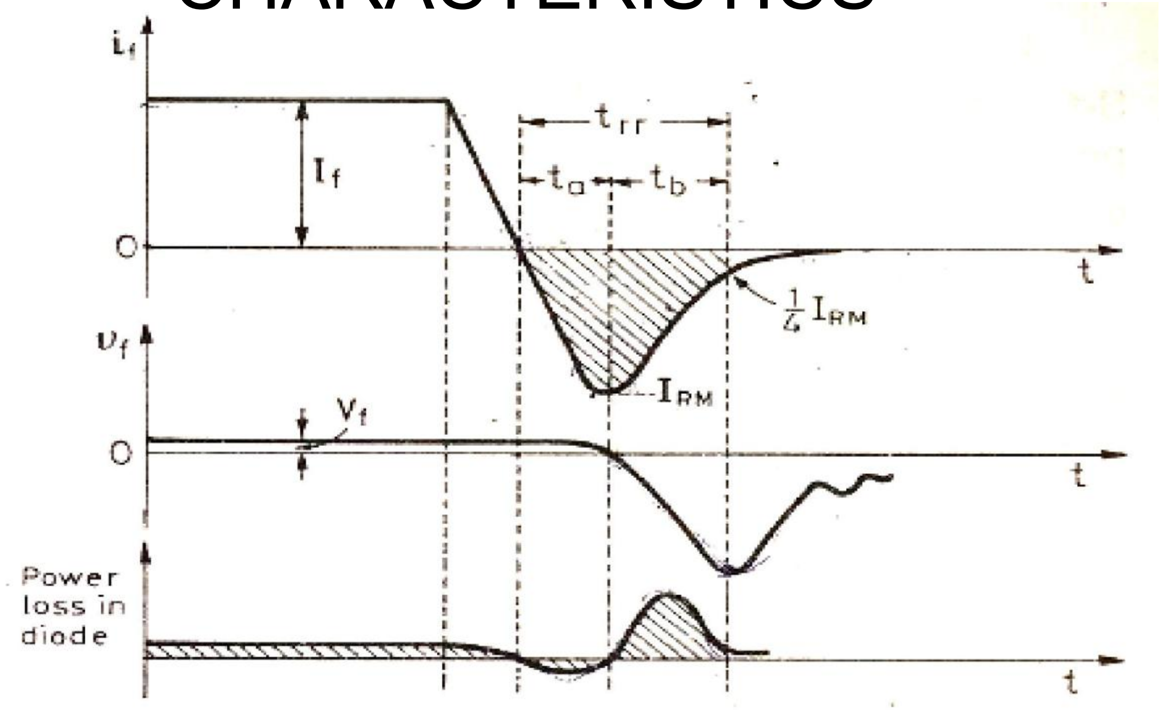
- Fast recovery
  - Very low t_{rr} (<1us).
  - Power levels at several hundred volts and several hundred amps
  - Normally used in high frequency circuits

- Schottky
  - Very low forward voltage drop (typical 0.3V)
  - Limited blocking voltage (50-100V)
  - Used in low voltage, high current application such as switched mode power supplies.

DIODE REVERSE RECOVERY CHARACTERISTICS

- After the forward diode current decays to zero, the diode continues to conduct in the reverse direction
- The reverse current flows for a time called reverse recovery time t_{rr}

DIODE REVERSE RECOVERY CHARACTERISTICS



- t_{rr} is the time required for the diode to regain its blocking capability.
- t_a is the time to remove the stored charge from the depletion region of the junction
- t_b is the time to remove the stored charge from two P N layers

TYPES OF POWER DIODES

- Based on reverse recovery time power diodes are classified as

$$t_{rr} = t_a + t_b$$

- Softness or S factor = t_b/t_a
  - S factor =1 Soft Recovery diode
  - S factor <1 fast Recovery diode

- Soft Recovery or General-purpose or line frequency diode:
  - ✓trr is 25µsec
  - ✓Available rating up to 5kV and 4KA
  - ✓Used in rectifiers, ups, battery chargers, welding and electrical traction.

Fast Recovery Diode:-

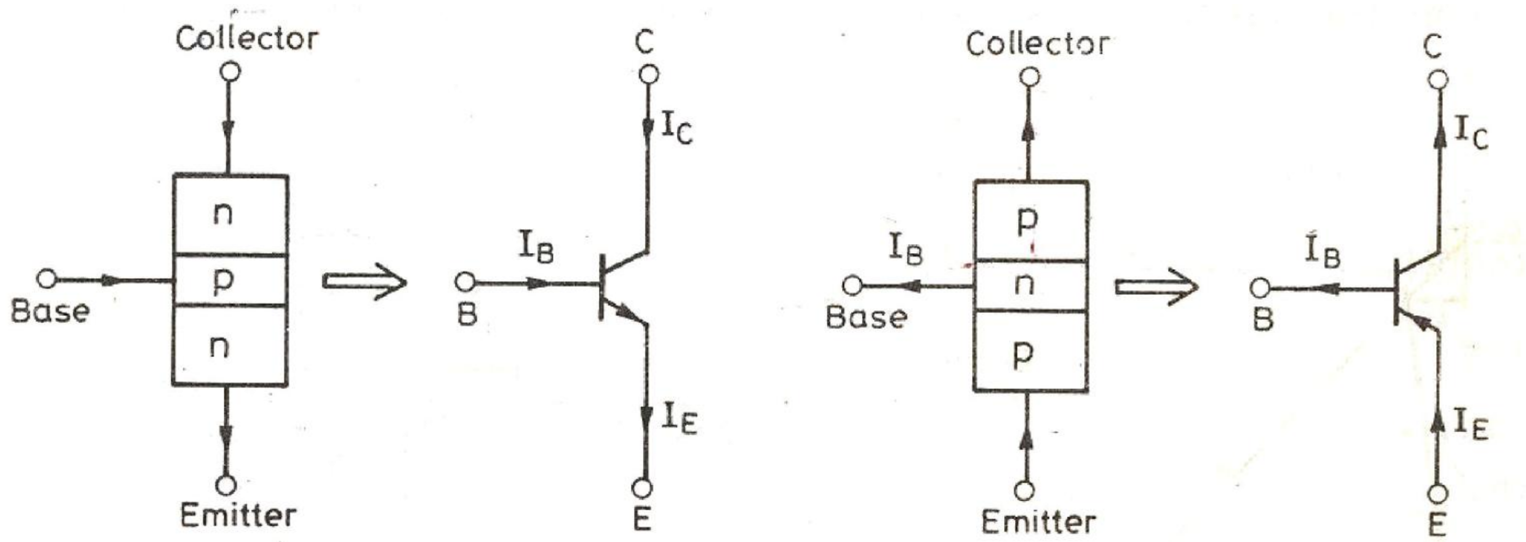
- ✓trr is less than 5μsec
- ✓Available rating up to 3kV and 3KA

Schotty Diode:-

- ✓trr is less than 50nsec
- ✓Available rating up to 400V
- ✓Used in SMPS, High Frequency

Instrumentation,   DC-DC converters etc

BJT

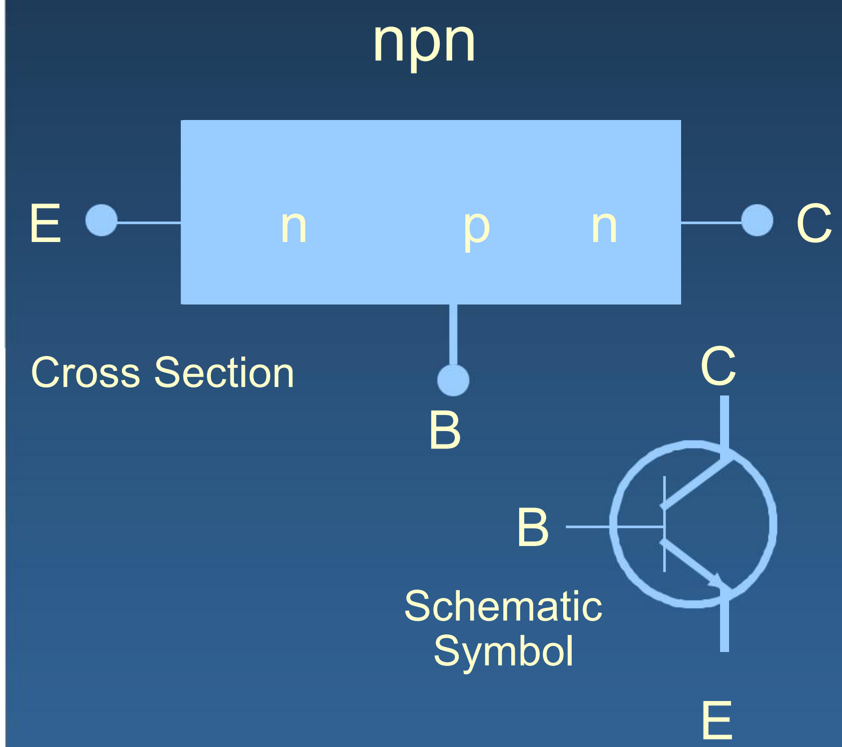

Collector
n
p
n
Base
Emitter
C
I_C
I_B
B
I_E
E
Collector
p
n
p
I_B
Base
Emitter
C
I_C
I_B
B
I_E
E

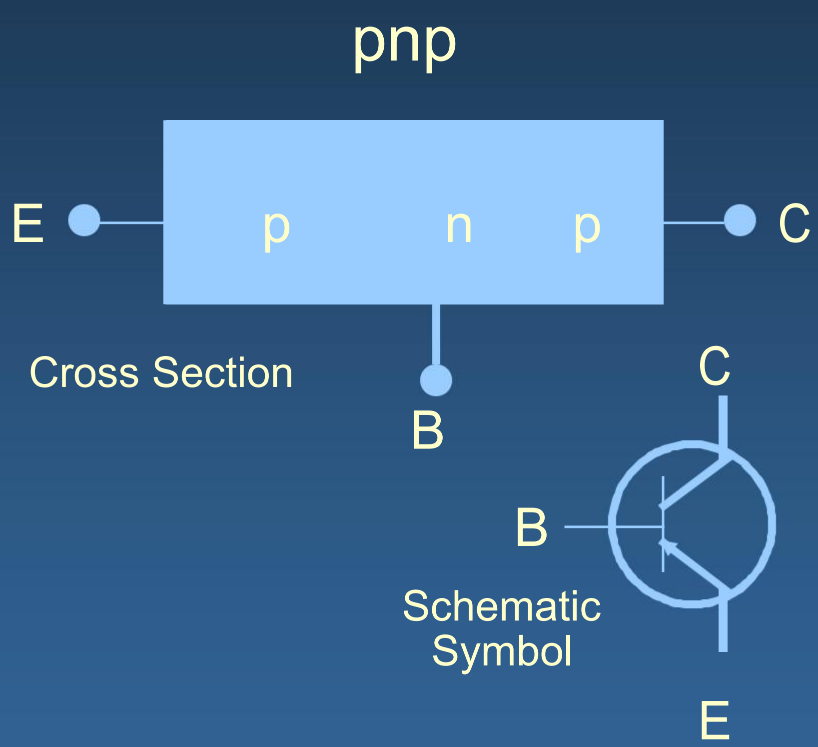
POWER BJT

- Three layer ,Two Junction npn or pnp type
- Bipolar means current flow in the device is due to the movement of BOTH holes and Electrons.

The BJT – Bipolar Junction Transistor

The Two Types of BJT Transistors:

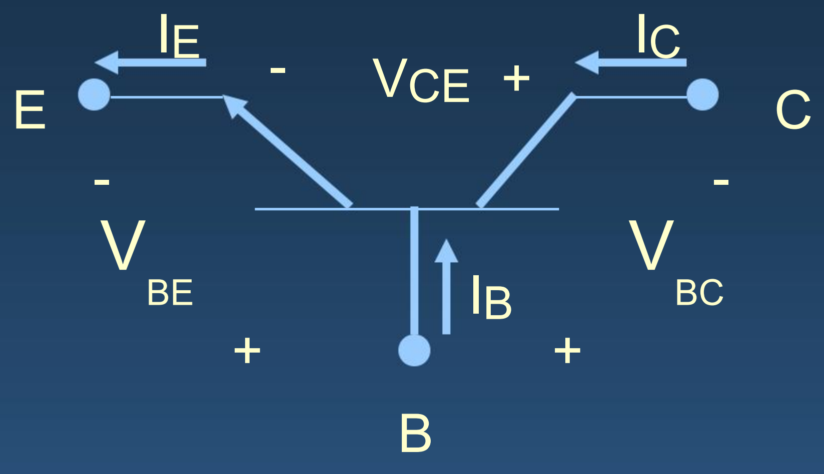




- Collector doping is usually ~ 10^6
- Base doping is slightly higher ~ $10^7 – 10^8$
- Emitter doping is much higher ~ 10^{15}

Kristin Ackerson, Virginia Tech EE
Spring 2002

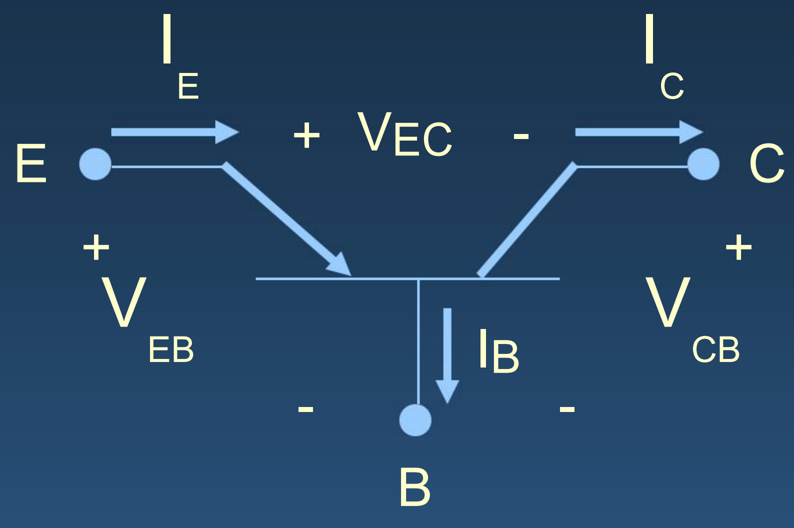
BJT Relationships - Equations



npn

$I_E = I_B + I_C$

$V_{CE} = -V_{BC} + V_{BE}$



pnp

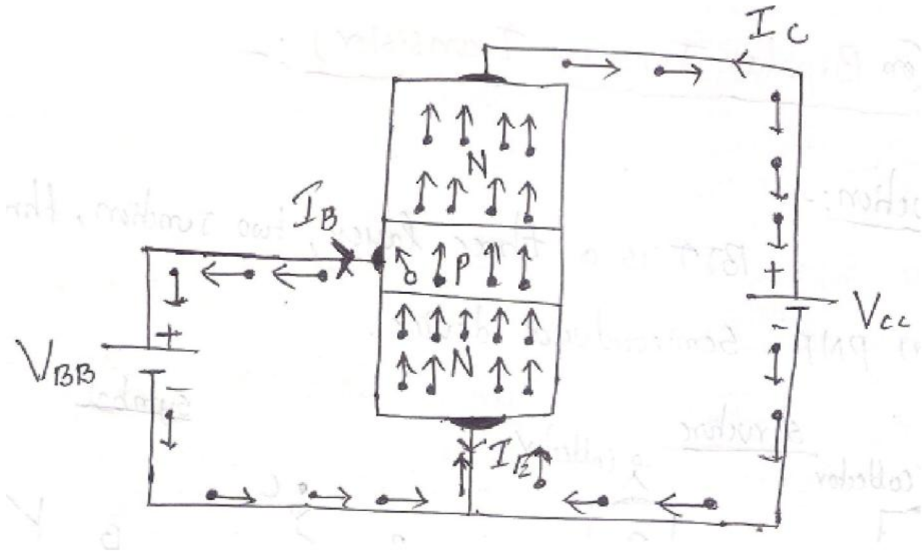
$I_E = I_B + I_C$

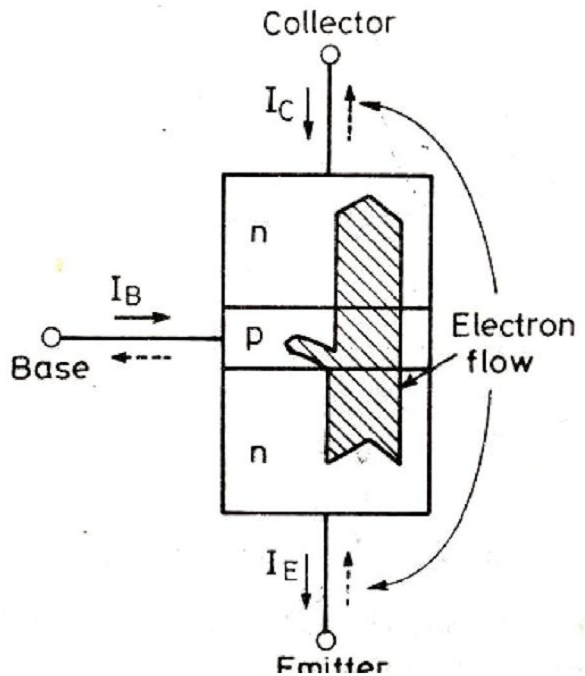
$V_{EC} = V_{EB} - V_{CB}$

Note: The equations seen above are for the transistor, not the circuit.

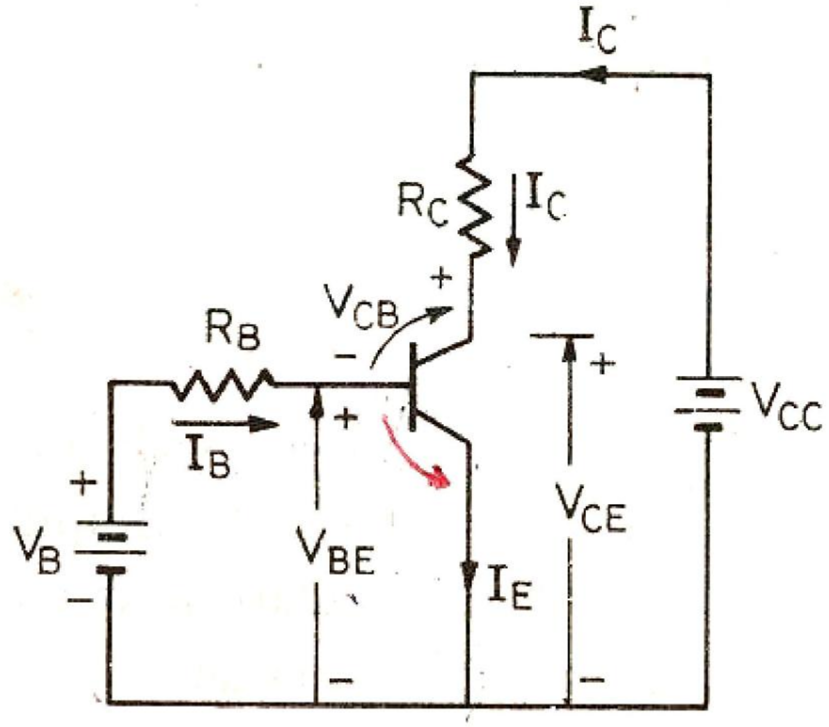
Kristin Ackerson, Virginia Tech EE
Spring 2002

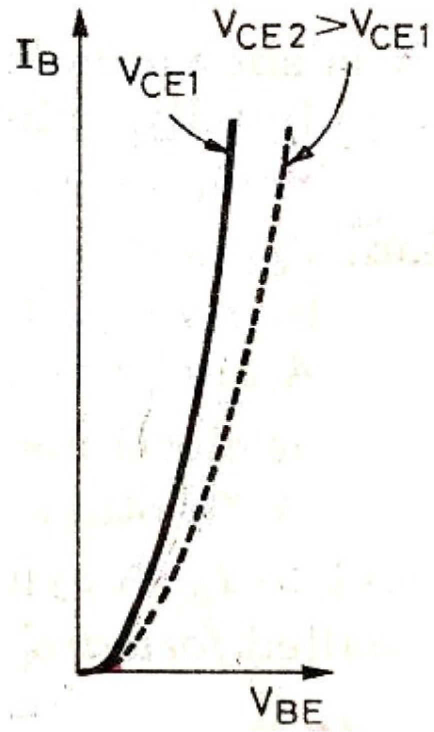
WORKING OPERATION OF BJT



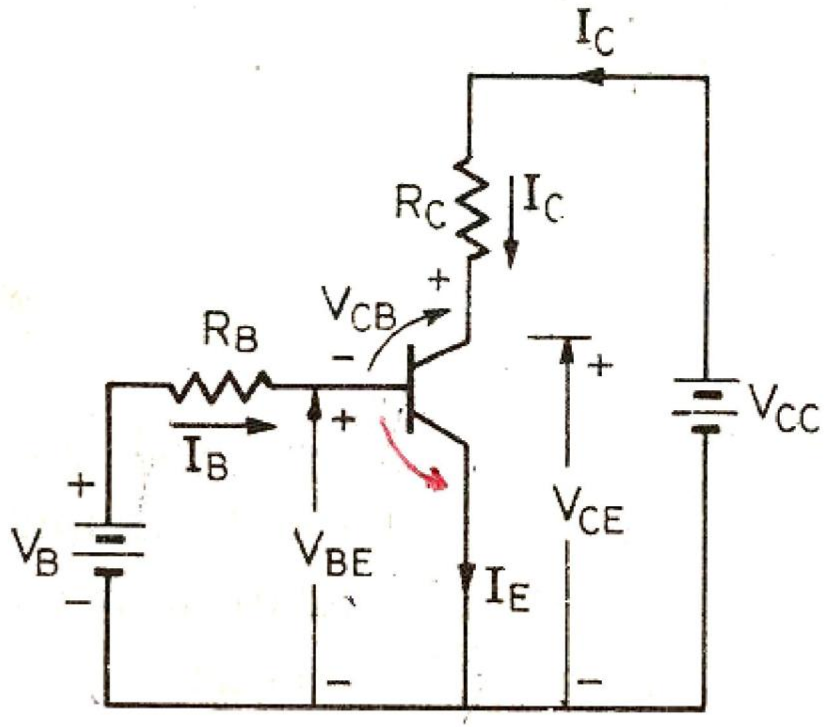


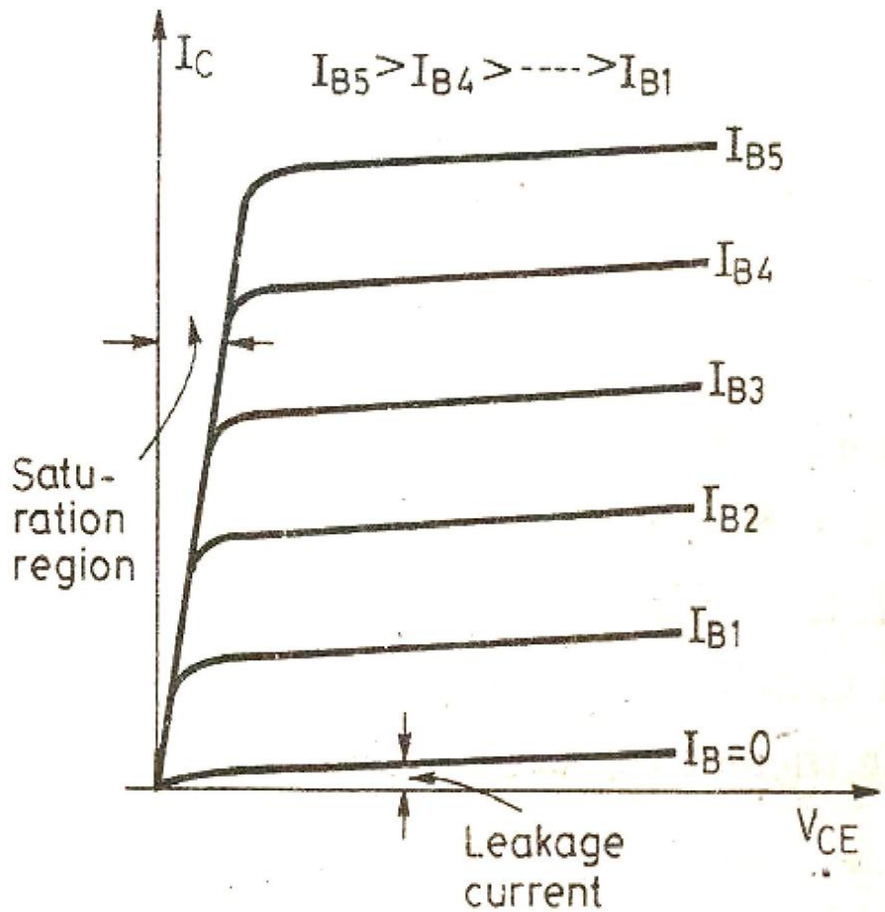
INPUT CHARACTERISTICS



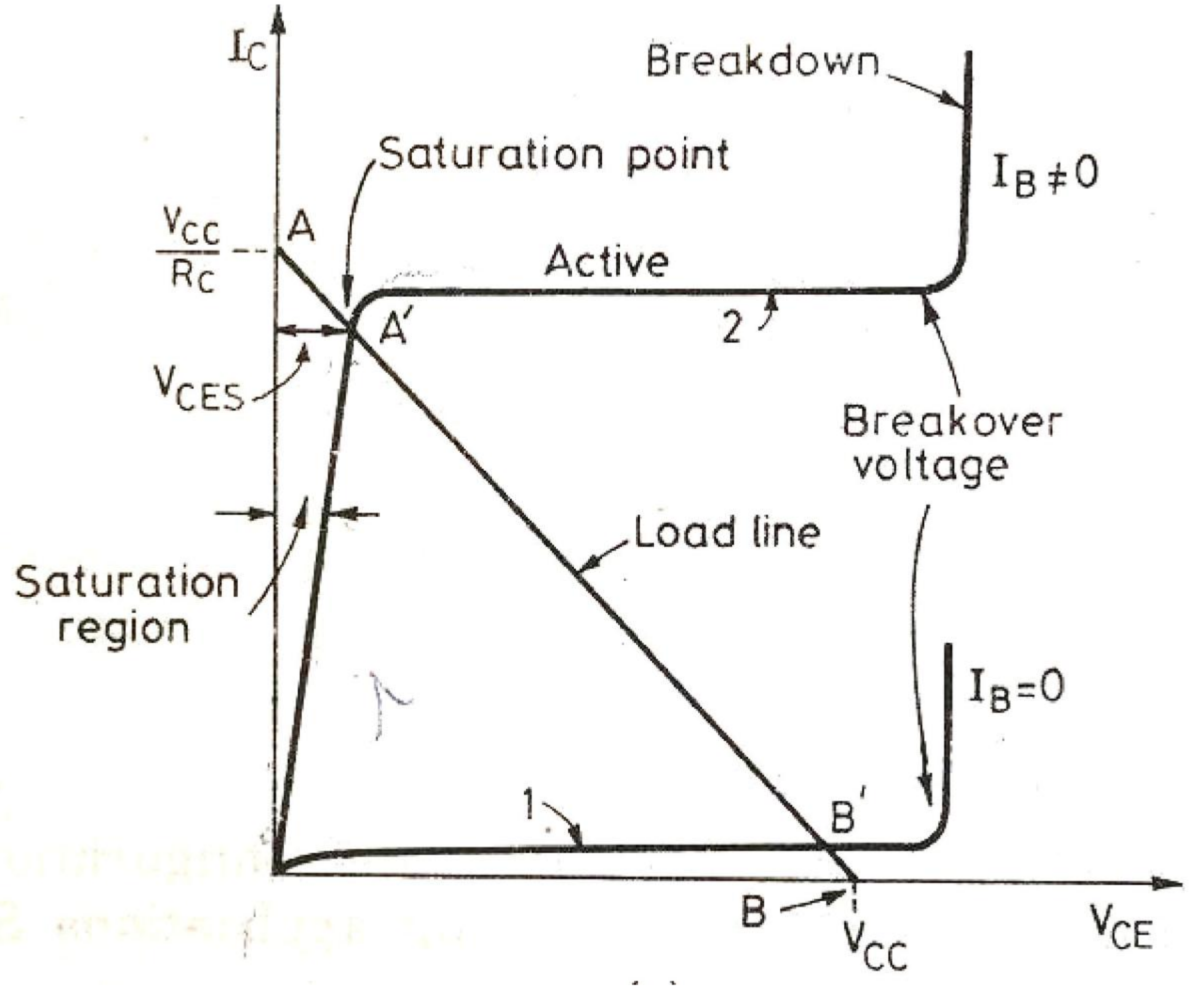


OUTPUT CHRACTRESTICS





TRANSISTOR ACT AS SWITCH



$$I_{CS} = \frac{V_{CC} - V_{CES}}{R_C}$$

$$I_{BS} = \frac{I_{CS}}{\beta}$$

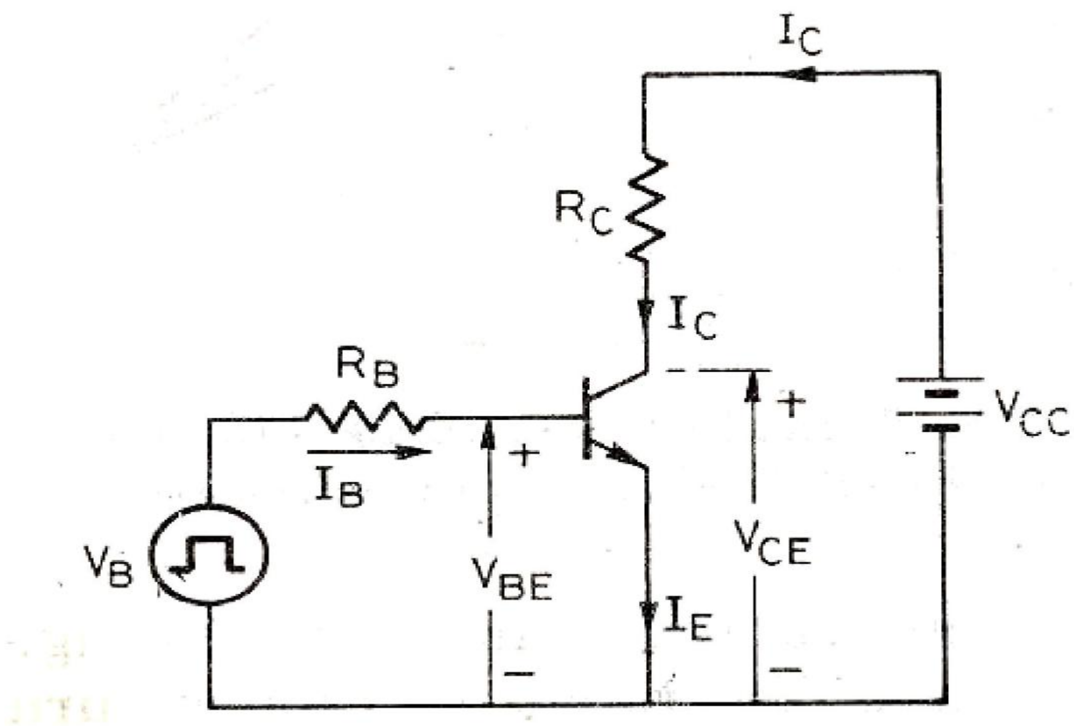
➢If base current is less than I_{BS} the transistor operates in the active region or some where between saturation and cut off region .

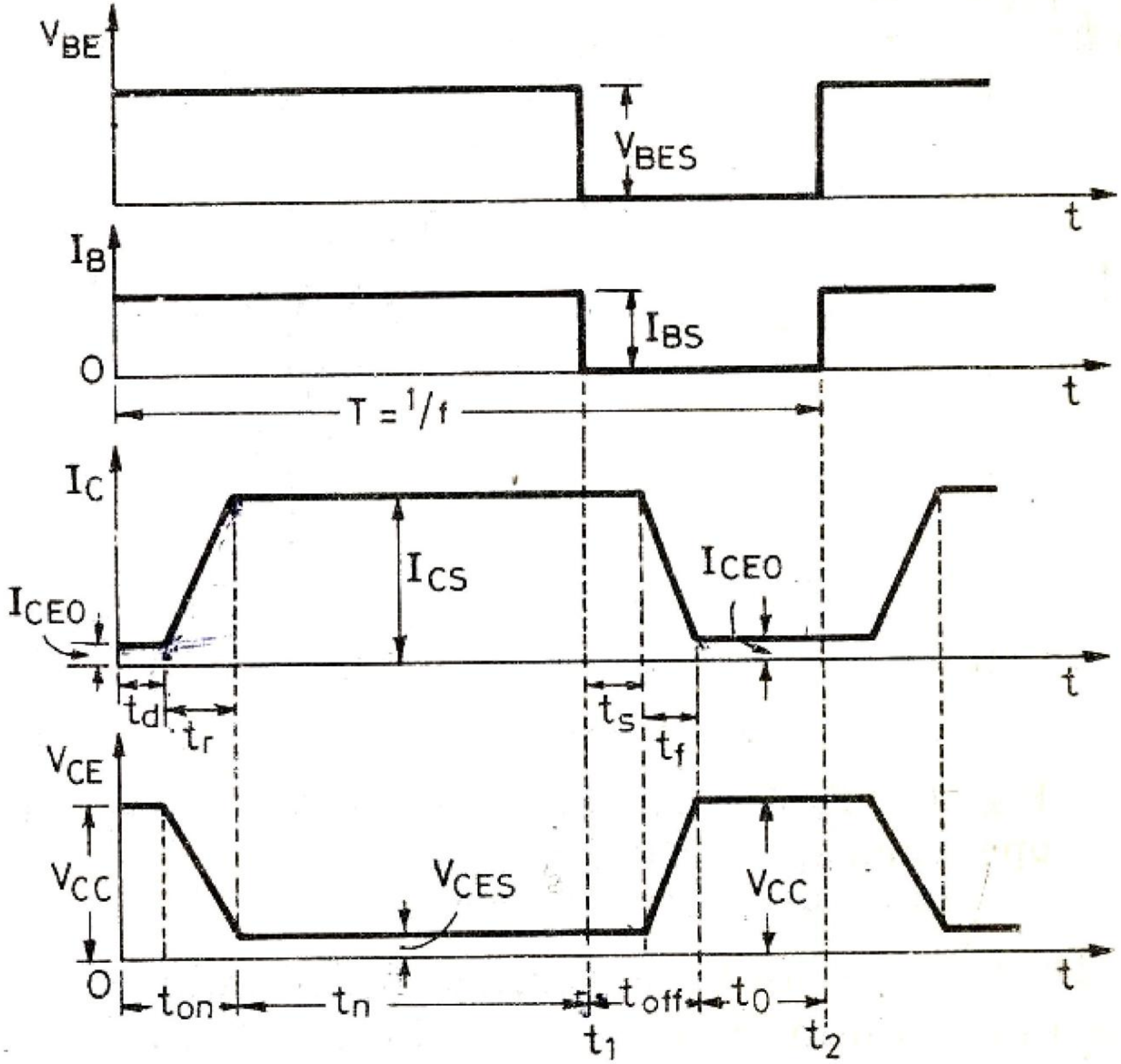
➢If base current is greater than I_{BS} hard drive of the transistor is obtained .

➢Over drive factor

$$ODF = \frac{I_B}{I_{BS}}$$

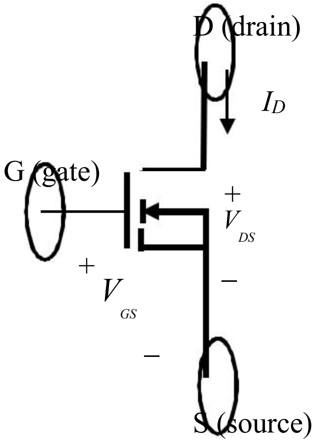
SWITCHING CHARACTERISTICS



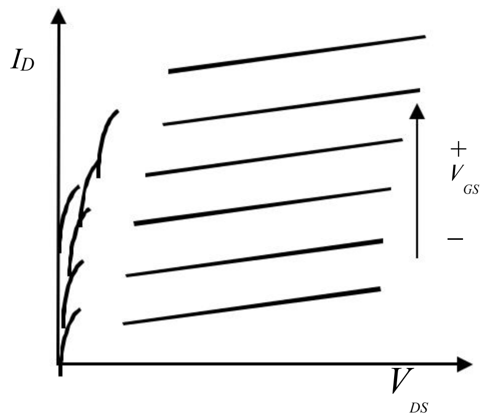


V_{BE}
V_{BES}
t
I_B
I_{BS}
O
t
T = 1/f
I_C
I_{CS}
I_{CEO}
I_{CEO}
t
t_d
t_r
t_s
t_f
V_{CE}
V_{CC}
V_{CES}
V_{CC}
O
t
t_{on}
t_n
t_{off}
t_0
t_1
t_2

Metal Oxide Silicon Field Effect Transistor (MOSFET)



MOSFET: symbol
(n-channel)



v-i characteristics

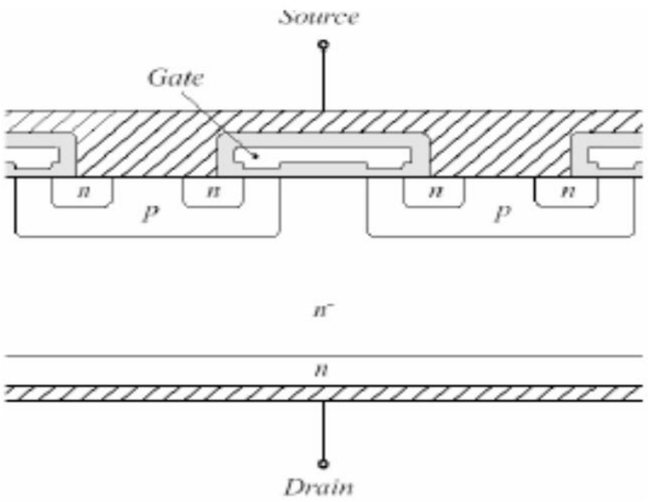
- Ratings: Voltage V_{DS}<500V, current I_{DS}<300A. Frequency f >100KHz. For some low power devices (few hundred watts) may go up to MHz range.
- Turning on and off is very simple.
  - To turn on: V_{GS} =+15V
  - To turn off: V_{GS} =0 V and 0V to turn off.
- Gate drive circuit is simple

1.4.3 Power metal- oxide- semiconductor field effect transistor—Power MOSFET

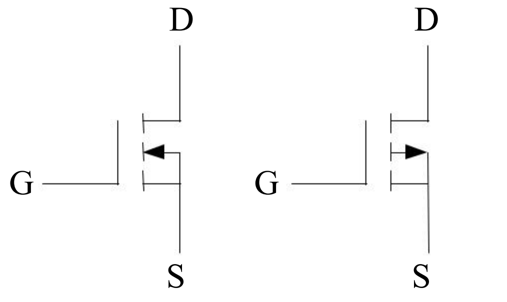
A classification

Field Effect Transistor (FET)
- Metal- onside-semiconductor FET (MOSFET) → Power MOSFET
  - n channel
  - p channel
- Junction FET (JFET) → Static induction transistor (SIT)

Basic structure



Symbol



N channel   P channel

POWER MOSFET

- Three Terminals – Drain, source And Gate
- Voltage Controlled Device
- Power MOSFET has much higher current handling capability in ampere range and drain to source blocking voltage(50-100V) than other MOSFETs
- Gate Circuit Impedance Is High (Of The Order Of Mega Ohm).Hence Gate Can Be Driven Directly From Microelectronic Circuits.
- Used In Low Power High Frequency Converters, SMPS And Inverters

MOSFET characteristics

- Basically low voltage device. High voltage device are available up to 600V but with limited current. Can be paralleled quite easily for higher current capability.

- Internal (dynamic) resistance between drain and source during on state, $R_{DS(ON)}$, , limits the power handling capability of MOSFET. High losses especially for high voltage device due to $R_{DS(ON)}$.

- Dominant in high frequency application (>100kHz). Biggest application is in switched-mode power supplies.

- Ratings: Voltage V_{DS}<500V, current I_{DS}<300A. Frequency f >100KHz. For some low power devices (few hundred watts) may go up to MHz range.

- Turning on and off is very simple.
  - To turn on: V_{GS} =+15V
  - To turn off: V_{GS} $=0$ V and 0V to turn off.

- Gate drive circuit is simple

MOSFET Terminals

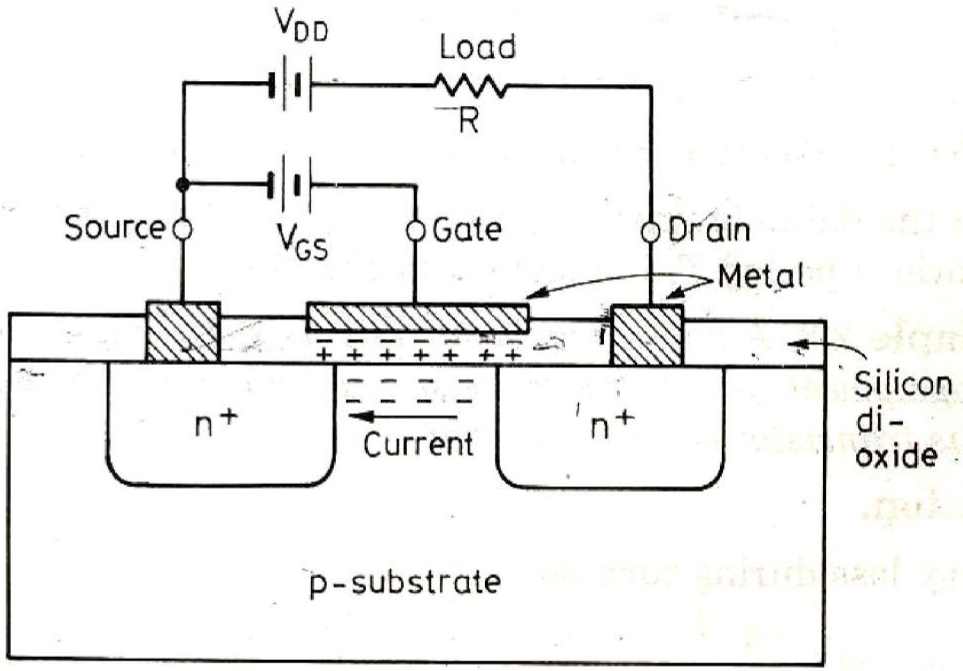
- The voltage applied to the GATE terminal determines whether current can flow between the SOURCE & DRAIN terminals.

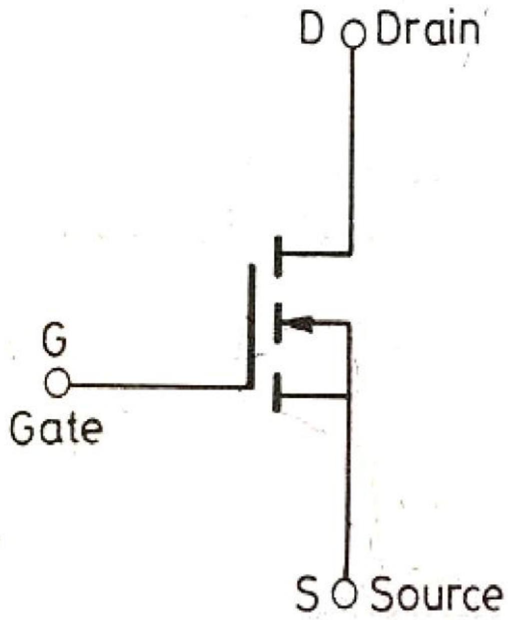
- For an n-channel MOSFET, the SOURCE is biased at a lower potential (often 0 V) than the DRAIN

(Electrons flow from SOURCE to DRAIN when VG > VT)

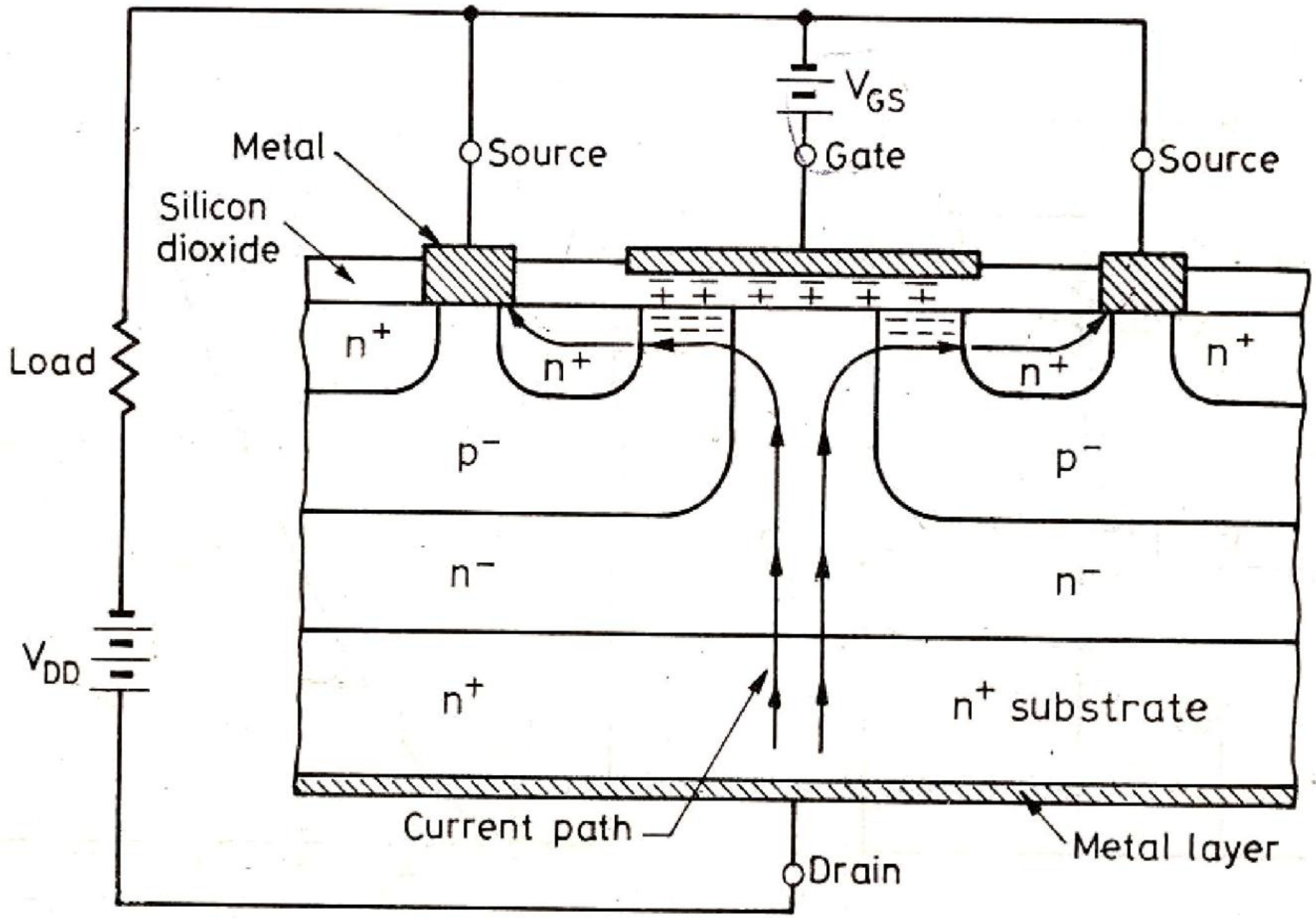
- For a p-channel MOSFET, the SOURCE is biased at a higher potential (often the supply voltage VDD) than the DRAIN
  (Holes flow from SOURCE to DRAIN when VG < VT)

MOSFET(LOW POWER)

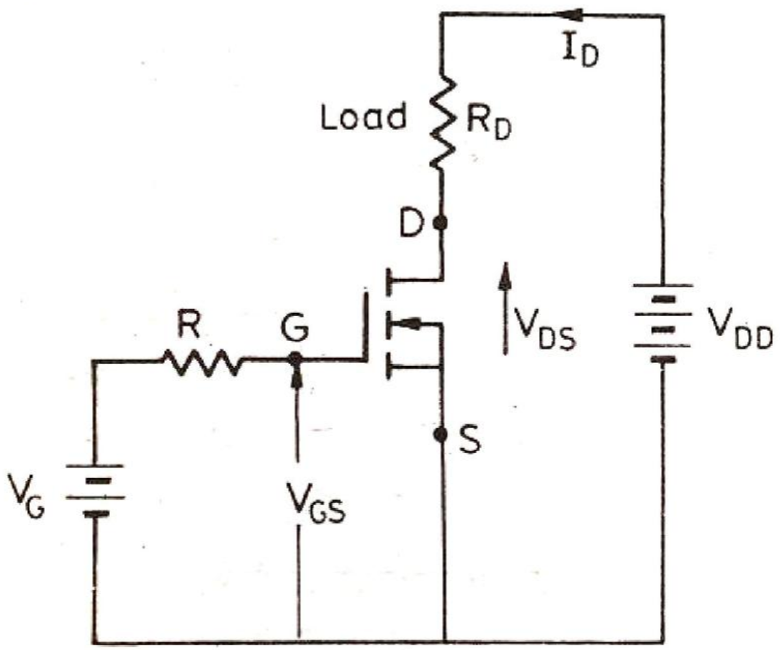


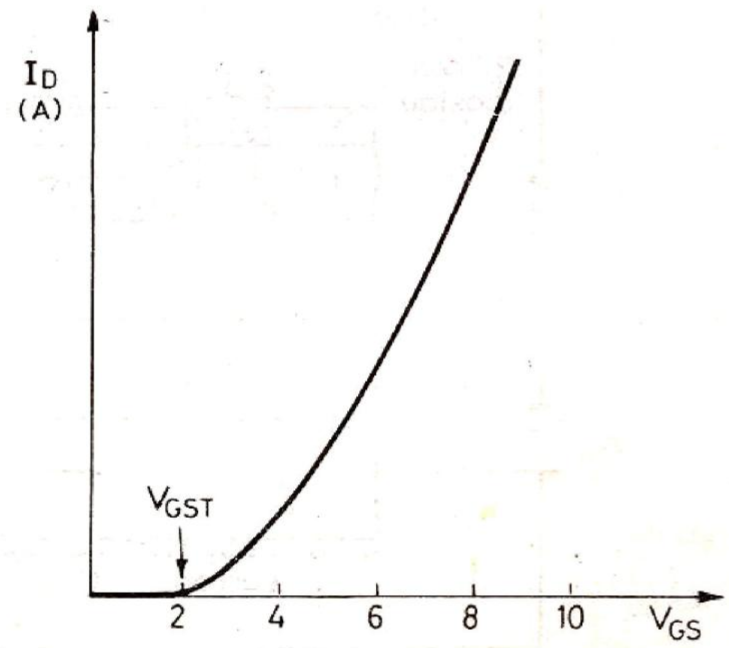


MOSFET(High Power)

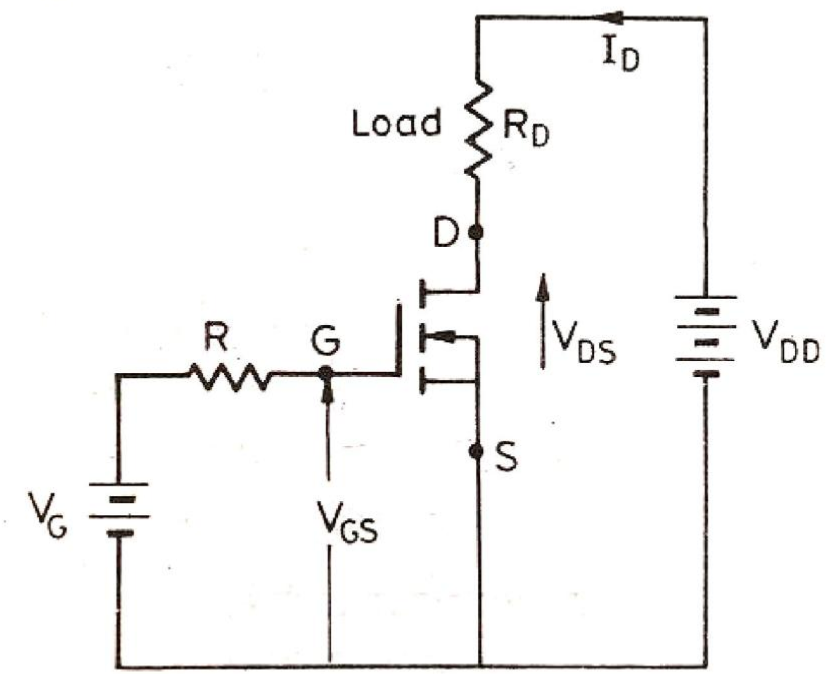


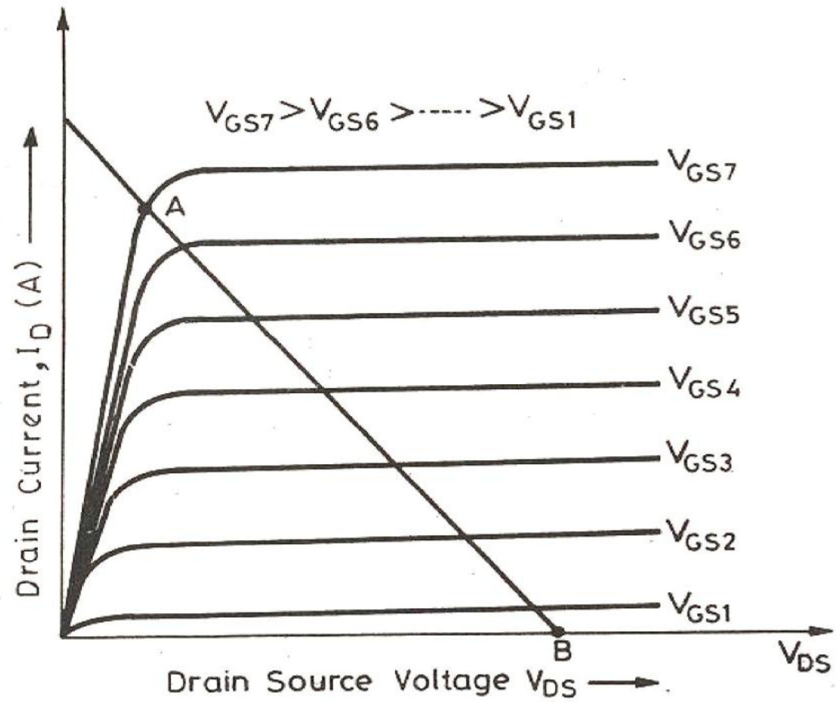
TRANSFER CHARACTERISTICS



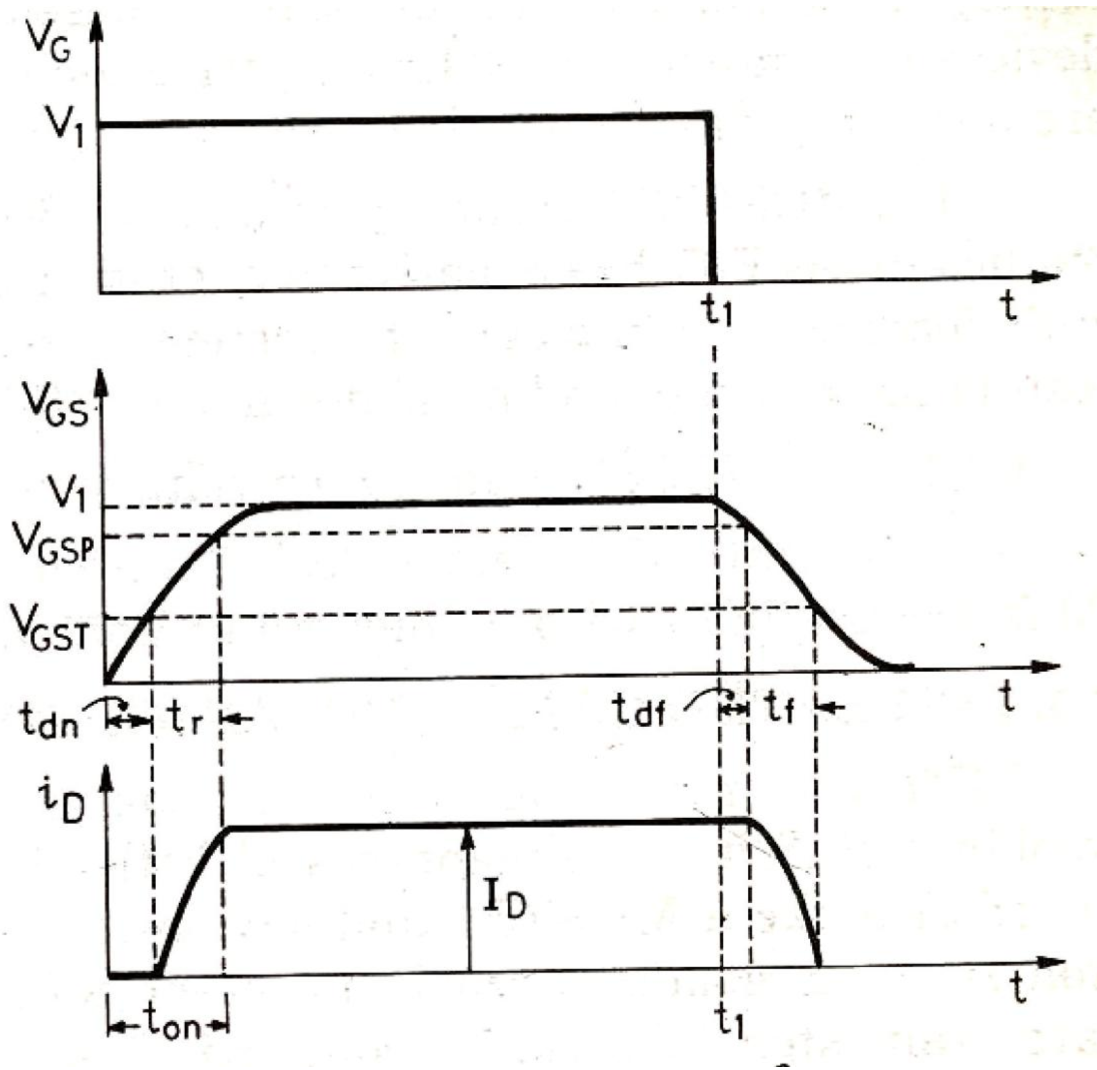


OUTPUT CHARACTERISTICS

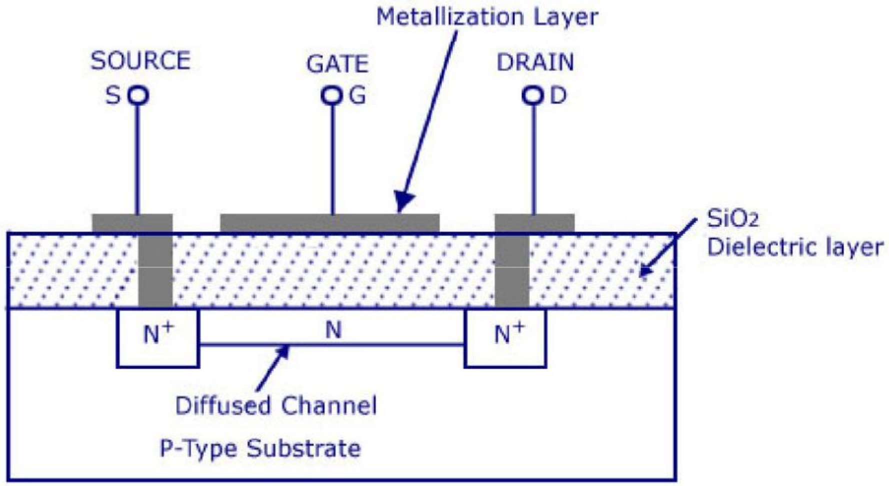




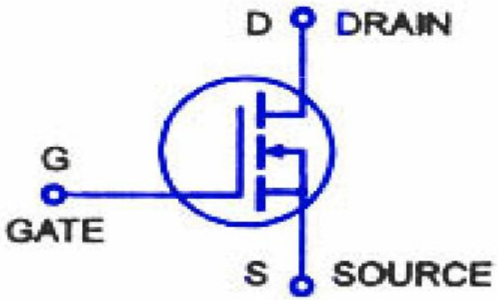
SWITCHING CHARACTERISTICS



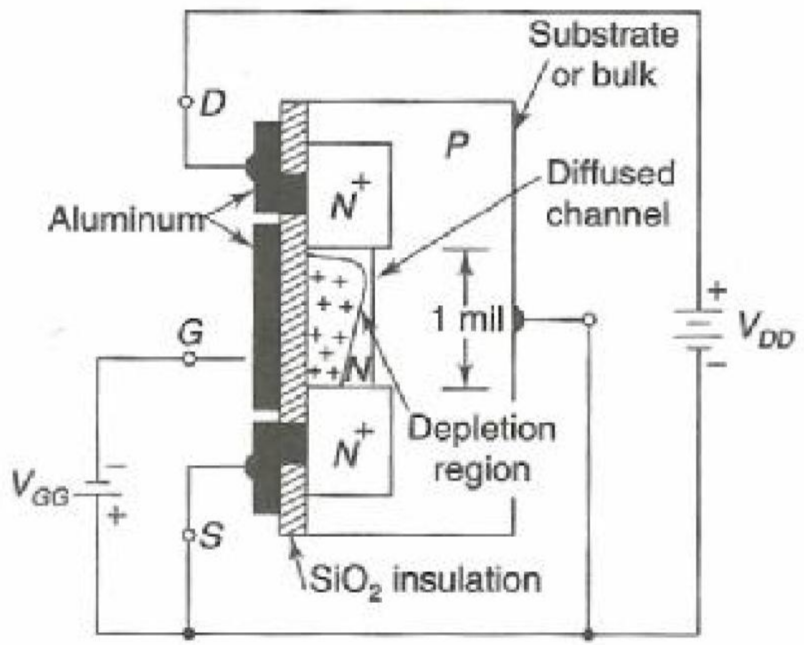
DE MOSFET

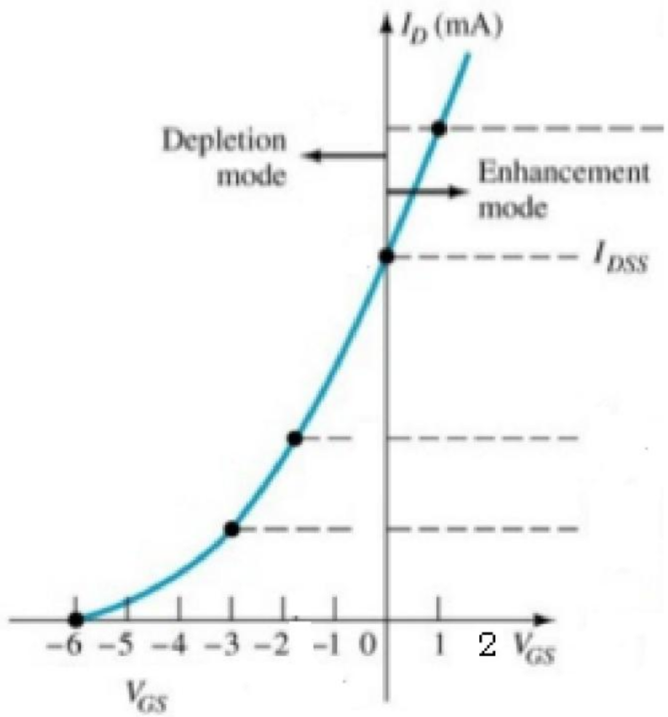


N-Channel DE-MOSFET Structure

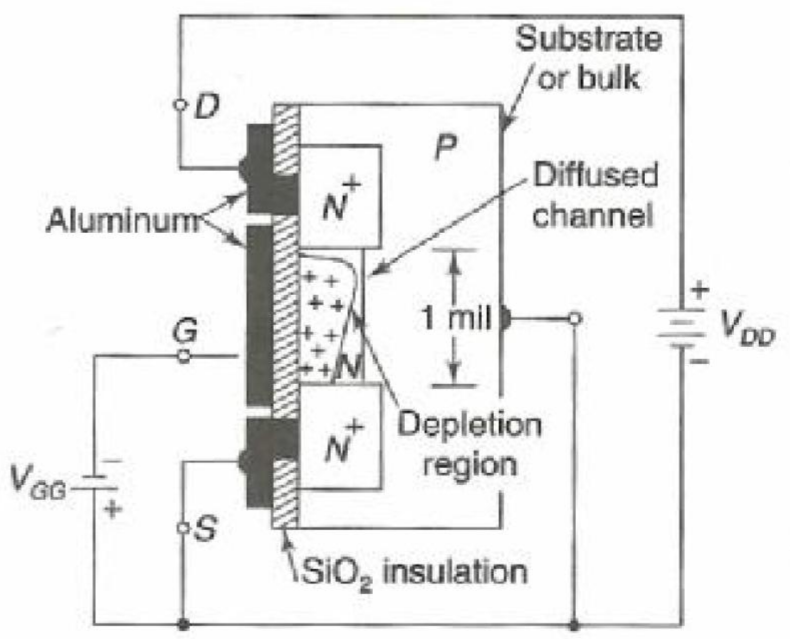


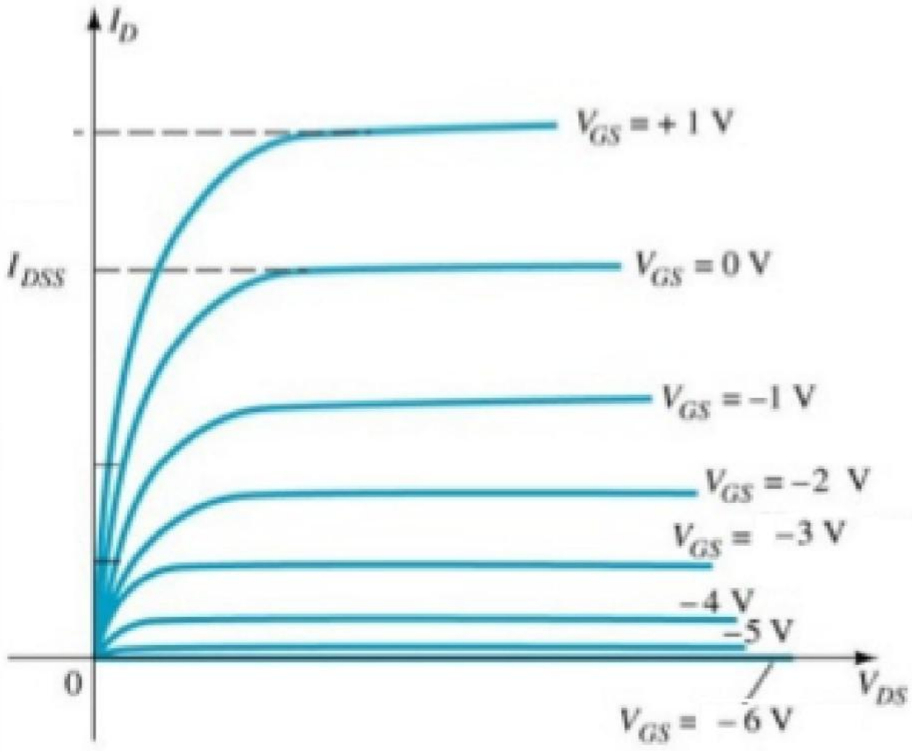
TRANSFER CHARACTERISTICS





OUTPUT CHARACTERISTICS





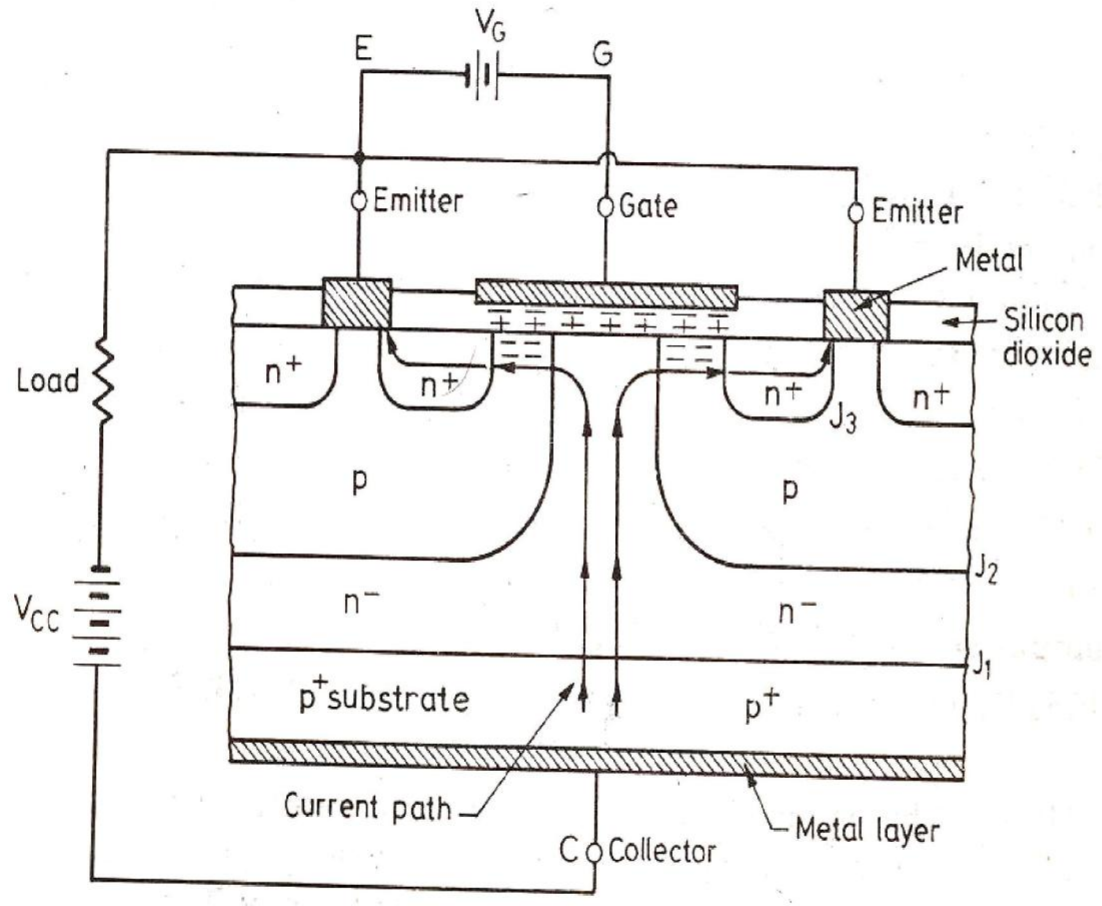
COMPARISON OF BJT AND MOSFET

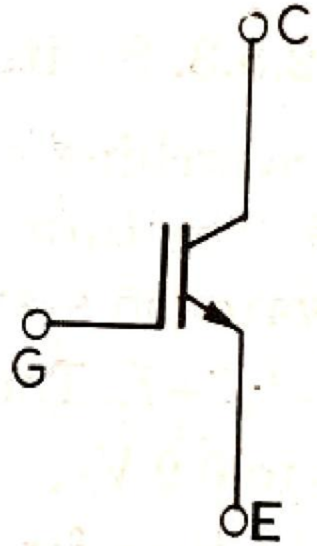
S.No	BJT	MOSFET
1	Bipolar Device	Unipolar Device
2	Low input impedance(kilo ohm)	High input impedance (mega ohm)
3	High switching losses but lower conduction losses	Lower switching losses but high on-resistance and conduction losses
4	Current controlled device	Voltage controlled device
5	Negative temperature coefficient of resistance. parallel operation is difficult. current sharing resistors should be used.	Positive temperature coefficient of resistance. parallel operation is easy
6	Secondary breakdown occurs.	Secondary breakdown does not occur.
7	Available with ratings 1200v,800a	Available with ratings 500v,140a

INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

- COMBINES THE BEST QUALITIES OF BOTH BJT AND MOSFET
- HAS HIGH INPUT IMPEDANCE AS MOSFET AND HAS LOW ON-STATE POWER LOSS AS IN BJT
- OTHER NAMES
  - ✓ MOSIGT (METAL OXIDE INSULATED GATE TRANSISTOR),
  - ✓ COMFET (CONDUCTIVELY-MODULATED FIELD EFFECT TRANSISTOR),
  - ✓ GEMFET (GAIN MODULATED FIELD EFFECT TRANSISTOR),
  - ✓ IGT(INSULATED GATE TRANSISTOR)

IGBT BASIC STRUCTURE



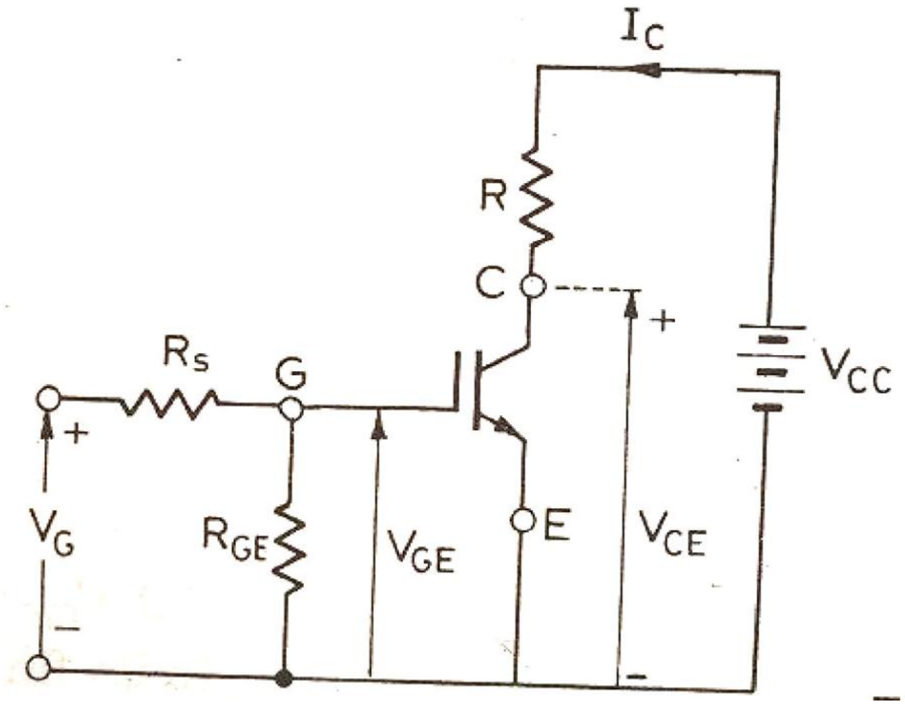


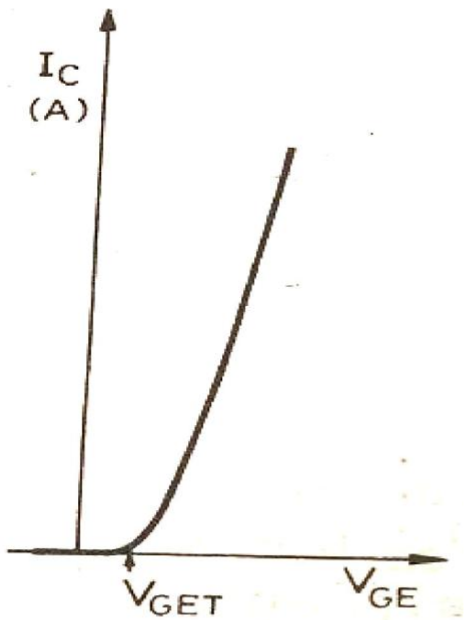
Insulated Gate Bipolar Transistor (IGBT)

- Combination of BJT and MOSFET characteristics.
  - Gate behaviour similar to MOSFET - easy to turn on and off.
  - Low losses like BJT due to low on-state Collector-Emitter voltage (2-3V).

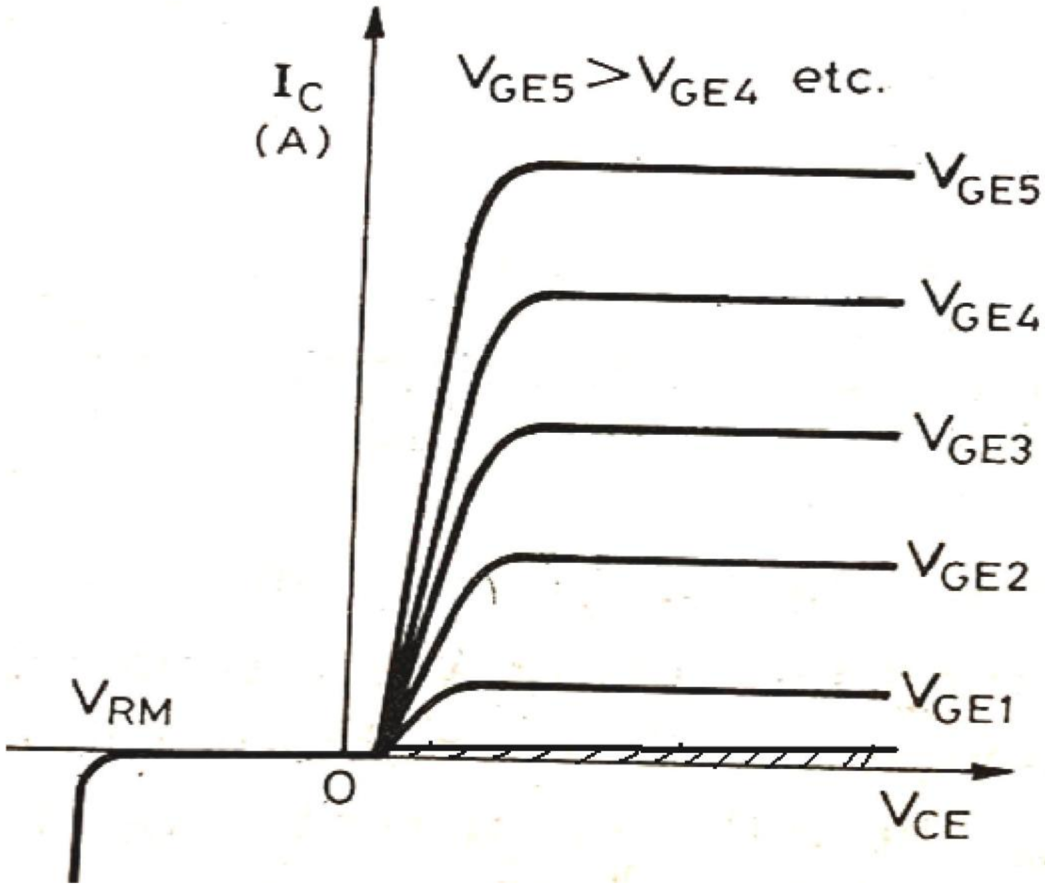
- Ratings: Voltage: V_{CE}<3.3kV, Current,: I_C<1.2kA currently available. Latest: HVIGBT 4.5kV/1.2kA.
- Switching frequency up to 100KHz.
  Typical applications: 20-50KHz.

TRANSFER CHARACTERISTICS

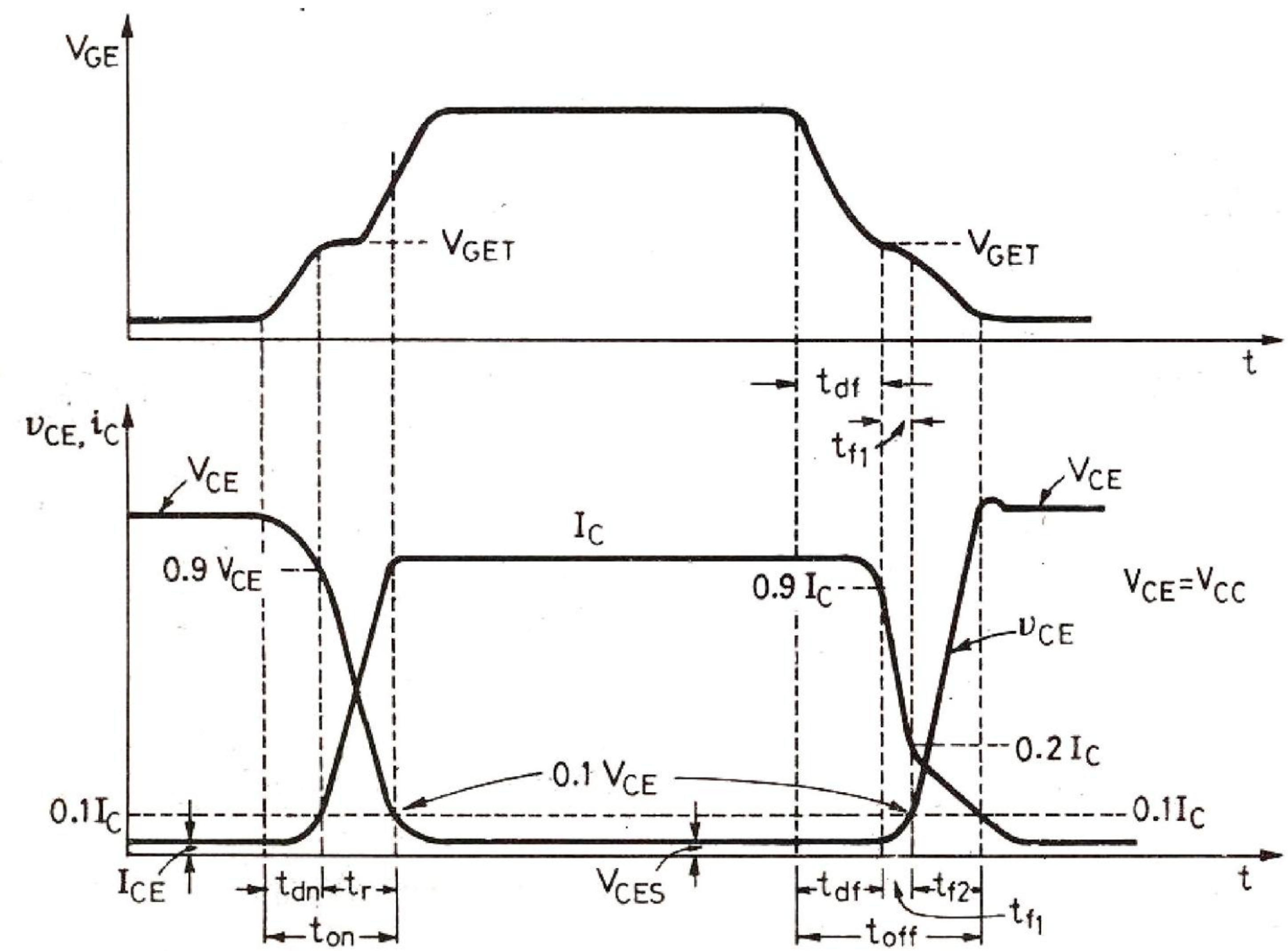




OUTPUT CHARACTERISTICS



DYNAMIC CHARACTERISTICS



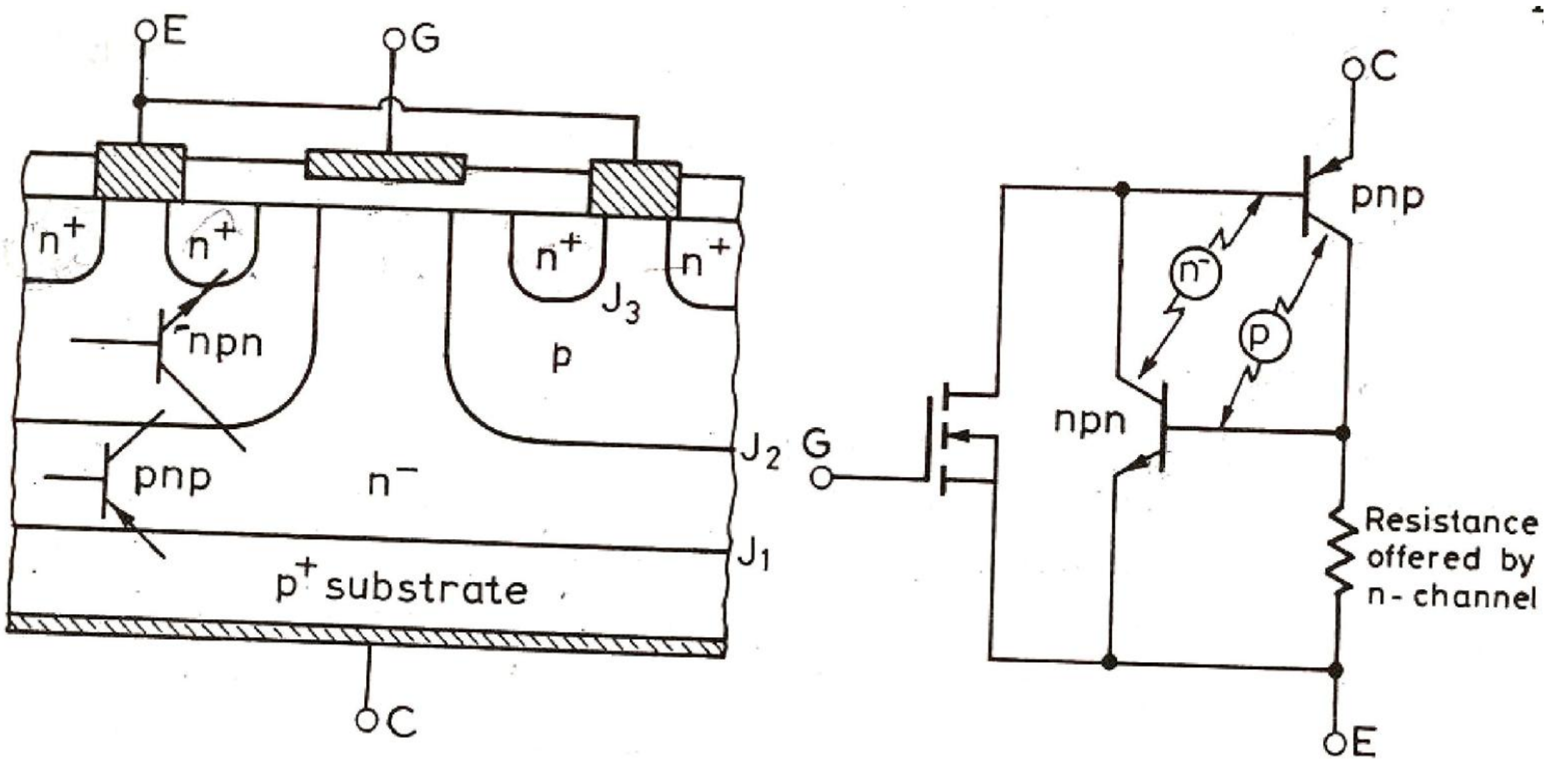
COMPARISON OF IGBT WITH MOSFET

S.No	MOSFET	IGBT
1.	Three terminals are Gate, source and drain.	Three terminals are Gate, emitter and collecto
2.	High input impedance	High input impedance
3.	Voltage controlled device	Voltage controlled device
4.	Ratings available up to 500V,140A	Ratings available up to 1200V,500A
5.	Operating frequency is up to 10Mhz	Operating frequency is up to 10khz
6.	With rise in Temperature, the increase in on-state resistance in MOSFET is mor pronounced than IGBT. SO, on-state voltage drop and losses rise rapidly i MOSFET than in IGBT rise in temperature.	
7.	with rise in voltage, the increment in on-state voltage drop is more dominant i MOSFET than it is in IGBT. this means IGBTS can be designed for highe voltage ratings than MOSFETS.	

APPLICATIONS OF IGBT

- DC AND AC MOTOR DRIVES
- UPS SYSTEMS,POWER SUPPLIES
- DRIVES FOR SOLENOIDS,RELAYS AND CONTACTORS

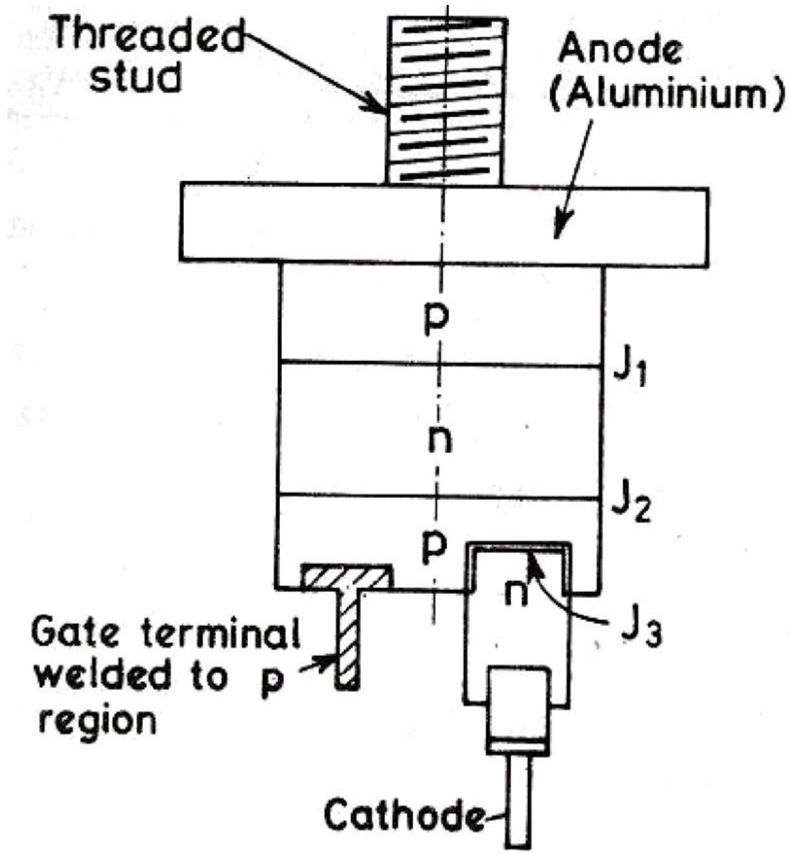
IGBT EQUIVALENT CIRCUIT



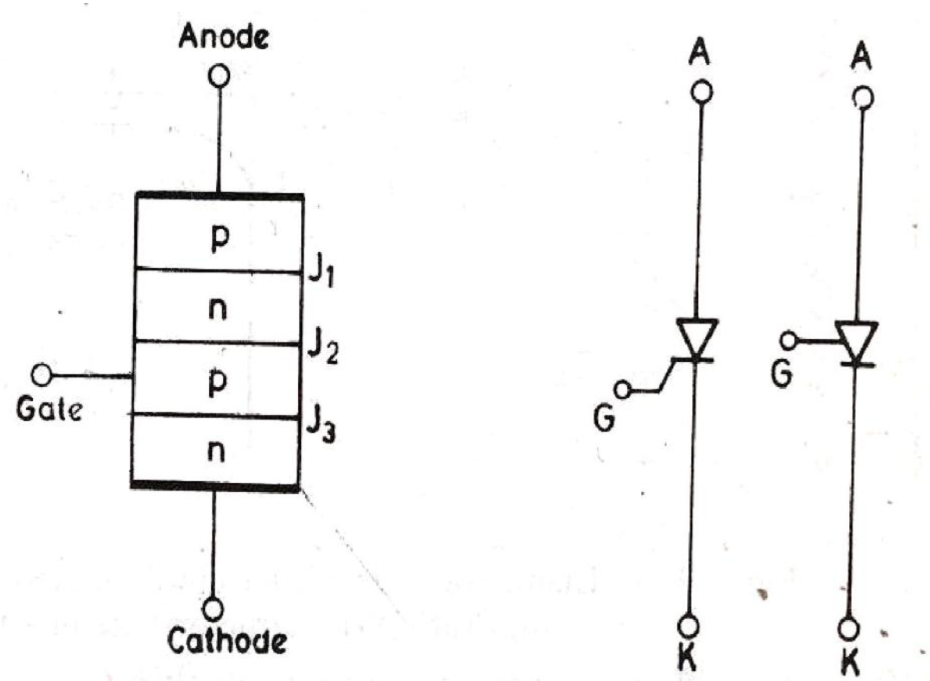
THYRISTOR FAMILY DEVISES

- SCR (Silicon Controlled Rectifier)
- TRIAC(Bidirectional thyristor)
- DIAC (Bidirectional thyristor)
- SUS (Silicon Unilateral Switch)
- SCS (Silicon Controlled Switch)
- LAT (Light Activated Thyristor)
- GTO (Gate turn off Thyristor)
- RCT (Reverse Conduction Thyristor)
- SITHS (Static Induction Thyristor)

THYRISTOR


Threaded stud
Anode (Aluminium)
p
J1
n
J2
p
n
J3
Gate terminal welded to p region
Cathode

THYRISTOR STRUCTURE AND SYMBOL



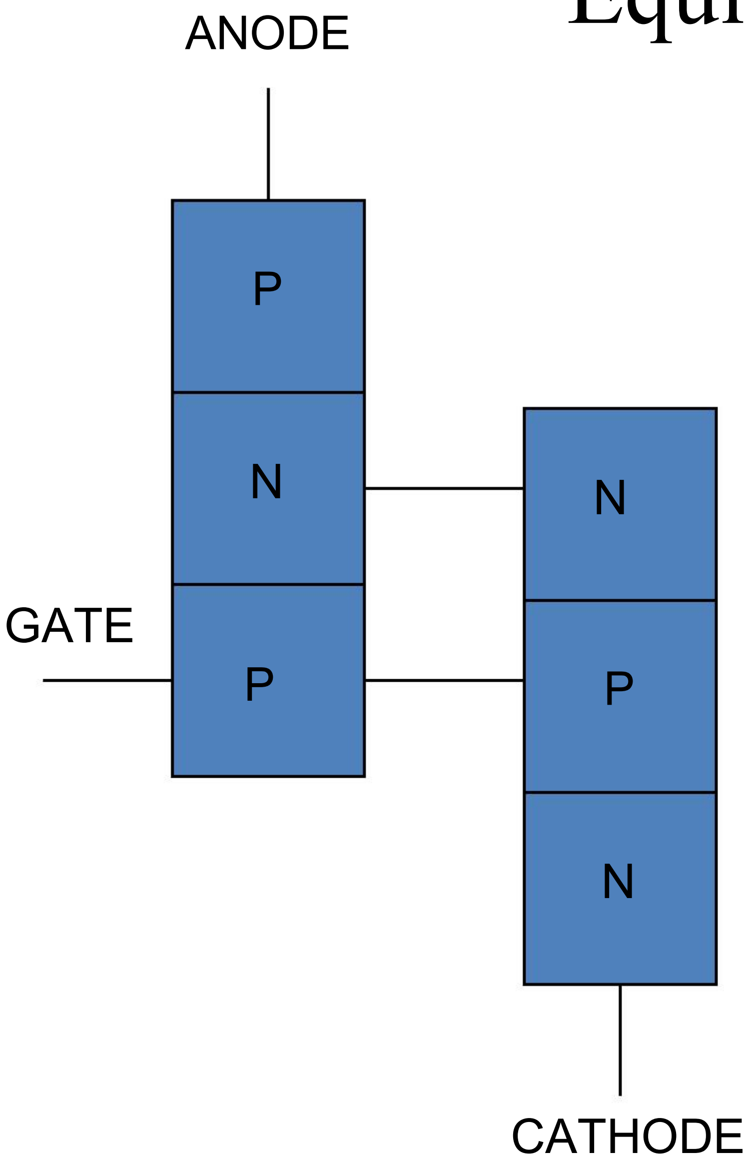
SILICON CONTROLLED RECTIFIER (SCR)

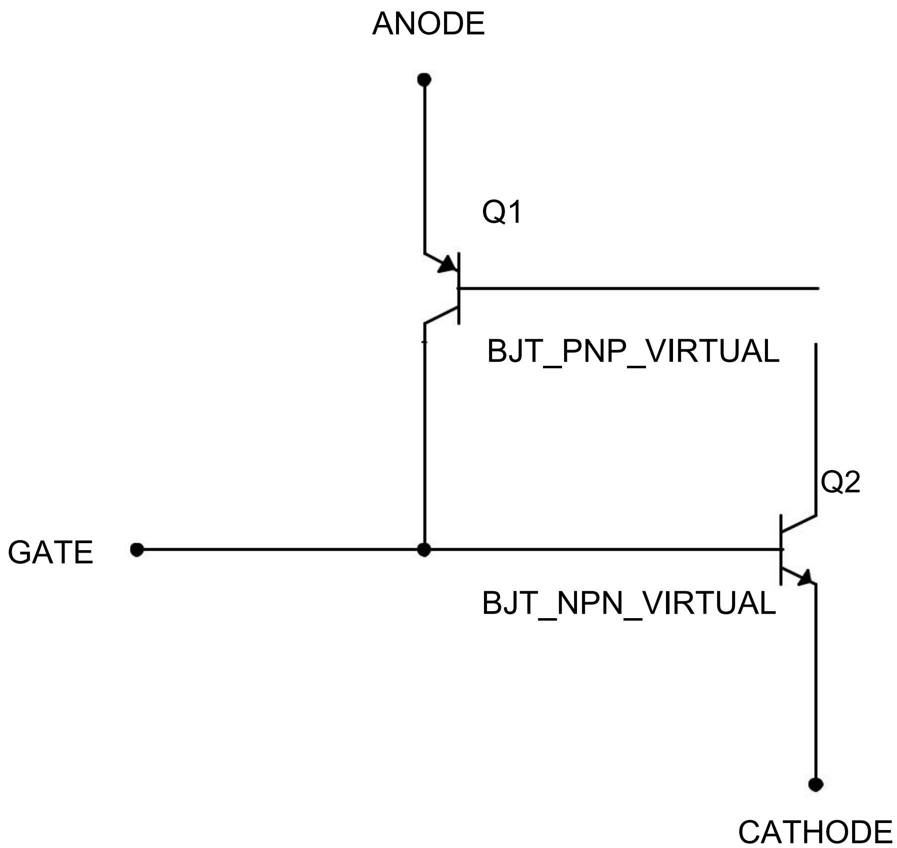
- Three terminal, four layers (P-N-P-N)
- Can handle high currents and high voltages, with better switching speed and improved breakdown voltage .
- Name ‘Thyristor’, is derived by a combination of the capital letters from THYRatron and transISTOR.
- Has characteristics similar to a thyratron tube But from the construction view point belongs to transistor (pnp or npn device) family.

SCR/ Thyristor

- An SCR (Thyristor) is a “controlled” rectifier (diode)
- SCR is an unidirectional device
- Thyristor also blocks the current flow from anode to cathode until it is triggered into conduction by proper gate signal between gate and cathode terminals

Equivalent Circuit

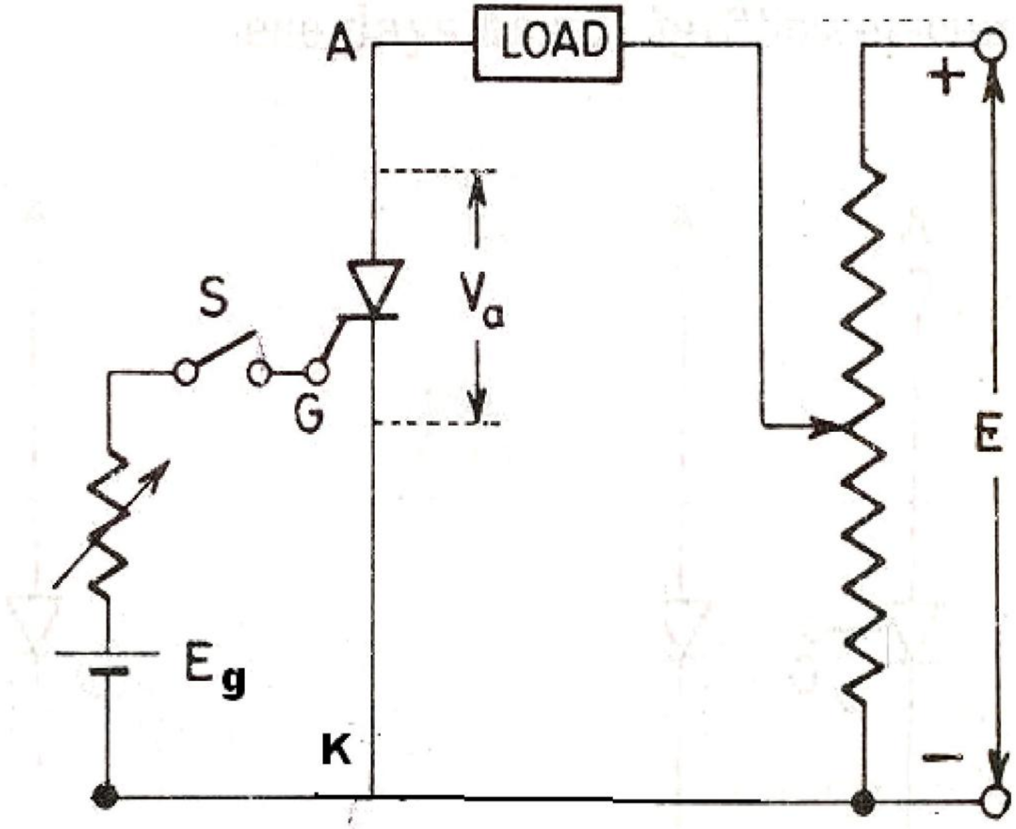




SCR OPERATING REGIONS

- Reverse blocking mode
- Forward blocking mode
- Forward conduction mode

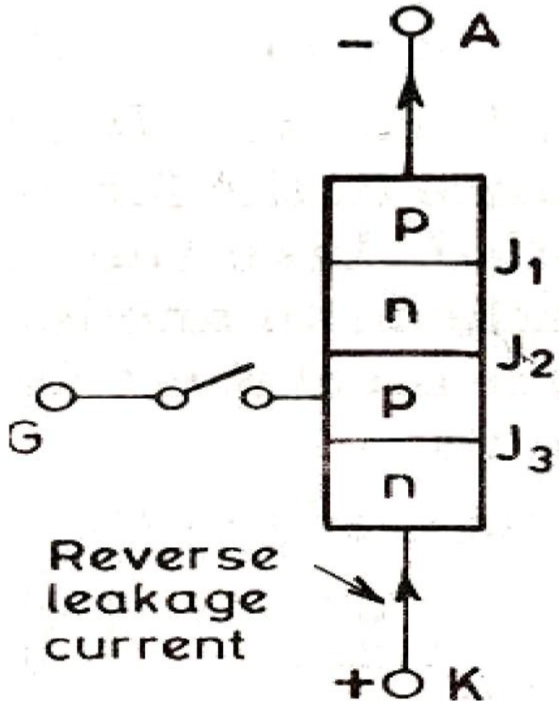
STATIC V-I CHARACTERISTICS

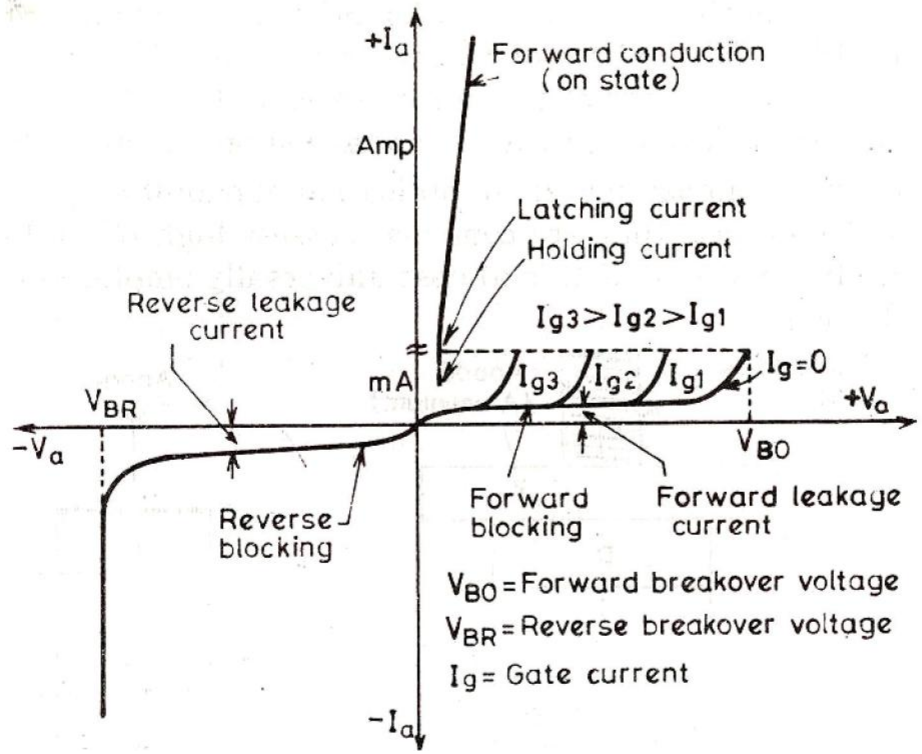


- Thyristors can only be turned on with three conditions:

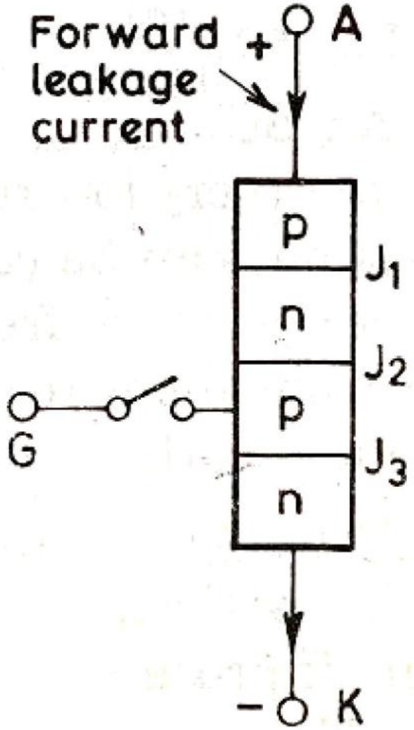
1. The device must be forward biased, i.e., the anode should be more positive than the cathode.
2. A positive gate current (Ig) should be applied at the gate.
3. The current through the thyristor should be more than the latching current. Once conducting ,the anode current is LATCHED (continuously flowing).

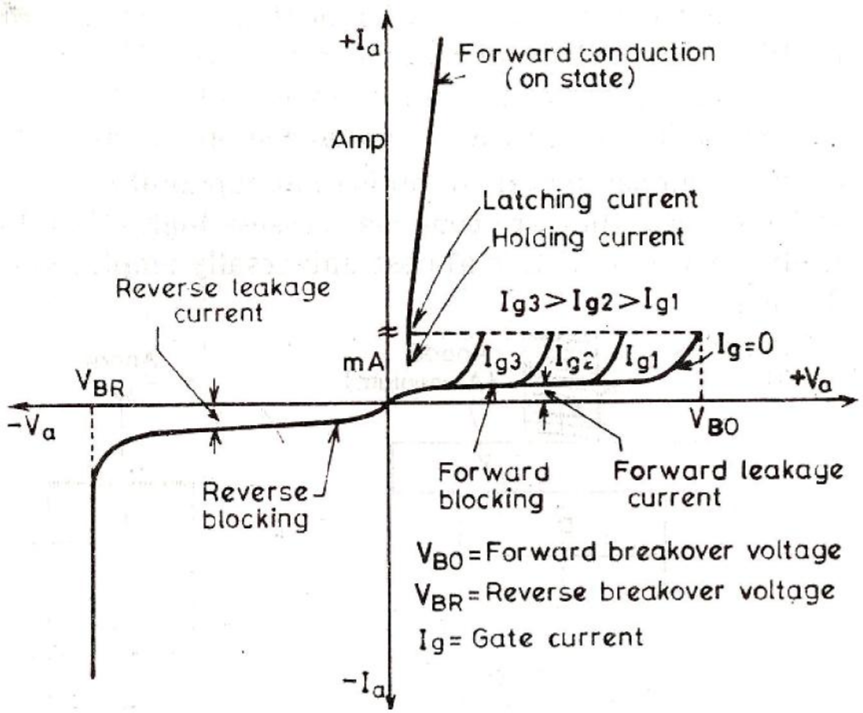
REVERSE BLOCKING MODE





FORWARD BLOCKING MODE





- Latching Current: This is the minimum anode current required to turn on the SCR device and convert it from the Forward Blocking State to the ON State.
- Holding Current: This is the minimum forward current flowing through the thyristor in the absence of the gate triggering pulse.
- Forward Breakover Voltage: This is the forward voltage required to be applied across the thyristor to turn it ON without the gate signal application.
- Max Reverse Voltage: This is the maximum reverse voltage to be applied across the thyristor before the reverse avalanche occurs.

SCR OPERATING MODES

FORWARD BLOCKING MODE: Anode is positive w.r.t cathode, but the anode voltage is less than the break over voltage (VBO) . only leakage current flows, so thyristor is not conducting .

FORWARD CONDUCTING MODE: When anode voltage becomes greater than VBO, thyristor switches from forward blocking to forward conduction state, a large forward current flows.

If the IG=IG1, thyristor can be turned ON even when anode voltage is less than VBO.

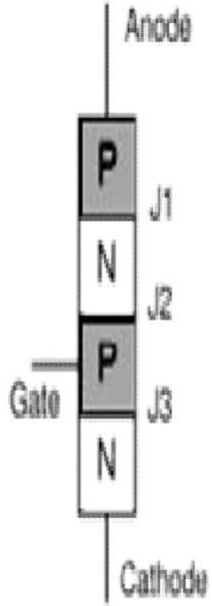
- The current must be more than the latching current (IL).
- If the current reduced less than the holding current (IH), thyristor switches back to forward blocking state.

REVERSE BLOCKING MODE: When cathode is more positive than anode , small reverse leakage current flows. However if cathode voltage is increased to reverse breakdown voltage , Avalanche breakdown occurs and large current flows.

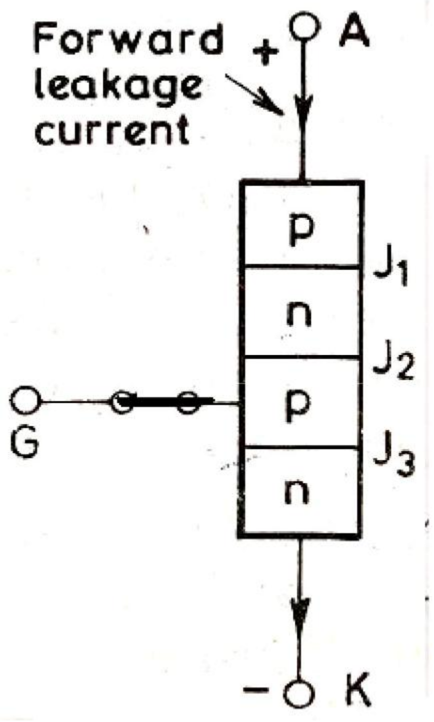
Thyristor- Operation Principle

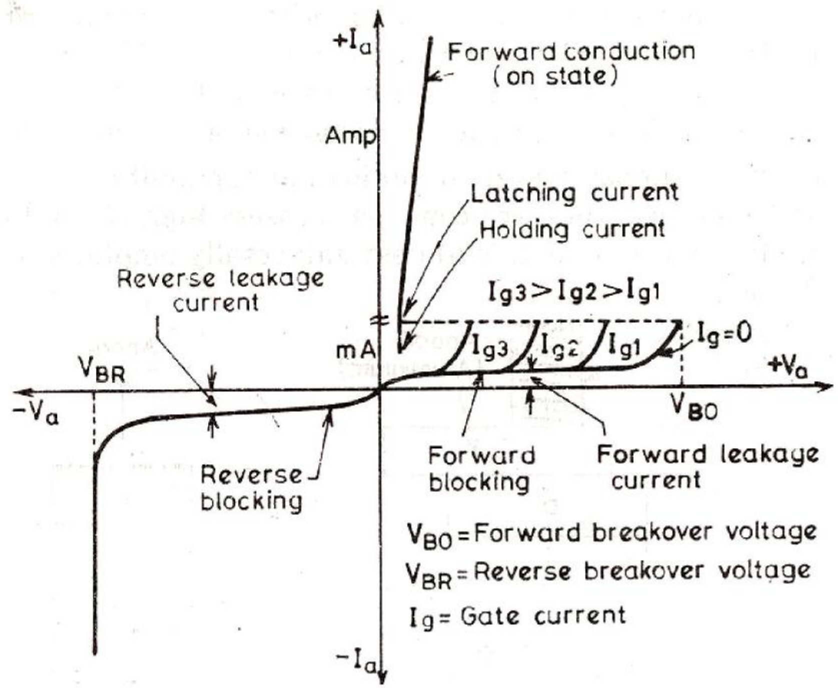
- Thyristor has three p-n junctions (J1, J2, J3 from the anode).
- When anode is at a positive potential (VAK) w.r.t cathode with no voltage applied at the gate, junctions J1 & J3 are forward biased, while junction J2 is reverse biased.
  - As J2 is reverse biased, no conduction takes place, so thyristor is in forward blocking state (OFF state).
  - Now if *V*AK (forward voltage) is increased w.r.t cathode, forward leakage current will flow through the device.
  - When this forward voltage reaches a value of breakdown voltage (*V*BO) of the thyristor, forward leakage current will reach saturation and reverse biased junction (J2) will have avalanche breakdown and thyristor starts conducting (ON state), known as forward conducting state .
- If Cathode is made more positive w.r.t anode, Junction J1 & J3 will be reverse biased and junction J2 will be forward biased.
- A small reverse leakage current flows, this state is known as reverse blocking state.
- As cathode is made more and more positive, stage is reached when both junctions A & C will be breakdown, this voltage is referd as reverse breakdown voltage (OFF state), and device is in

reverse blocking state



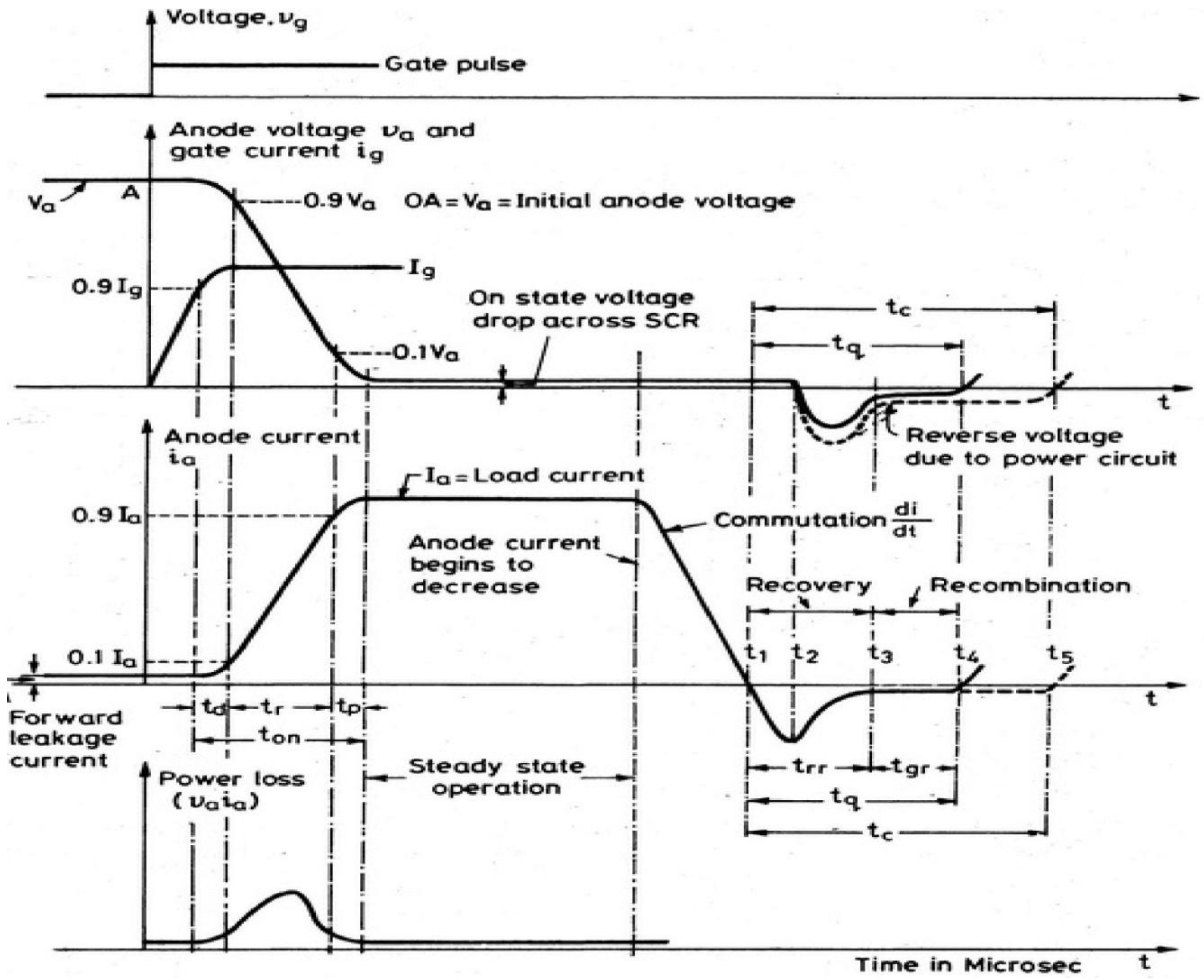
FORWARD CONDUCTION MODE





Once SCR is turned on it looses gate control.

SWITCHING CHARACTERISTICS OF SCR

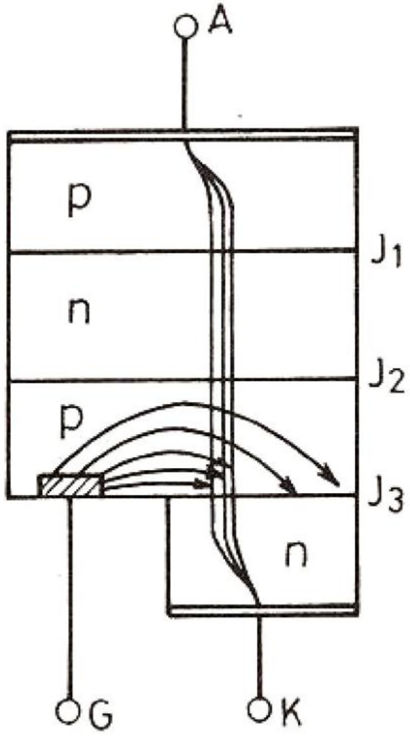


Turn on time(t_{on}):- (t_d +t_r+t_P)

- Delay time(t_d)
- Rise time(t_r)
- Spread time(t_P)

Turn off time(t_{off}):- (t_{rr} +t_{gr})

- Reverse recovery time(t_{rr})
- Reverse recovery time(t_{gr})

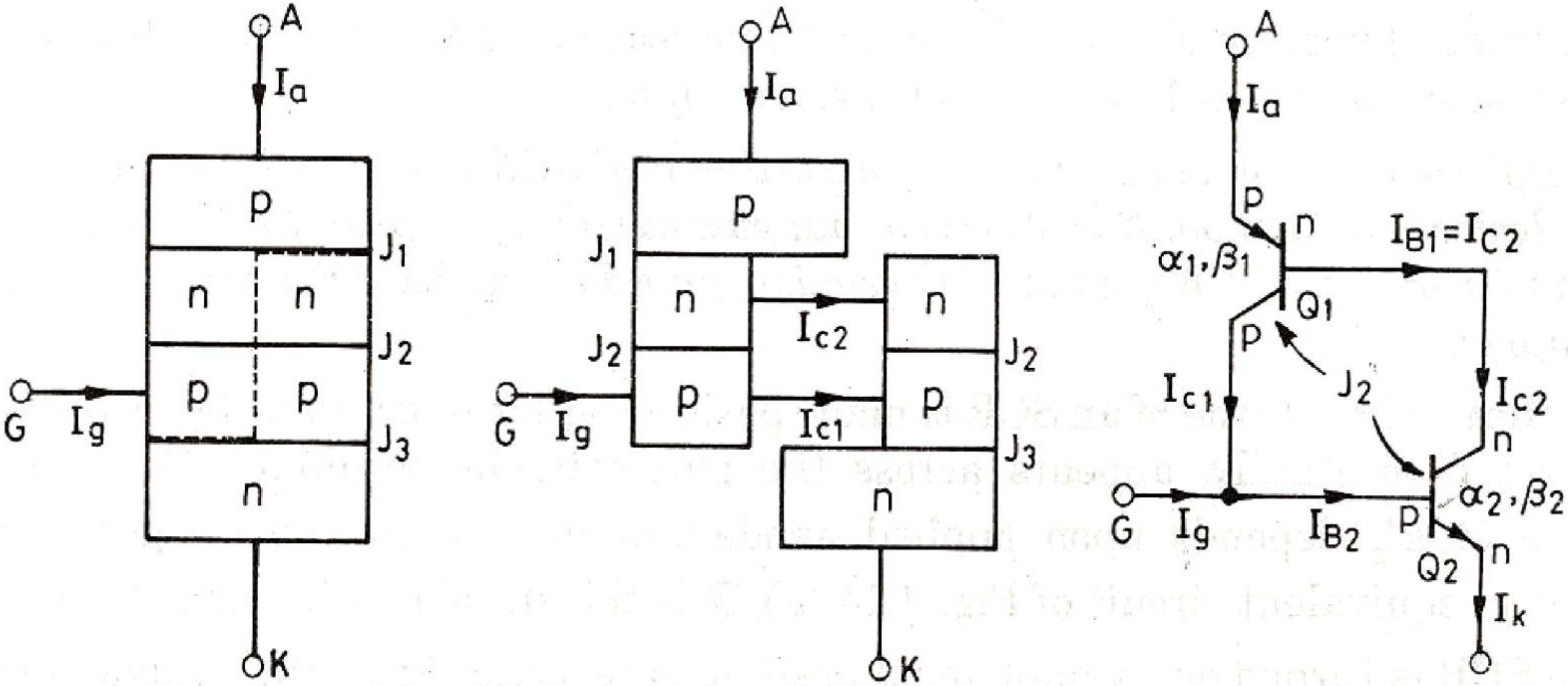


(a)

(b)

Fig. 4.6. (a) Distribution of gate and anode currents during delay time (b) Conducting area of cathode (i) during t_d (ii) after t_r (iii) after t_p.

TWO TRANSISTOR MODEL OF SCR



$$I_C = \alpha I_E + I_{CBO}$$

$$I_{C1} = \alpha_1 I_a + I_{CBO1}$$

α_1 = common–base current gain of Q_1

I_{CBO1} = common–base leakage current of Q_1.

$$I_{C2} = \alpha_2 I_k + I_{CBO2}$$

α_2 = common–base current gain of Q_2

I_{CBO2} = common–base leakage current of Q_2

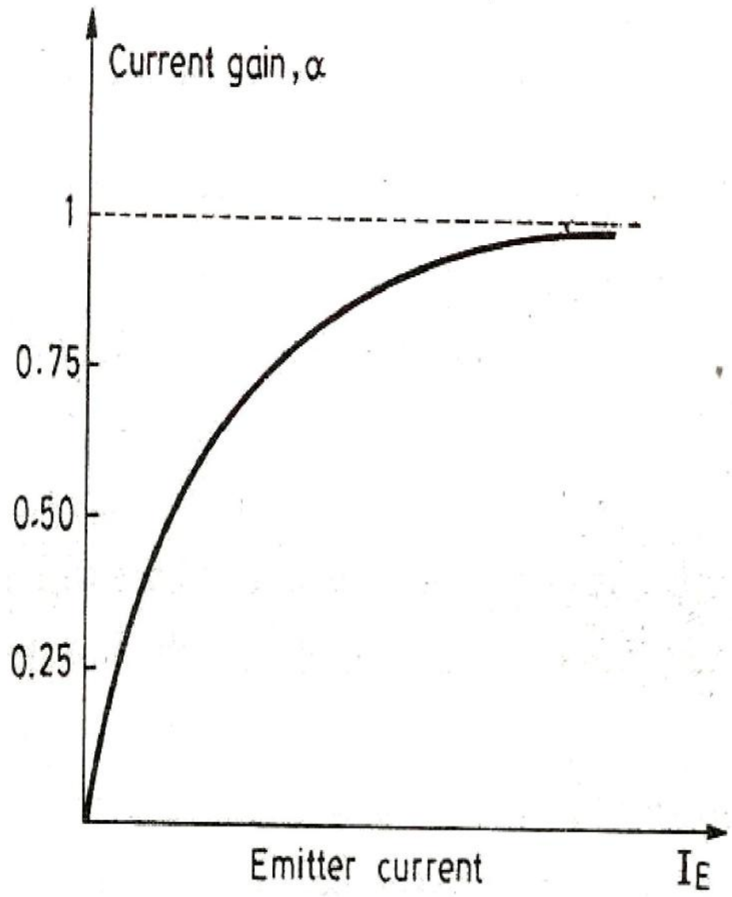
I_k = emitter current of Q_2.

$$\therefore \quad I_a = I_{C1} + I_{C2}$$

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2}$$

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 (I_a + I_g) + I_{CBO2}$$

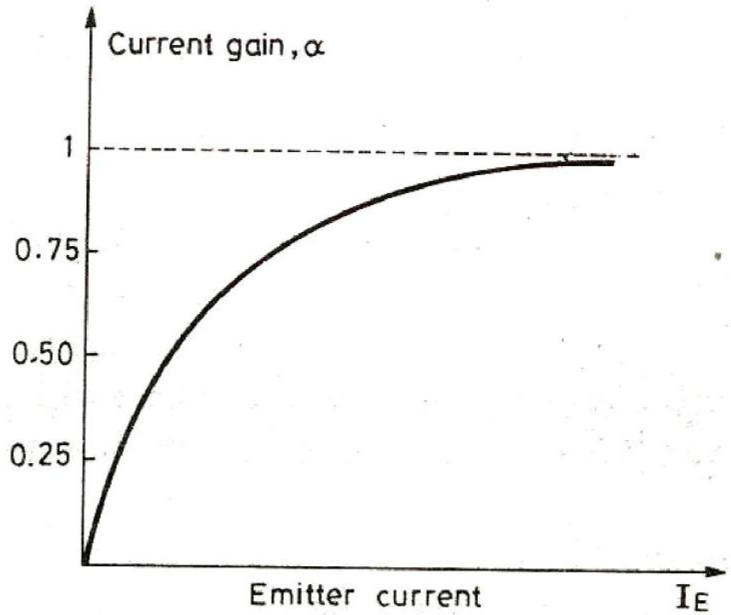
$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

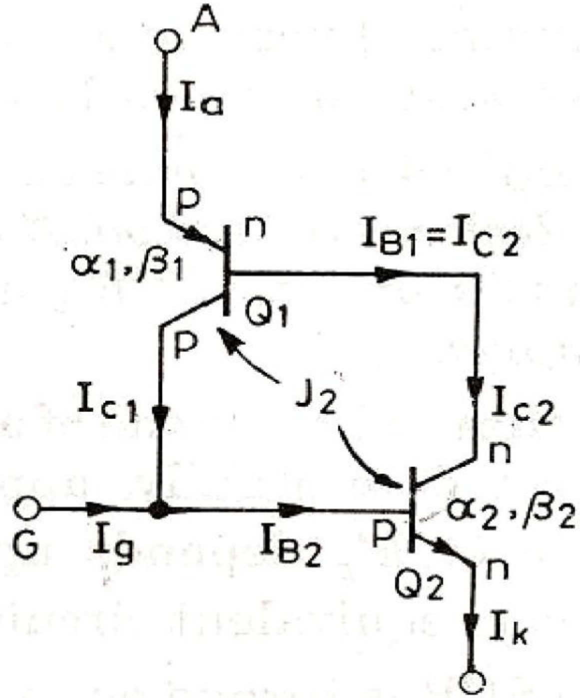


TURN ON METHODS OF SCR

- Gate triggering
- Forward voltage triggering
- dv/dt triggering
- Temperature triggering
- Light triggering

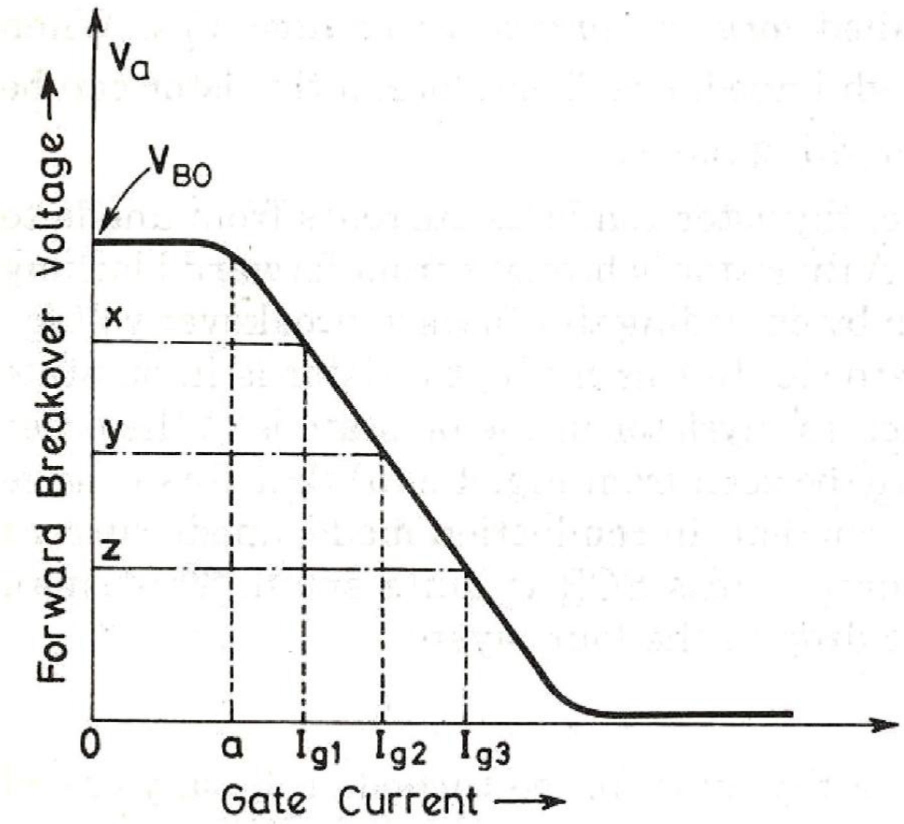
GATE TRIGGERING METHOD





$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

GATE TRIGGERING



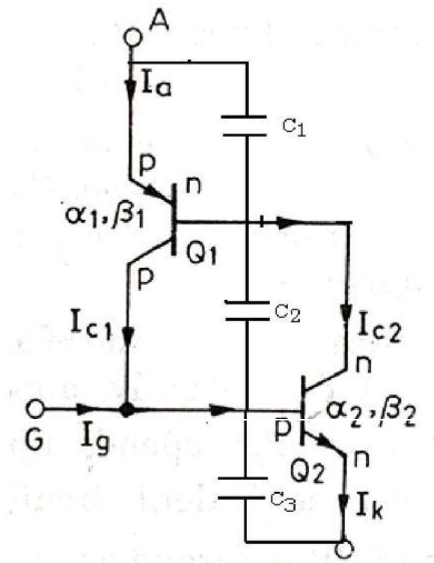
FORWARD VOLTAGE TRIGGERING

- In forward voltage triggering voltage is applied between anode and cathode with gate circuit open, junction j_2 is reverse biased.
- The width of depletion layer across junction j_2 decreases with an increase in anode cathode voltage
- If forward voltage across anode-cathode is gradually increases ,the depletion layer across junction j_2 will decrease.
- When voltage reaches to forward break over voltage depletion region completely vanished and device will turns on

dV/dT TRIGGERING METHOD

- With forward voltage across anode & cathode of a thyristor, two outer junctions (A & C) are forward biased but the inner junction (J2) is reverse biased.
- The reversed biased junction J2 behaves like a capacitor because of the space-charge present there.
- If a voltage ramp is applied across the anode-to-cathode, a current will flow in the device to charge the device capacitance according to the relation:

$$i = C_j \frac{dv_a}{dt}$$



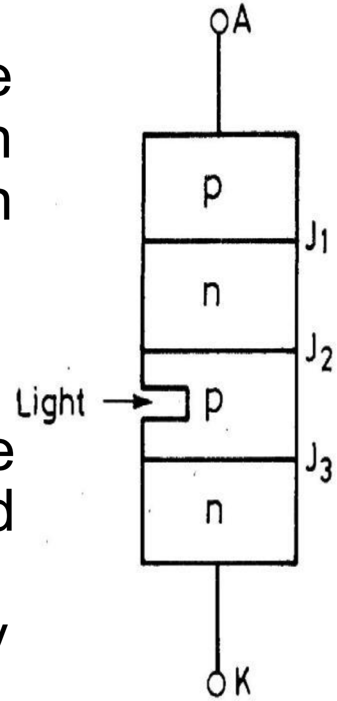
- This method of triggering is not desirable because high charging current (I_c) may damage the thyristor.

TEMPERATURE TRIGGERING

- During forward blocking, most of the applied voltage appears across reverse biased junction J2.
- This voltage across junction J2 associated with leakage current may raise the temperature of this junction.
- With increase in temperature, leakage current through junction J2 further increases.
- This cumulative process may turn on the SCR at some high temperature.
- High temperature triggering may cause Thermal runaway and is generally avoided.

Light triggering

- In this method light particles (photons) are made to strike the reverse biased junction, which causes an increase in the number of electron hole pairs and triggering of the thyristor.
- For light-triggered SCRs, a slot (niche) is made in the inner p-layer.
- When it is irradiated, free charge carriers are generated just like when gate signal is applied b/w gate and cathode.
- Pulse light of appropriate wavelength is guided by optical fibers for irradiation.
- If the intensity of this light thrown on the recess exceeds a certain value, forward-biased SCR is turned on. Such a thyristor is known as light-activated SCR (LASCR).
- Light-triggered thyristors is mostly used in high-voltage direct current (HVDC) transmission systems.



SCR TURN OFF METHODS

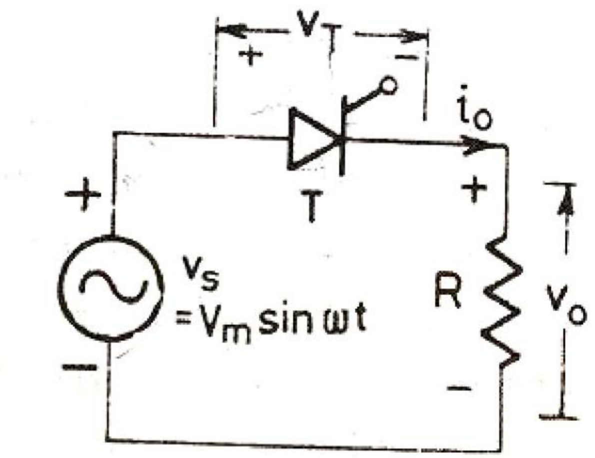
- Natural commutation
- Forced commutation

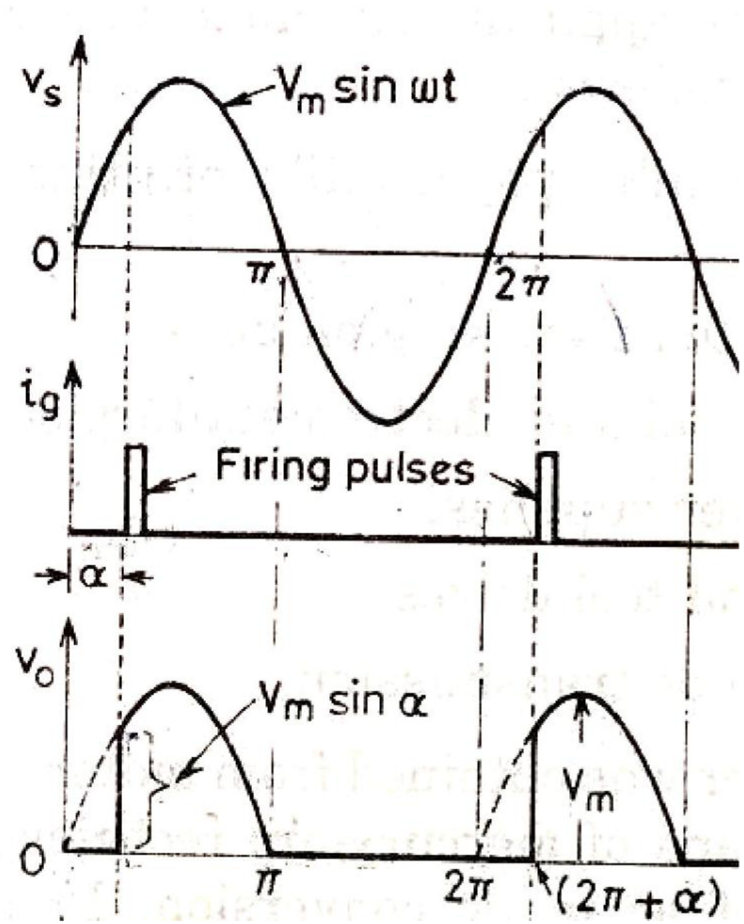
- The process of turning OFF SCR is defined as "Commutation".
- Thyristor cannot be turned off by applying negative gate current. It can only be turned off if the current I through it goes negative (reverse).
- In all commutation techniques, a reverse voltage is applied across the thyristor during the turn OFF process.
- There are two methods by which a thyristor can be turned OFF.
- i. Natural Commutation ii. Forced Commutation

- Natural Commutation
- In AC circuit, the current always passes through zero for every half cycle.
- As the current passes through natural zero, a reverse voltage will simultaneously appear across the device. This will turn OFF the device immediately.
- This happens when negative portion of the of sine-wave occurs. This process is called as "natural commutation" since no external circuit is required for this purpose.

- Forced Commutation
- Another method of turning off is known as "forced commutation".
- The anode current is “diverted” to another circuitry.
- To turn OFF a thyristor, the forward anode current should be brought to zero for sufficient time to allow the removal of charged carriers.
- In case of DC circuits the forward current should be forced to zero by means of some external circuits.

LINE COMMUTAATION





GR14 **SET-1**

III-year B.Tech I semester Regular Examinations, May/June -2016

Power Electronics

(EEE)

Time: 3 hours **Max Marks: 70**

PART - A

Answer all the questions, all questions carry equal marks

*****

10*2 Marks = 20 Marks

1. a. Define Latching current and Holding current of a Thyristor. [2]

b. Give the details of Snubber circuit. [2]

c. Distinguish between Midpoint type and Bridge type connections used in converter topology. [2]

d. A 230V,50Hz supply is given to a 1-phase Half wave controlled converter which is delivering power to load R= 10 Ω, for a firing angle delay of 60^0 , Calculate the average value of output Voltage. [2]

e. List out the advantages of Three phase converters over single phase converters. [2]

f. Write down the type of commutation technique used in Inverter in which if the Switching device is
i) SCR ii) MOSFET [2]

g. Write the principle of operation of Cyclo-converter and classify them? [2]

h. What is an AC voltage controller and the average value of an AC voltage controller? [2]

i. Principle of chopper and types. [2]

j. Describe different control strategies of chopper. [2]

PART – B

Answer any FIVE questions. All questions carry equal marks

5*10 Marks = 50 Marks

2. a) Explain Dynamic V - I characteristics of an SCR and mention the salient points. [5]

b) Describe the types of commutation of an SCR, explain in detail. [5]

3. a) Analyse 1-Phase Half wave controlled converter for $\alpha = 45^0$ with RLE-Load and derive the expression for RMS value of output. [5]

b) Explain about Line commutated Inverters and derive the expression for RMS value of output voltage. [5]

4. a) Describe about Three phase six pulse converters with the help of wave forms. [5]
b) Explain the operation of Basic series Inverter with the help of waveforms. [5]

5. a) Explain the operation of AC voltage controller designed using TRIAC and write down the average value of the converter? [5]

b) Obtain the waveforms of a Cyclo-converter in which the output voltage frequency is 1/3 rd of input frequency, if input Frequency Fs = 50 Hz. [5]

6. a) Describe different control strategies of a Chopper. [5]

b) Analyse the principle of operation of Morgan’s chopper with the help of waveforms. [5]

7. a) Explain the modes of operation of an SCR. [5]

b) Define Active power Input and Reactive power Input to the converters. And [5]

Give the purpose of freewheeling diode in three phase semi converter circuit with RL-load. [5]

8. a) A 1-Phase AC regulator feeds power to a resistive load of 4Ω from 230v ac supply. Calculate V_0, V_{rms}, for a firing angle of 60^0. [5]

b) Describe the operation of Boost converter with the help of waveforms. [5]

GR14

MODEL QUESTION PAPER-2

III-year B.Tech I semester Regular Examinations, May/June -2016

Power Electronics

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks:70**

PART-A

Answer ALL questions. All questions carry equal marks

*****

10*2 Marks=20 Marks

1(a) What is Holding Current? [2]

(b) Define String Efficiency. [2]

(c) Determine the average and RMS output voltages of single phase full converter. [2]

(d) Define overlap angle. [2]

(e) Express the advantages of freewheeling diode. [2]

(f) What is the principle of operation of Inverters? [2]

(g) Derive the expression for the Power dissipated in the load, for a single phase AC voltage controller feeding Resistive load. [2]

(h) Determine the applications of Cycloconverter. [2]

(i) What are the different control strategies of Choppers? [2]

(j) What is Duty Ratio? [2]

PART-B

Answer any FIVE questions. All questions carry equal marks.

*****

5*10 Marks = 50 Marks

2(a) Explain the working of Class-D commutation circuit with neat circuit diagram and waveforms. [5]

(b) Draw the equivalent circuit of a UJT and explain its working. [5]

3(a) Describe the operation of a single phase two pulse midpoint converter with relevant waveforms. Derive an expression for average output voltage. [5]

(b) Explain the effect of source inductance in full converter with relevant waveforms. [5]

4 (a) Explain the operation of three phase, half wave controlled converter with R load for $\alpha = 60^0$ with relevant waveforms. [5]

(b)What are the different pulse width modulation techniques used for inverters. [5]

5 (a) Derive the expressions for the Power dissipated in the load, for a single phase AC voltage controller feeding Resistive-inductive load for discontinuous operation of current. [5]

(b) Explain the operation of the single phase bridge type cycloconverter with RL load for Continuous conduction. [5]

6 (a) Explain the operation of DC Morgan's Chopper for resistive load with neat circuit diagram and output voltage and current waveforms. [5]

(b) Explain the operation of a basic dc chopper and obtain the average output voltage and current as a function of Edc, R and duty cycle δ. [5]

7 (a) Explain the parallel operation of SCR's [5]

(b) Draw and explain the simple SCR series inverter circuit employing class A type commutation with the help waveforms. [5]

8 (a) A step-up chopper with a pulse width of 150 μs operating on 220V, dc supply. Compute the load voltage if the blocking period of the device is 40 μs. [5]

(b) A single phase full wave ac voltage controller has a resistance load of 10ohms. The input ac voltage is 230V, 50Hz. For a delay angle of 90^0, determine the rms load voltage, rms load current, rms thyristor current and input powerfactor for above two loads. [5]

Unit-1

1. Explain the series and parallel operation of SCR's.
2. Explain the construction and static V-I characteristics of SCR clearly with neat diagrams.
3. Define triggering. What are the different turn-on methods of SCR? Explain.
4. List out and explain the Voltage and Current ratings of SCR.
5. Explain the two transistor analogy of SCR with necessary conclusions.
6. Explain the necessity of Snubber circuit for SCR and give its operation.
7. Define the commutation. Describe the types of forced commutation of an SCR, explain in detail.
8. Explain different types of firing circuits of SCR.

Unit-2

1. Describe the operation of a single phase **semi converter** RLE Load by using freewheeling diode with relevant waveforms. Derive an expression for average output voltage.
2. Explain the operation of single phase **half wave converter** with RL-Loadat $\alpha=60^{o}$ with necessary wave forms. Also derive the output voltage, output current and RMS output voltages
3. Explain the operation of single phase **full wave bridge converter** for RLE load at a $\alpha=60^{o}$with necessary output wave waveforms. Also derive the output voltage, output current & RMS voltage equation.
4. a) Give the difference between midpoint and bridge type converters
   b) Give the difference between discontinuous mode and continuous mode of operation
5. a) Differentiate between fully controlled and half controlled Converters.
   b) Explain about Line commutated Inverters and derive the expression for RMS value of output voltage.
6. A single phase half wave converter is operated from a 120v,60Hz supply. If the load is resistive of value 10 ohms and delay angle is alpha is 60^{0}. Determine i) the efficiency ii)formfactor iii)ripple factor iv) Transformer utilization factor v)peak inverse voltage of thyristor
7. Explain the effect of source inductance in full converter with relevant waveforms with R L Load.

Unit-3

1) Explain the operation of 3 phase half wave controlled rectifier (3-pulse Converter) with resistive load and also derive the average and RMS load voltage.
2) Explain the operation of 3 phase full wave controlled rectifier (6-pulse Converter) with resistive load and also derive the average and RMS load voltage.
3) Explain the operation of single phase full bridge voltage source inverter and the help of voltage and current waveforms?
4) Explain the operation of single phase half bridge voltage source inverter.
5) Explain the operation of parallel inverter with neat circuit and waveforms.
6) Explain the operation of Basic series Inverter with the help of waveforms.
7) Describe different types of pulse width modulation techniques (PWM) inverter.
8) Explain about Voltage Control Techniques for Inverter.

SET - 1 **GR 11** CODE: GR11A3080

BI B. Tech I Semester Regular Examinations, Nov, 2013
Power Electronics

(Electrical & Electronics Engineering)

Time: 3 hours **Max Marks: 75**

Answer any FIVE questions
All questions carry equal marks

*****

1). What is the necessity of connecting SCRs in series? Explain the problems associated with series connection of SCRs. How are they eliminated? Explain the design of static & dynamic equalizing circuits with necessary derivations. **[15]**

2). a Explain the operation of a three phase fully controlled bridge converter with R – L Load. Draw waveforms neatly for a firing angle of 120^{o} in continuous mode. Derive expressions for average and RMS values of load voltage. **[10]**

b Explain clearly the effect of source inductance on the output voltage of a single phase fully controlled bridge converter. **[5]**

3). a A 1-ϕ 230V, 50 HZ source connected to an anti parallel connected thyristor circuit controlling power to the load R = 10Ω; L = 20mH, when $\alpha = 30^{o}$. Calculate output voltage and output current and load power factor. **[8]**

b What is a cyclo converter? Classify them and explain the advantages and limitations. **[7]**

4). a A type A chopper feeds power to RLE load with R=2 ohms; L= 5mH; E= 15V; Source voltage = 230V; Chopping frequency is 1KHZ. Output voltage pulse duration is 400μsec. Determine the following **[8]**

(i) Whether the load current is continuous or not
(ii) Average values of output voltage & current
(iii) RMS values of output voltage & current
(iv) Maximum & Minimum values of output current

b Explain the operation of DC Morgans chopper for RL loads with neat circuit diagram and output voltage and current waveforms. **[7]**

5). a Explain the operation of modified single phase Mc Murray - Bedford half bridge inverter with neat circuit diagram and load voltage and current waveforms. **[8]**

b Draw the circuit diagram of a 3-ph Dual converter. Give the differences between the circulating and non circulating current modes. **[7]**

6). a Explain the operation of class D commutation with neat circuit and waveforms. **[8]**

b What is snubber circuit? Explain the design of snubber circuit. **[7]**

7). a Explain the operation of parallel inverter with neat circuit and waveforms. **[8]**

b Explain the various voltage control techniques of an inverter. **[7]**

*****

SET - 4 | GR 11 | CODE: GR11A3080

BI B. Tech I Semester Supplementary Examinations, June, 2014
Power Electronics

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 75**

Answer any FIVE questions
All questions carry equal marks

*****

1). a Explain the necessity of Snubber circuit for SCR and give its operation. **[10]**

b Explain in detail various voltage ratings and current ratings of a Thyristor. **[5]**

2). a Explain two transistor analogy of SCR with neat diagrams. **[10]**

b What is meant by Commutation? Differentiate between line Commutation and forced Commutation. **[5]**

3). a Explain the operation of single phase half-controlled bridge converter with RL load. Sketch the circuit and draw the waveforms for $\alpha = 60^0$. **[8]**

b Derive an expression for average output voltage and current for above circuit. **[7]**

4). a A three phase, six pulse fully controlled converter is connected to three phase ac supply of 440V and 50Hz and operates with a firing angle of $\pi/5$ radians. The load current is maintained constant at 5 Amps and load voltage is 440V. Calculate load resistance, source inductance and overlap angle. **[8]**

b Differentiate between fully controlled and half controlled Converters. **[7]**

5). a Explain the functioning of singe phase ac voltage controller feeding a resistive load with the aid of waveforms of source voltage, gating signals, output voltage, source and output currents and voltage across SCRs. **[8]**

b Discuss the working of a single phase bridge type cyclo converter with RL load and draw relevant output waveforms and circuit diagram for $f_0 = 1/2\ fs$. **[7]**

6). a Explain the operation of AC Chopper with neat circuit diagram and output voltage and current waveforms. **[8]**

b Describe time ratio control and current limit control strategies for Chopper. **[7]**

7). a Describe single phase parallel Inverter functioning with neat diagrams. **[8]**

b Explain the operation of Mc Murray inverter with neat diagram. **[7]**

*****

III B. Tech I Semester Supplementary Examinations, May/June 2015

Power Electronics

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 75**

Answer any FIVE questions
All questions carry equal marks
*****

1). a Explain the construction and static V-I characteristics of SCR clearly with neat diagrams. Define Latching Current, Holding Current, Forward Break-over Voltage and Reverse Breakdown Voltage. Indicate them in V-I characteristics. **[10]**

b What are the different turn-on methods of SCR? Explain. **[5]**

2). a Explain the operation of a single phase fully controlled bridge converter with R – L Load. Draw waveforms neatly for a firing angle of 60^{o} in continuous mode. Derive expressions for average and RMS values of load voltage. **[10]**

b Explain clearly the effect of source inductance on the output voltage of a single phase fully controlled Bridge Converter. **[5]**

3). a Discuss the working of a single phase bridge type cyclo-converter with RL load for discontinuous operation with the necessary output waveforms and circuit diagram for $f_0 = 1/2$ fs. **[8]**

b Explain the operation of a TRIAC. Also list its advantages. **[7]**

4). a A type A chopper feeds power to RLE load with R=2 ohms; L= 5mH; E= 15V; Source voltage = 230V; Chopping frequency is 1KHZ. Output voltage pulse duration is 400µsec. Determine the following **[8]**

(i) Whether the load current is continuous or not
(ii) Average values of output voltage & current
(iii) RMS values of output voltage & current
Maximum & Minimum values of output current

b Explain the operation of DC Jones Chopper for RL loads with neat circuit diagram, output voltage and current waveforms. **[7]**

5). a Explain the operation of Parallel Inverter with neat circuit and waveforms. **[8]**

b Explain the various voltage control techniques of an Inverter. **[7]**

6). a	Explain the operation of a three phase semi converter with RL load. Also give the range of firing angle for which the Semi Converter acts as a three pulse and six pulse converter.	**[8]**
b	List out and explain the Voltage and Current ratings of SCR.	**[7]**
7). a	Explain the two transistor analogy of SCR with necessary conclusions.	**[8]**
b	Explain the operation of a step up Cyclo Converter with neat circuit diagram and waveforms.	**[7]**

*****

FEEDBACK OF FACULTY BY STUDENTS

DEPT:EEE YEAR:III B-TECH SEMESTER :I ACADEMIC YEAR:2018-19

31.10.2018

S.NO	FACULTY ID	FACULTY NAME	SUBJECT NAME	DEPT	NO. OF SECTIONS	FEEDBACK 1 (4 POINTS) (AVG OF ALL SECTIONS)
1	361	V.Vijaya Rama Raju	Power Transmission System	EEE	2	3.30
2	1279	M Prashanth	Power Transmission System	EEE	2	3.30
3	1055	P Prashanth Kumar	Microcontrollers	EEE	2	3.27
4	1494	Dr T Suresh Kumar	Power Electronics	EEE	1	3.31
5	760	D Karuna Kumar	Power Electronics	EEE	1	3.20
6	692	U Vijaya Lakshmi	Electrical Measurements and Instrumentation	EEE	2	3.24
7	931	P Sri Vidya Devi	Solar & Wind Energy Systems	EEE	2	3.12
9	931	P Sri Vidya Devi	Sensors/Measurements and Instrumentation Lab	EEE	1	3.39
10	692	U Vijaya Lakshmi	Sensors/Measurements and Instrumentation Lab	EEE	1	3.53
11	934	P Sirisha	Sensors/Measurements and Instrumentation Lab	EEE	2	3.41
12	695	Syed Sarfaraz Nawaz	Power Electronics Lab	EEE	1	3.11
13	933	M Rekha	Power Electronics Lab	EEE	2	3.19
14	609	P Praveen Kumar	Power Electronics Lab	EEE	1	3.55
15	657	R. Anil Kumar	Microcontrollers Lab	EEE	1	3.31
16	760	D Karuna Kumar	Microcontrollers Lab	EEE	2	3.31
17	1055	P Prashanth Kumar	Microcontrollers Lab	EEE	1	3.20

Signature of HOD

Gokaraju Rangaraju Institute of Engineering & Technology
(Autonomous)

Summation of Teacher Appraisal by Student
Academic Year 2018-19

Name of the Instructor	D Karuna Kumar
Faculty ID	760
Branch	EEE
Class and Semester/Section	III / I / A
Academic Year	2018-19
Subject Title	MC Lab
Total No. of Responses/class strength	45/71

Average rating on a scale of 4 for the responses considered:

S. No	Questions of Feedback	Average
1	How do the teacher explain the subject?	3.2826086956521738
2	The teacher pays attention to	3.4130434782608696
3	The Language and communication skills of the teacher is	3.3913043478260869
4	Is the session Interactive?	3.3913043478260869
5	Rate your teacher's explanation in clearing the doubts	3.3913043478260869
6	Rate your teachers commitment in completing the syllabus	3.4130434782608696
7	Rate your teachers punctuality	3.4130434782608696
8	Rate your teachers use of teaching aids	3.4130434782608696
9	Rate your teacher's guidance in other activities like NPTEL. Moodle. Swayam. Projects.	3.3913043478260869
10	What is your overall opinion about the teacher?	3.4347826086956523

Scanned by CamScanner

Gokaraju Rangaraju Institute of Engineering and Technology (Autonomous)

Bachupally, Kukatpally, Hyderabad

Evaluation Strategy
Electrical and Electronics Engineering

Academic Year : 2019-20

Semester : I

Name of the Program : B.Tech III Year I Sem

Course/Subject : Power Electronics (PE)

Name of the Faculty :Dr Pakkiraiah B.

Designation : Associate Professor.

1. TARGET:

A) Percentage for pass: 40%

B) Percentage of class: 95.6 %

2. COURSE PLAN & CONTENT DELIVERY

- PPT presentation of the Lectures
- Solving exercise problems
- Model questions

3. METHOD OF EVALUATION

3.1 ☐ Continuous Assessment Examinations (CAE-I, CAE-II)

3.2 ☐ Assignments/Seminars

3.3 ☐ Mini Projects

3.4 ☐ Quiz

3.5 ☐ Semester/End Examination

3.6 ☐ Others

4. List out any new topic(s) or any innovation you would like to introduce in teaching the subjects in this Semester.

Advanced power electronics converters

Signature of HOD — Signature of faculty

Date: — Date:

Gokaraju Rangaraju Institute of Engineering and Technology
(An Autonomous Institute under JNTUH)
Dept of Electrical and Electronics Engineering

Assessment methods:

1. Regular attendance to classes.
2. Internal exam.
3. Daily performance
4. Theory assessment techniques like regular Viva

1. Program Educational Objectives (PEOs) – Vision/Mission Matrix (Indicate the relationships by mark "X")

Vision/Mission PEOs	**Vision of the Institute**	**Mission of the Institute**	**Mission of the Program**
1	X		X
2	X	X	X
3	X	X	X
4		X	X

2. Program Educational Objectives(PEOs)-Program Outcomes(POs) Relationship Matrix (Indicate the relationships by mark "X")

P-Outcomes PEOs	1	2	3	4	5	6	7	8	9	10	11	12
1	X	X	X	X	X		X		X	X	X	
2	X	X	X	X	X	X	X	X		X	X	X
3		X	X	X				X	X		X	X
4				X		X	X		X	X		X

3. Course Objectives-Course Outcomes Relationship Matrix (Indicate the relationships by mark "X")

Course-Outcomes Course-Objectives	1	2	3	4	5	6	7
1	X		X			X	
2		X		X			
3			X		X		
4	X		X				X
5		X		X	X		

4. Course Objectives-Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark "X")

P-Outcomes C-Objectives	1	2	3	4	5	6	7	8	9	10	11	12
1	X		X		X	X	X	X		X	X	X
2	X	X	X		X	X	X	X	X	X	X	X
3	X	X	X		X	X	X		X	X	X	X
4	X	X		X	X		X	X		X		X
5	X		X	X	X				X		X	

5. Course Outcomes-Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark "X")

P-Outcomes C-Outcomes	1	2	3	4	5	6	7	8	9	10	11	12
1	X				X	X	X	X		X	X	X
2	X	X	X	X	X	X	X	X	X	X		X
3	X	X		X	X		X	X	X		X	

4		X	X			X		X	X	X		X
5			X		X		X	X		X	X	
6		X			X	X	X	X	X		X	X
7	X				X				X	X		X

6. **Courses (with title & code)-Program Outcomes (POs) Relationship Matrix** (Indicate the relationships by mark "X")

P-Outcomes Courses	1	2	3	4	5	6	7	8	9	10	11	12
FACTS	X	X	X	X	X		X	X	X	X		X

7. **Program Educational Objectives (PEOs)-Course Outcomes Relationship Matrix** (Indicate the relationships by mark "X")

P-Objectives (PEOs) Course-Outcomes	1	2	3	4
1		X	X	X
2	X	X	X	X
3	X	X	X	X
4		X	X	X
5		X	X	X
6	X	X	X	X
7		X	X	X

8. **Assignments & Assessments-Program Outcomes (POs) Relationship Matrix** (Indicate the relationships by mark "X")

P-Outcomes Assessments	1	2	3	4	5	6	7	8	9	10	11	12
1	X			X	X		X	X	X	X	X	X
2	X	X			X	X	X		X	X		
3	X				X	X		X	X	X	X	X
4	X			X	X	X	X	X		X	X	X
5	X	X		X			X		X		X	

9. **Assignments & Assessments-Program Educational Objectives (PEOs) Relationship Matrix** (Indicate the relationships by mark "X")

P-Objectives (PEOs) Assessments	1	2	3	4
1		X	X	X
2	X	X	X	X
3	X	X		X
4		X		X
5	X	X	X	X

10.Constituencies -Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark "X").

P-Outcomes Constituencies	1	2	3	4	5	6	7	8	9	10	11	12
1		X					X			X		X
2					X			X	X		X	
3			X	X		X					X	
4	X								X	X	X	X
5				X				X		X		
6	X								X		X	X

Gokaraju Rangaraju Institute of Engineering and Technology
(Autonomous)
Department of Electrical and Electronics Engineering
M.Tech-Power Electronics

FACTS RUBRIC
OBJECTIVE: **Work effectively with others**
STUDENT OUTCOME: **Ability to function in a multi-disciplinary team**

S.No.	Student Name	Performance Criteria	Unsatisfactory	Developing	Satisfactor Y	Exemplar y	Scor e
			1	2	3	4	
1.	GUGLOTH MANGILAL	**Research & Gather Information**	Does not collect any information that relates to the topic.	Collects very little information some relates to the topic	Collects some basic Informatio n most relates to the topic.	Collects a great deal of Informati on all relates to the topic.	2
		Fulfill team role's	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties ofassigne d team role.	2
		Share Equally	Always relies on others to Do the work.	Rarely does the assigned work-- often needs reminding.	Usually does the assigned work-- rarely needs reminding.	Always does the assigned Work without having to be reminded	2
		Listen to other team mates	Is always talking--never allows anyone else to speak.	Usually doing most of the talking-- rarely	Listens, but sometimes talks too much.	Listens and speaks a fair amount.	3

						Average score	2.5

2.	MANCHALA SANJAY KUMAR	**Research & Gather Information**	Does not collect any information that relates to the topic.	Collects very little information --some relates to the topic	Collects some basic informatio n--most relates to the topic.	Collects a great deal of informati on--all relates to the topic.	4
		Fulfill team role's	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.	3
		Share Equally	Always relies on others to do the work.	Rarely does the assigned work--often needs reminding.	Usually does the assigned work--rarely needs reminding.	Always does the assigned work without having to be reminded.	4
		Listen to other team mates	Is always talking--never allows anyone else to speak.	Usually doing most of the talking--rarely allows others to speak.	Listens, but sometimes talks too much.	Listens and speaks a fair amount.	3

						Average score	4

3	R MADHURI	**Research & Gather Information**	Does not collect any information that relates to the topic.	Collects very little information --some relates to the topic	Collects Some Basic informatio n--most relates to the topic.	Collects a great deal of informati on--all relates to the topic.	5
		Fulfill team role's	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.	5
		Share Equally	Always relies on others to do the work.	Rarely does the assigned work-- often needs reminding.	Usually does the assigned work-- rarely needs reminding.	Always does the assigned work without having to be reminded .	4
		Listen to other team mates	Is always talking--never allows anyone else to speak.	Usually doing most of the talking-- rarely allows others to speak.	Listens, but sometimes talks too much.	Listens and speaks a fair amount.	5
						Average score	4.5

Assessment process and Relevant Surveys conducted:

Constituencies -Program Outcomes (POs) Relationship Matrix
(Indicate therelationships by mark "X").

1. **Alumni**
2. **Government employers**
3. **Students**

P-Outcomes / Constituencies	1	2	3	4	5	6
1	X	X	X	X	X	X
2	X	X	X	X	X	X
3	X	X			X	X

Assessment Process and Areas of improvements:

Prepare the following Matrix:

11. The improvements Matrix are summarized below and described in the textthat follows.

Hint:

Format:

Proposed change	**Year proposed**	**Year implemented**	**Old version**	**New version**	**Comments**
Add new Operating System course	2022-23		No operating system course in curriculum	IT ….. Operating System Concepts & Administration	To address need for additional material for operating systems

Academic Year: **2022-23**
Year: **III**
Semester: **I**

MID Exam – I (Descriptive)
Subject Name: Power Electronics
Subject Code: GR20A3013

Date: 10/10/2022
Duration: **90 min**
Max Marks: **15**

Note: Answer any ALL questions. All questions carry equal marks.

Answer ALL questions. All questions carry equal marks
3 * 5 = 15 Marks

Q. No	Questions	Marks	CO	BL	PI
1.	(a) Draw the static V-I & transfer characteristic curves of IGBT	[2 1/2]	CO1	BL2	3
	(b) Draw the static V-I & transfer characteristic curves of MOSFET	[2 1/2]	CO1	BL2	3
	OR				
2.	(a) Deduce the expression for anode current (I_a) using two transistor analogy with neat sketch	[2 1/2]	CO1	BL4	4
	(b) Mention the triggering (turn-on) methods of a thyristor	[2 1/2]	CO1	BL3	3
3.	(a) Give a brief note on significance of a freewheeling diode in the converters	[2 1/2]	CO2	BL3	3
	(b) Articulate on Single phase fully-controlled converter with RL load for discontinuous mode of operation	[2 1/2]	CO2	BL4	4
	OR				
4.	(a) Elaborate on, the effect of source impedance on the performance of converters	[2 1/2]	CO2	BL4	4
	(b) Analyze the 3-phase, 6-pulse semi-controlled (half-controlled) converter with RLE & F.D load	[2 1/2]	CO2	BL4	4
5	For type-A chopper dc source voltage=230V, load resistance R=10Ω. Take a voltage drop of 2V across chopper when it is on. For a duty cycle of 0.4, calculate (i) average & rms values of o/p voltage & current and (ii) chopper efficiency	[5]	CO3	BL5	5
	OR				
6.	A type-A chopper has input dc voltage of 200V and a load R=10 Ω in series with L=80Mh. If load current varies linearly between 12A and 16A. find time ratio T_{on}/T_{off} for this chopper	[5]	CO3	BL4	4

Academic Year: **2022-23**
Year: **III**
Semester: **I**

MID Exam – I (Objective)
Subject Name: Power Electronics
Subject Code: GR20A3013

Date: 10/10/2022
Duration: **10 min**
Max Marks: **5M**

Roll No:

Note: Answer ALL questions carry **questions. All equal marks.**

Answer all Objective Questions. All questions carry equal marks

Q.No	Questions	Option	CO	BL	PI
1	Which of the below mentioned statements is false regarding a p-n junction diode? A) Diodes are uncontrolled devices B) Diodes are rectifying devices C) Diodes are unidirectional devices **D) Diodes have three terminals**	[ ]	**CO1**	**BL2**	**3**
2	The power loss in which of the following cases would be the maximum? A) When both V & I are minimum **B) When both V & I are maximum** C) When only V is maximum D) When only I is maximum	[ ]	**CO1**	**BL3**	**3**
3	The controlling parameter in MOSFET is A) V_{ds} B) I_g **C) V_{gs}** D) I_s	[ ]	**CO1**	**BL3**	**3**
4	A thyristor can be bought from the forward conduction mode to forward blocking mode by A) the dv/dt triggering method B) applying a negative gate signal C) applying a positive gate signal **D) applying a reverse voltage across anode-cathode terminals**	[ ]	**CO1**	**BL4**	**4**
5	When a SCR is in the forward blocking state, A) All the 3 junctions are reverse biased **B) The anode and cathode junctions are forward biased but the gate junction is reverse biased** C) The anode junction is forward biased but the cathode and gate junctions are reverse biased D) The anode and gate junctions are forward biased but the cathode junction is reverse biased	[ ]	**CO2**	**BL3**	**3**
6	The frequency of the ripple present in the output voltage of the 3 phase half controlled bridge rectifier depends on the A) Firing angle B) Load inductance C) Load resistance **D) Supple frequency**	[ ]	**CO2**	**BL5**	**5**
7	In a single phase half-wave thyristor circuit with R load & Vs=Vm sinwt, the maximum value of the load current can be given by A) $2V_m/R$ B) V_s/R **C) $V_m/2$** D) $V_s/2$	[ ]	**CO2**	**BL4**	**4**
8	For a single phase thyristor circuit with R load & firing angle α, the conduction angle can be given by A) ∏+ α B) 2∏+ α **C) ∏- α** D. α	[ ]	**CO2**	**BL3**	**3**
9	Mention the duty cycle of a chopper ? A) Ton/Toff **B) Ton/T** C) T/Ton D) Toff x Ton	[ ]	**CO3**	**BL2**	**3**
10	Find the output voltage for a step-up chopper when it is operated at a duty cycle of 50 % and Vs = 240 V. A) 240 V **B) 480** V C) 560 V D) 120 V	[ ]	**CO3**	**BL4**	**4**

BL – Bloom's Taxonomy Levels
CO – Course Outcomes
PI – Performance Indicator Code3

Academic Year: **2022-23**
Year: **III**
Semester: **I**

MID Exam – II (Descriptive)
Subject Name: Power Electronics
Subject Code: GR20A3013

Date: 10/10/2022
Duration: **90 min**
Max Marks: **15**

Note: Answer any ALL questions. All questions carry equal marks.

Answer ALL questions. All questions carry equal marks **3 * 5 = 15 Marks**					
Q. No	**Questions**	**Marks**	**CO**	**BL**	**PI**
1.	(a) Analyze the operation of step up (boost) chopper with neat circuit and waveforms	**[2 M]**	CO3	**BL4**	**4**
	(b) Articulate the working the Type D chopper with neat diagram and waveforms	**[3 M]**	CO3	**BL5**	**5**
OR					
2	(a) Analyze the operation of Type E chopper with neat circuit and waveforms	**[5 M]**	CO3	**BL5**	**5**
3.	(a) Describe the performance of 3-phase 6-pulse inverter using 180^o conduction mode with neat switching topologies and waveforms	**[5 M]**	CO4	**BL5**	**5**
OR					
4.	(a) Elaborate on, the operation of uni-polar sinusoidal modulation with neat diagram and waveforms	**[2 M]**	CO4	**BL4**	**4**
	(b) Analyze the operation of bipolar sinusoidal modulation with neat sketch and waveforms	**[3 M]**	CO4	**BL5**	**5**
5	(a) Describe the working of 1-phase full wave AC voltage controller for RL load with neat circuit and waveforms	**[2 M]**	CO5	**BL4**	**4**
	(b) Give the clear analysis on the operation of step down cyclo-converter using R load (for $f_0=f_s/4$) with neat layout and waveforms	**[3 M]**	CO5	**BL5**	**5**
OR					
	(a) Articulate on the operation of step-up cyclo-converter (for $f_0=6f_s$) with neat sketch and waveforms	**[3 M]**	CO5	**BL5**	**5**

Academic Year: **2022-23**
Year: **III**
Semester: **I**

MID Exam – II (Objective)
Subject Name: Power Electronics
Subject Code: GR20A3013

Date: 10/10/2022
Duration: **10 min**
Max Marks: **5M**

	(b) Elaborate on the performance of 1-phase half wave AC voltage controller for R load with neat diagram and waveforms	**[2 M]**	CO5	**BL4**	**4**

Roll No:

Note: Answer ALL questions carry **questions. All equal marks.**

Answer all Objective Questions. All questions carry equal marks					
Q.No	**Questions**	**Option**	**CO**	**BL**	**PI**
1	The load voltage of a chopper can be controlled by varying the (A). duty cycle (B). firing angle (C). reactor position (D). extinction angle	[ ]	**CO3**	**BL3**	**3**
2	A step down chopper is operated at 240V at duty cycle of 75%. Find the value of RMS switch (IGBT/MOSFET) current. Take R = 10 ?. (A). 2.07 A (B). 200 mA (C). 1.58 A (D). 2.4 A	[ ]	**CO3**	**BL5**	**5**
3	A three-phase three-pulse converter would operate as a line commutated inverter when (A). $30° < \alpha < 60°$ (B). $90° < \alpha < 180°$ (C). $\alpha > 90°$ (D). it can never operate as a line commutated inverter	[ ]	**CO4**	**BL4**	**4**
4	In case of a three phase full controlled converter with 6 SCRs, commutation occurs every (A). 120° (B). 60° (C). 180° (D). 30°	[ ]	**CO4**	**BL4**	**4**
5	A three phase full converter will require __________ number of SCRs. (A). 3 (B). 6 (C). 9 (D). 2	[ ]	**CO4**	**BL3**	**3**
6	In a 3-phase 6-pulse converter, the conduction sequence for the negative group of SCRs is (A). T4-T6-T2 (B). T1-T2-T3 (C). T2-T6-1 (D). T2-T4-T6	[ ]	**CO4**	**BL3**	**3**
7	Three-phase to three-phase cycloconverter employing 18 SCRs and 36 SCRs have the same voltage and current ratings for their component thyristors. The ratio of VA rating of 36 SCR device to that of 18 SCR device is (A). 1/2 (B). 1 (C). 2 (D). 4	[ ]	**CO5**	**BL5**	**5**
8	Three phase to three phase cycloconverter employing 18 SCRs are 36 SCRs have the same voltage and current ratings for their component thyristors. The ratio of power handled by 36 SCR device to that handled by 18 SCR device is (A). 4 (B). 2 (C). 1 (D). 1/2	[ ]	**CO5**	**BL5**	**5**
9	In AC voltage controllers the (A). variable ac with fixed frequency is obtained (B). variable ac with variable frequency is obtained (C). variable dc with fixed frequency is obtained (D). variable dc with variable frequency is obtained	[ ]	**CO5**	**BL3**	**3**
10	The TRIACs terminals are (A). gate anode cathode (B). MT1 MT2 gate (C). gate1 gate2 anode cathode (D). MT1 MT2 gate1 gate2	[ ]	**CO5**	**BL3**	**3**

BL – Bloom's Taxonomy Levels
CO – Course Outcomes
PI – Performance Indicator Code3

Gokaraju Rangaraju Institute of Engineering and Technology,
(Autonomous)

III B.Tech-(PE-GR20A3013) I-Sem Mid-I Marks (2022-23) of SECTION A

Department of Electrical and Electronics Engineering

S. NO	**ROLL NO**	**1 (CO1)**	**2 (CO 1)**	**3 (CO 2)**	**4 (CO 2)**	**5 (CO 3)**	**6 (CO 3)**	**Descriptive Marks**	QUIZ Marks	**Total Marks**	**%**
1	20241A0201		5	1		5		**11**	1	**12**	**60**
2	20241A0202							**0**		**0**	**0**
3	20241A0203							**0**		**0**	**0**
4	20241A0204	5		4			5	**14**	5	**19**	**95**
5	20241A0205		5	5			5	**15**	5	**20**	**100**
6	20241A0206	5		4.5			5	**14.5**	5	**19.5**	**97.5**
7	20241A0207		2.5	2.5			5	**10**	5	**15**	**75**
8	20241A0208		5	4.5		3		**12.5**	5	**17.5**	**87.5**
9	20241A0209							**0**		**0**	**0**
10	20241A0210	4		0			5	**9**	2	**11**	**55**
11	20241A0211	5		1			5	**11**	5	**16**	**80**
12	20241A0212		5	5		5		**15**	5	**20**	**100**
13	20241A0215		5	5		5		**15**	5	**20**	**100**
14	20241A0216		5	4.5			5	**14.5**	5	**19.5**	**97.5**
15	20241A0217	0			1		1	**2**	5	**7**	**35**
16	20241A0218		5	5		5		**15**	5	**20**	**100**
17	20241A0219		5	3		5		**13**	5	**18**	**90**
18	20241A0220		5	3		5		**13**	5	**18**	**90**
19	20241A0221	5		1.5			5	**11.5**	4.5	**16**	**80**
20	20241A0222		5	4.5			5	**14.5**	5	**19.5**	**97.5**
21	20241A0223	5		5			5	**15**	5	**20**	**100**
22	20241A0224	5					5	**10**	5	**15**	**75**
23	20241A0225			0				**0**	5	**5**	**25**
24	20241A0226	5		2.5			5	**12.5**	5	**17.5**	**87.5**
25	20241A0227		5			1		**6**	5	**11**	**55**
26	20241A0228		5				5	**10**	5	**15**	**75**
27	20241A0229		5	5		4.5		**14.5**	5	**19.5**	**97.5**
28	20241A0230	5		4.5			5	**14.5**	5	**19.5**	**97.**

											5
29	20241A0231							0		0	0
30	20241A0233	5		4.5		5		14.5	5	19.5	97.5
31	20241A0234		2.5	2.5			5	10	5	15	75
32	20241A0235	5		4.5		5		14.5	4.5	19	95
33	20241A0236		2.5	2.5			5	10	5	15	75
34	20241A0237		3.5	4.5		5		13	5	18	90
35	20241A0238	5		4			5	14	5	19	95
36	20241A0239		4	4.5			5	13.5	5	18.5	92.5
37	20241A0240		5	5		5		15	4.5	19.5	97.5
38	20241A0241	5		4			5	14	5	19	95
39	20241A0242		5	4			5	14	5	19	95
40	20241A0243	5		4.5			5	14.5	5	19.5	97.5
41	20241A0244		2.5	3.5			5	11	5	16	80
42	20241A0245		5	5		5		15	5	20	100
43	20241A0246		5	5			5	15	5	20	100
44	20241A0247		2.5				5	7.5	5	12.5	62.5
45	20241A0248		5	5			5	15	5	20	100
46	20241A0249	5			3.5	5		13.5	5	18.5	92.5
47	20241A0250	5		4			5	14	5	19	95
48	20241A0251	3.5		2.5			5	11	5	16	80
49	20241A0252							0		0	0
50	20241A0253		2.5	3.5			5	11	4.5	15.5	77.5
51	20241A0254	5			5		5	15	5	20	100
52	20241A0255						5	5	5	10	50
53	20241A0256	5			1	3		9	5	14	70
54	20241A0257	5		5			5	15	4.5	19.5	97.5
55	21245A0201		5	5		5		15	5	20	100
56	21245A0202	5			5		5	15	5	20	100
57	21245A0203		5	2		5		12	5	17	85
58	21245A0204	5		5			5	15	5	20	100
59	21245A0205		5	4.5		5		14.5	5	19.5	97.5
60	21245A0206		5	5		5		15	5	20	100
61	21245A0207	5		4.5			5	14.5	5	19.5	97.5
62	21245A0208		5	4			5	14	5	19	95

63	21245A0209		5	4.5		5		**14.5**	5	**19.5**	**97.5**
	Total	112.5	142.5	183.5	15.5	96.5	176				
	No of students attempted(NSA)	24	32	48	5	21	36				
	Attempt %=(NSA /Total no of students)*100	36.36363636	48.48	72.73	7.58	31.82	54.55				
	Average (attainment)= Total/NSA	4.6875	4.45	3.82	3.10	4.60	4.89				
	Attainment % = (Total/no.of max marks*no.of students attempted)*100	93.75	89.06	76.46	62.00	91.90	97.78				
		1 (CO1)	**1 (CO1)**	**2 (CO2)**	**2 (CO2)**	**3 (CO3)**	**3 (CO3)**				

A

CO1	91.41	
CO2	69.23	
CO3	94.84	

Final Average values of A		CO1	91.41
		CO2	69.23
		CO3	94.84

Gokaraju Rangaraju Institute of Engineering and Technology,
(Autonomous)

III B.Tech-(PE-GR20A3013) I-Sem Mid-II Marks (2022-23) of SECTION A

Department of Electrical and Electronics Engineering

S. NO	ROLL NO	1 (CO3)	2 (CO 3)	3 (CO 4)	4 (CO 4)	5 (CO 5)	6 (CO 5)	Descriptive Marks	QUIZ Marks	Total Marks	%
1	20241A0201		5		4		1	**10**	4	**14**	**70**
2	20241A0202	1		5			2	**8**	5	**13**	**65**
3	20241A0203		5	1		0		**6**	5	**11**	**55**
4	20241A0204		5		5		5	**15**	5	**20**	**100**
5	20241A0205	5		5			3	**13**	5	**18**	**90**
6	20241A0206	2		1			3	**6**	5	**11**	**55**
7	20241A0207		5		2			**7**	5	**12**	**60**
8	20241A0208		5		2		3	**10**	5	**15**	**75**
9	20241A0209			4				**4**	4	**8**	**40**
10	20241A0210		1		3			**4**	4	**8**	**40**
11	20241A0211		4		5		0	**9**	4	**13**	**65**
12	20241A0212	3		5			4	**12**	5	**17**	**85**
13	20241A0215		5	5		2		**12**	5	**17**	**85**
14	20241A0216	3		5			3	**11**	5	**16**	**80**
15	20241A0217		5		5			**10**	4	**14**	**70**
16	20241A0218	3		5			4	**12**	5	**17**	**85**
17	20241A0219	3		4	0		0	**7**	4	**11**	**55**
18	20241A0220	3		2		1		**6**	5	**11**	**55**
19	20241A0221		1	5				**6**	5	**11**	**55**
20	20241A0222	3		5			1	**9**	5	**14**	**70**
21	20241A0223		3	4		4		**11**	5	**16**	**80**
22	20241A0224		2	4			3	**9**	4	**13**	**65**
23	20241A0225		1		5			**6**	4	**10**	**50**
24	20241A0226							**0**	0	**0**	**0**
25	20241A0227		2		5		2	**9**	5	**14**	**70**
26	20241A0228		2		5		2	**9**	4	**13**	**65**
27	20241A0229		5	5			2	**12**	5	**17**	**85**
28	20241A0230	3					4	**7**	4	**11**	**55**
29	20241A0231		2		3			**5**	4	**9**	**45**
30	20241A0233		5	5				**10**	5	**15**	**75**
31	20241A0234	1		1		1		**3**	5	**8**	**40**
32	20241A0235	5		5			4	**14**	5	**19**	**95**
33	20241A0236	3		2				**5**	5	**10**	**50**
34	20241A0237		5	4				**9**	5	**14**	**70**

35	20241A0238	2					2	**4**	5	**9**	**45**
36	20241A0239	5		5		4		**14**	5	**19**	**95**
37	20241A0240		5	5		1		**11**	5	**16**	**80**
38	20241A0241							**0**	0	**0**	**0**
39	20241A0242	3		5			2	**10**	5	**15**	**75**
40	20241A0243	3			2		3	**8**	5	**13**	**65**
41	20241A0244			4		1		**5**	4	**9**	**45**
42	20241A0245		5	5			2	**12**	5	**17**	**85**
43	20241A0246	3		3		2		**8**	5	**13**	**65**
44	20241A0247		5					**5**	4	**9**	**45**
45	20241A0248		5	5			4	**14**	5	**19**	**95**
46	20241A0249	3		4				**7**	4	**11**	**55**
47	20241A0250		1		3			**4**	4	**8**	**40**
48	20241A0251				5		5	**10**	4	**14**	**70**
49	20241A0252			3			0	**3**	5	**8**	**40**
50	20241A0253	2			4	1		**7**	4	**11**	**55**
51	20241A0254		5	5			1	**11**	5	**16**	**80**
52	20241A0255							**0**	0	**0**	**0**
53	20241A0256		5		3			**8**	4	**12**	**60**
54	20241A0257	5			5	4		**14**	5	**19**	**95**
55	21245A0201		5	5			5	**15**	5	**20**	**100**
56	21245A0202	3					4	**7**	4	**11**	**55**
57	21245A0203	2		1		0		**3**	5	**8**	**40**
58	21245A0204		5	5			5	**15**	5	**20**	**100**
59	21245A0205	4		5			5	**14**	5	**19**	**95**
60	21245A0206	5		5			5	**15**	5	**20**	**100**
61	21245A0207			2			1	**3**	5	**8**	**40**
62	21245A0208						4	**4**	4	**8**	**40**
63	21245A0209	4		3			3	**10**	4	**14**	**70**
	Total	82	109	152	66	21	97				
	No of students attempted(NSA)	26	28	38	18	12	34				
	Attempt %=(NSA /Total no of students)*100	39.39393939	42.42	57.58	27.27	18.18	51.52				
	Average (attainment)= Total/NSA	3.153846154	3.89	4.00	3.67	1.75	2.85				

	Attainment % = (Total/no.of max marks*no.of students attempted)*100	63.07692308	77.86	80.00	73.33	35.00	57.06					
		1 (CO3)	**2 (CO3)**	**3 (CO4)**	**4 (CO4)**	**5 (CO5)**	**6 (CO5)**					

A

CO1	91.41	
CO2	69.23	
CO3	94.84	

Final Average values of A		CO1	91.41
		CO2	69.23
		CO3	78.59
		CO4	76.67
		CO5	46.03

III/IV B. Tech I Semester Regular Examinations, December 2022
POWER ELECTRONICS
(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

PART – A **(Answer ALL questions. All questions carry equal marks)** **10 * 2 = 20 Marks**				
1. a.	Draw the static V-I & transfer characteristic curves of MOSFET	**[2]**	**CO1**	**BL 2**
b.	Plot I-V characteristics of IGBT and mark the region in which the device is operated as a switch.	**[2]**	**CO1**	**BL 3**
c.	Give the importance of freewheeling diode in controlled rectifiers	**[2]**	**CO2**	**BL 3**
d.	Name the triggering (turn-on) methods of a thyristor	**[2]**	**CO2**	**BL 3**
e.	Define duty ratio	**[2]**	**CO3**	**BL 2**
f.	Mention the various control strategies in the chopper circuits	**[2]**	**CO3**	**BL 2**
g.	Give the statement for bipolar sinusoidal modulation	**[2]**	**CO4**	**BL 3**
h.	Mention the advantages of inverter	**[2]**	**CO4**	**BL 3**
i.	Give the statement for step up cyclo converter	**[2]**	**CO5**	**BL 3**
j.	List out the applications of AC voltage controller	**[2]**	**CO5**	**BL 3**
PART – B **(Answer ALL questions. All questions carry equal marks)** **5 * 10 = 50 Marks**				
2.a	Illustrate how a UJT firing circuit will generate pulse for an SCR	**[5]**	**CO1**	**BL 3**
2.b	Snubber circuit which is connected across SCRs.	**[5]**	**CO1**	**BL 3**
OR				
3.a	Elaborate on dv/dt and di/dt rating of SCRs? What happens if these ratings are exceeded?	**[5]**	**CO1**	**BL 4**
3.b	Describe briefly about line commutation circuits of a thyristor	**[5]**	**CO1**	**BL 4**
4.a	Articulate on Single phase fully-controlled converter with RL load for discontinuous mode of operation	**[5]**	**CO2**	**BL 4**
4.b	Elaborate on, the effect of source impedance on the performance of converters	**[5]**	**CO2**	**BL 4**
OR				
5.a	Analyze the 3-phase, 6-pulse semi-controlled (half-controlled) converter with RLE & F.D load	**[5]**	**CO2**	**BL 4**
5.b	A 1-phase 230 V, 1kW heater is connected across 1-phase 230 V 50 Hz supply through an SCR. For firing angle delays of 45^o and 90^o, calculate the power absorbed in the heater element	**[5]**	**CO2**	**BL 5**
6.a	Elaborate on working of type D chopper	**[5]**	**CO3**	**BL 4**
6.b	For type-A chopper dc source voltage=230V, load resistance R=10Ω. Take a voltage drop of 2V across chopper when it is on. For a duty cycle of 0.4, calculate (i) average & rms values of o/p voltage & current and (ii) chopper efficiency	**[5]**	**CO3**	**BL 5**
OR				
7.a	Articulate on working of type E chopper	**[5]**	**CO3**	**BL 4**

7.b	A type-A chopper has input dc voltage of 200V and a load R=10 Ω in series with L=80Mh. If load current varies linearly between 12A and 16A. find time ratio T_{on}/T_{off} for this chopper	**[5]**	**CO3**	**BL 5**
8.a	Analyze the operation of 1-phase full bridge inverter with neat circuit diagram and o/p waveforms	**[5]**	**CO4**	**BL 4**
8.b	A single phase half bridge inverter, connected to 230V dc source, feeds a resistive load of 10Ω. Determine fundamental rms output voltage, total output power, distortion factor and total harmonic distortion	**[5]**	**CO4**	**BL 5**
OR				
9.a	Give the clear Analysis on the operation of 3-phase 6-pulse inverter with 180^{o} of conduction mode	**[5]**	**CO4**	**BL 5**
9.b	A star connected load of 15 Ω per phase is fed from 420V dc source through a 3-phase bridge inverter in 120^{0} mode. Determine the rms value of load current and thyristor current.	**[5]**	**CO4**	**BL 5**
10.a	Describe the operation of a 1-phase full bridge AC voltage controller with neat circuit diagram and output waveforms for RL load	**[5]**	**CO5**	**BL 4**
10.b	A single phase AC voltage controller has input voltage of 230V, 50Hz and a load of R=15Ω. For 6 cycles on and 4 cycles off, Determine rms output voltage, input pf, average and rms thyristor currents	**[5]**	**CO5**	**BL 5**
OR				
11.a	Articulate on principle of operation of a step up cyclo converter for $f_0=6f_s$ with neat circuit diagram and o/p wave forms	**[5]**	**CO5**	**BL 4**
11.b	A single phase bridge-type cyclo-converter has input voltage of 230V, 50Hz and load of R=10Ω. Output frequency is one-third of input frequency. For a firing angle delay of 30^{0}, Determine rms value of output voltage, rms current of each thyristor and input power factor	**[5]**	**CO5**	**BL 5**

*****

Academic Year: **2022-23**
Year: **III**
Semester: **I**

Assignments (Descriptive)
Subject Name: Power Electronics
Subject Code: GR20A3013

Date: 7/10/2022
Duration: 3 days
Max Marks: **5**

Note: Answer any ALL questions. All questions carry equal marks.

Q. No	Questions	Marks	CO	BL	PI
	ASSIGNMENT -I				
1.	(a) Draw the static V-I & transfer characteristic curves of IGBT	**[2 1/2]**	**CO1**	**BL2**	**3**
	(b) Draw the static V-I & transfer characteristic curves of MOSFET	**[2 1/2]**	**CO1**	**BL2**	**3**
2.	(a) Deduce the expression for anode current (I_a) using two transistor analogy with neat sketch	**[2 1/2]**	**CO1**	**BL4**	**4**
	(b) Mention the triggering (turn-on) methods of a thyristor	**[2 1/2]**	**CO1**	**BL3**	**3**
	ASSIGNMENT -II				
3.	(a) Give a brief note on significance of a freewheeling diode in the converters	**[2 1/2]**	**CO2**	**BL3**	**3**
	(b) Articulate on Single phase fully-controlled converter with RL load for discontinuous mode of operation	**[2 1/2]**	**CO2**	**BL4**	**4**
4.	(a) Elaborate on, the effect of source impedance on the performance of converters	**[2 1/2]**	**CO2**	**BL4**	**4**
	(b) Analyze the 3-phase, 6-pulse semi-controlled (half-controlled) converter with RLE & F.D load	**[2 1/2]**	**CO2**	**BL4**	**4**
	ASSIGNMENT -III				
5	For type-A chopper dc source voltage=230V, load resistance R=10Ω. Take a voltage drop of 2V across chopper when it is on. For a duty cycle of 0.4, calculate (i) average & rms values of o/p voltage & current and (ii) chopper efficiency	**[5]**	**CO3**	**BL4**	**4**
6.	A type-A chopper has input dc voltage of 200V and a load R=10 Ω in series with L=80Mh. If load current varies linearly between 12A and 16A. find time ratio T_{on}/T_{off} for this chopper	**[5]**	**CO3**	**BL4**	**4**
7.	(a) Analyze the operation of step up (boost) chopper with neat circuit and waveforms	**[2 M]**	**CO3**	**BL4**	**3.1.1**
	(b) Articulate the working the Type D chopper with neat diagram and waveforms	**[3 M]**	**CO3**	**BL5**	**3.1.4**
	OR				
8	Analyze the operation of Type E chopper with neat circuit and waveforms	**[5 M]**	**CO3**	**BL5**	**3.1.6**
	ASSIGNMENT -IV				
9.	Describe the performance of 3-phase 6-pulse inverter using 180° conduction mode with neat switching topologies and waveforms	**[5 M]**	**CO4**	**BL5**	**3.1.6**
	OR				
10.	(a) Elaborate on, the operation of uni-polar sinusoidal modulation	**[2 M]**	**CO4**	**BL4**	**3.1.1**

	with neat diagram and waveforms				
	(b) Analyze the operation of bipolar sinusoidal modulation with neat sketch and waveforms	[3 M]	CO4	BL5	3.1.4
ASSIGNMENT -V					
5	(c) Describe the working of 1-phase full wave AC voltage controller for RL load with neat circuit and waveforms	[2 M]	CO5	BL4	3.1.1
	(d) Give the clear analysis on the operation of step down cyclo-converter using R load (for $f_0=f_s/4$) with neat layout and waveforms	[3 M]	CO5	BL5	3.1.4
OR					
6.	(c) Articulate on the operation of step-up cyclo-converter (for $f_0=6f_s$) with neat sketch and waveforms	[3 M]	CO5	BL5	3.1.1
	(d) Elaborate on the performance of 1-phase half wave AC voltage controller for R load with neat diagram and waveforms	[2 M]	CO5	BL4	3.1.4

Gokaraju Rangaraju Institute of Engineering & Technology *(Autonomous)*
Electrical and Electronics Engineering Department

Power Electronics
Action Taken Report (ATR)

ATR for the not attainment of CO2: Illustrate the performance of controlled rectifiers and AC-DC converters

- **Seminars will be taken to reach that outcome**
- **The following of the seminar topics will be given to reach that CO2**

[1]. Operation of 1-phase half wave controlled rectifier with RL load
[2]. Working of 1-phase half-controlled rectifier with RLE load for discontinuous load current mode of operation
[3]. Performance of 1-phase half-controlled rectifier with RL load for continuous load current mode of operation
[4]. Working of 1-phase half-controlled rectifier with RL & freewheeling diode load
[5]. Description of 1-phase fully controlled rectifier with RLE load for continuous load current mode of operation
[6]. Performance of 1-phase fully controlled rectifier with RL load for discontinuous load current mode of operation
[7]. Operation of 3-phase half-controlled rectifier for R load with neat speed-torque characteristics & waveforms
[8]. Working of 3-phase fully controlled rectifier for RL load with neat speed-torque characteristics and waveforms
[9]. Performance of 3-phase half wave controlled rectifier for RLE load with neat speed-torque characteristics and waveforms

ATR for the not attainment of CO5: Illustrate the performance of the AC-AC converters

- **Concepts will be revised to reach that outcome**
- **The following concepts will be revised to reach that CO5**

[1]. Revision on 1-phase half wave ac voltage controller with R load
[2]. Revision on 1-phase full wave ac voltage controller with RL load
[3]. Revision on 1-phase to 1-phase step down cyclo converter with RL load
[4]. Revision on 1-phase to 1-phase step up cyclo converter

- And also some of the quizzes will be conducted to reach that outcome, as follows

[1]. Three-phase to three-phase cycloconverter employing 18 SCRs and 36 SCRs have the same voltage and current ratings for their component thyristors. The ratio of VA rating of 36 SCR device to that of 18 SCR device is
(A). 1/2 (B). 1 (C). 2 (D). 4

[2]. Three phase to three phase cycloconverter employing 18 SCRs are 36 SCRs have the same voltage and current ratings for their component thyristors. The ratio of power handled by 36 SCR device to that handled by 18 SCR device is
(A). 4 (B). 2 (C). 1 (D). 1/2

[3]. In AC voltage controllers the
(A). variable ac with fixed frequency is obtained
(B). variable ac with variable frequency is obtained
(C). variable dc with fixed frequency is obtained
(D). variable dc with variable frequency is obtained