GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Course File

Subject: Power Electronic

Subject Code: GR15A3018

Academic Year: 2018-19

Regulation: GR15

Year: III **Semester:** I

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Course Title: <u>Power Electronics</u>

Following documents are available in Course File.

S.No.	Points	Yes	No
1	Institute and Department Vision and Mission Statements	√	
2	PEO & PO Mapping	√	
3	Academic Calendar	√	
4	Subject Allocation Sheet	√	
5	Class Time Table, Individual Timetable (Single Sheet)	√	
6	Syllabus Copy	√	
7	Course Handout	√	
8	CO-PO Mapping	√	
9	CO-Cognitive Level Mapping	√	
10	Lecture Notes	√	
11	Tutorial Sheets With Solution	√	
12	Soft Copy of Notes/Ppt/Slides	√	
13	Sessional Question Paper and Scheme of Evaluation	√	
14	Best, Average and Weak Answer Scripts for Each Sessional Exam. (Photocopies)	√	
15	Assignment Questions and Solutions	√	
16	Previous University Question Papers	√	
17	Result Analysis	√	
18	Feedback From Students	√	
19	Course Exit Survey	√	
20	CO Attainment for All Mids.	√	
21	Remedial Action.		√

Course Instructor / Course Coordinator **Course Instructor / Course Coordinator**

Karunakumar Davala **D karunakumar**

(Name) **(Signature)**

Department of Electrical & Electronics Engineering

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

- To become an internationally leading department for higher learning.
- To build upon the culture and values of universal science and contemporary education.
- 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.
- To develop partnership with industrial, R&D and government agencies and actively participate in conferences, technical and community activities.

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Department of Electrical & Electronics Engineering

Programme Educational Objectives (B.Tech. – EEE)

This programme is meant to prepare our students to professionally thrive and to lead. During their progression:

Graduates will be able to

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

Programme Outcomes (B.Tech. – EEE)

At the end of the Programme, a graduate will have the ability to

PO 1: Apply knowledge of mathematics, science, and engineering.
PO 2: Design and conduct experiments, as well as to analyze and interpret data.
PO 3: 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.
PO 4: Function on multi-disciplinary teams.
PO 5: Identify, formulates, and solves engineering problems.
PO 6: Understanding of professional and ethical responsibility.
PO 7: Communicate effectively.
PO 8: Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
PO 9: Recognition of the need for, and an ability to engage in life-long learning.
PO 10: Knowledge of contemporary issues.
PO 11: Utilize experimental, statistical and computational methods and tools necessary for engineering practice.
PO 12: 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.

PEOs & POs Mapping

Programme Educational Objectives (PEOs)	Programme Outcomes (POs)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	M	M	-	-	H	-	-	H	H	-	H	H
2	-	-	M	M	H	H	H	-	-	-	-	H
3	-	-	-	-	H	H	M	M	M	M	H	H
4	-	-	-	M	M	H	M	H	H	-	M	H

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

HOD-EEE

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

GRIET/DAA/1H/G/18-19 05 May 2018

ACADEMIC CALENDAR
Academic Year 2018-19

III & IV B.TECH – FIRST SEMESTER

S. No.	EVENT	PERIOD	DURATION
1	1st Spell of Instructions	02-07-2018 to 01-09-2018	9 Weeks
2	1st Mid-term Examinations	03-09-2018 to 05-09-2018	3 Days
3	2nd Spell of Instructions	06-09-2018 to 24-10-2018	7 Weeks
4	2nd Mid-term Examinations	25-10-2018 to 27-10-2018	3 Days
5	Preparation	29-10-2018 to 06-11-2018	1 Week3 Days
6	**End Semester Examinations (Theory/ Practicals) Regular/Supplementary**	**08-11-2018 to 08-12-2018**	**4 Weeks 3 Days**
7	Commencement of Second Semester, A.Y 2018-19	10-12-2018	

III&IV B.TECH – SECOND SEMESTER

S. No.	EVENT	PERIOD	DURATION
1	1st Spell of Instruction	10-12-2018 to 02-02-2019	8 Weeks
2	1st Mid-term Examinations	04-02-2019 to 06-02-2019	3 Days
3	2nd Spell of Instruction	07-02-2019 to 06-04-2019	**8 Weeks 3 Days**
4	2nd Mid-term Examinations	08-04-2019to 10-04-2019	3 Days
5	Preparation	11-04-2019 to 17-04-2019	1 Week
6	**End Semester Examinations(Theory/ Practicals) Regular**	18-04-2019 to 08-05-2019	3 Weeks
7	**Supplementary and Summer Vacation**	**09-05-2019 to 22-06-2019**	**6 Weeks 3 Days**
8	Commencement of First Semester, A.Y 2019-20	24-06-2019	

Copy to Director, Principal, Vice Principal, DOA, DOE, Balaji Kumar, DCGC, All HODs

(Dr. K. Anuradha)
Dean of Academic Affairs

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

2018-19 I sem Subject allocation sheet

II YEAR(GR17)	Section-A	Section-B
Special Functions and Complex Variable	Dr GS	Dr GS
Electromagnetic Fields	SN	SN
Network Theory	MS	MS
DC Machines and Transformers	Dr BPB	Dr BPB
Computer Organization	PRK	PRK
DC Machines Lab	MP/DSR	PRK/DSR
Electrical Networks Lab	YSV/GBR	YSV/GBR
Electrical Simulation Lab	GSR/PS	GSR/PS
Environmental Science		
III YEAR (GR15)	Section-A	Section-B
Power Transmission System	VVRR/MP	VVRR/MP
Microcontrollers	PK	PK
Power Electronics	**Dr TSK**	**DKK**
Electrical Measurements& Instrumentation (PE-1)	UVL	UVL
Solar & Wind Energy Systems (OE-1)	PSVD/Dr JP	PSVD/Dr JP
Sensors/Measurements& Instrumentation Lab	PSVD/PS	UVL/PS
Power Electronics Lab	PPK/MRE	SN/MRE
Microcontrollers Lab	RAK/DKK	PK/DKK
IV YEAR(GR15)	Section-A	Section-B
Power Semiconductor Drives	YSV	Dr DGP
Power System Operation & Control	Dr JSD	Dr JSD
High Voltage DC Transmission Systems	MRE	Dr SVJK
Electrical Distribution Systems (PE-3)	VVSM	
High Voltage Engineering (PE-3)	VUR	

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Soft Computing Techniques (OE-3)	RAK	RAK
DSP based Electrical Lab	AVK/DKK	AVK/DKK
Power Systems Simulation Lab	VVSM / GSR	VVSM / GSR
Power Electronic Drives Lab	MP/GBR	MP/GBR
I/I BEE(AICTE)	A/B	C/D/E
BEE	ML	
BEE	KS	
BEE	MK	
BEE	MVK	
BEE	MNSR	
Civil II/I (GR15)	A	B
ET	PPK	PPK
M.Tech (PE)(AICTE)	A	
Electric Drives System	Dr DGP	
Power Electronic Converters	Dr TSK	
Power Quality	AVK	
Electric and Hybrid Vehicles	Dr BPB	
Electrical Drives Laboratory	AVK/GBR	
Power Electronics Lab	SN/MS	
M.Tech (PS)(AICTE)	A	
Power System Analysis	Dr JSD	
Power System Dynamics	Dr SVJK	
Power Quality	AVK	
Electric and Hybrid Vehicles	Dr BPB	
Power System Steady State Analysis Lab	VVSM/VVRR	
Power System Dynamics Lab	Dr SVJK/YSV	

HoD-EEE

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Department of Electrical & Electronics Engineering

GRIET/PRIN/06/G/01/18-19 **Wef**

BTech - EEE - B **III year - I Semester**

DAY/ HOUR	9:00 - 9:50	9:50 - 10:40	10:40 - 11:30	11:30 - 12:00	12:00-12:45	12:45-1:30	1:30 - 2:15	2:15 -3:00
MONDAY	**PE**	**PE**	MC	BREAK	SMI Lab / PE Lab B1/ B2			
TUESDAY	**PE**	**PE**	MC		MCLab / SMI Lab B1/ B2			
WEDNESDAY	**PE**	**PE**	PTS		EMI		SWE	
THURSDAY	PTS	PTS	EMI		SWE		MC	
FRIDAY	PTS	PTS	EMI		MC		SWE	
SATURDAY	PTS	EMI	EMI		PELab / MC Lab B1/ B2			

Room No	
Theory	4404
Lab	SMI Lab - 4507 MC Lab - 4505 PE Lab - 4405

Class Incharge:	M Lohita

Subject Code	Subject Name	Faculty Code	Faculty name	Almanac	
GR15A3016	Power Transmission System	VVRR/MP	V Vijaya Rama Raju/M Prashanth	1st Spell of Instructions	02-07-2018 to 01-09-2018
GR15A2055	Microcontrollers	PK	P Prashanth	1st Mid-term Examinations	03-09-2018 to 05-09-2018
GR15A3018	**Power Electronics**	**DKK**	**D Karuna Kumar**	2nd Spell of Instructions	06-09-2018 to 24-10-2018
GR15A3017	Electrical Measurements and Instrumentation	UVL	U Vijaya Lakshmi	2nd Mid-term Examinations	25-10-2018 to 27-10-2018
GR15A3152	Solar & Wind Energy Systems	PSVD/Dr JP	P Sri Vidya Devi/Dr J Praveen	Preparation	29-10-2018 to 06-11-2018
GR15A3019	Sensors/Measurements and Instrumentation Lab	UVL/PS	U Vijaya Lakshmi/ P Sirisha	End Semester Examinations (Theory/ Practicals) Regular / Supplementary	08-11-2018 to 08-12-2018
GR15A3020	Power Electronics Lab	SN/MRE	Syed Sarfaraz Nawaz/ M Rekha		
GR15A2059	Microcontrollers Lab	PK/DKK	P Prashanth Kumar/ D Karuna Kumar	Commencement of Second Semester	10-12-2018

HOD **Co-ordinator** **DAA**

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Department of Electrical & Electronics Engineering

Work Load / D Karuna Kumar								
	9.00 PM	10.00 PM	11. 00 PM	12. 00 PM	1. 00 PM	2. 00 PM	3. 00 PM	4. 00 PM
MON	Power Electronic							
TUE	Power Electronic							
WED	Power Electronic							
THU								
FRI								
SAT								

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Syllabus

Subject– Power Electronics

Course Code: GR15A3018

B.Tech III Year I Sem

L:3T:1 P:0 C:4

UNIT-I

Power Semiconductor Devices: Thyristors Silicon Controlled Rectifiers (SCR's) BJTPower MOSFET and Power IGBT and their characteristics and other thyristors Basic theory of operation of SCR Static characteristics Turn on and Turn off methods-Dynamic characteristics of SCR Turn on and Turn off times-Salient points.

Two transistor analogy of SCR R,RC,UJT firing circuits Series and parallel connections of SCR's Snubber circuit details Specifications and Ratings of SCR's, BJT, IGBT - Numerical problems Line Commutation and Forced Commutation circuits.

UNIT-II

Single Phase Half Wave Controlled Converters: Phase control technique, Single phase Line commutated converters, Mid point and Bridge connections– Half wave controlled converters with Resistive, RL load and RLE load Derivation of average load voltage and current Active and Reactive power inputs to the converters without and with Freewheeling Diode Numerical problems

Single Phase Fully Controlled Converters: Fully controlledconverters, Midpoint and Bridge connections with Resistive, RL loads and RLE load Derivation of average load voltage and current Line commutated inverters, semi-converters, active and Reactive power inputs to the converters, Effect of source inductance Expressions of load voltage and current, Dualconverters Numerical problems.

UNIT-III

Three phase converters: Three pulse and six pulse converters Mid-Point and bridge connections average load voltage with R, RL load voltage and current with R and RL load and Semi converter Effect of Source inductance Waveforms Numerical Problems.

Inverters: Inverters Single phase inverter Basic series inverter, parallel Capacitor inverter, bridge inverter Waveforms, Voltage control techniques for inverters- Pulse width modulation techniques Numerical problems. Basics of Resonant Inverters.

UNIT-IV

AC Voltage Controllers &Cyclo Converters: AC voltage controllers Single phase two SCR's in antiparallel with R and RL loads, modes of operation of TriacTriac with R and RL loads Derivation of RMS load voltage, current and power factor- waveforms , Numerical problems, Cyclo converters Single phase mid pointcyclo converters with Resistive and inductive load (Principle of operation only) Bridge configuration of single phase cyclo converter(Principle of operation only)Waveforms.

UNIT-V

Choppers: Time ratio control and Current limit control strategies Step down choppers-Derivation of load voltage and currents with R, RL and RLE loads-Step up Chopper load voltage expression. Morgan's chopper Jones chopper Oscillation choppers (Principle of operation only) -waveforms AC Chopper Problems.

Text Books

1. P.S.Bhimbra, “Power Electronics“, Khanna publications.

2. M.D.Singh&K.B.Kanchandhani, Power Electronics, Tata McGrawHillPublishing company, 1998.

Reference Books

1. VedamSubramanyam, Power Electronicsby New Age International (P) Limited, Publishers

2. P.C.Sen, Power Electronics, Tata McGraw-Hill Publishing.

Department of Electrical & 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.

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CO-PO Mapping

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

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

<u>Thyristors</u>: 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.

<u>Controllable switches</u>: 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

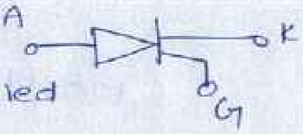
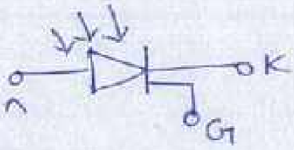
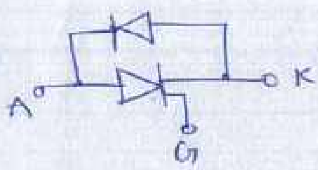
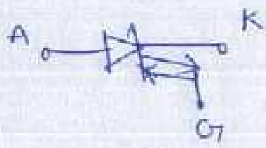
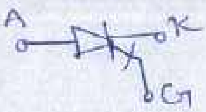
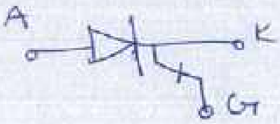
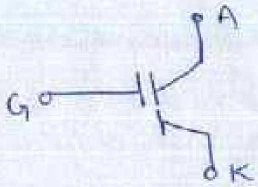
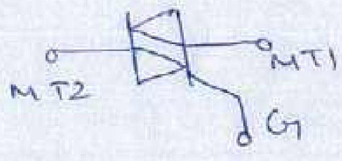
→ A P.E system consists of one or more P.E converters.

→ 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, electro plating, power supplies, UPS, welding etc.

Maximum ratings of Power semiconductor devices

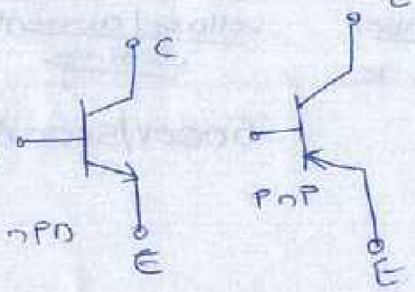
Device	circuit symbol	voltage/current ratings	upper operating freq(kHz)
1. Diode		5000V/5000A	1.0
2. Thyristors			
(a) SCR Silicon controlled Rectifier		7000V/5000A	1.0
(b) LASCR Light Activated SCR		6000V/3000A	1.0
(c) ASCR/RCT Asymmetrical SCR/ Reverse conducting thyristor		2500V/400A	2.0
(d) GTO gate turnoff thyristor	 or 	3000V/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 | voltage / current ratings | upper operating freq (KHz)

3. Transistors

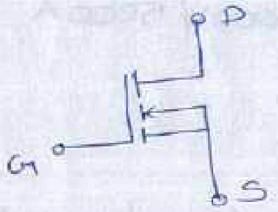
(a) BJT

Bipolar Junction Transistor



1400V / 400A — 10.0

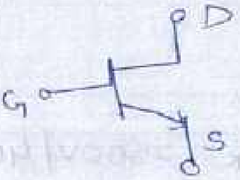
(b) MOSFET (n-channel)



1000V / 50A — 100.0

(c) SIT

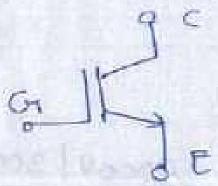
Static induction transistor



1200V / 300A — 100.0

(d) IGBT

Insulated Gate bipolar 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 thyristors.

→ 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 voltage 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.

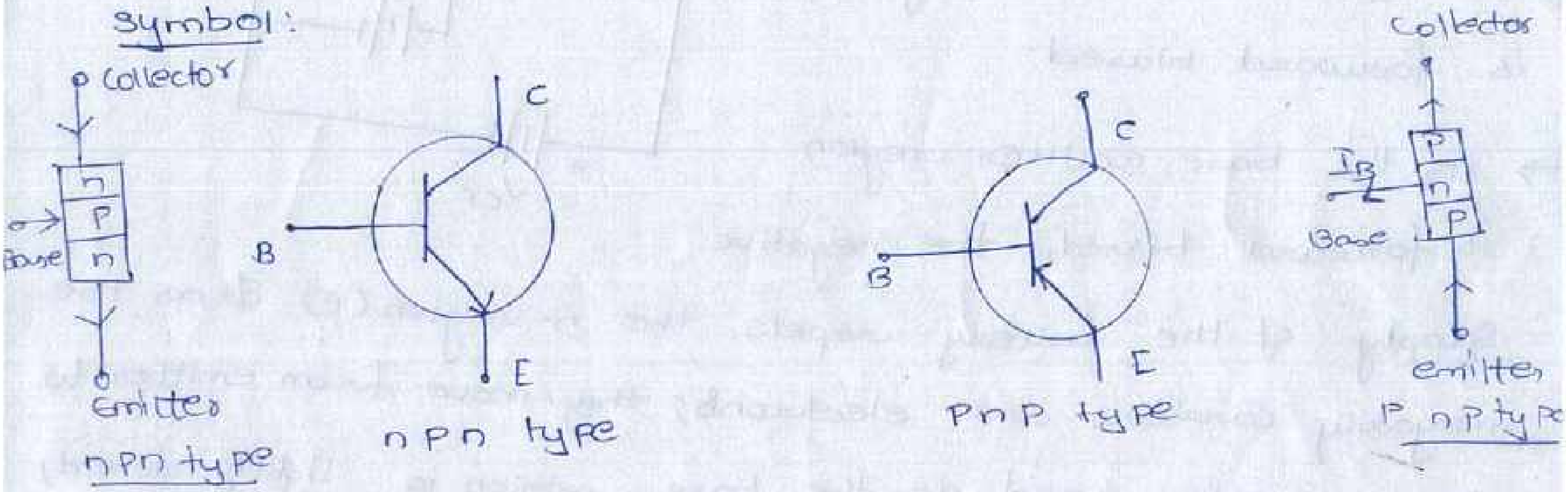
(b) cycloconverters : These circuits converts i/p power at one frequency to output power at a different frequency through one stage conversion.

6. Static Switches: The power semiconductor devices can operate as static switches or contactors. Static switches posses 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 ~~one~~ two p-regions sandwiched one n-region, pnp transistor is obtained

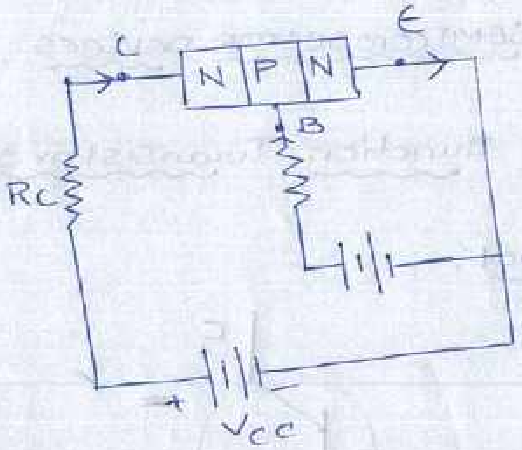
→ the term Bipolar denotes that the current flow in the device is due to the movement of both holes & electrons

→ 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

$$I_B = I_E - I_C$$

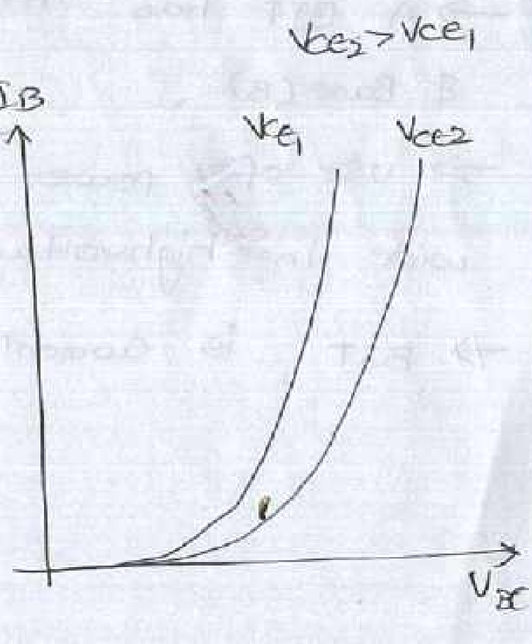
the currents I_E, I_B & I_C are assumed positive when they enter into the transistor.

CHARACTERISTICS

Steady state characteristics

Input characteristics:

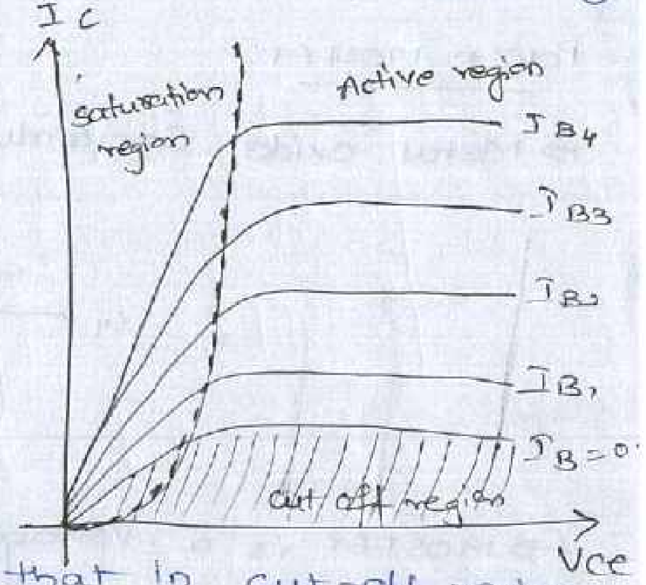
The Input characteristics are drawn between the base emitter voltage and base current by keeping the value of the collector emitter voltage to a constant value.



Output characteristics:

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

The output characteristics are drawn between V_{CE} and I_C 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 voltage is less.

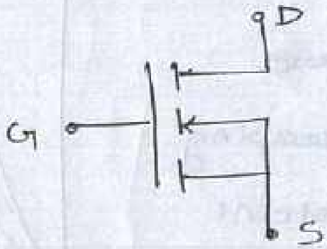
Switching characteristics

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

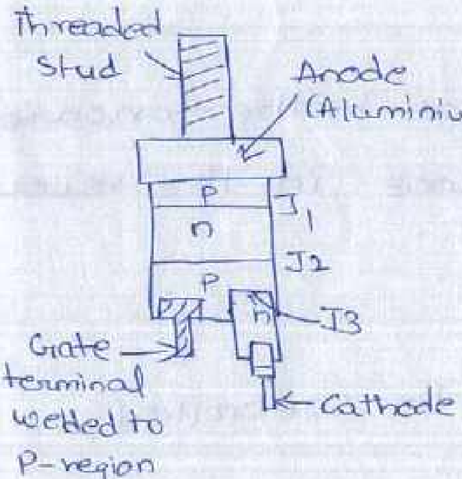
→ Two types
- n-channel MOSFET → more commonly used. of higher mobility of electrons.
- P-channel MOSFET

THYRISTORS

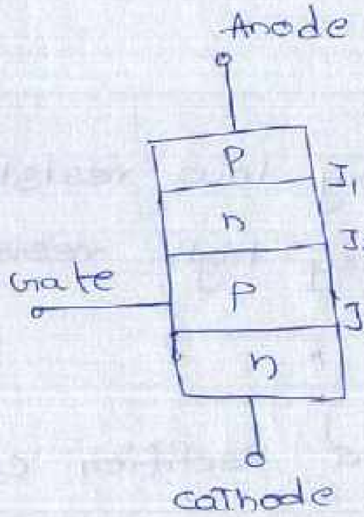
→ Bell laboratories were the first to fabricate a Silicon-based semiconductor device called thyristor.

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

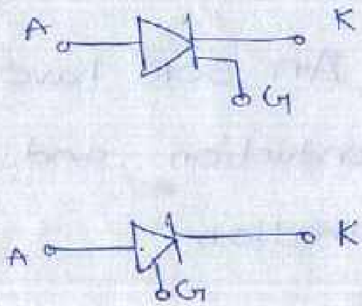
→ The word thyristor have become synonymous with SCR.



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:

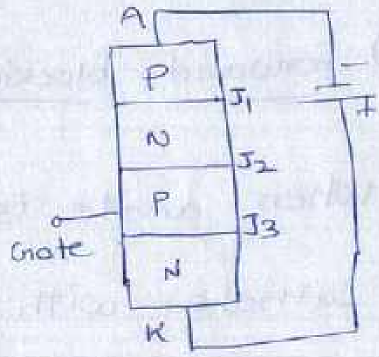
→ The thyristor operates in three modes

(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 μA flows.

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

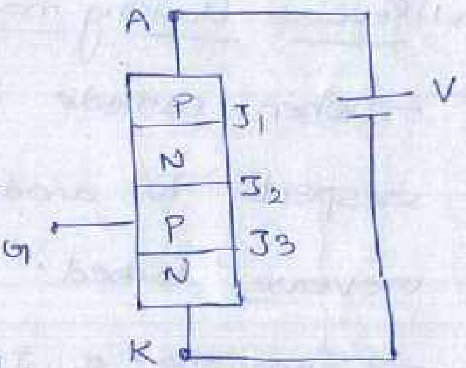
→ If the reverse voltage is increased, then at critical breakdown level, called reverse breakdown voltage V_{BR}, an avalanche occurs at J_1 & J_3 & the reverse current increase rapidly.

→ 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.

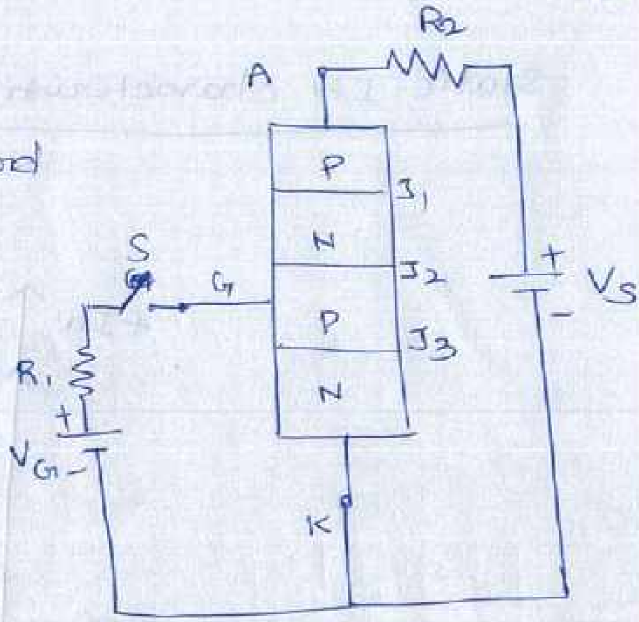
→ The junctions J_1 & J_3 are forward biased but Junction J_2 is reverse biased.

⇒ 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}

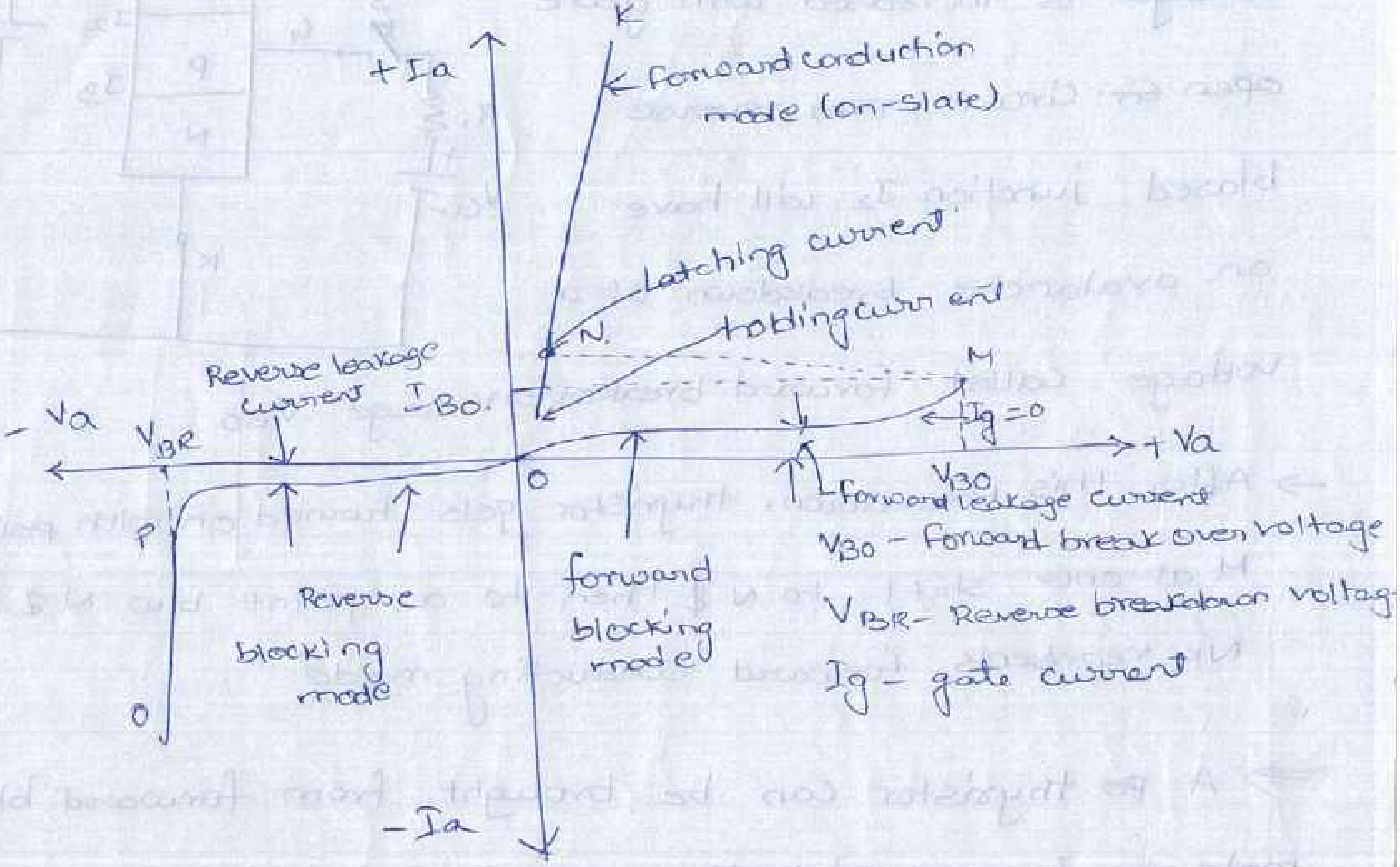
→ After this breakdown, thyristor gets turned on with point M at once shift to N & then to a point b/w N & K. NK represents forward conducting mode.

→ 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

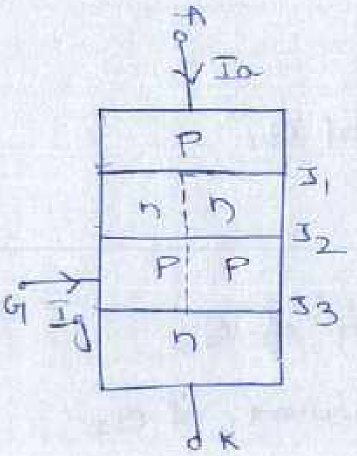


V_{BO} - Forward break over voltage

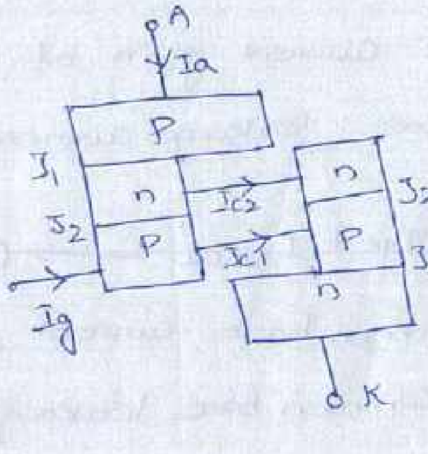
V_{BR} - Reverse breakdown voltage

I_g - gate current

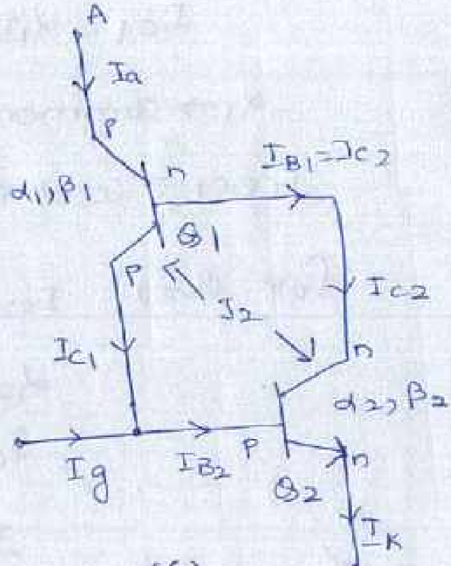
Two transistor model of thyristor.



(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

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

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

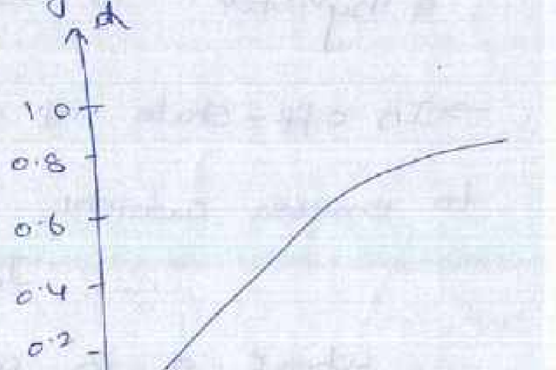
when gate current is applied, then $I_K = I_a + I_g$, substituting in eq ③ gives

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

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

$\alpha \approx I_C / I_E$

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:-

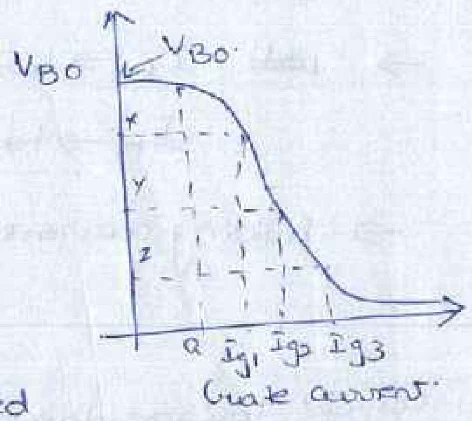
→ This Turning on of thyristors by gate triggering is simple, reliable and efficient, most usual method.

→ 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.

→ <u>Latching current</u>:- 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.

→ <u>Holding current</u>: 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 charging 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:-

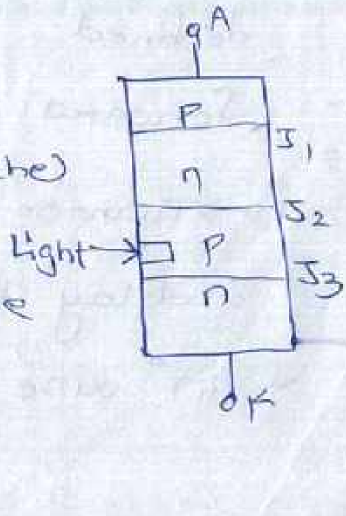
→ During F.B mode, most of applied voltage appears across reverse biased junction J_2.

→ 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.

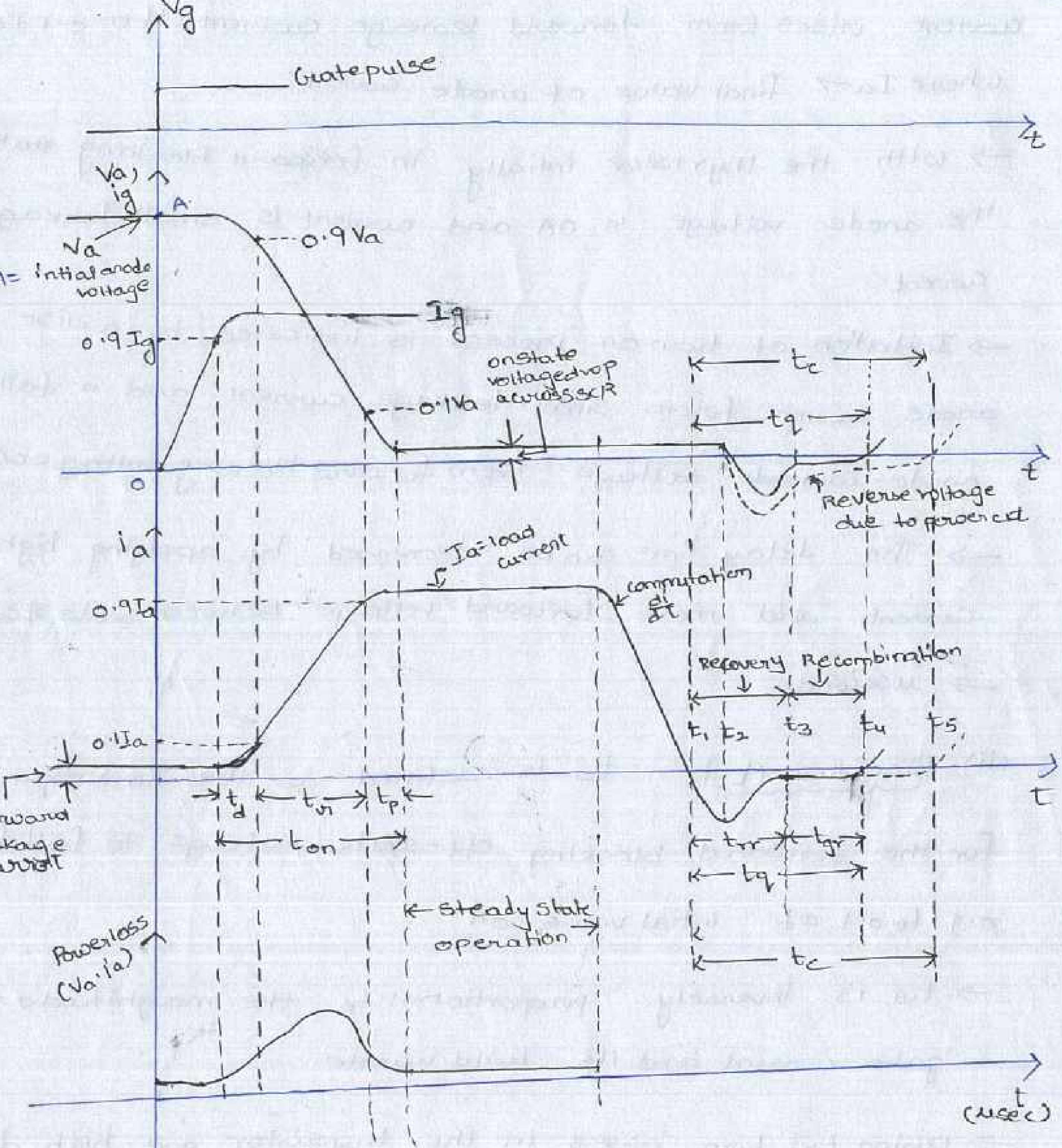
(a) switching characteristics during turn-on:-

~~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.

Turnon

(i) Delaytime t_d: t_d is defined as the time during which anode voltage falls from Va to 0.9 Va where Va → initial value of anode voltage.
(or)

t_d is defined as the time during which anode

current rises from forward leakage current to 0·1 Ia
where Ia → 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 Va & high Ia occuring together in thyristor

(iii) Spread time (t_p) :- t_p is the time taken by the anode current to rise from 0·9 to Ia.

(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 ve. 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 & ~~tas~~ 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.

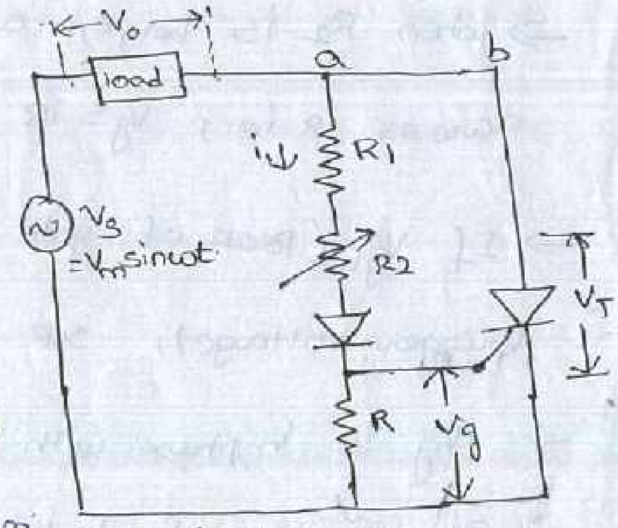
→ the gate circuit is also called firing or triggering circuit

(1) Resistance firing circuit:-

→ It is simple & most economical.

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

→ R_2 is variable resistance.



·R-firing circuit·

→ 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_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. i.e., 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 i.e., $V_g = iR$ 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. (i.e., $V_{gp} < V_{gt}$ → 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 $\alpha = 90°$ 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 $2° - 4°$.

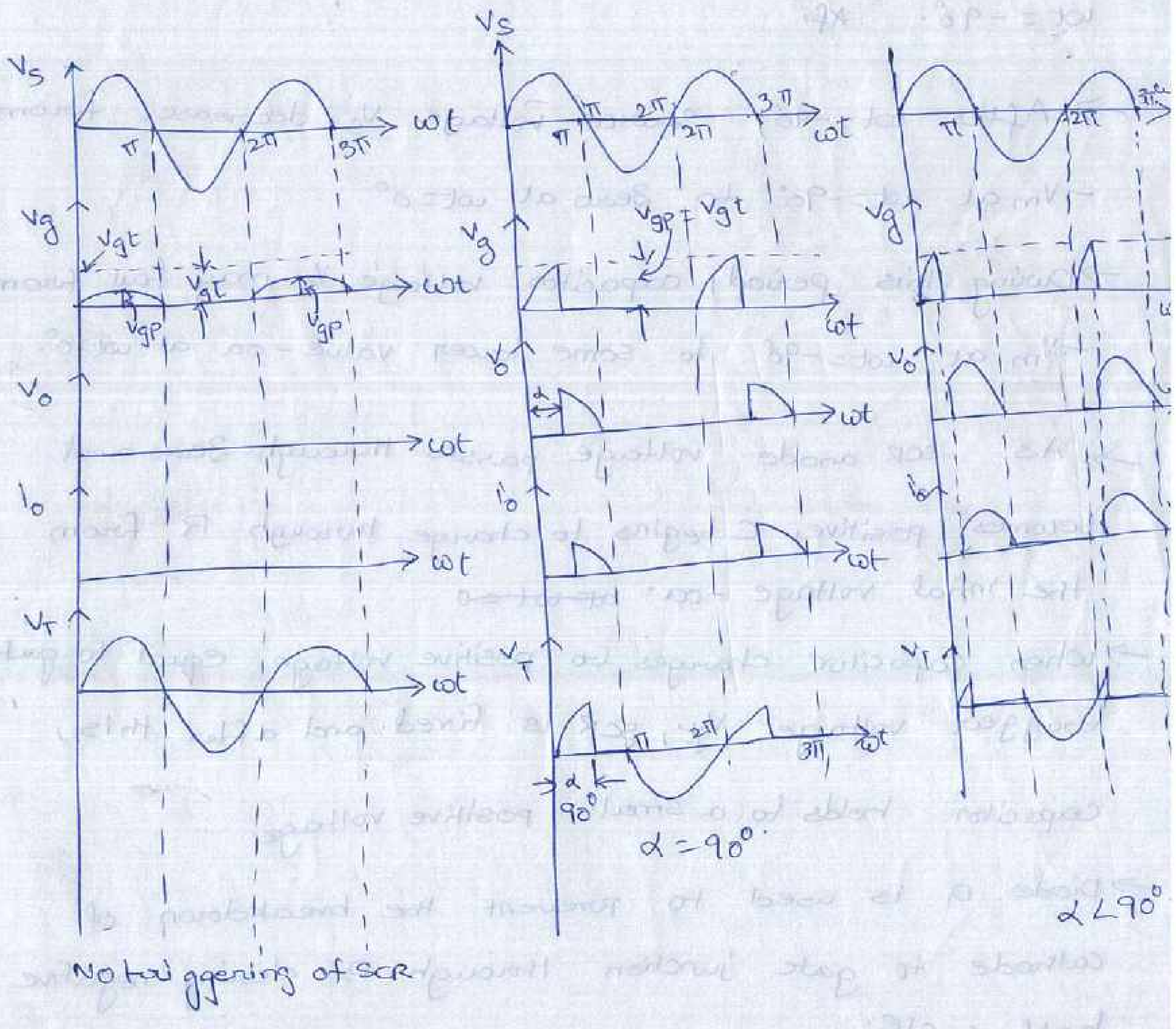
$$V_{gp} \sin\alpha = V_{gt}$$

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

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

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

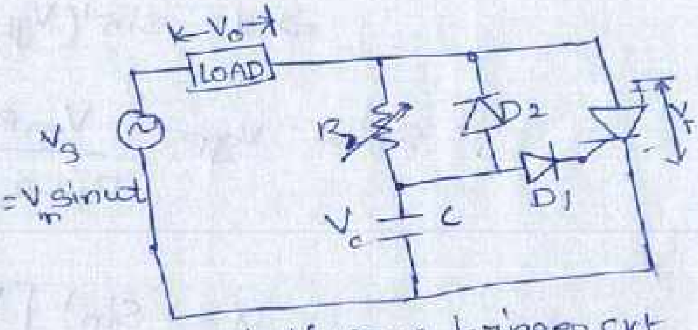
As V_{gt}, R_1, R and V_m are fixed, $\alpha = \sin^{-1}(R_2)$ or $\alpha = R_2$



No triggering of SCR

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 D_2 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 $\omega t = 0°$

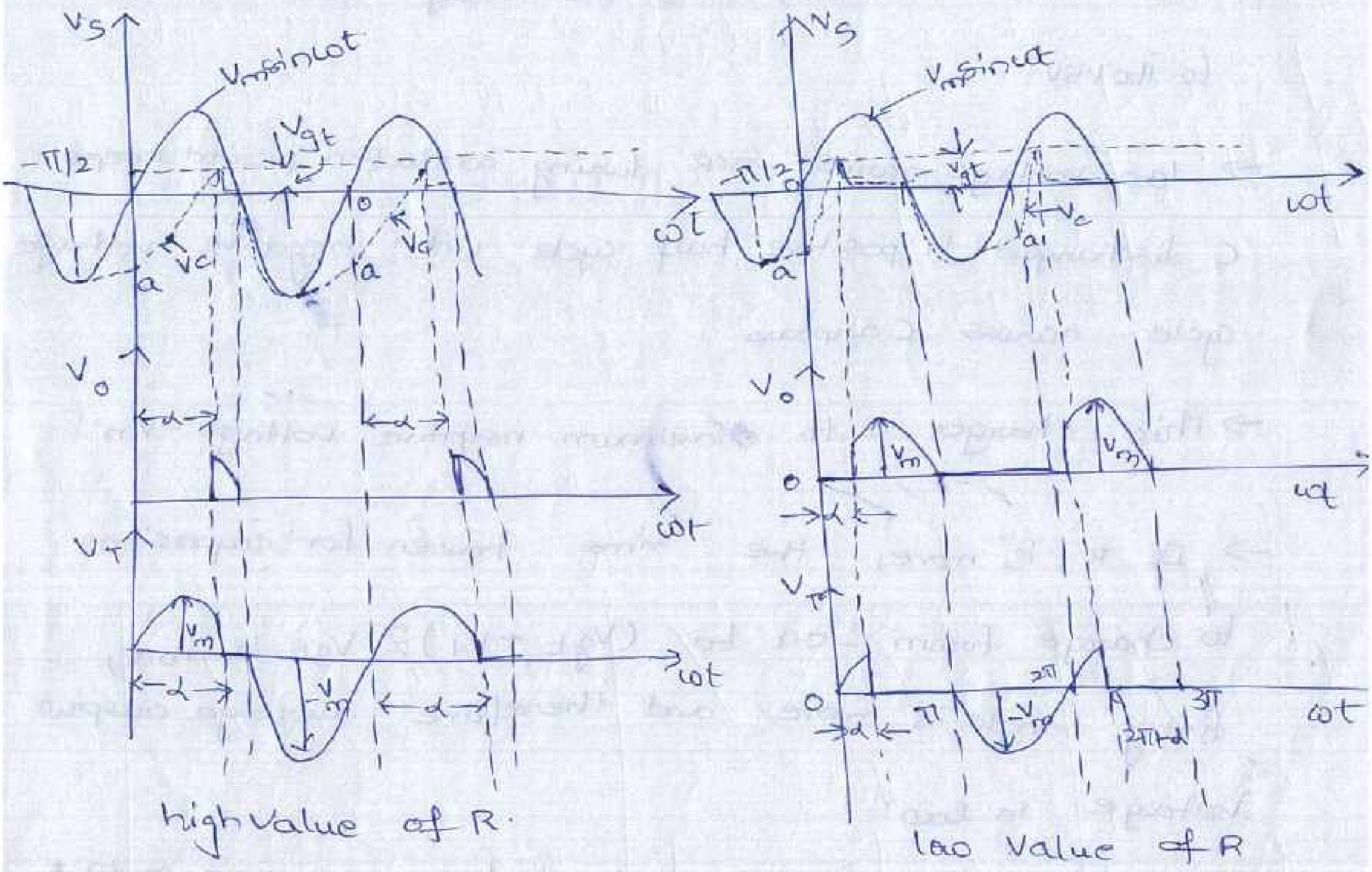
→ During this period, capacitor voltage V_c may fall from $-V_m$ at $\omega t = -90°$ to some lower value $-oa$ at $\omega t = 0°$.

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

→ 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 D_2 during negative half cycle.

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



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 $(V_{gt}+V_d) \cong V_{gt}$ is more, firing angle is more and therefore average output voltage is low.

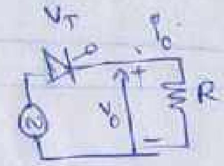
→ If R is less, firing angle is low, average output voltage is more

Class F Line commutation or natural commutation

→ only when source is ac

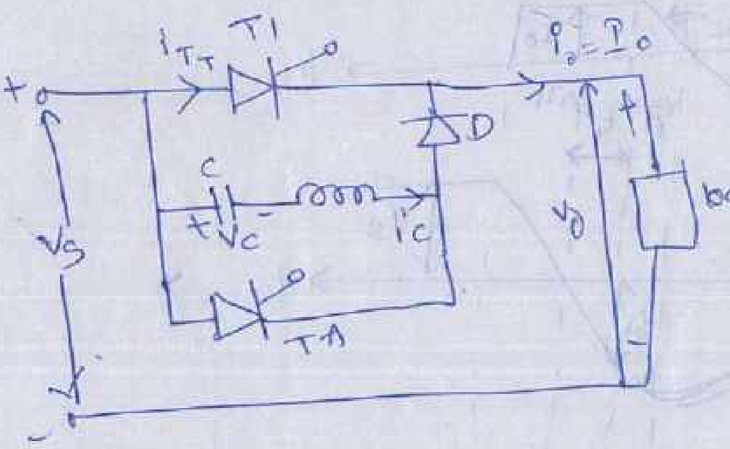
→ current has to pass through its natural zero at the end of every positive half cycle

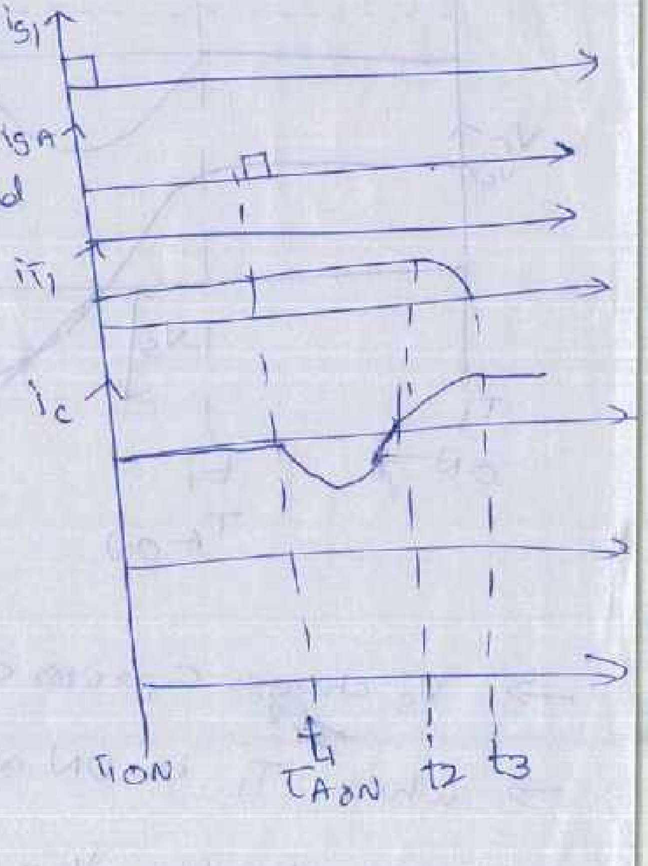
→ Then ac source applies a reverse bias across SCR

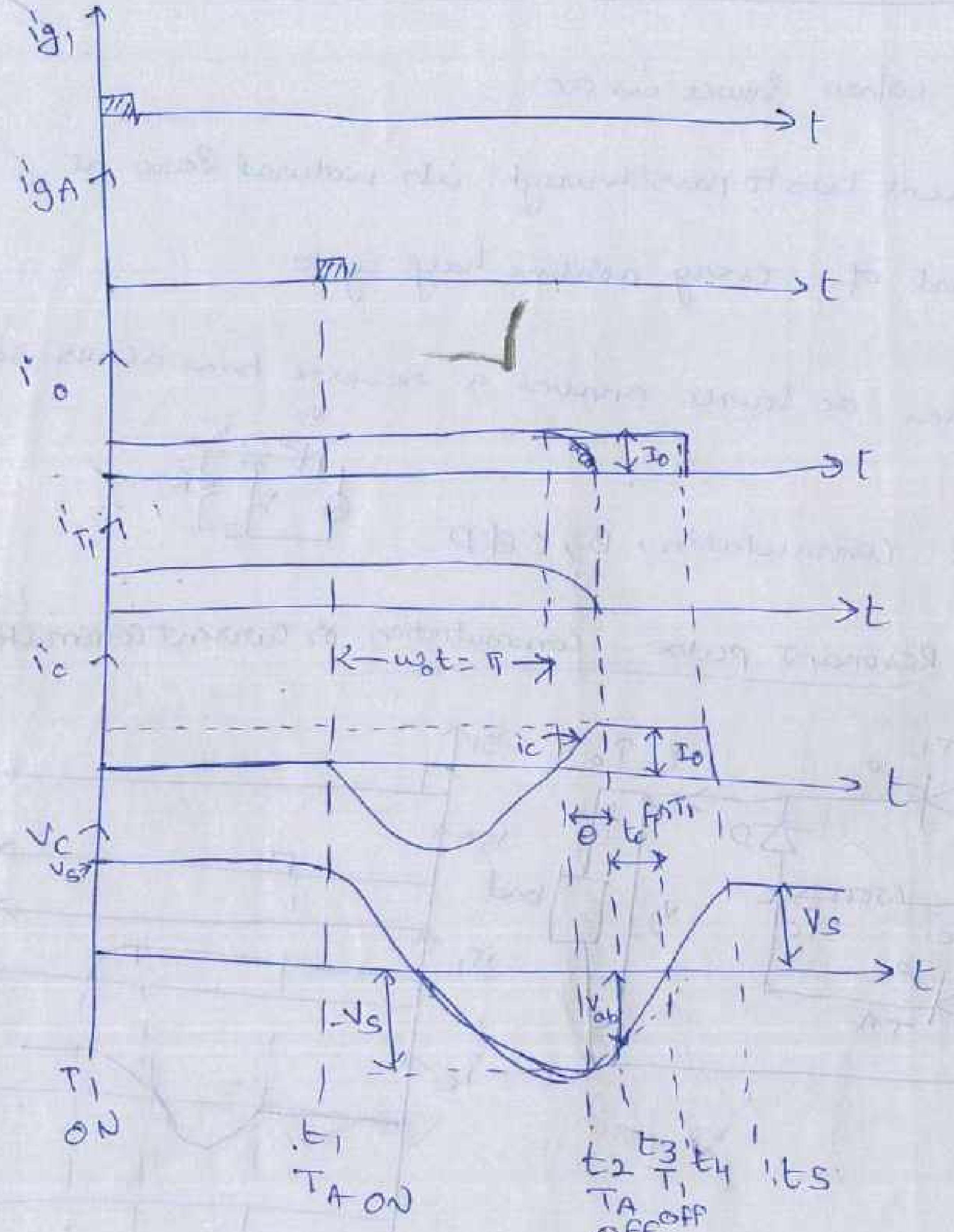


Forced commutation, B, C & D

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 $i_{T_1} = I_0$

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

→ i_c begins to flow from C, TA, 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.

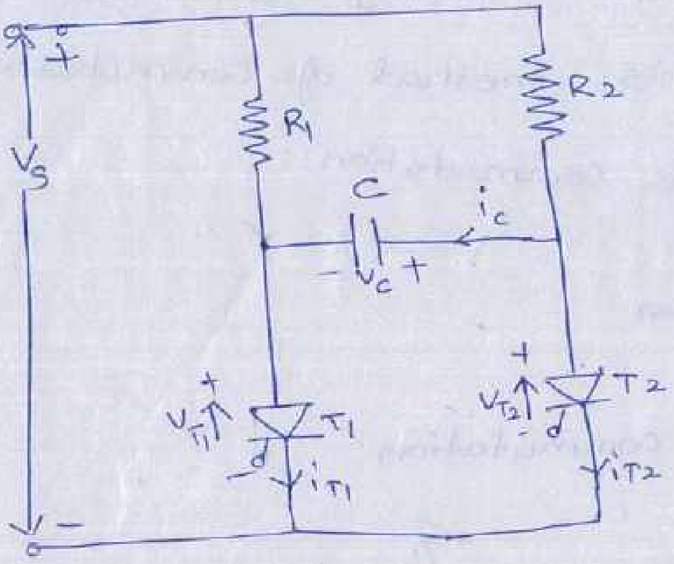
$$t_c = t_4 - t_3 = C\frac{V_{ab}}{I_0}$$

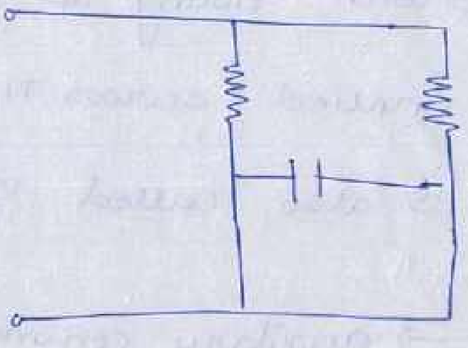
t_c dependent on load current.

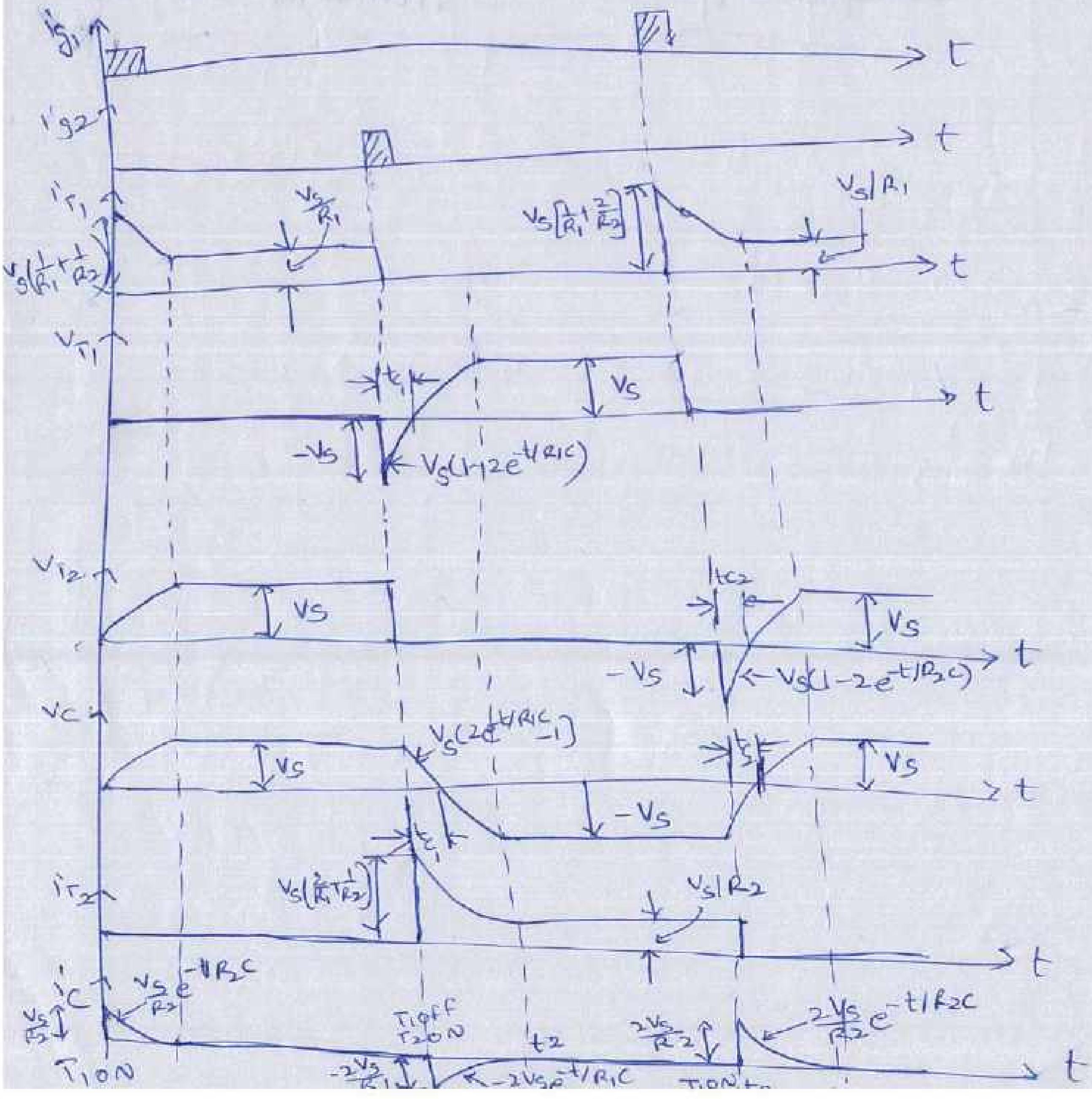
$V_{ab} = V_s \cos\omega_0 (t_3 - t_2)$ V across T_1 at time of commutation

Class C Commutation:

Complementory commutation:







→ again capacitor charges from -Vs to +Vs

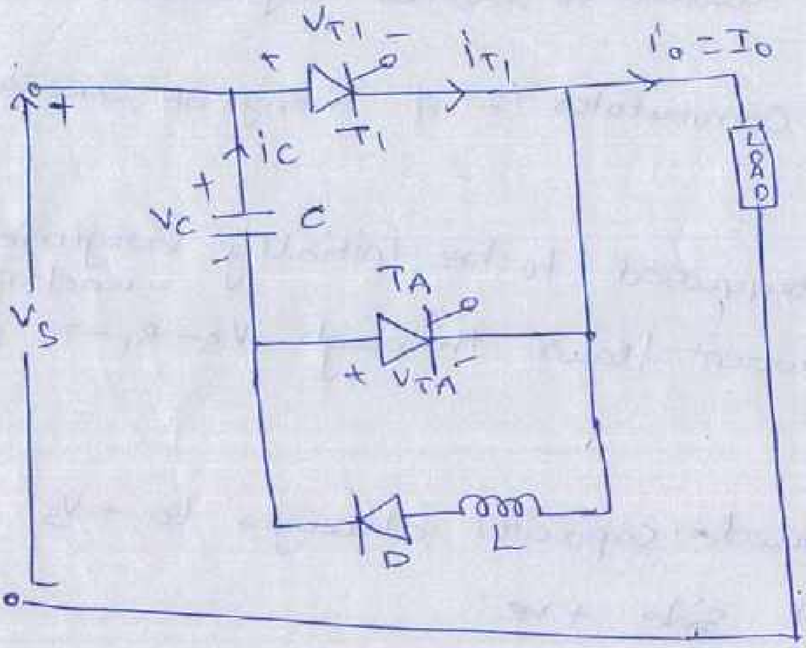
→ with firing of TA, reverse voltage Vs is suddenly applied across T1. this method of commutation is also called voltage commutation.

→ auxilary commutation

→ parallel capacitor commutation.

Waveforms & Derivations from text

class D Commutation: or Impulse Commutation



→ Initially T_1 & TA 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 i.e., 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, T_2 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

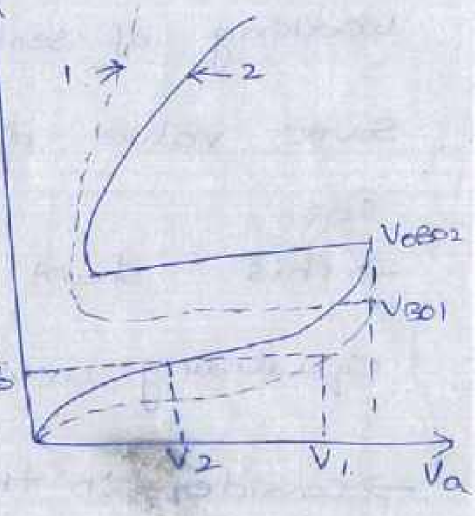
Series operation of SCR

→ 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 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

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.

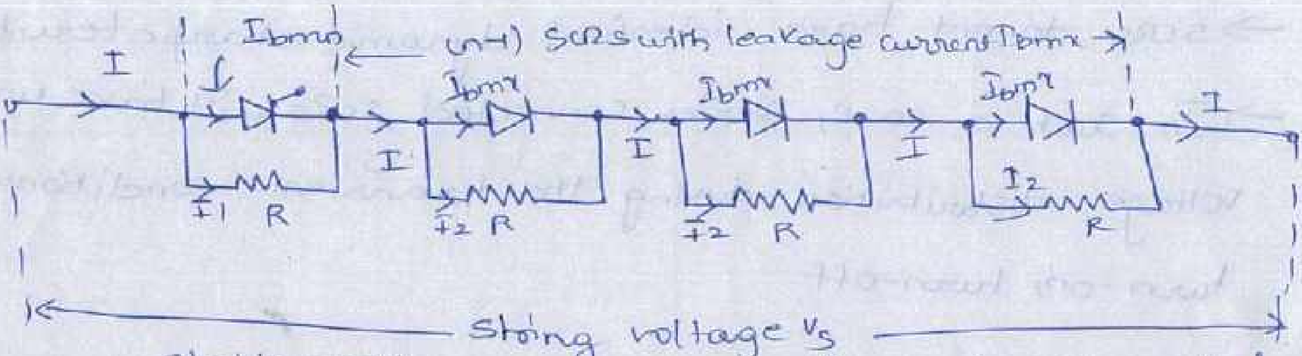
→ Consider 'n' thyristors connected in series

→ 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 SCR1.



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

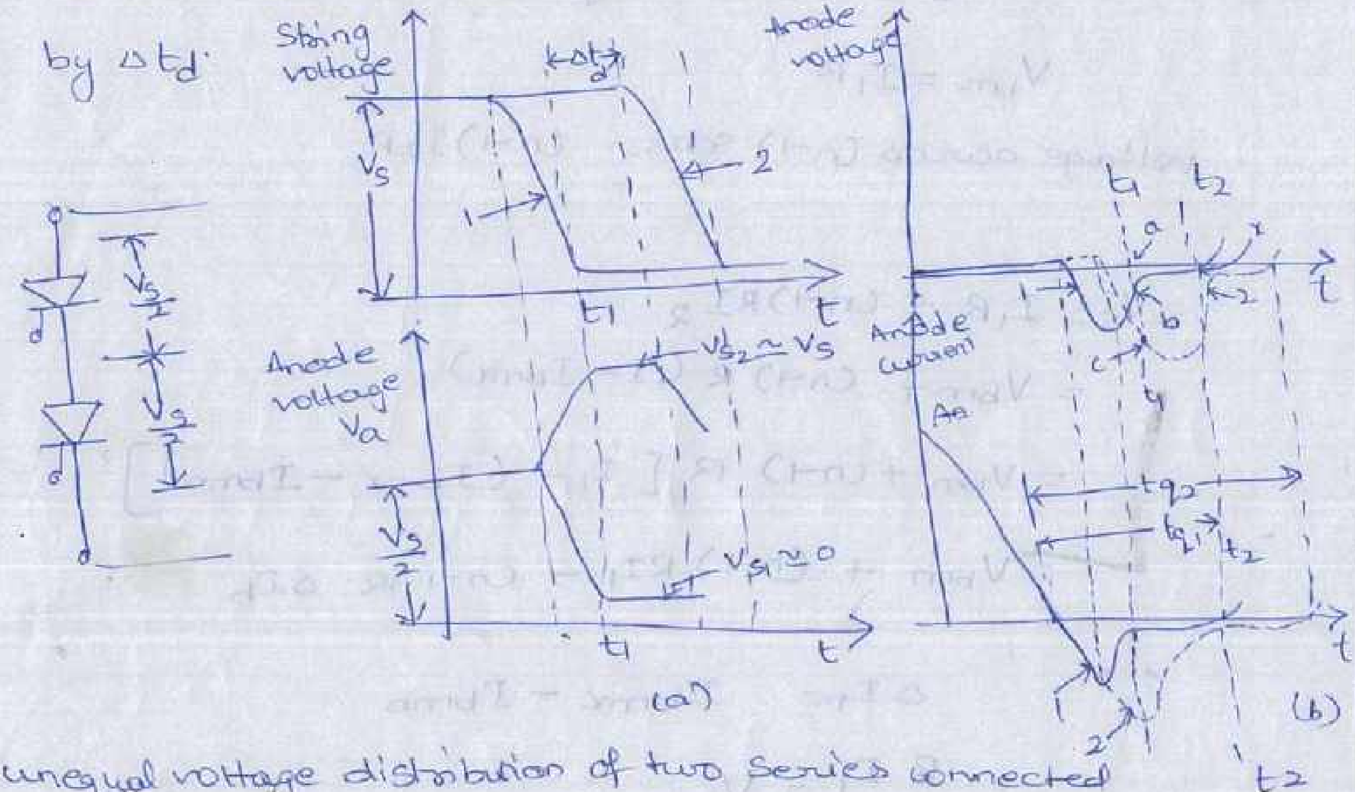
In such case $\Delta I_b = I_{bmx}$ with $I_{bm} = 0$

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 t1, whereas SCR 2 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.

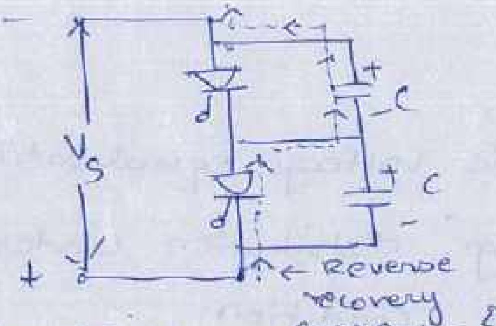
→ Voltage equilization under these conditions can be achieved by employing shunt capacitors.

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

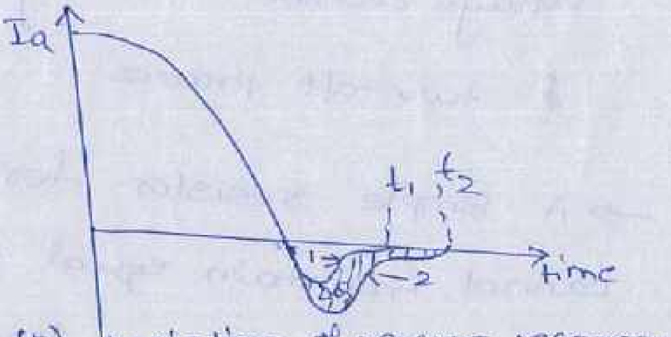
→ In otherwords, during turn-on and turn-off periods, the resultant of shunt capacitance & self capacitance of each SCR tend to be equal for each of the series connected SCRs

→ 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 there fore 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.

→ SCR 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 $V_s = V_1 + (n-1)V_2$

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

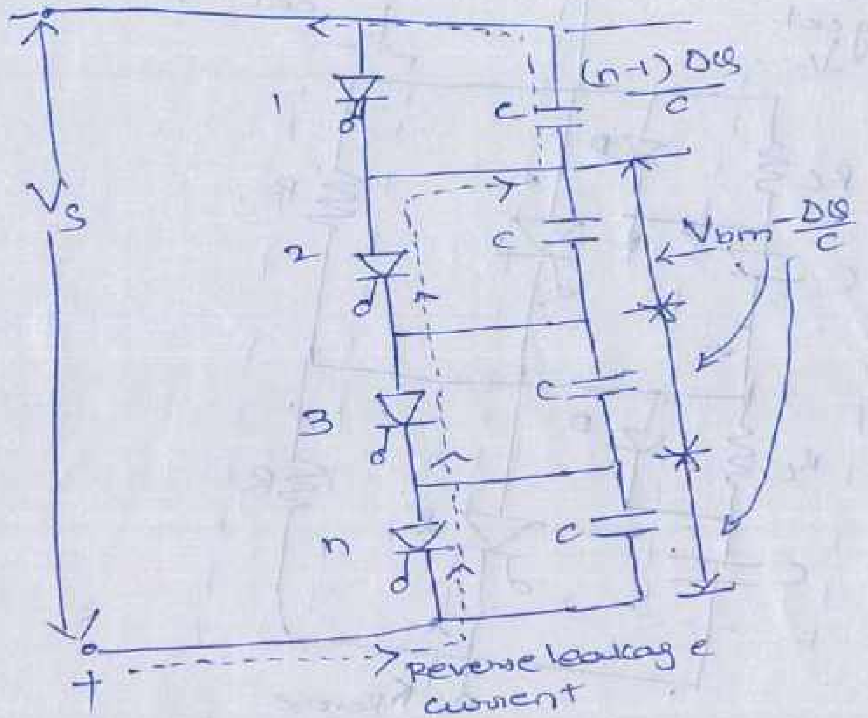
$$V_{bm} = \frac{1}{n}\left[V_s + \frac{(n-1)\cdot\Delta Q}{C}\right]$$

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

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

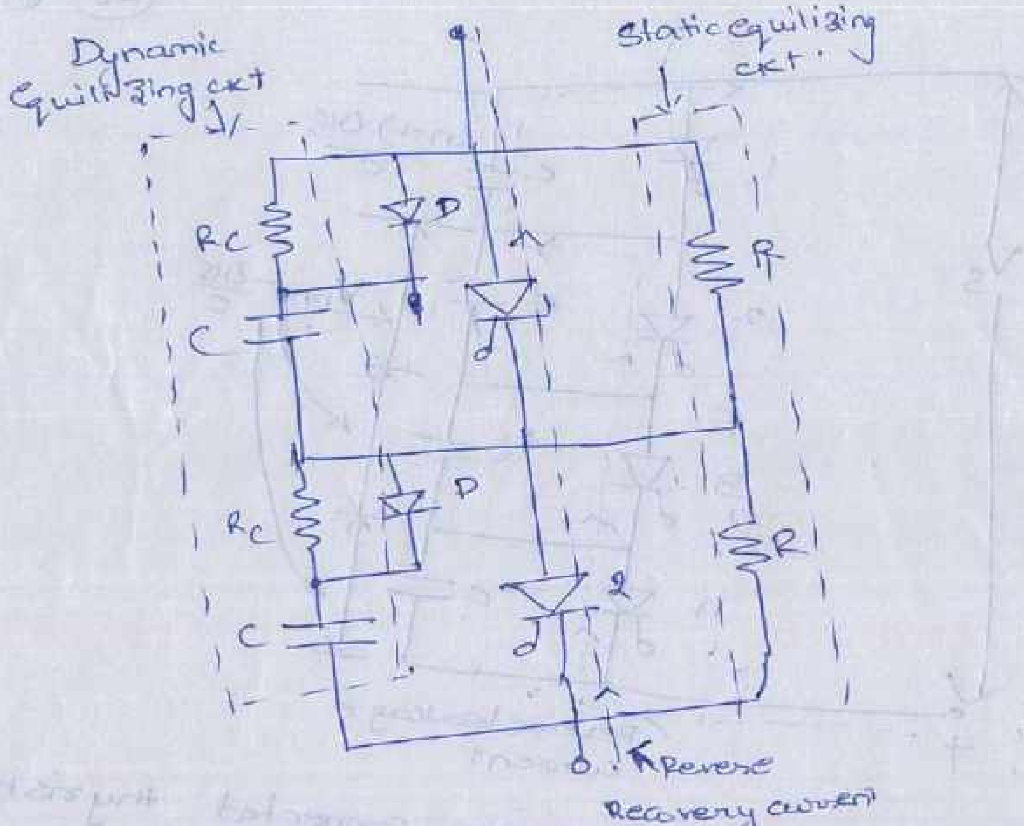
→ The transient voltage which each scr must be able to withstand is V_{bm}

→ 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 $n \cdot V_{bm}$.

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

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

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



→ when any scr1 is F.B. state, capacitor connected across it gets charge 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 dampsout high frequency oscillations that may arise due to Rc, shunt capacitor & ckt inductance.

→ combination of R_c & 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 R_c during charging time of capacitor C, makes capacitor more effective in voltage equalization & for limiting $\frac{dv}{dt}$ across scr.

→ During capacitor discharge R_c 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 overvoltages 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) <u>dv/dt protection:</u> 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.

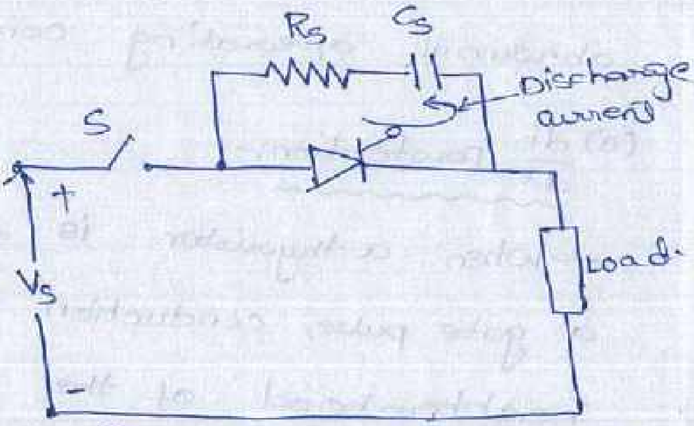
→ dv/dt (rate of rise of forward anode to cathode voltage dV_a/dt must be kept below specified rated limit.

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

<u>Design of snubber circuit:</u>

→ 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

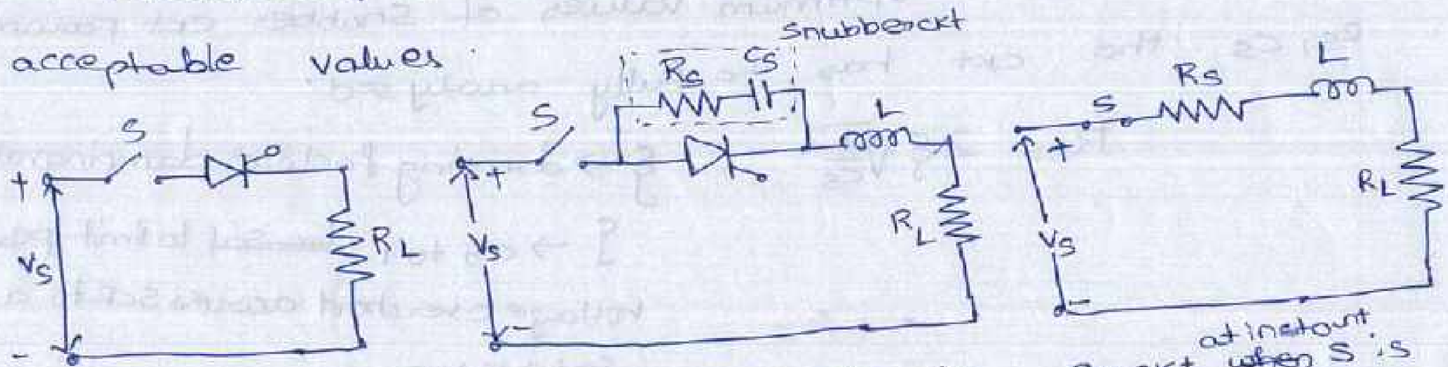
Capacitor discharges through the SCR & sends a current equal to Vs/(resistance of local path formed by Cs and SCR).

→ 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 limit.

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



SCR in series with R_L (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), $V_S = (R_S + R_L)i + L\frac{di}{dt}$

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

→ (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.

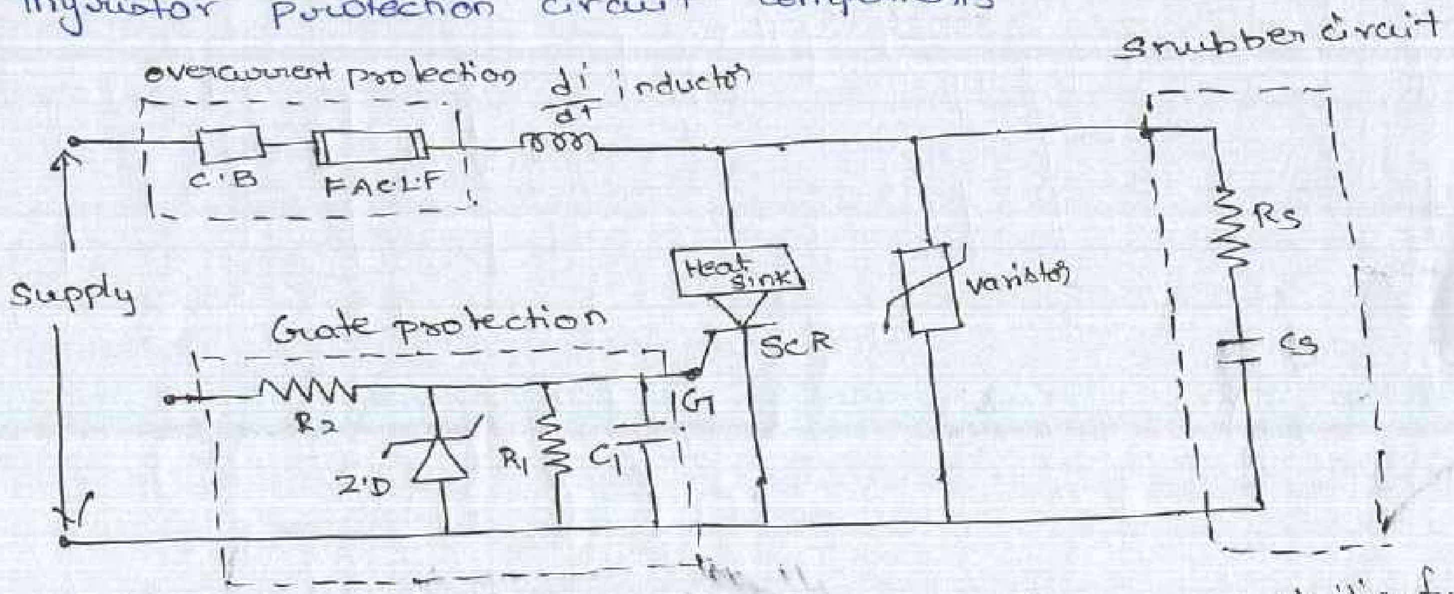
-> Resistor connected in series with gate ckt provides protection against over currents.

-> 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 waveshape of gate pulse

Thyristor protection circuit components



C.B -> Circuit Breaker, FACLF -> fast acting current limiting fu

Z.D -> Zener diode

Thyristor

STATIC I-V characteristics of a Thyristor:

→ ~~When~~ During forward bias

J_1 & J_3 → forward biased,

J_2 → Reverse biased

→ Presence of depletion layer at J_2, 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 J_2 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 J_2 Vanishes

→ The reverse biased junction J_2 will breakdown due to the large voltage gradient across its depletion layer. This phenomenon is known as the <u>Avalanche Breakdown</u>

→ Since J_1 & J_3 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.

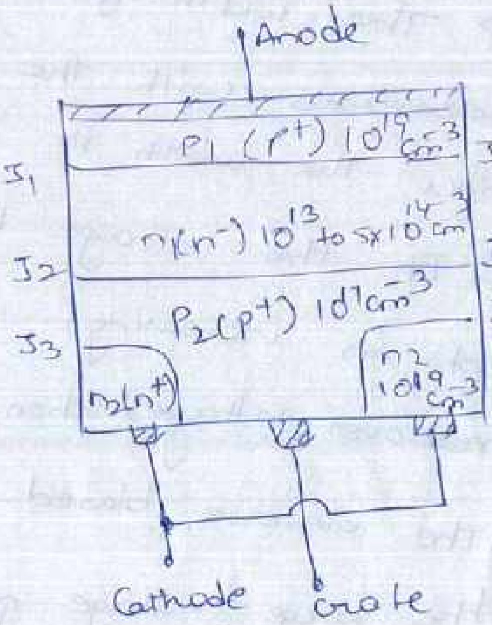
Reverse blocking state

→ when Cathode is made positive w.r.t. to end p layers, 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 commut-ation".

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

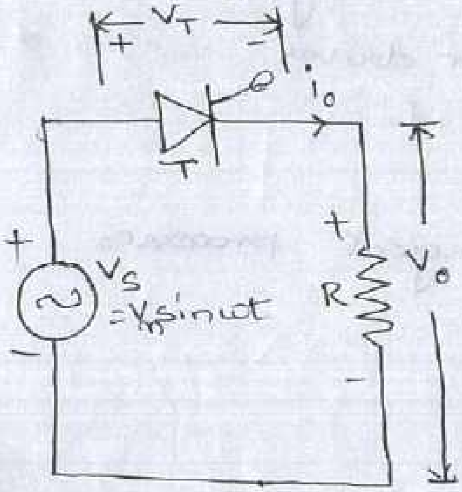
(i) there is no voltage drop across them

(ii) no reverse current exists under reverse voltage conditions

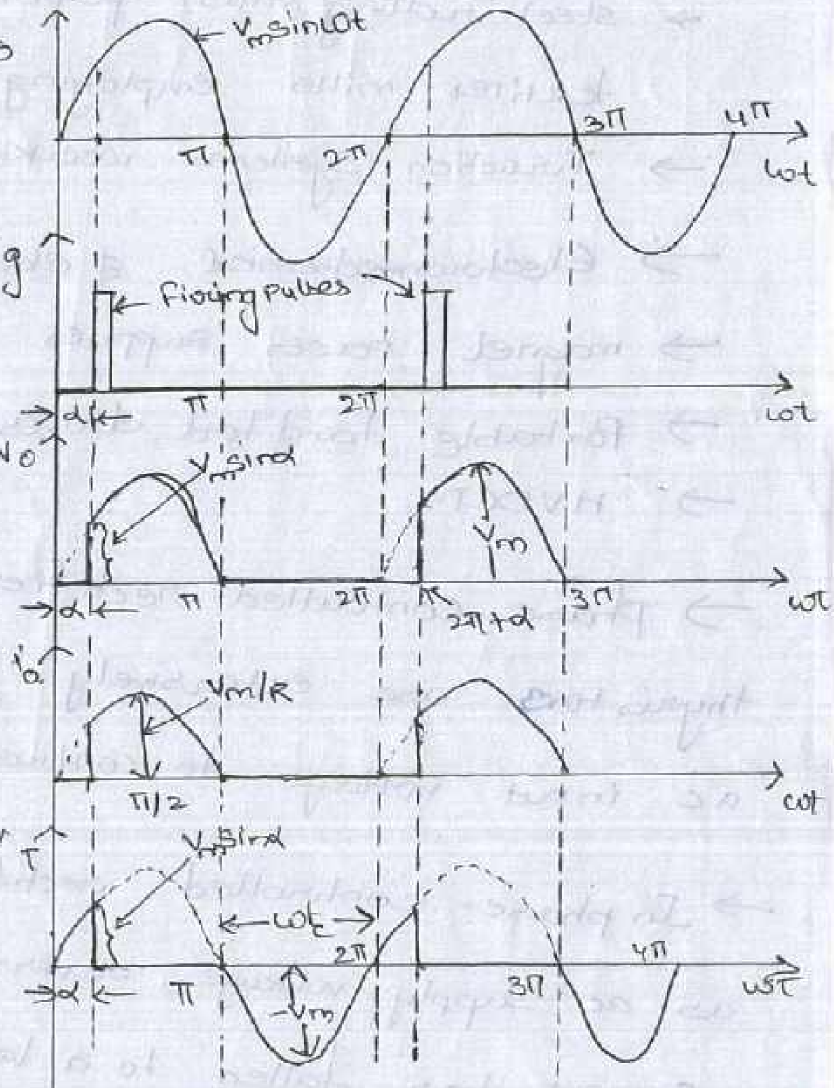
(iii) holding current is zero.

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 $\omega t = \pi, 3\pi$ etc.

→ At these angles of $\pi, 3\pi, 5\pi$ 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 relationship 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

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

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

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

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

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

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

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

$$V_{o(rms)} = \sqrt{\frac{1}{T}\int_0^T V_0^2 \, d\omega t}$$

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

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

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

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

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

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

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

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

$$P_0 = (V_{o(rms)})(I_{o(rms)}) = \frac{V_{o(rms)}^2}{R} = I_{o(rms)}^2 R$$

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

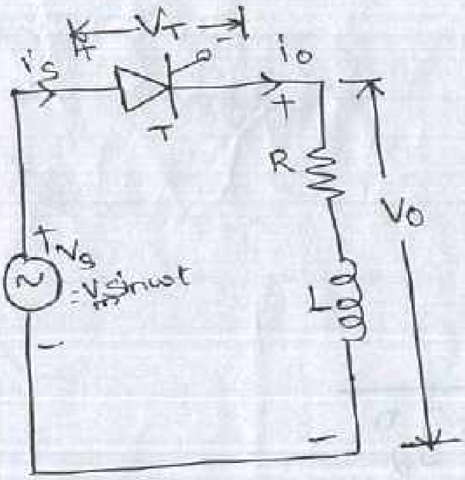
Input VA $= V_S I_{orms}$ $\quad V_{max} = \sqrt{2} V_{Srms}$

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

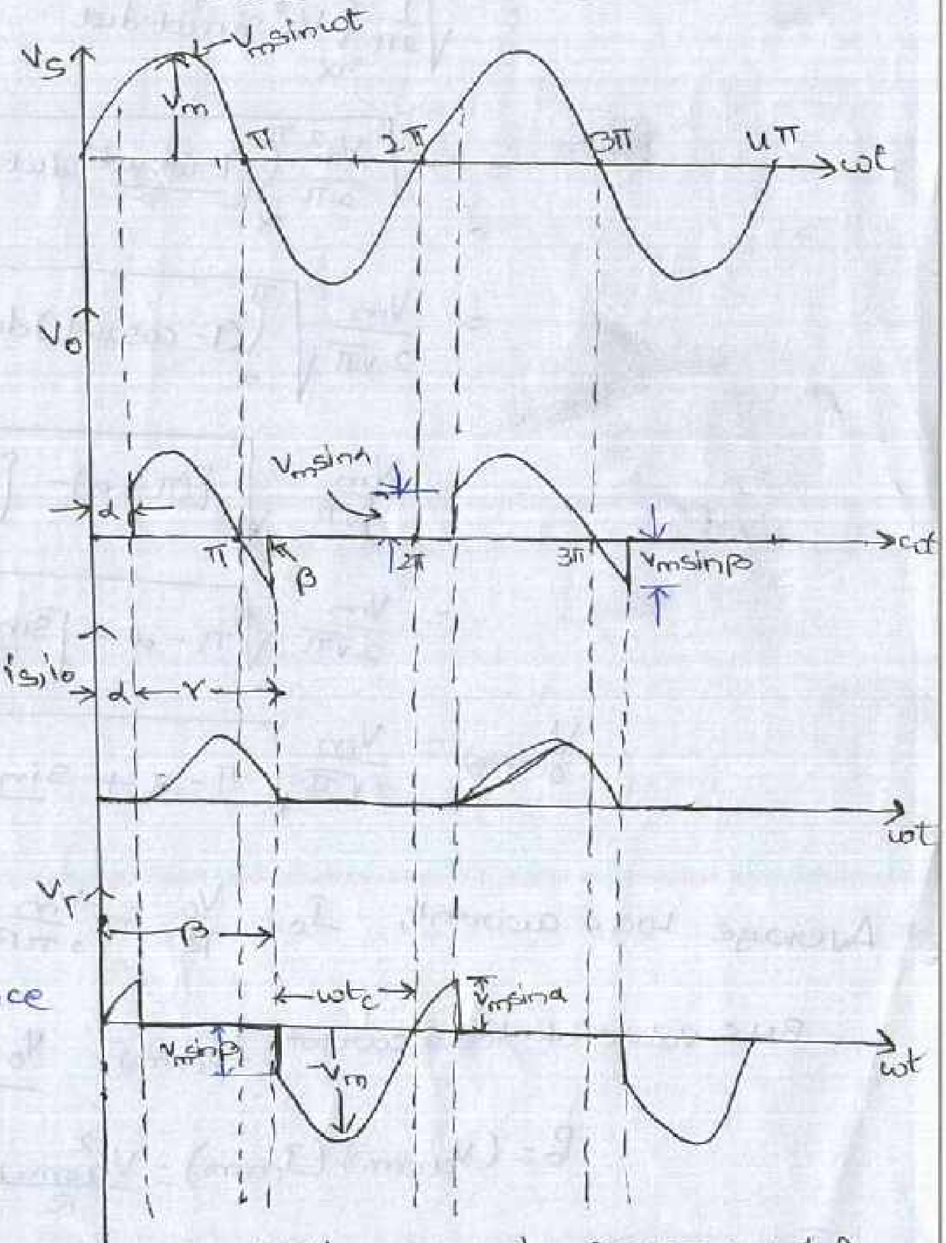
Input powerfactor = ~~$\frac{1}{\sqrt{2}\pi}\left[(\pi-\alpha)+\right.$~~ $\dfrac{\text{Power delivered to load}}{\text{Input VA}}$

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

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_0 to rise gradually

→ After some time i_0 reaches maximum value and then begins to decrease.

→ At $\omega t = \pi$, V_0 is zero but i_0 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_0 is not less than its holding current.

→ At some angle $\beta > \pi$, i_0 reduces to zero and SCR is turned off as its is already reverse biased.

→ After $\omega t = \beta$, $V_0 = 0$ and $i_0 = 0$.

→ At $\omega t = 2\pi + \alpha$ SCR is triggered again, V_0 is applied to load current develops as before.

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

→ 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

$$V_m \sin\omega t = R i_0 + L\frac{di_0}{dt}$$

The load current i_0 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

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

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

$$\therefore \; i_0 = i_s + i_t = \frac{V_m}{Z}\sin(\omega t - \phi) + A e^{-(R/L)t} \longrightarrow (1)$$

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

At this time $t = \frac{\alpha}{\omega}$, $i_0 = 0$.

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

$$i_0 = \frac{V_m}{Z}\sin(\omega t - \phi) - \frac{V_m}{Z}\sin(\alpha - \phi)\exp\left[-\frac{R}{\omega L}(\omega t - \alpha)\right] \rightarrow (2)$$

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 $V_0 = \frac{V_m}{2\pi}\left[\cos\alpha - \cos\beta\right]$

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

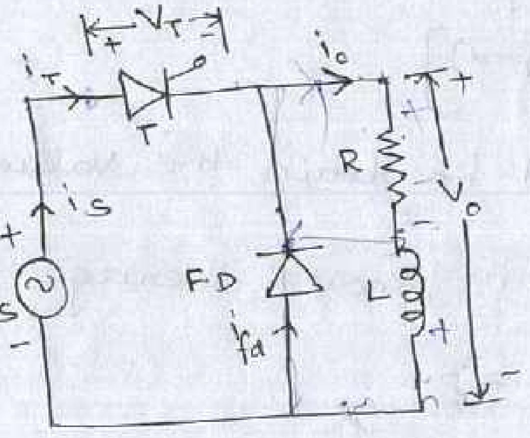
RMS load voltage $V_{0(rms)} = \left[\frac{1}{2\pi}\int_{\alpha}^{\beta} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$

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

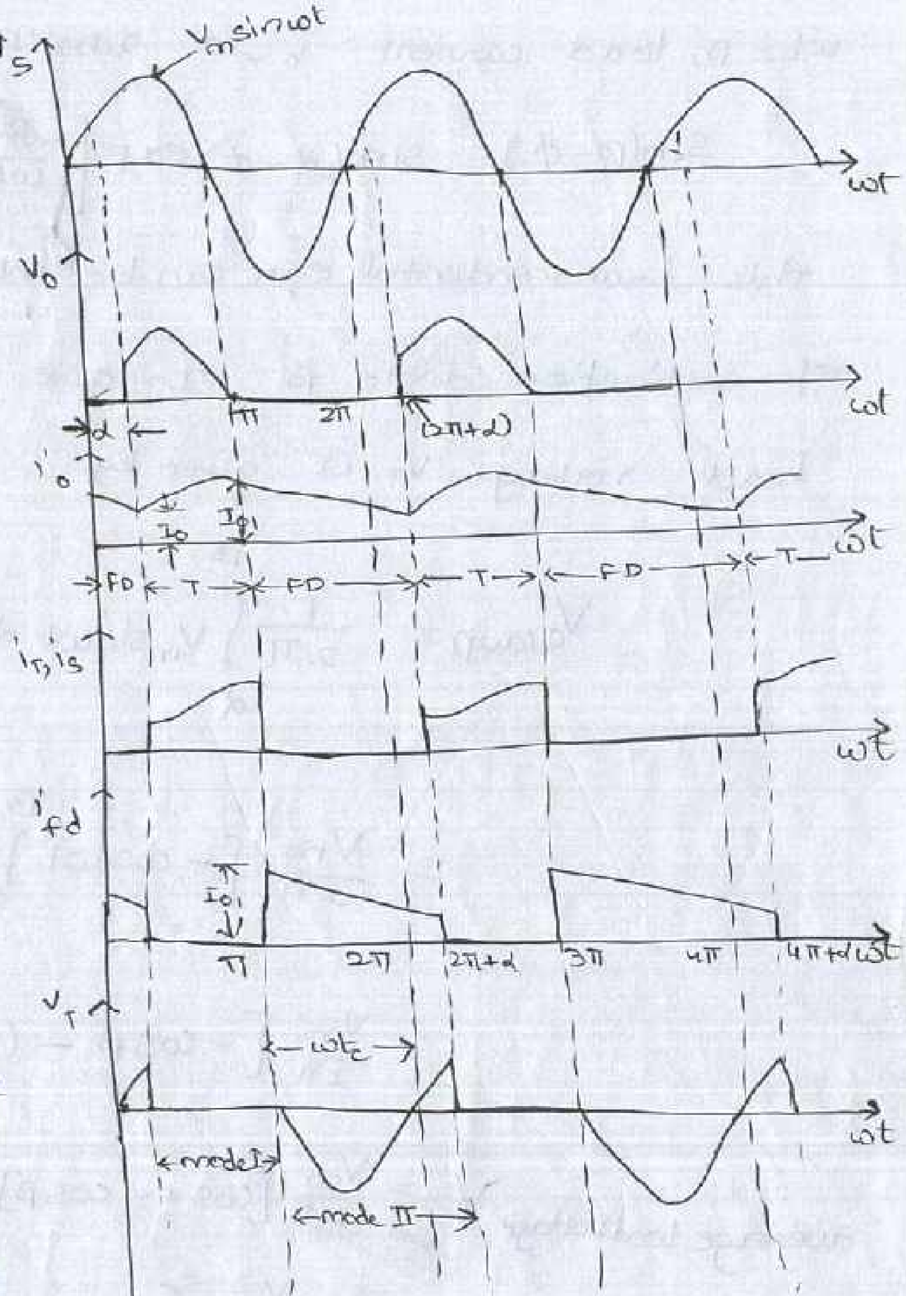
$$= \frac{V_m}{2\sqrt{\pi}}\sqrt{(\beta - \alpha) - \frac{1}{2}\left[\sin 2\beta - \sin 2\alpha\right]}$$

Rms load current can be found from eq ②.

Single phase Halfwave circuit with RL Load and Free wheeling Diode



Circuit Diagram



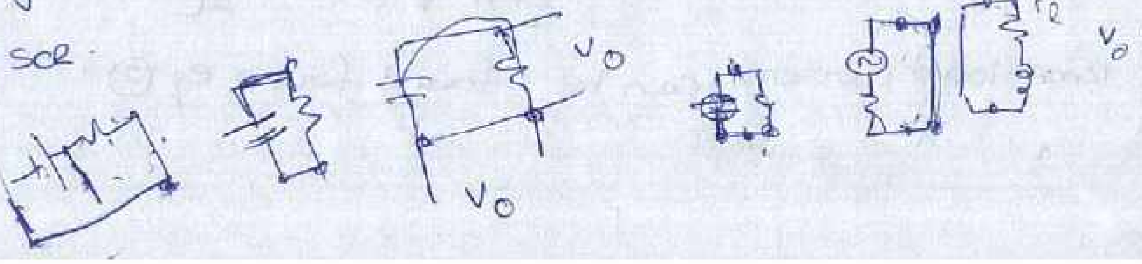
Voltage & current wave forms

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

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



→ As a result, load current i_0 is immediately transferred from SCR to FD as V_s tends to reverse.

→ At the same time, SCR is subjected to reverse ~~biase~~ 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_0 is therefore, zero during the FW period

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

→ The ~~Sco~~ 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_0

→ voltage equation is $V_m \sin \omega t = R i_0 + L \frac{di_0}{dt}$.

$$\Rightarrow i_0 = \frac{V_m}{Z} \sin(\omega t - \phi) + A e^{-\left(\frac{R}{L}\right)t}$$

At $\omega t = \alpha$, $i_0 = I_0$, ie, at $t = \frac{\alpha}{\omega}$, $i_0 = I_0$

$$\therefore A = \left[I_0 - \frac{V_m}{Z} \sin(\alpha - \phi) \right] e^{R\alpha/\omega L}$$

$$i_0 = \frac{V_m}{Z} \sin(\omega t - \phi) + \left[I_0 - \frac{V_m}{Z} \sin(\alpha - \phi) \right] \exp\left[-\frac{R}{L}\left(t - \frac{\alpha}{\omega}\right) \right]$$

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

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

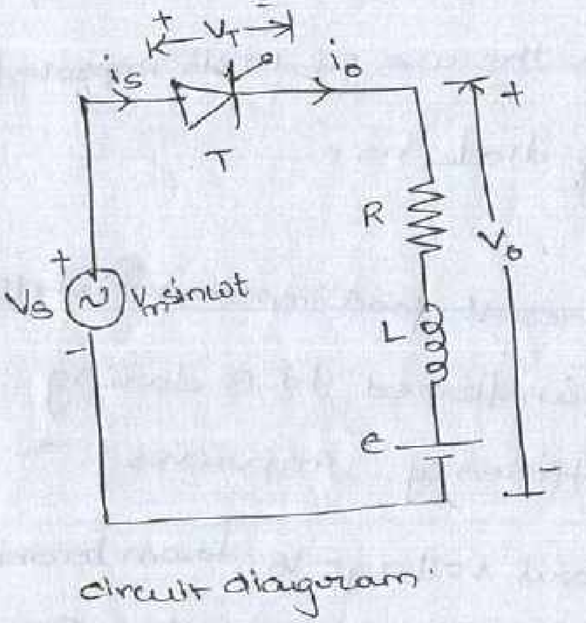
Average load current, $I_0 = \frac{V_0}{R} = \frac{V_m}{2\pi R}(1+\cos\alpha)$

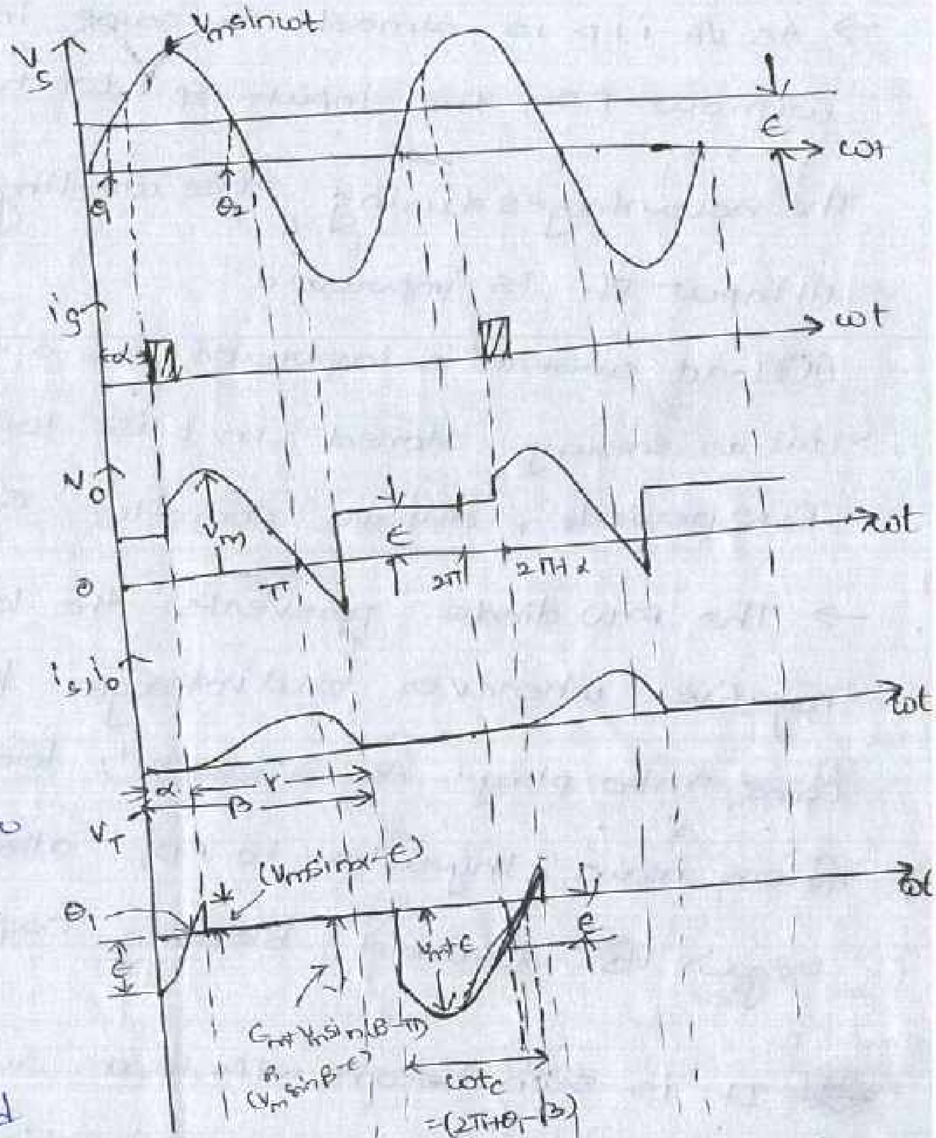
→ Load current i_0 is contributed by SCR from α to π, $(2\pi+\alpha)$ to 3π ..
& " " " " by FD from 0 to α, π to $(2\pi+\alpha)$ & so on

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:





→ 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 the ckts 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 transformers 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_o is given by $i_o = i_{s1} + i_{s2} + i_t = \frac{V_m}{Z}\sin(\omega t - \phi) - \frac{E}{R} + Ae^{-\frac{(R)t}{L}}$

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

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

eq (1) is applicable for $\alpha \leq \omega t \leq \beta$. 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.

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

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

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

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

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

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

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 $\omega t = \beta$, $V_T = -[V_m\sin(\beta-\pi) + E]$

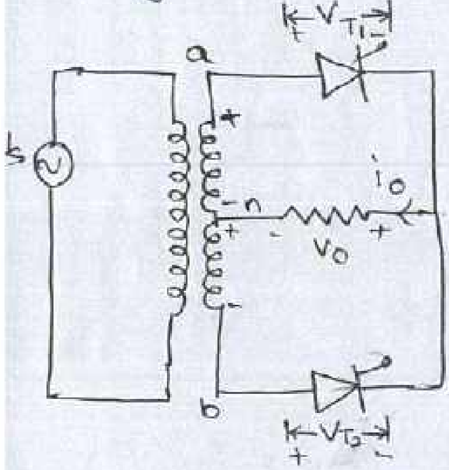
$V_T = V_m\sin\beta - E$ at $\omega t = \beta$; $\because V_m\sin\beta$ is $-$ve for $\beta > \pi$

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

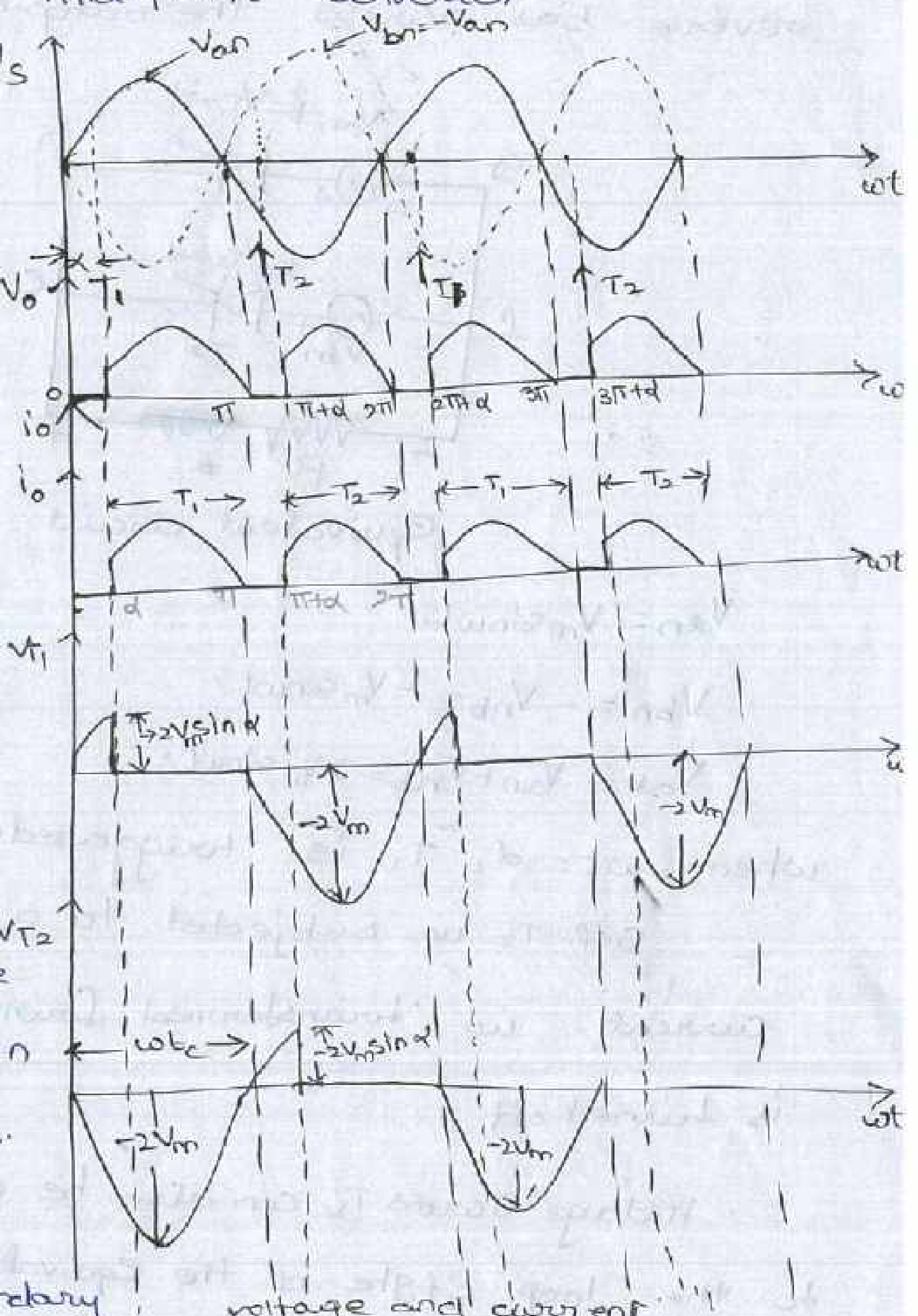
circuit turn-off time is $\dfrac{2\pi + \theta_1 - \beta}{\omega}$ sec

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 " .

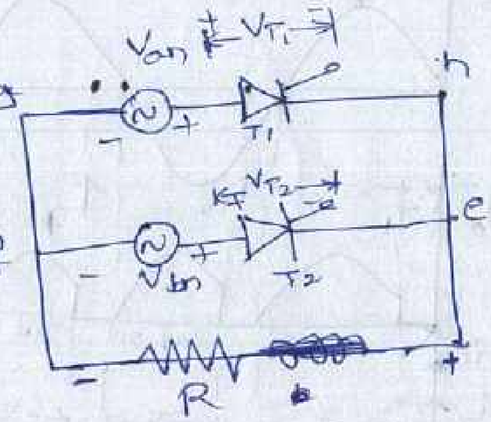
these are therefore triggered accordingly.

→ At $ωt=0$, 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 $2V_m \sin α$ 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 ~~but~~ 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

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

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

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

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

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

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

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

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

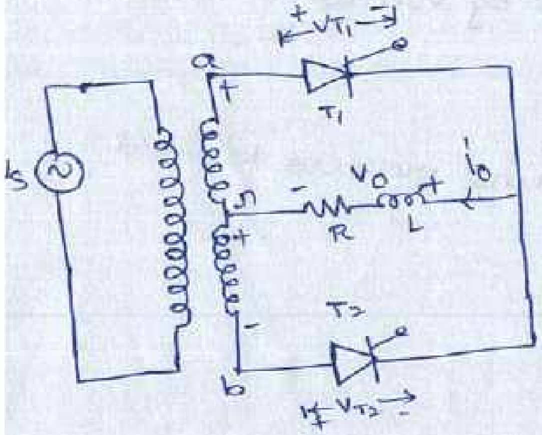
$$=V_m\left[\frac{1}{2\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha-\sin 2\pi}{2}\right]\right]^{1/2}$$

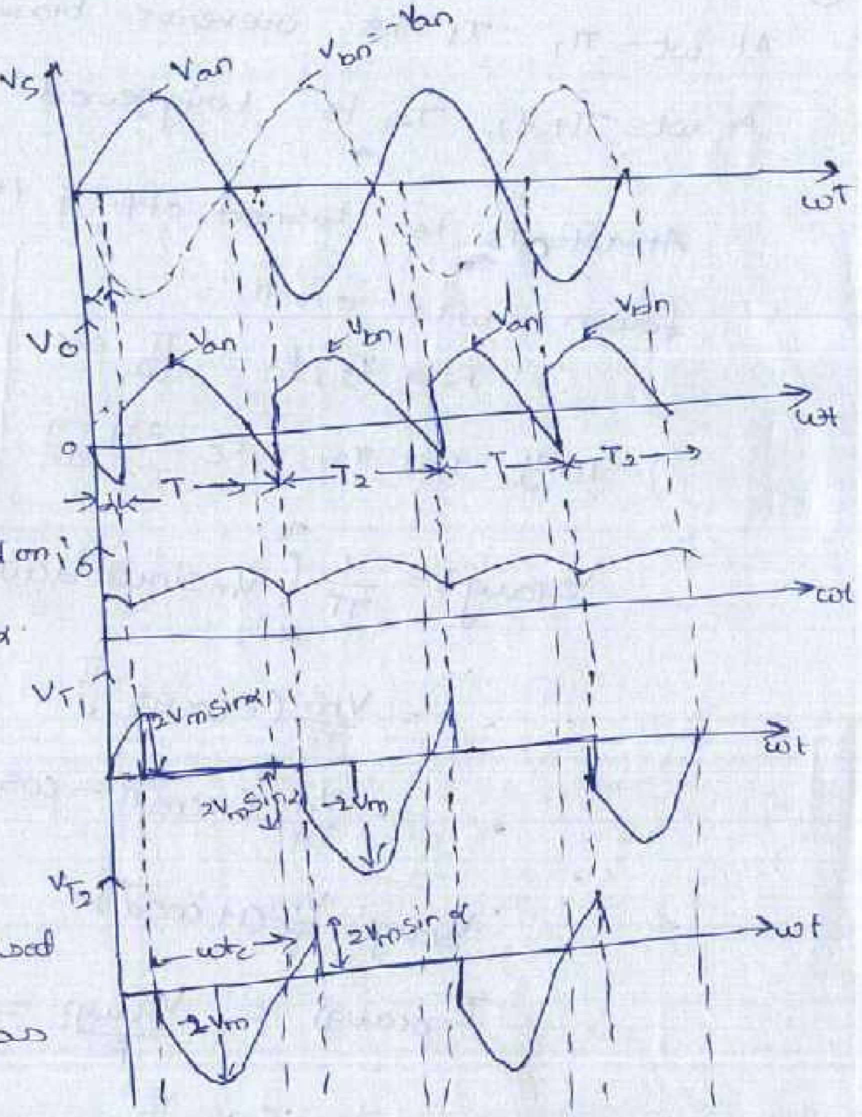
$$\therefore V_{o(rms)}=V_m\left[\frac{1}{2\pi}\left(\pi-\alpha+\frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

→ 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, $t_c = \frac{2\pi-(\pi+\alpha)}{\omega} = \frac{\pi-\alpha}{\omega}$

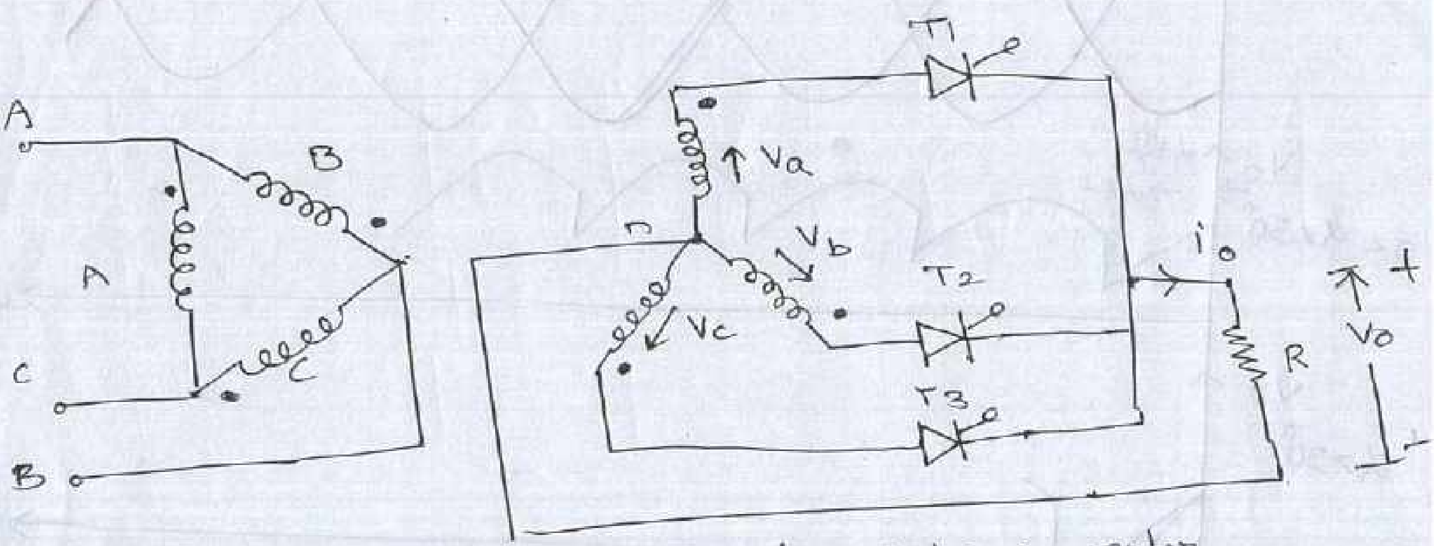
$$V_{o(avg)} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t) = \frac{V_m}{\pi}\left(-\cos\omega t\right)_{\alpha}^{\pi+\alpha}$$

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

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

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°.

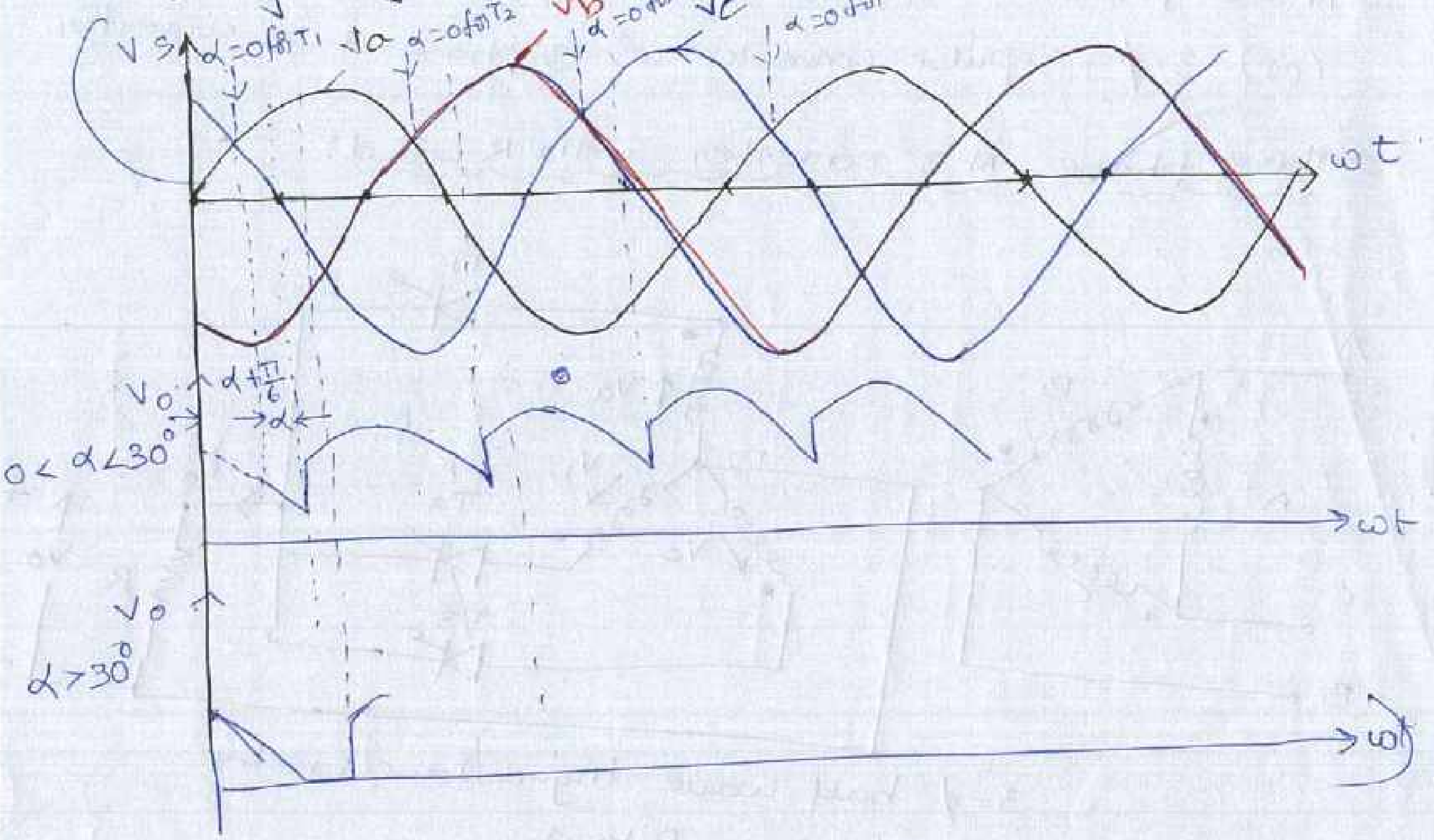
T_2 from ωt = 150° to 270°.

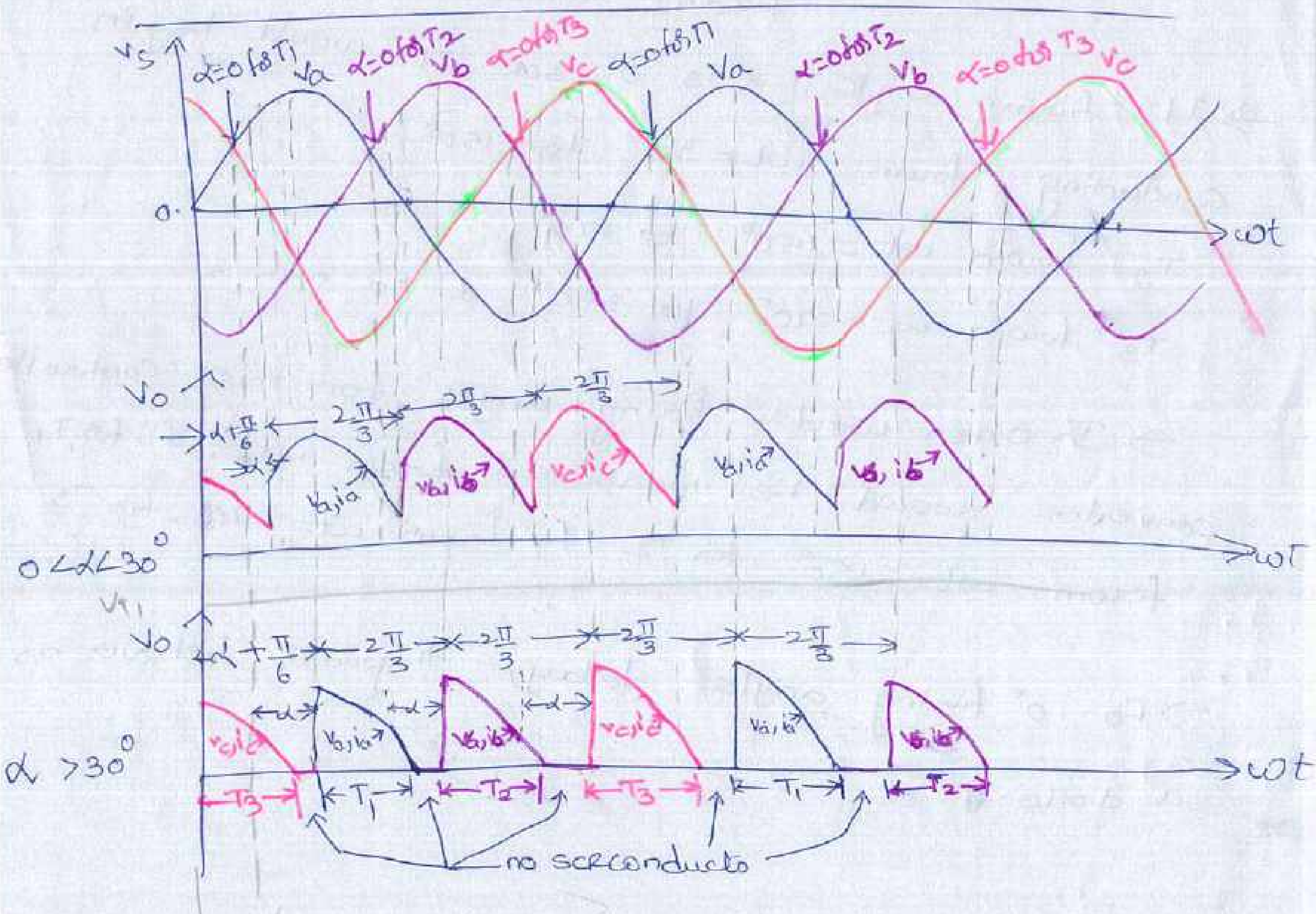
T_3 from ωt = 270° to 390° & so on.

→ 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 $< 30^\circ$





Firing angle $< 30°$:-

The o/p voltage V_0 for $\alpha < 30°$ (ie, 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.

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

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

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

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

$V_{mp} \rightarrow$ 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, $I_0 = \frac{V_0}{R} = \frac{3 V_{ml}}{2\pi R} \cos\alpha$

RMS value of o/p or load voltage is

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

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

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

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

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

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

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

(21)

for firing angle > 30°:

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

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

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

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

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

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

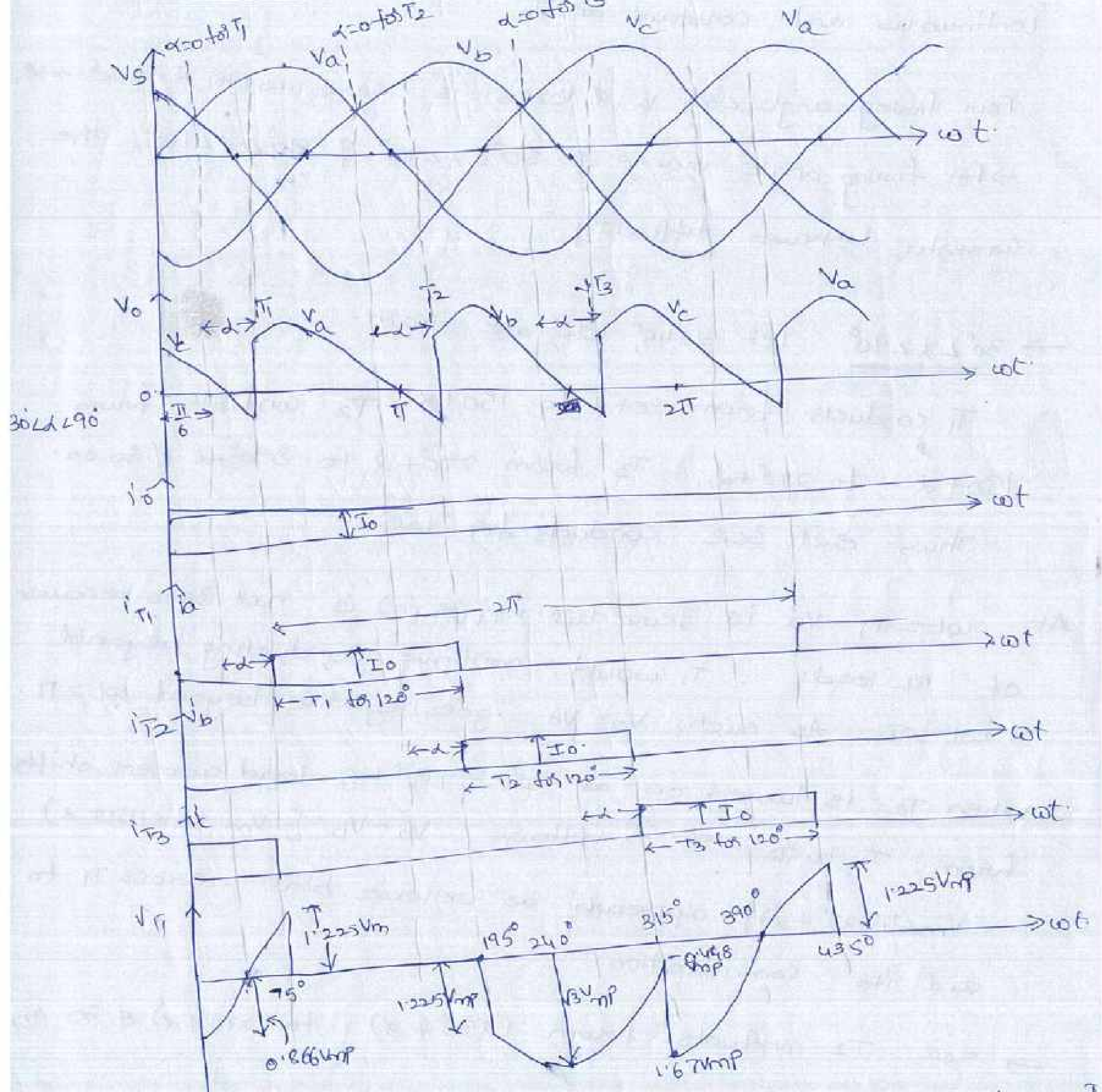
$$= \frac{3V_{mp}}{2\pi}\left[1 + \cos(\alpha + 30^\circ)\right]$$

$$\therefore V_{0\,rms} = \left[\frac{3}{2\pi}\int_{\alpha+\pi/6}^{\pi} V_{mp}^2 \sin^2\omega t \cdot d(\omega t)\right]^{1/2}$$

$$V_{0\,rms} = \frac{\sqrt{3}\cdot V_{mp}}{2\sqrt{\pi}}\left[\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2}\sin(2\alpha + \pi/3)\right]^{1/2}$$

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

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 at I_0.

Four firing angle $<30^\circ$, V_0 & V_{orms} is same as for R-load $\alpha<30^\circ$.

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

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

T_1 conducts from $30+\alpha$ to $150+\alpha$, T_2 conducts from $150+\alpha$ to $270^\circ+\alpha$, T_3 from $270^\circ+\alpha$ to $390^\circ+\alpha$ & 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 $\omega t=150^\circ+\alpha$, load current shifts from T_1 to T_2 & a voltage V_a-V_b [$=V_m\sin(150+\alpha)$ to $-V_m\sin(30^\circ+\alpha)$] appears as reverse bias across T_1 to aid its commutation.

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

Let $\alpha=45^\circ$.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

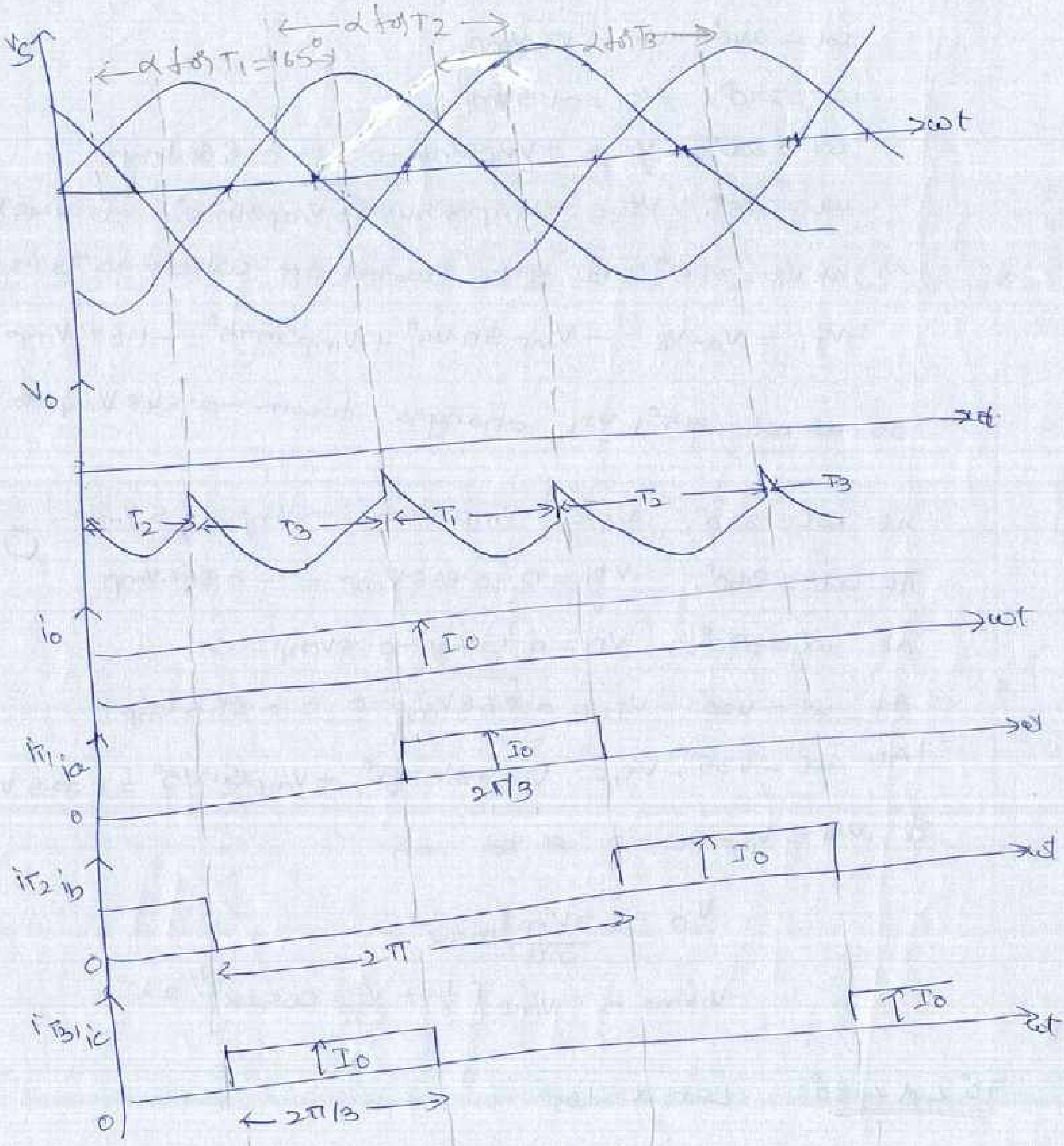
→ o/p V_0 is below ref. line, V_0 must be negative.

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

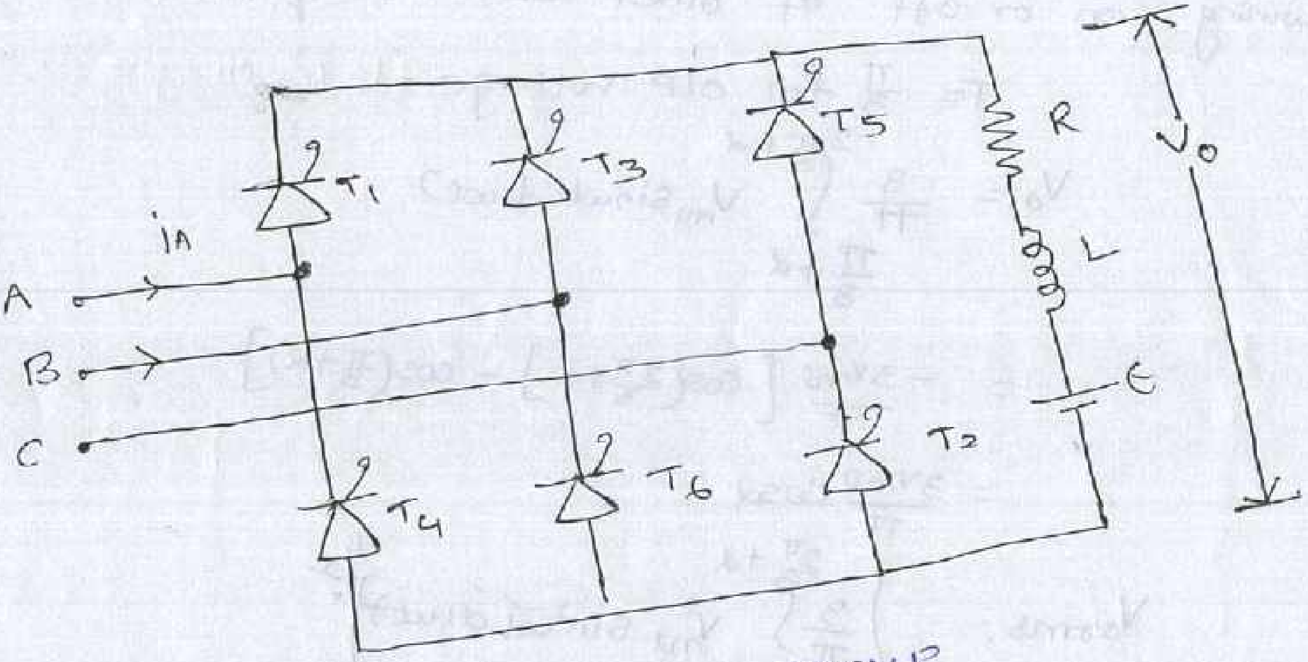
for $\alpha > 90°$, 3-φ 3 pulse converter operates as a line-commutated inverter which is possible only if load ckt has dc voltage source of reverse polarity.

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 α=0°, T1, T2 ... T6 behaves like diodes
If α=0°, T1 is triggered at ωt=30°, T2 at 150°,
T3 at 300° ....

→ For α=60°, T1 is turned at 60°+60°=120°
T2 is turned at 60°+120°=180°
T3 at 60+240°=300°
T4 at 60+360=420° & so on...

Each SCR conducts for 120°.

→ when T1 is turned on at ωt=120°, T5 is turned off,
T6 is already conducting
→ As T1 & T6 are connected to A and B resp, load voltage must be Vab
→ when T2 is turned on, T6 will be turned off & T1 is already conducting
as T1 & T2 are connected to A & C resp, load voltage must be V_{AC}

→ In this manner, load voltage w/f 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)

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

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

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

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

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

Source current for phase A, i.e., i_A flows for 120° for every 180°.
∴ o/p current is assumed constant,

∴ 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 " " $\alpha + 240°$

|||ly T_4 is at $\alpha + 180°$

T_6 is at $\alpha + 120° + 180° = \alpha + 300°$

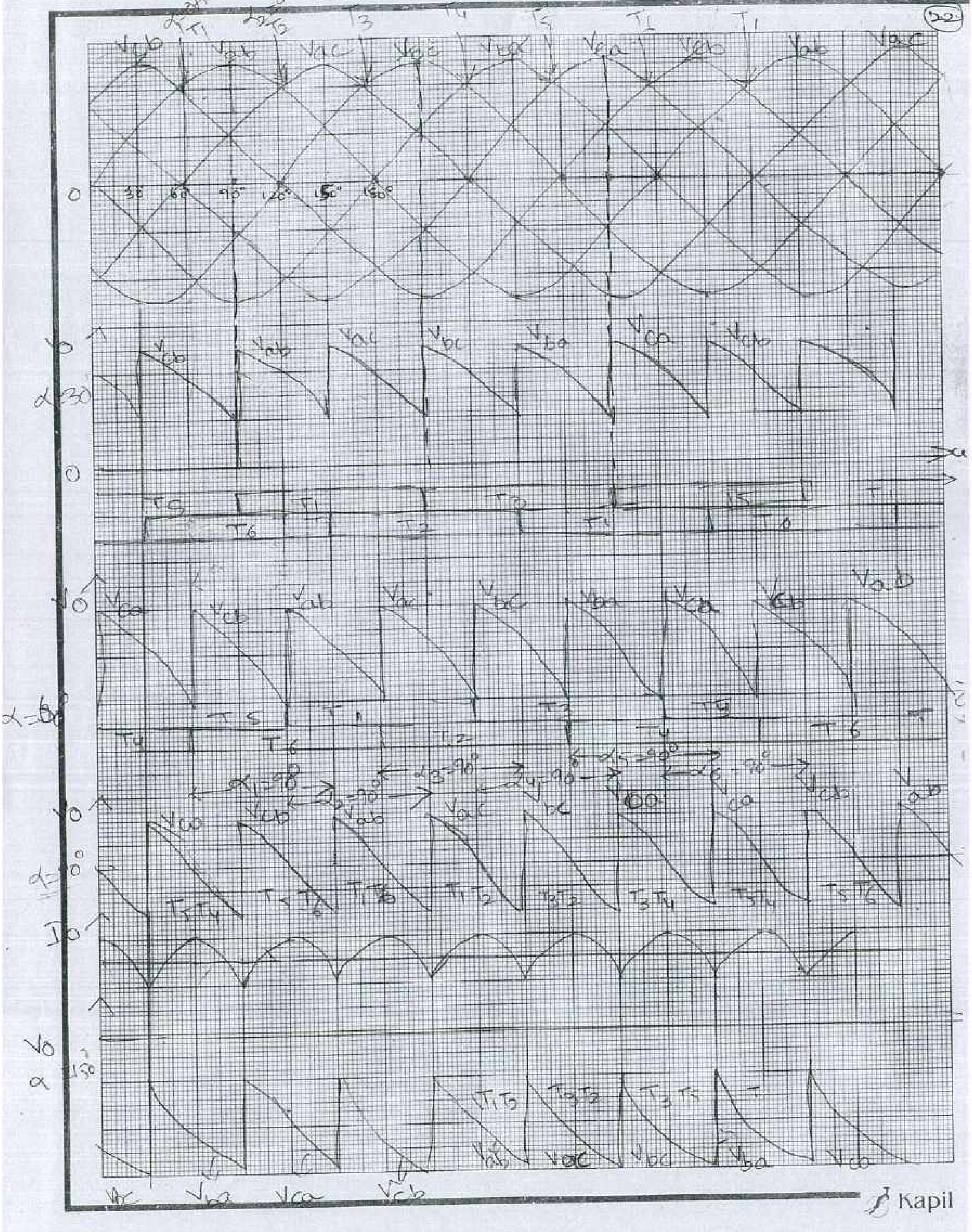
T_2 is at $\alpha + 240° + 180° = \alpha + 420°$

i.e., if $\alpha = 30°$, $T_1 \rightarrow 30°$ $T_4 \rightarrow 210°$

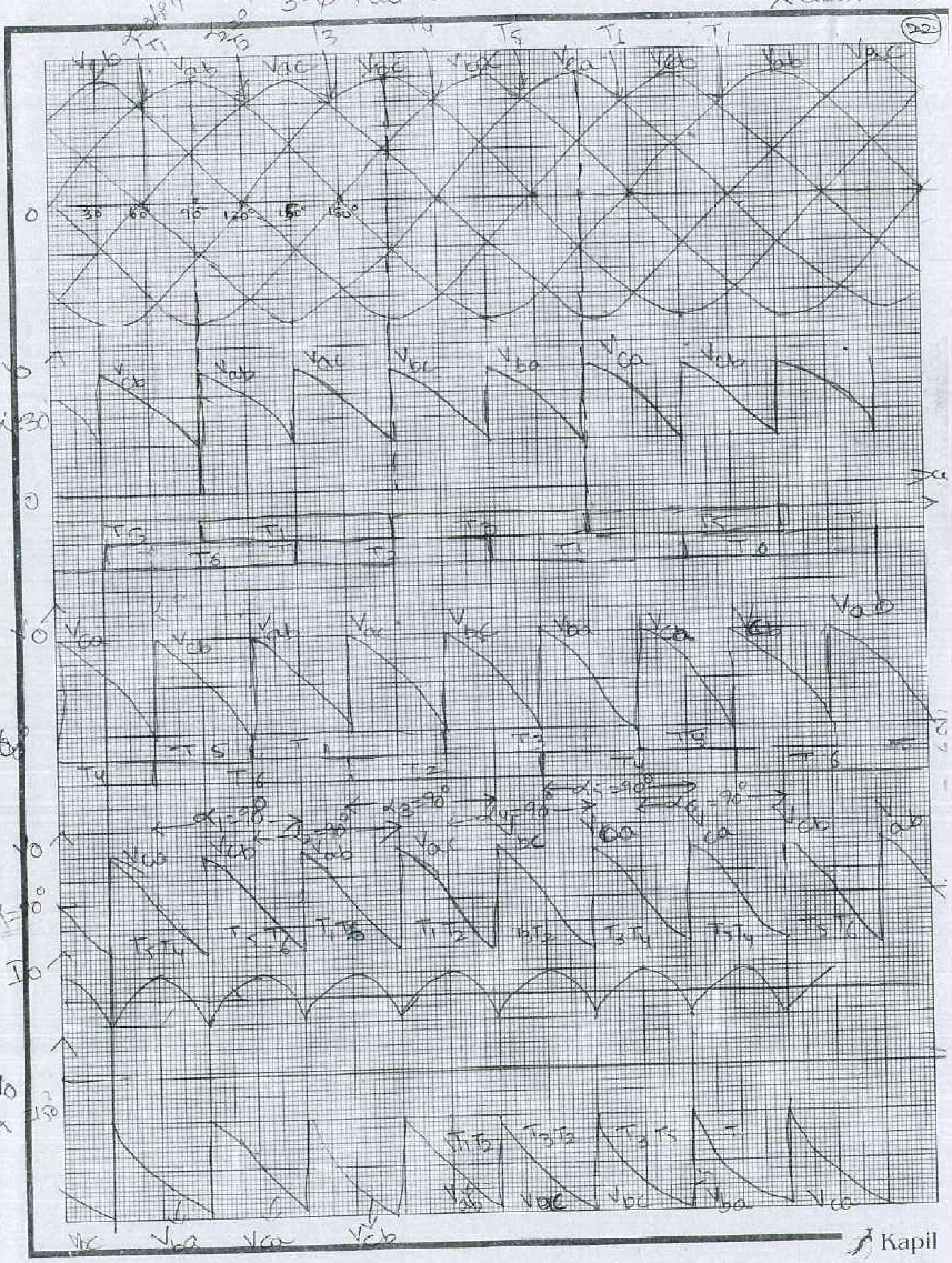
$T_3 \rightarrow 150°$ $T_6 \rightarrow 330°$

$T_5 \rightarrow 270°$ $T_2 \rightarrow 450°$ or $(360° + 90°)$ (or 90°)

3-ϕ Full W.R with RLE Load

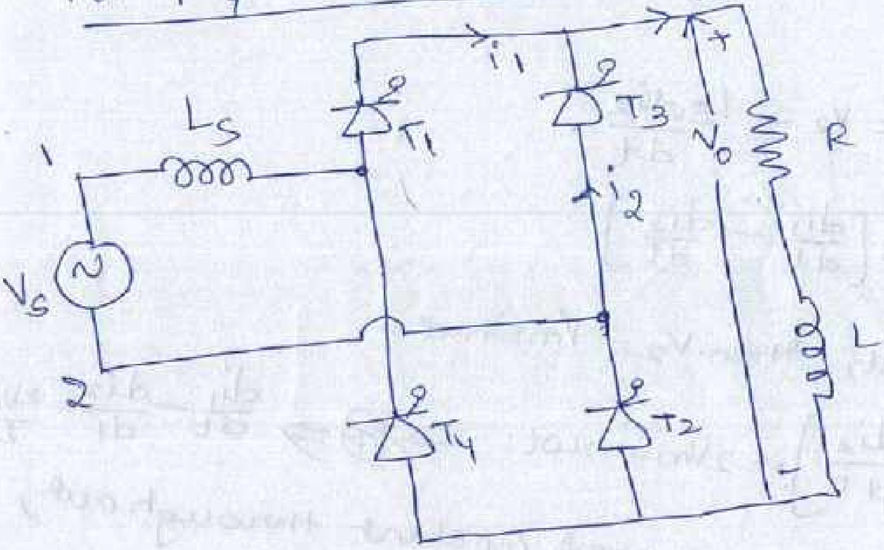


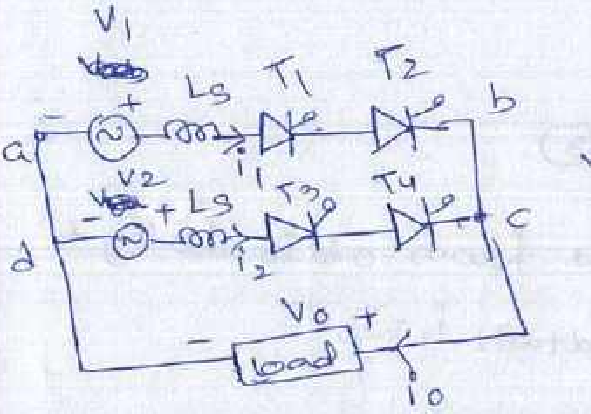
3-Ø Full W.R with RLE Load X-axis→1unit=

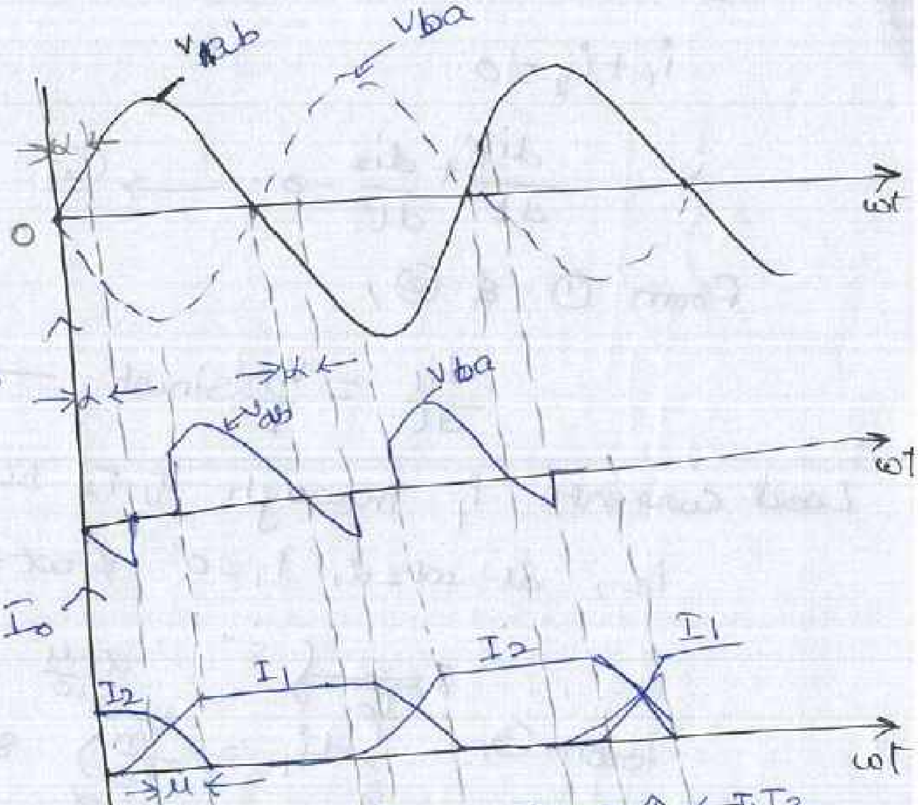


Effect of Source Impedance

For $1-\phi$ 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 $V_2 = -V_m \sin\omega t$

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

As load current is assumed constant throughout,

$$i_1 + i_2 = 0$$

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

from (1) & (2),

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

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

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

from (3),

$$\int_0^{I_0} di_1 = \frac{V_m}{L_S}\int_{\alpha/\omega}^{\frac{\alpha+\mu}{\omega}} \sin\omega t\, dt$$

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

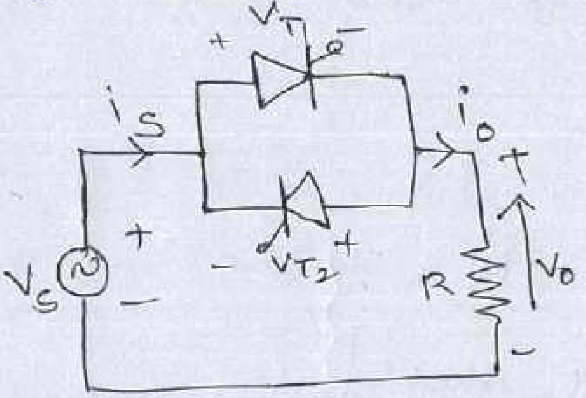
o/p V_0 is zero from α to $(\alpha + \mu)$.

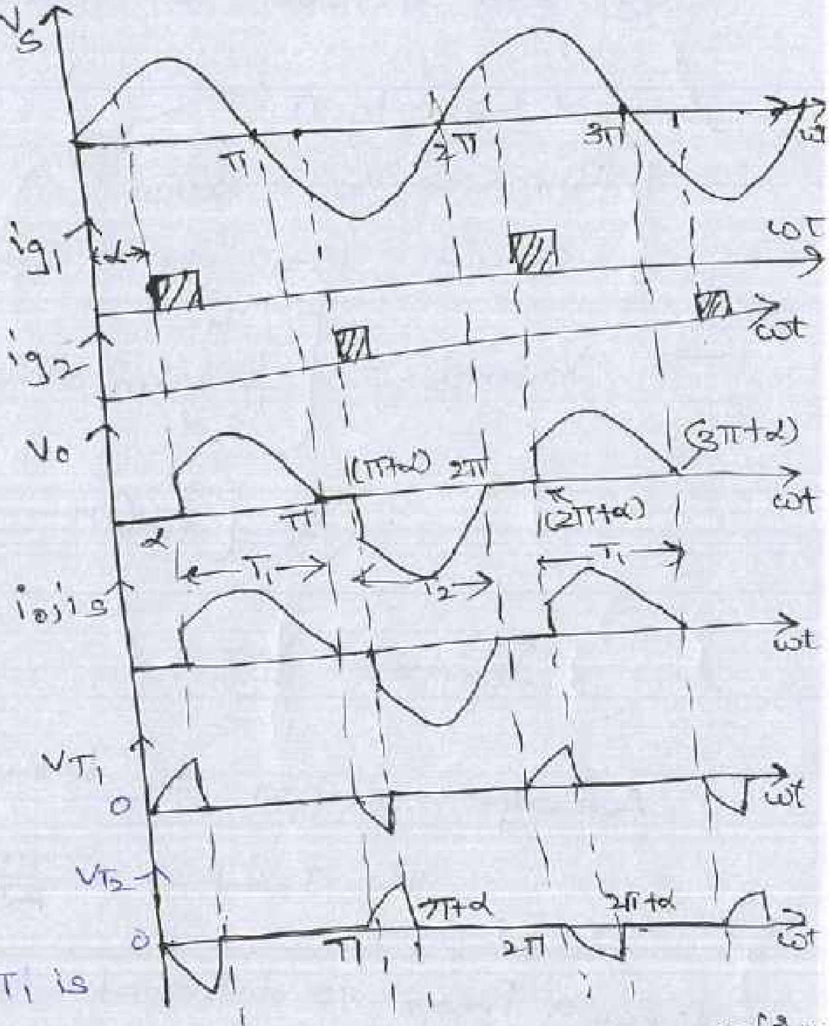
$$\therefore V_{0x} = \frac{V_m}{\pi}\int_{\alpha+\mu}^{\alpha+\pi} \sin\omega t\, d\omega t = \frac{V_m}{\pi}\left[\cos\alpha + \cos(\alpha + \mu)\right]$$

UNIT-II

1-Ø 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 waveform.

→ From 0 to α, T_1 is forward blocking mode, $V_{T1} = V_s$.

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

→ 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)

→ $\alpha \rightarrow 0$ to π.

& $V_{rms} \rightarrow V_s$ 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 $\alpha = 0$.

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

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

$I_1 = \frac{I_{1m}}{\sqrt{2}}$ = rms value of fundamental component of load or source current

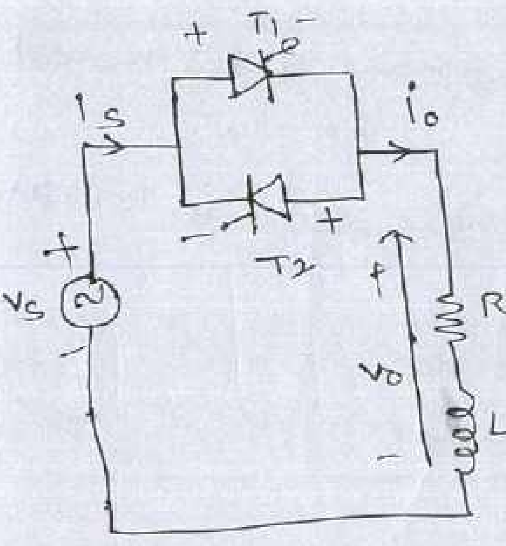
I_{orms} = rms value of load or source current

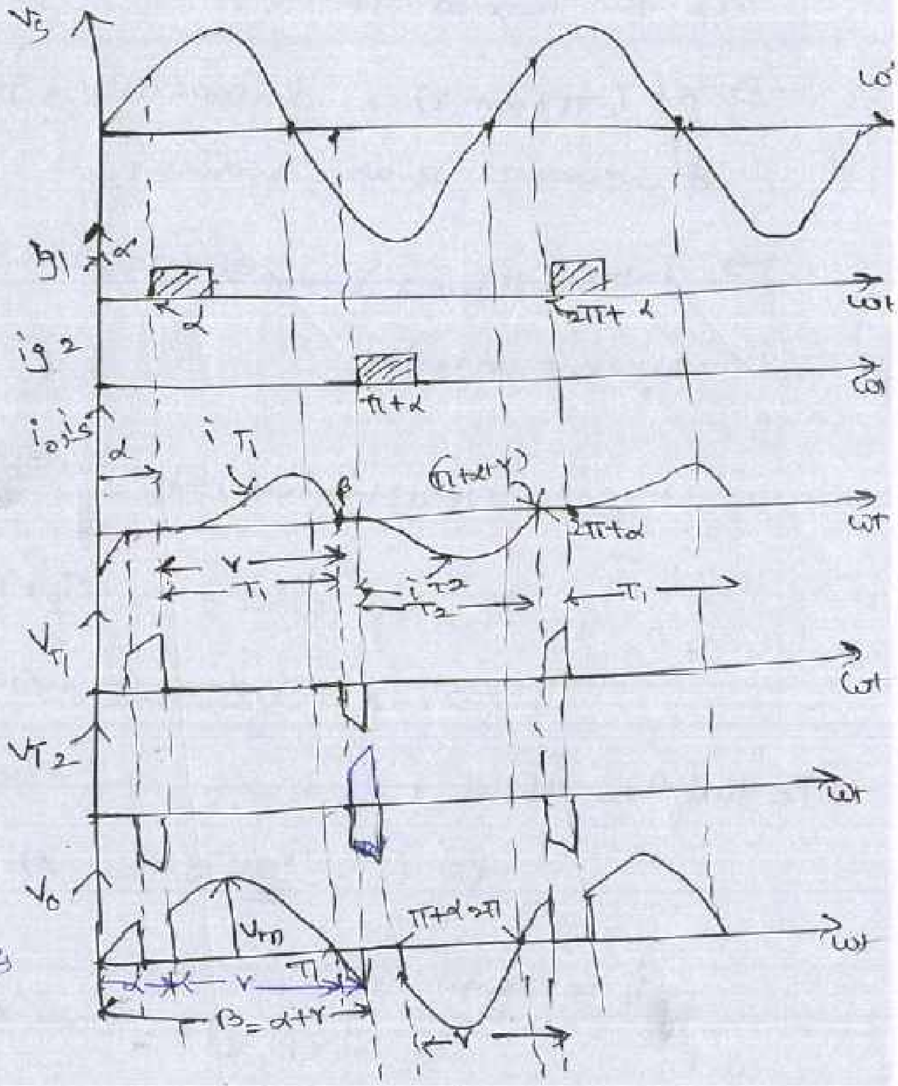
ϕ_1 = Phase angle b/w V_s & I_1.

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:





$\alpha > \phi$

→ During 0 to π, T_1 is F.B.
At $\omega t = \alpha$, T_1 is triggered &
$i_0 = i_{T_1}$ starts building up
through load.

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

→ At $\beta > \pi$, load current reduces to zero. β → extinction angle

→ After π, T_1 is reverse biased but does not turn off because
i_0 is not zero. At β only, when i_0 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, $V_0 = 0$, $V_{T_1} = -V_s$,
$V_{T_2} = V_s$.

→ When T_2 is turned on at $(\pi+\alpha) > \beta$, current $i_0 = i_{T_2}$
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 a 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

$$V_s = V_m \sin\omega t = Ri_0 + \frac{L\,di_0}{dt}$$

$$\Rightarrow i_0 = \frac{V_m}{Z}\sin(\omega t - \phi) + Ae^{-(R/L)t}$$

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

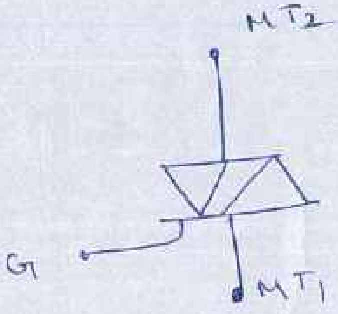
$$\phi \le \alpha \le \pi$$

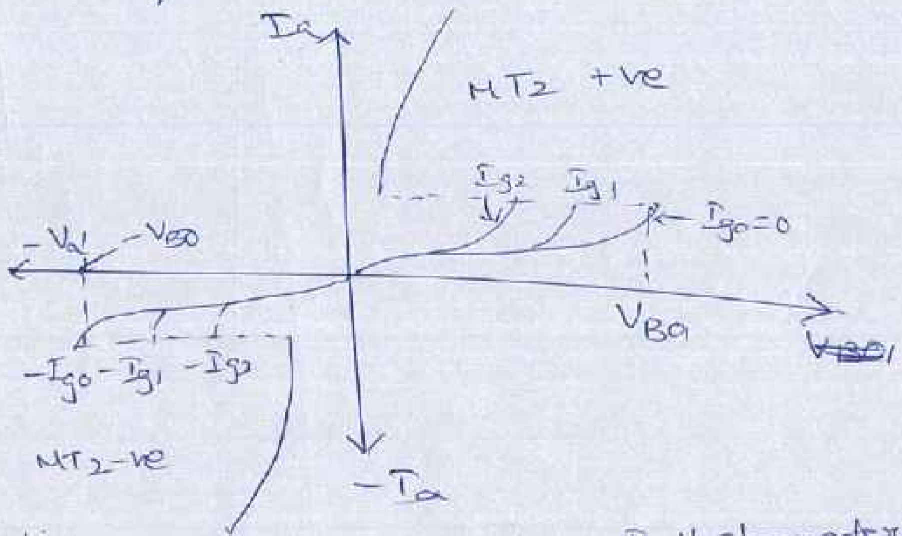
3. If $\alpha \le \phi$, load current would not change with α, but both SCRs conduct for π. T_1 would turn on at $\omega t = \phi$ & T_2 at $\pi + \phi$

→ TRIAC → conducts in both directions

→ It is a bidirectional thyristor with 3 terminal

→ operation is equivalent to two SCRs connected in antiparallel.





Circuit symbol

Static I-V characteristic's

→ It can conduct in both directions,

→ when gate signal is not given, triac will block both half cycle 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. $f_o > f_s$]

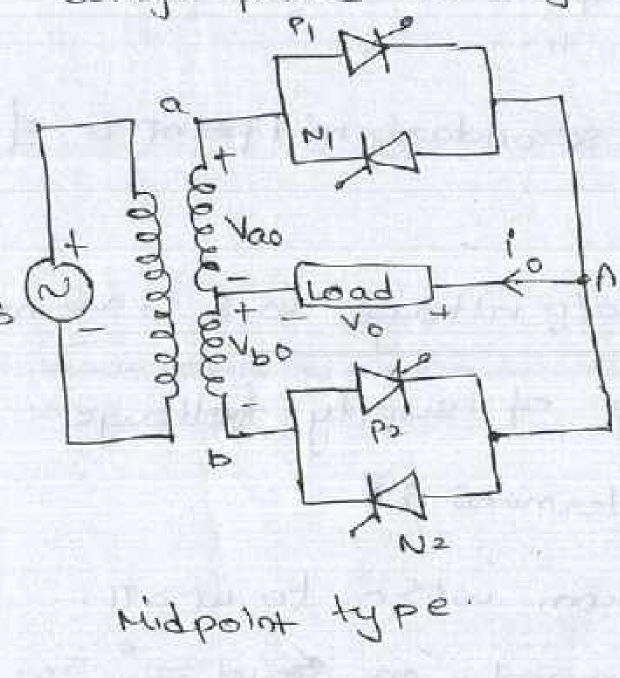
Applications → speed control of high power ac drives

→ Induction heating

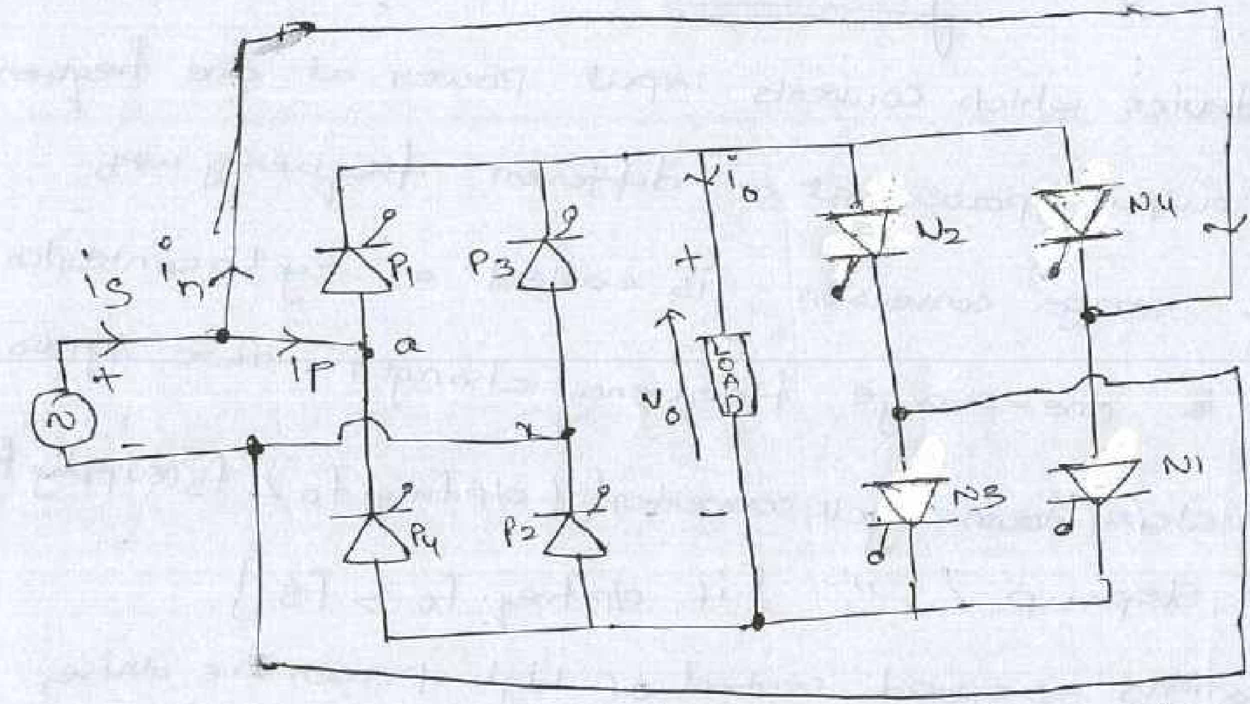
→ static VAr compensation

→ for converting variable speed alternator voltage to constant freq. o/p voltage

Principle of cycloconverter operation
(single phase to single phase cycloconverter)



Midpoint type



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 ".

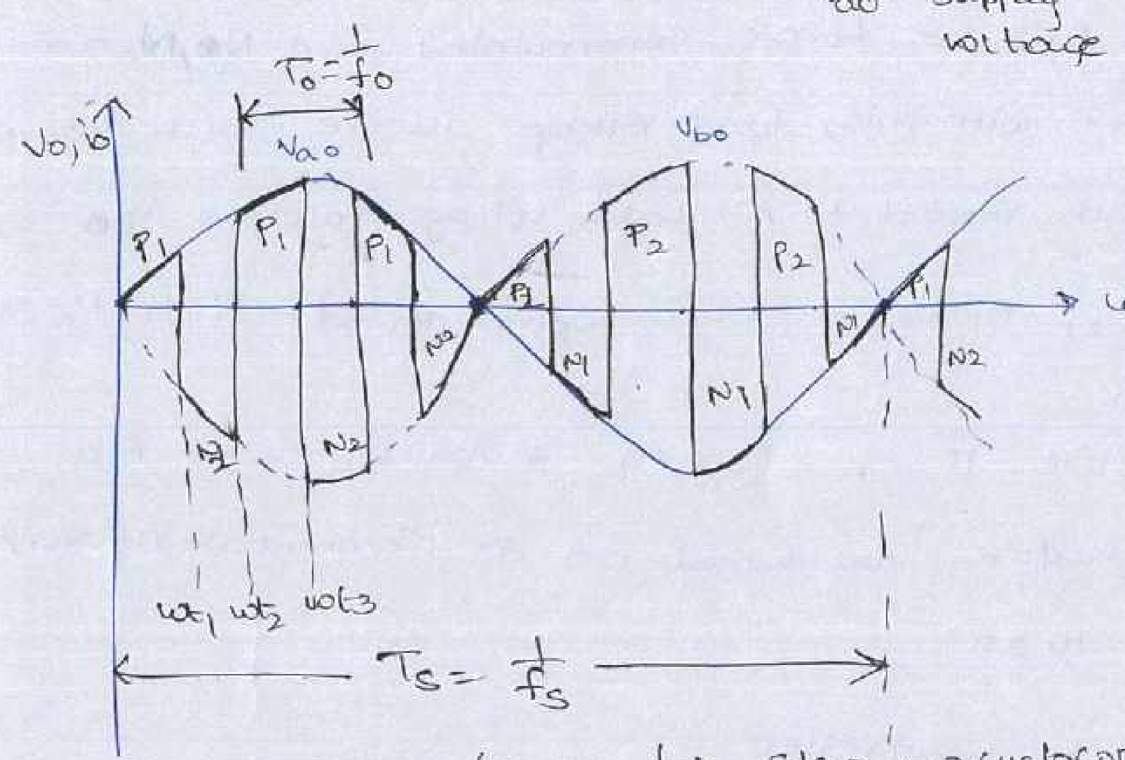
→ Load is connected b/w secondary mid point o & terminal A.

→ positive directions for o/p voltage V_o & i_o are marked

→ During positive half cycle of supply ~~v~~oltage terminal a is +ve w.r.t terminal b.

→ ∴ P_1 & N_2 are F.B from $\omega t = 0$ to $\omega t = \pi$.

→ As such SCR P1 is turned on at $\omega t = 0^\circ$ 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

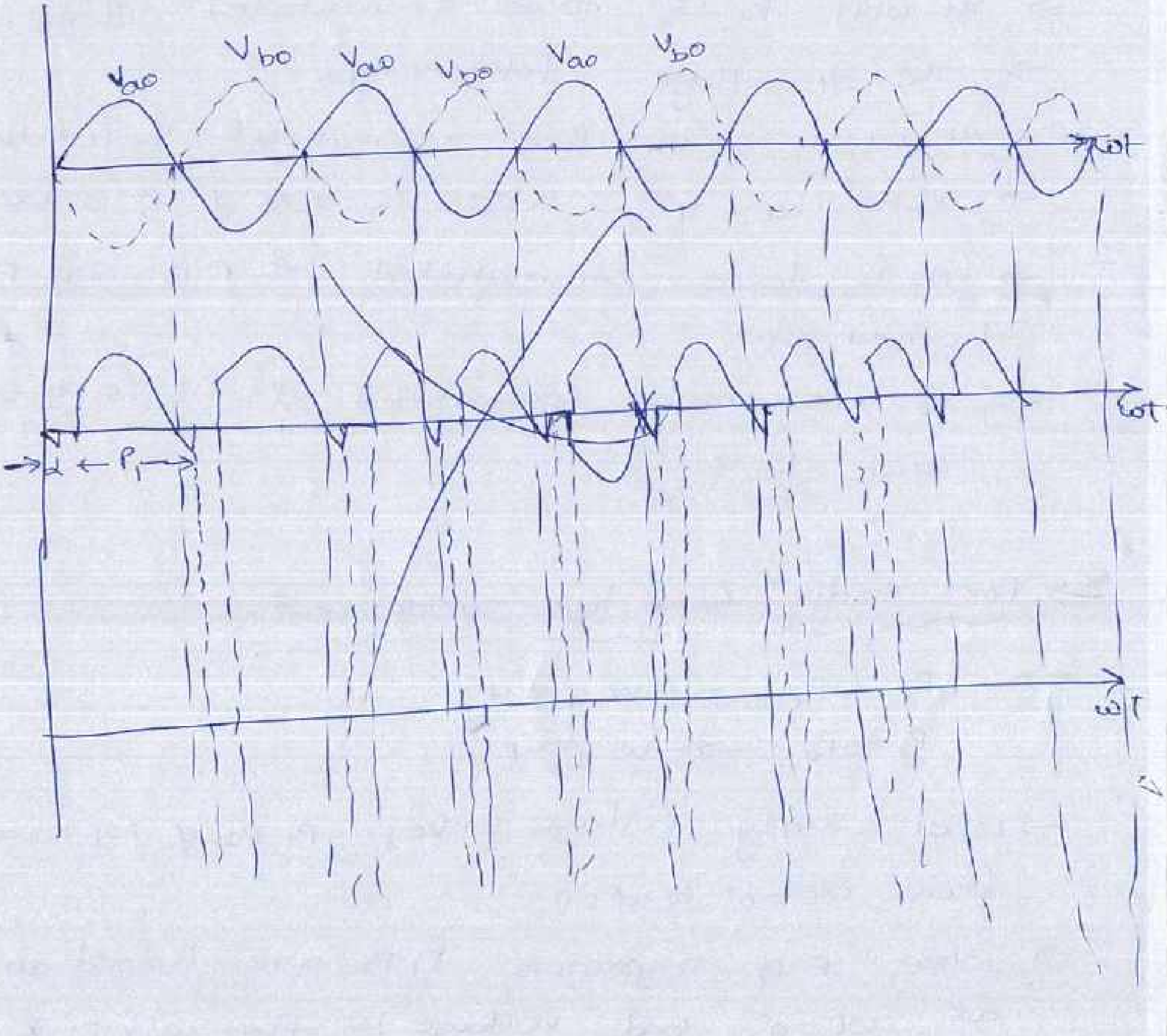
→ At ωt_1, P_1, P_2 are force commutated and N_1, N_2 are turned on. With this, load voltage is -ve with terminal O +ve with respect to A, Load voltage follows V_{bo}.

→ At ωt_2, $N_1 N_2$ are force commutated & P_1, P_2 are turned on.

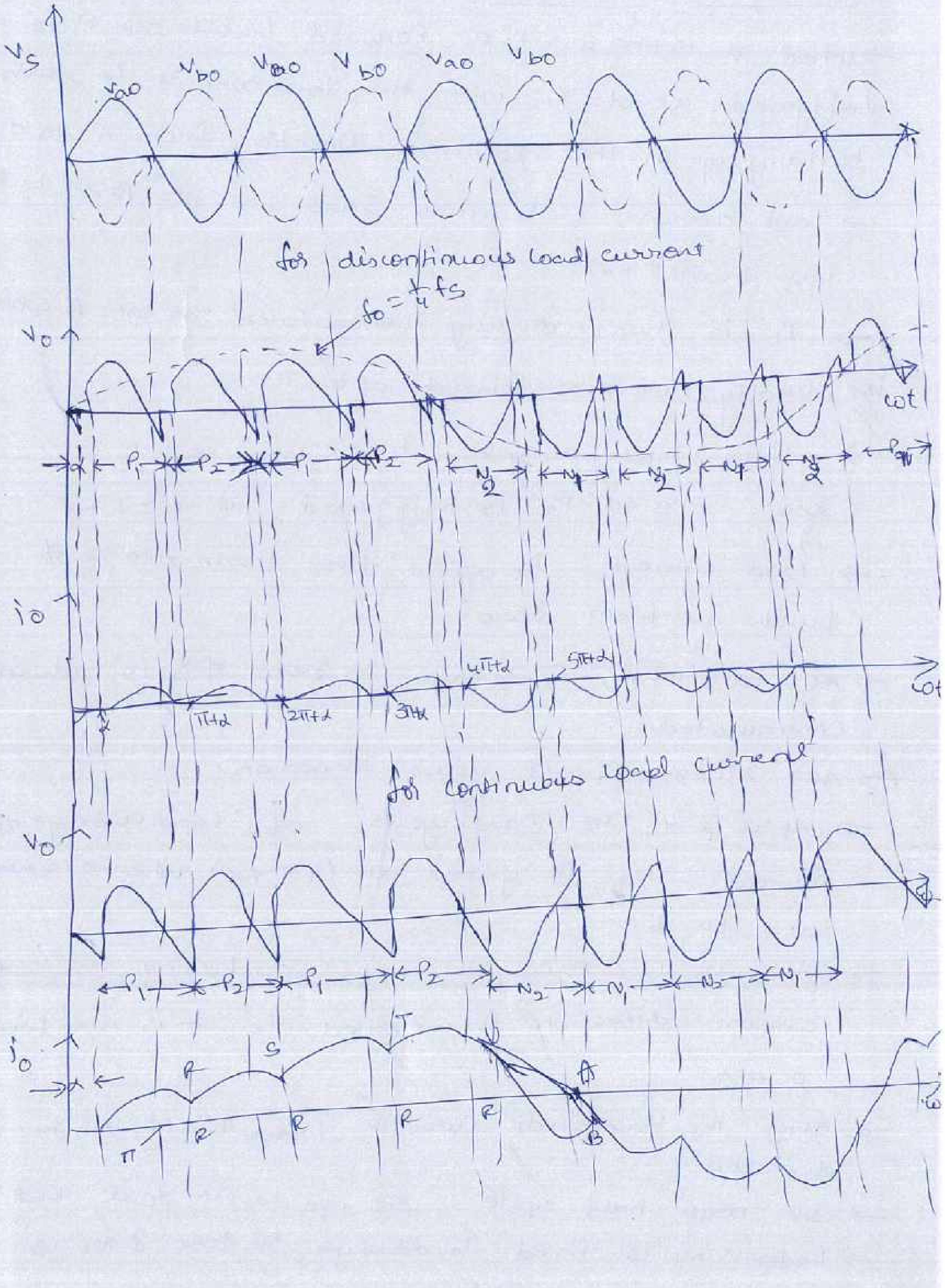
→ After $\omega t = \pi$, P_3, P_4 & N_3, N_4 are F.B these can therefore be turned on & commutated from $\omega t = \pi$ to 2π.

Step-down cyclo converter:

(i) Mid point cycloconverter:



$f_0 = \frac{1}{4} f_s$



vs
vao
vbo
vao
vbo
vao
vbo
for discontinuous load current
fo = 1/4 fs
vo
ωt
P1
P2
P1
P2
N2
N1
N2
N1
N2
io
π+α
2π+α
3π+α
4π+α
5π+α
ωt
for continuous load current
vo
P1
P2
P1
P2
N2
N1
N2
N1
io
T
S
R
A
B
π

(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 & 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, ie, it is now from O to A.

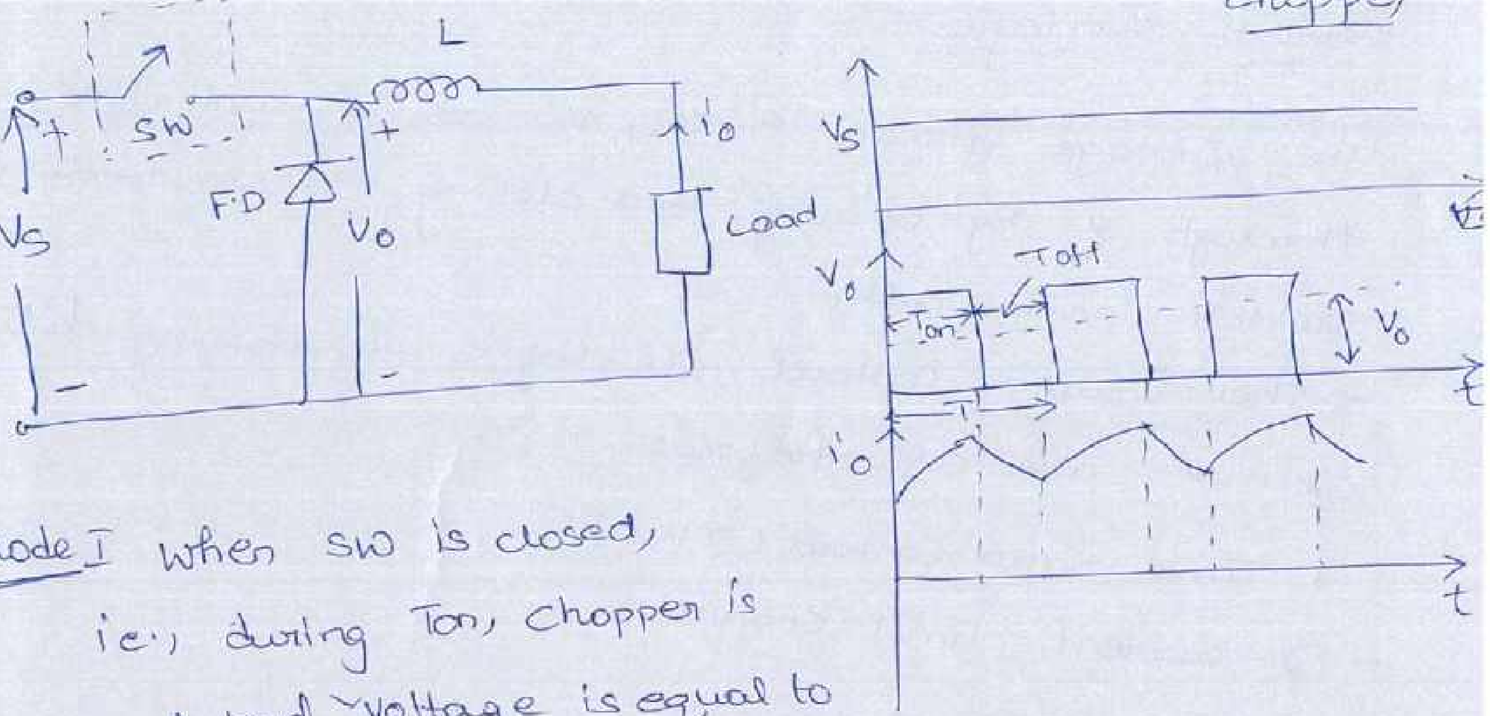
→ After N_2 triggered, current ~~flows~~ builds up in -ve direction.

→ 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 againgated.

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 $V_0 = \frac{T_{on}}{T_{on}+T_{off}} V_S = \frac{T_{on}}{T} V = \alpha V_S$

$\alpha = \frac{T_{on}}{T} \rightarrow$ duty cycle

$T = T_{on} + T_{off}$ = chopping period

$V_0 = f \cdot T_{on} V_S$

$f = \frac{1}{T}$ = 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.

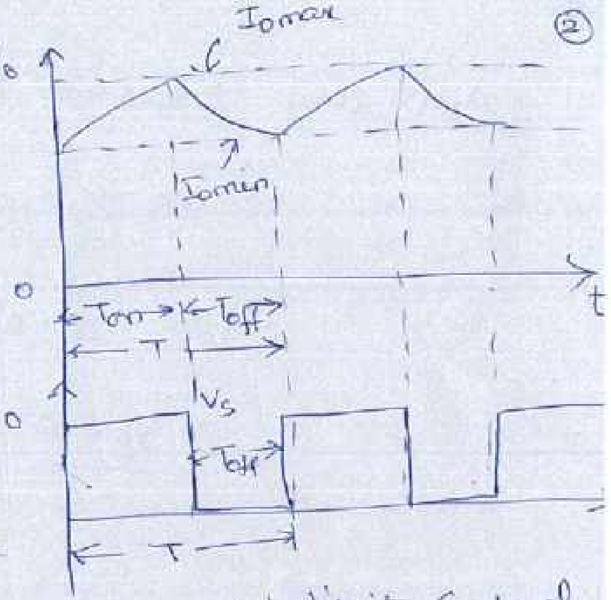
(ii) Variable frequency system:

→ 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 chopper

→ The on & off of chopper circuit guided by the previous set value of load current

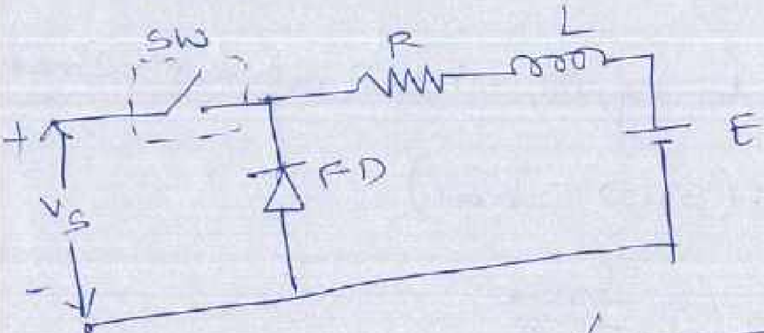
→ These two set values are max load current Iomax & minimum load current Iomin

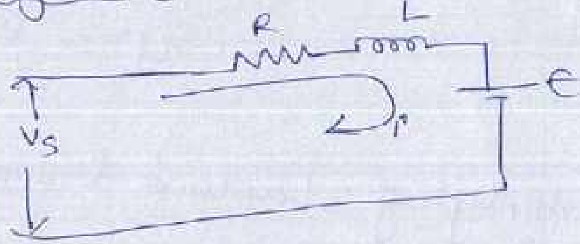
→ when load current reaches the upper limit Iomax, chopper is switched off

→ now load current freewheels and begins to decay exponentially

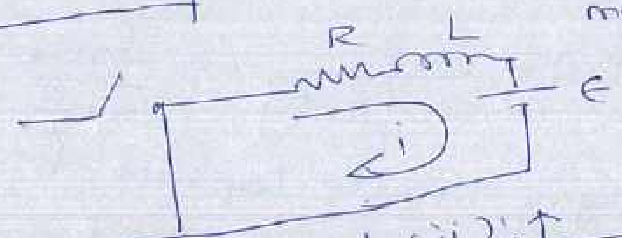
→ when it falls to lower limit Iomin, chopper is switched on & load current begins to rise

Steady state time domain analysis of Stepdown chopper

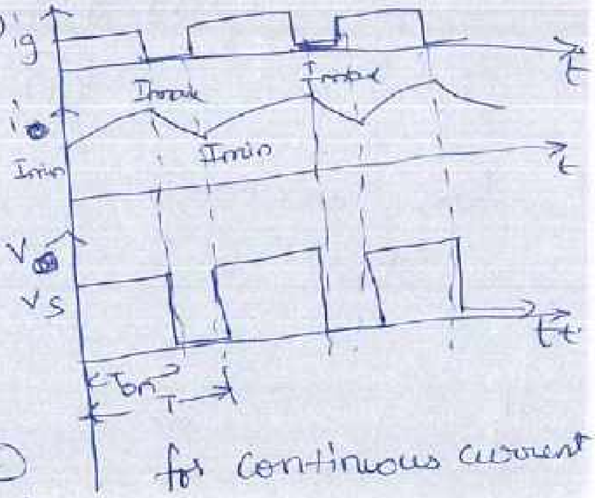




mode (i)



mode (ii)



for continuous current

mode (i) when switch is on, the equivalent is shown in fig. $0 \le t \le T_{on}$

$$V_s = Ri + L\frac{di}{dt} + E \rightarrow (1)$$

mode (ii) when switch is off,

$$0 = Ri + L\frac{di}{dt} + E \rightarrow (2)$$

$T_{on} \le t \le T$

Applying Laplace transform to eq ①, initial current = I_{min}

$$\frac{V_S - E}{S} = R I(S) + L(S I(S) - I_{min})$$

$$\Rightarrow I(S) = \frac{V_S - E}{S} - \frac{L(S I(S) - I_{min})}{R}$$

$$\Rightarrow \frac{V_S - E}{S} = I(S)\left[R + LS\right] - L I_{min}$$

$$\Rightarrow I(S) = \frac{V_S - E}{S(R+LS)} + \frac{L I_{min}}{(R+LS)}$$

$$I(S) = \frac{V_S - E}{LS\left[S+\frac{R}{L}\right]} + \frac{L I_{min}}{L(S+\frac{R}{L})}$$

$$I(S) = \frac{V_S - E}{S \cdot L\left[S+\frac{R}{L}\right]} + \frac{I_{min}}{S+\frac{R}{L}}$$

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 $t = T_{on}$, $i(t) = I_{max}$

$$\Rightarrow I_{max} = \frac{V_s - E}{R}\left[1 - e^{-\frac{T_{on}}{T_a}}\right] + I_{min}\, e^{-\frac{T_{on}}{T_a}} \longrightarrow ⑤$$

where $T_a = \frac{L}{R}$

eq ④ at $t' = T_{off} = T - T_{on}$, $i(t') = I_{min}$

$$\Rightarrow I_{min} = -\frac{E}{R}\left[1 - e^{-\left(\frac{T - T_{on}}{T_a}\right)}\right] + I_{max}\, e^{-\left(\frac{T - T_{on}}{T_a}\right)} \longrightarrow ⑥$$

sub eq ⑥ in eq ⑤,

$$I_{max} = \frac{V_s - E}{R}\left[1 - e^{-\frac{T_{on}}{T_a}}\right] + \left[-\frac{E}{R}\left(1 - e^{-\left(\frac{T - T_{on}}{T_a}\right)}\right) + I_{max}\, e^{-\left(\frac{T - T_{on}}{T_a}\right)}\right] e^{-\frac{T_{on}}{T_a}}$$

$$\Rightarrow I_{max} = \frac{V_s}{R}\left[\frac{1 - e^{-\frac{T_{on}}{T_a}}}{1 - e^{-\frac{T}{T_a}}}\right] - \frac{E}{R} \longrightarrow ⑦$$

IIIly 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

$$I_{max} - I_{min} = \frac{V_s}{R}\left[\frac{1-e^{-\frac{T_{on}}{T_a}}}{1-e^{-\frac{T}{T_a}}} - \frac{e^{\frac{T_{on}}{T_a}}-1}{e^{\frac{T}{T_a}}-1}\right]$$

$$= \frac{V_s}{R}\left[\frac{1-e^{-\frac{T_{on}}{T_a}}}{1-e^{-\frac{T}{T_a}}} - \frac{\left(1-e^{-\frac{T_{on}}{T_a}}\right)e^{\frac{T_{on}}{T_a}}}{\left(1-e^{-\frac{T}{T_a}}\right)e^{\frac{T}{T_a}}}\right]$$

$$= \frac{V_s}{R}\left[\frac{\left(1-e^{-\frac{T_{on}}{T_a}}\right)-\left(1-e^{-\frac{T_{on}}{T_a}}\right)e^{\left(\frac{T_{on}-T}{T_a}\right)}}{1-e^{-\frac{T}{T_a}}}\right]$$

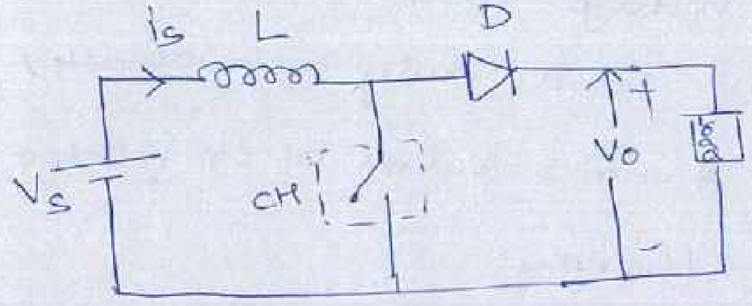
$$= \frac{V_s}{R}\left[\frac{\left(1-e^{-\frac{T_{on}}{T_a}}\right)\left(1-e^{-\left(\frac{T-T_{on}}{T_a}\right)}\right)}{1-e^{-\frac{T}{T_a}}}\right]$$

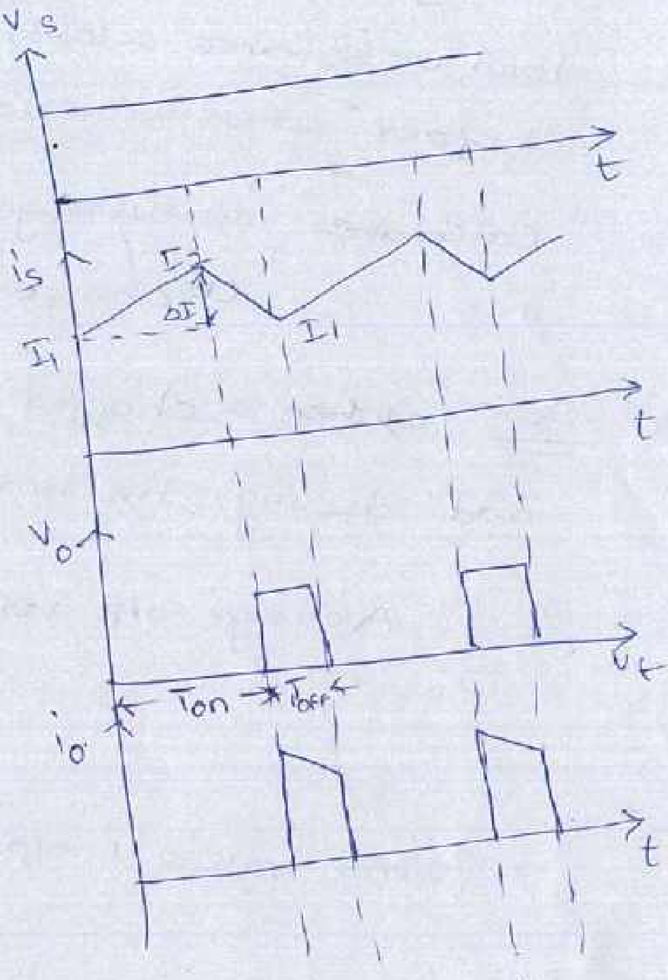
∴ the ripple current is independent of E.

with $T_{on} = \alpha T$ & $T - T_{on} = (1-\alpha)T$,

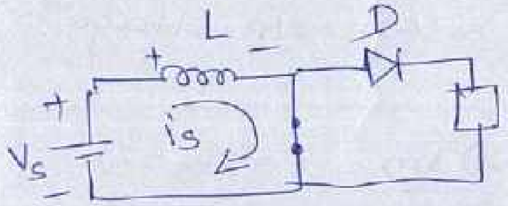
$$I_{max} - I_{min} = \frac{V_s}{R}\left[\frac{\left(1-e^{-\frac{\alpha T}{T_a}}\right)\left(1-e^{-\frac{(1-\alpha)T}{T_a}}\right)}{1-e^{-\frac{T}{T_a}}}\right]$$

Step-up chopper:

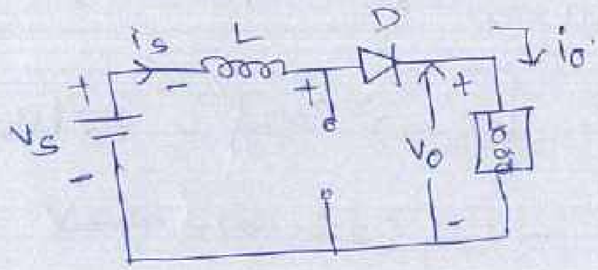




Step up chopper



L stores energy



$L\frac{di}{dt}$ is added to Vs

during Ton,

energy i/p to inductor from source

win = (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 thru L) Toff

$$w_{off} = (V_0 - V_S)\left[\frac{I_1+I_2}{2}\right] T_{off}.$$

$$V_S\left[\frac{I_1+I_2}{2}\right] T_{on} = (V_0 - V_S)\left[\frac{I_1+I_2}{2}\right] T_{off}$$

$$\Rightarrow V_S \cdot T_{on} = (V_0 - V_S) T_{off}$$

$$\Rightarrow V_0 T_{off} = V_S (T_{on} + T_{off}) = V_S \cdot T$$

$$\therefore V_0 = \frac{T}{T_{off}} \cdot V_S = V_S \cdot \frac{T}{T - T_{on}} = V_S \cdot \frac{1}{1-\alpha}$$

→ 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

∴ 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 $= \left[(V_S-2)^2 \frac{T_{on}}{T}\right]^{1/2} = \sqrt{\alpha}(V_S-2)$

$= \sqrt{0.4}\,(230-2) =$ ~~91.2 V~~

$= 144.2\,V$

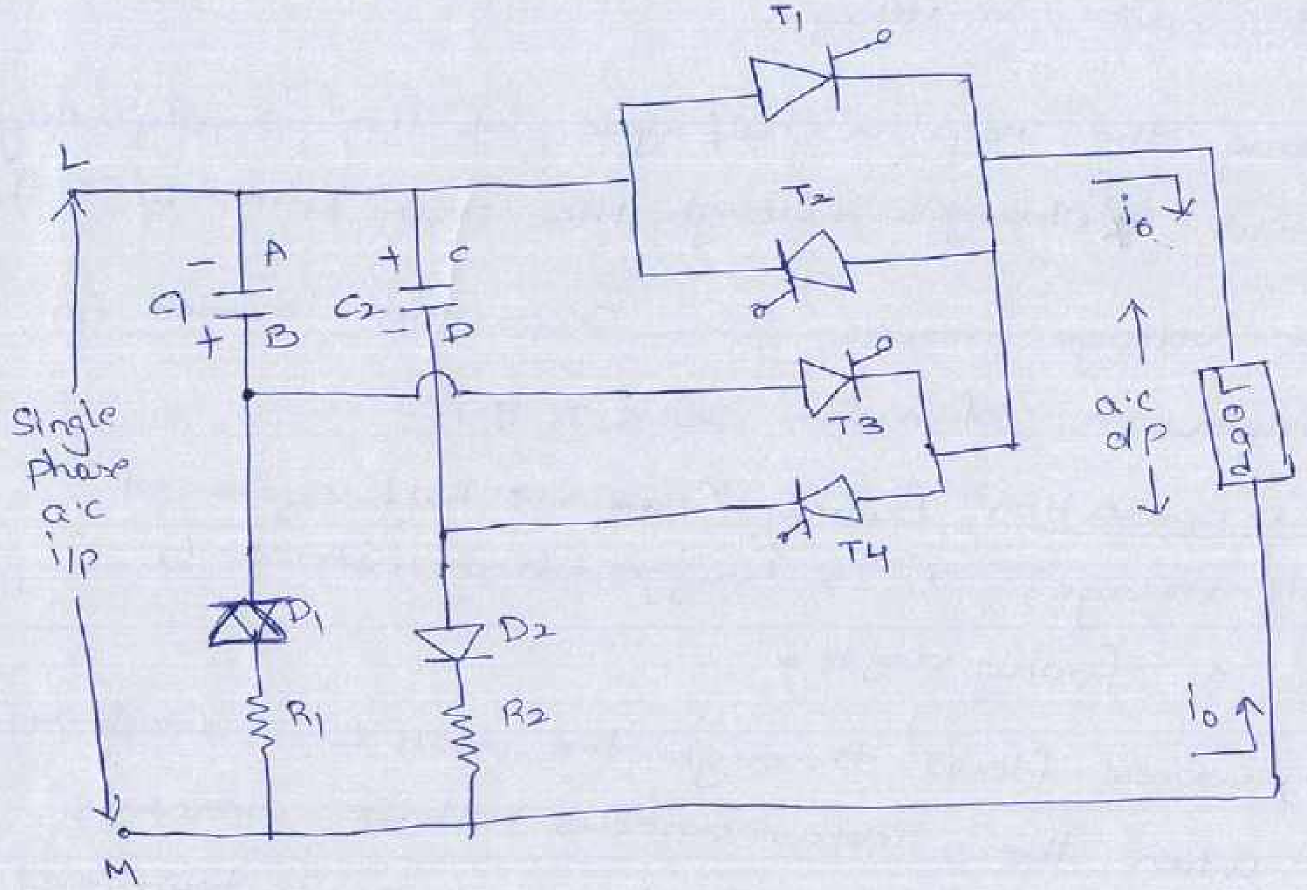
(b) power o/p or power delivered to load,

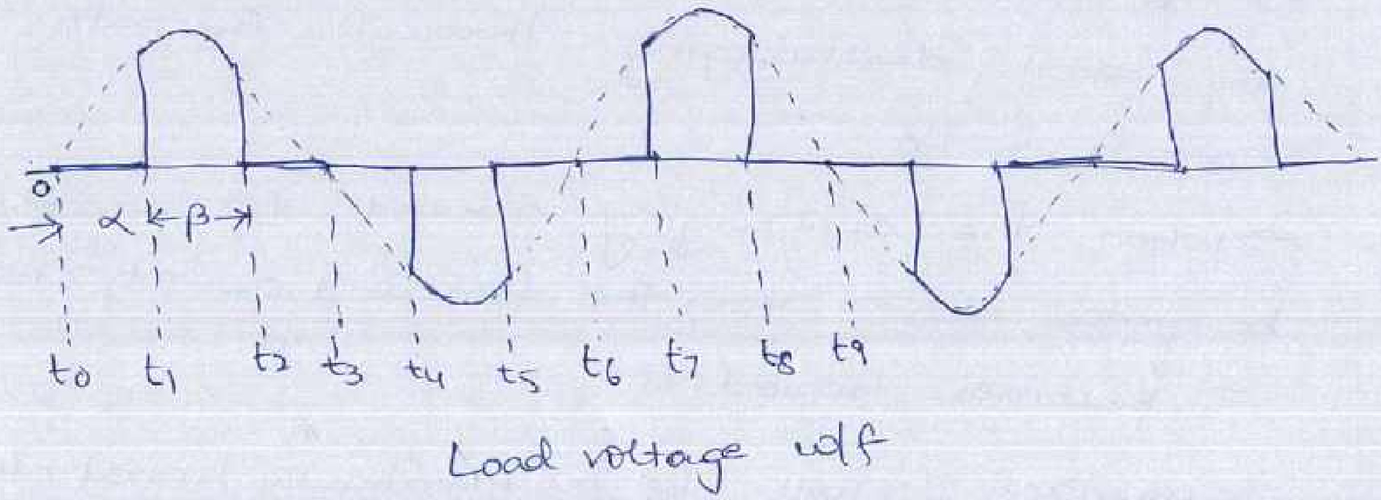
$P_o = \frac{V_{or}^2}{R} = \frac{(144.2)^2}{10} = 2079.364\,W$

Power i/p to chopper $P_i = V_s I_o = 230 \times \frac{91.2}{10} = 2097.6\,W$

chopper efficiency $= \frac{P_o}{P_i} = 99.13\%$.

<u>Ac chopper</u> - 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 four 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–

→ When the instantaneous voltage reaches the instant t_5, SCR T_4 is triggered.

→ As soon as thyristor T_4 is triggered, capacitor 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.

$$V_o = V_s \cdot \frac{1}{1-\alpha}$$

$$\Rightarrow 660 = 220 \frac{1}{1-\alpha} \Rightarrow \alpha = \frac{2}{3} = \frac{T_{on}}{T}.$$

$$T_{on} = \frac{2}{3}T = 100\mu s.$$

$$\therefore \text{chopping period } T = 100 \times \frac{3}{2} = 150\mu s.$$

$$\therefore \text{Pulse width of o/p voltage} = T_{off} = T - T_{on}$$

$$= 150 - 100 = 50\mu s.$$

when pulse width of o/p voltage is halved,

$$T_{off} = \frac{50}{2} = 25\mu s$$

for constant frequency operation, $T = 150\mu s$

$T_{on} = 150 - 25 = 125\mu s$

$$\alpha = \frac{T_{on}}{T} = \frac{125}{150} = \frac{5}{6}.$$

$$\therefore V_o = 220 \times \frac{1}{1 - \frac{5}{6}} = 1320V$$

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

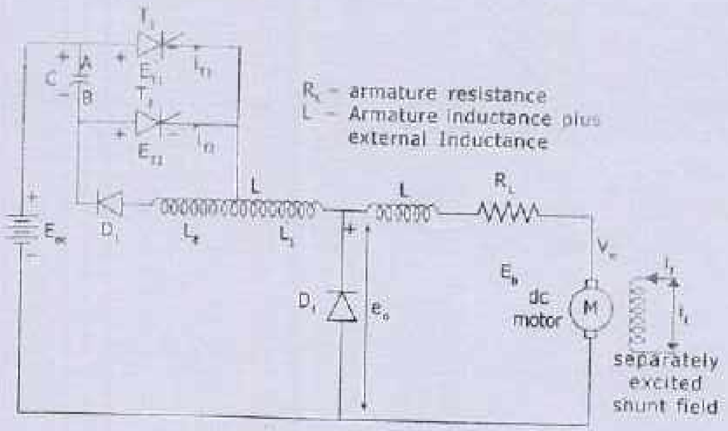


Figure 4.21(a)

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 1: 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

$$C_A - T_1 - LL_2 - D_1 - C_B$$

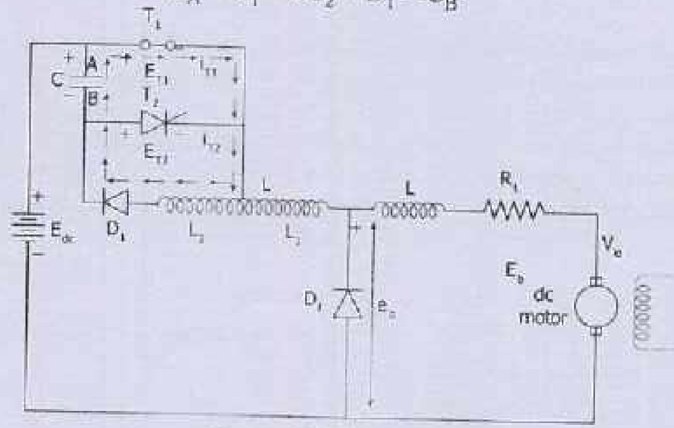


Figure 4.21(b)

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)

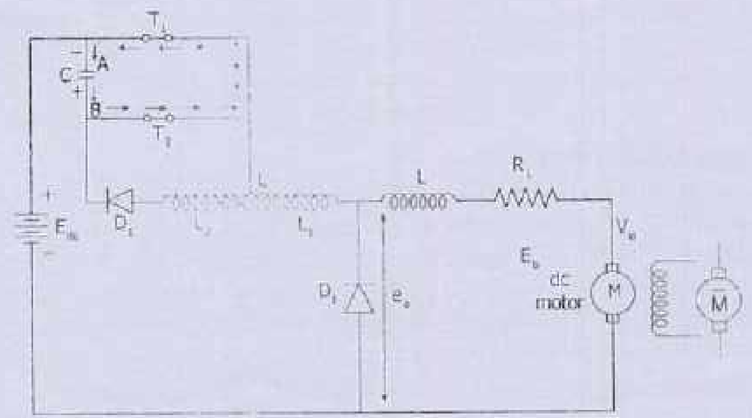


Figure 4.21(c)

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.

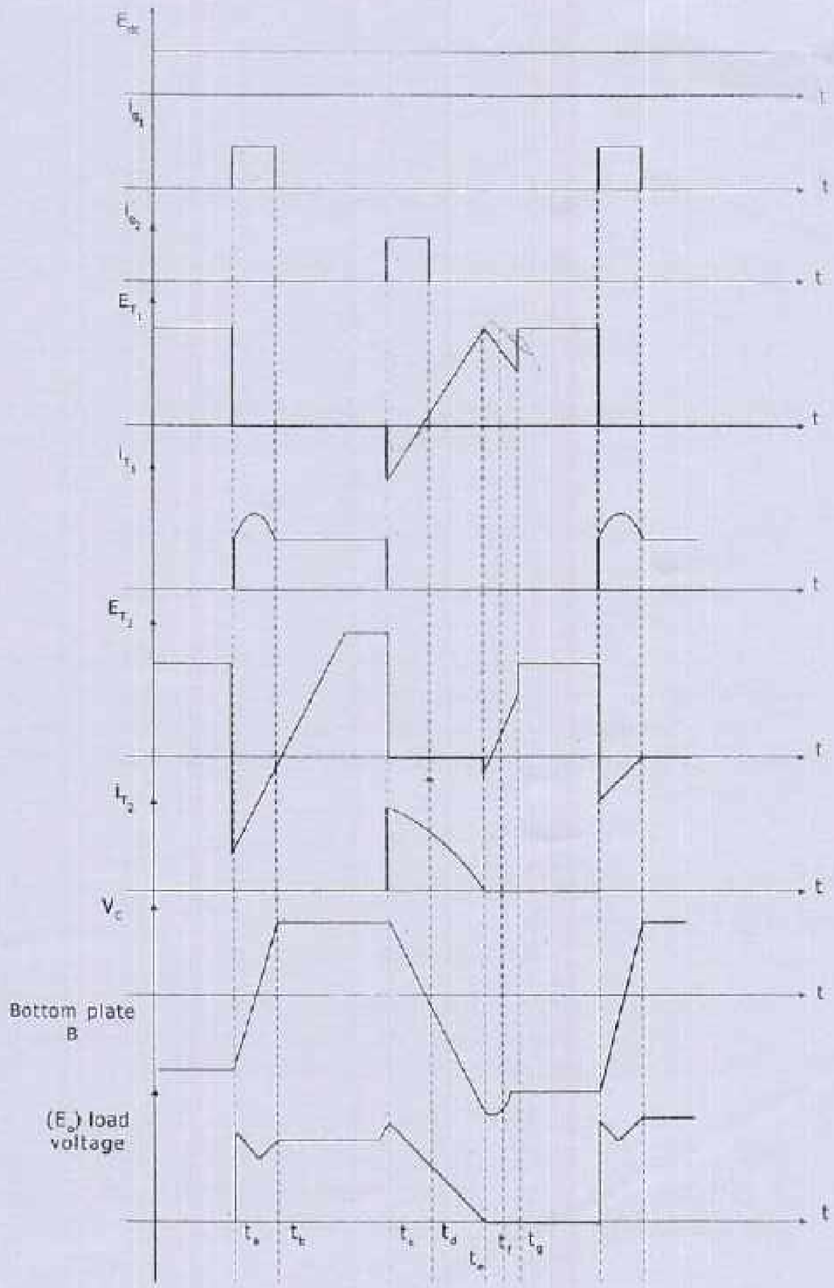


Figure 4.21(d) Voltage and current waveforms in D.C Jones Chopper

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 $$V_c = I_{omax}\sqrt{\frac{L_1}{C}} \quad (1)$$

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

$$\frac{V_c}{E_{dc}} = \frac{I_{omax}}{E_{dc}}\sqrt{\frac{L_1}{C}} \quad (2)$$

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

$$E_{dc} = 60\text{v}$$

$$\text{turn off time } (t_q) = 10\ \mu\text{ sec.}$$

$$I_o = I_{T1} = 100\text{A}$$

$$g = 4\ mho$$

$$g = \frac{1}{R_m}\sqrt{\frac{L_1}{C}}$$

$$R_m = \frac{E_{dc}}{I_o} = \frac{60}{100} = 0.6\Omega$$

or $$\sqrt{\frac{L_1}{C}} = 4(0.6) = 2.4 \quad (1)$$

But we know that,

$$t_q = \sqrt{L_1 C} \text{ or } \sqrt{L_1 C} = 10 \times 10^{-6} \quad (2)$$

from (1) and (2)

$$\sqrt{\frac{L_1}{C}}\sqrt{L_1 C} = (2.4)\ 10 \times 10^{-6}$$

$$L_1 = 24 \times 10^{-6} = 24\mu\text{H}$$

Substutitute L_1 value in equation (2) gives

$$\sqrt{24\times 10^{-6}} \times \sqrt{C} = 10 \times 10^{-6}$$

$$24 \times 10^{-6} \times C = (10)^2 \times (10^{-6})^2$$

$$C = \frac{100\times10^{-12}}{24\times10^{-6}} = 4.16\ \mu F$$

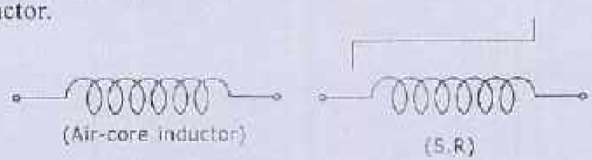
$\because$ $L_1 = L_2$

$L_2 = 24\mu H$

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.

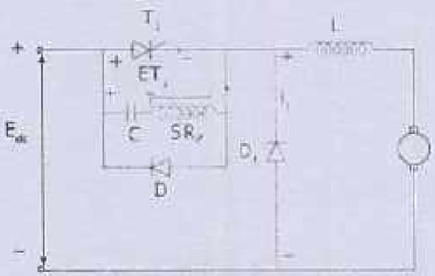


Figure 4.22(a) Morgans chopper

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)

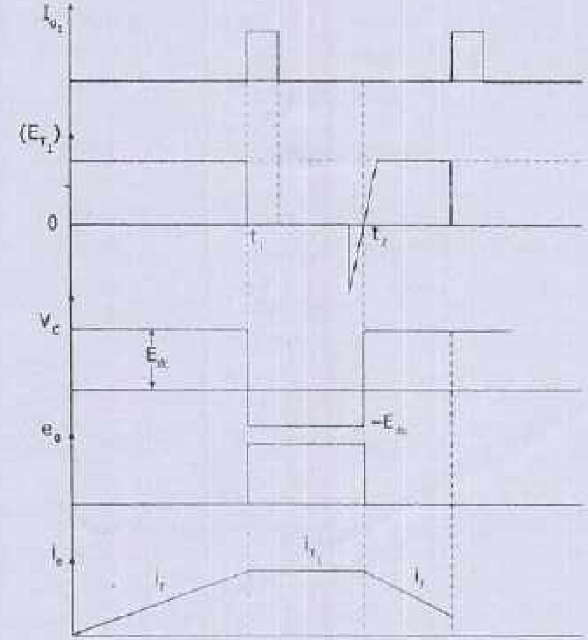


Figure 4.22(b) Voltage and current waveforms in a Morgan chopper

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:

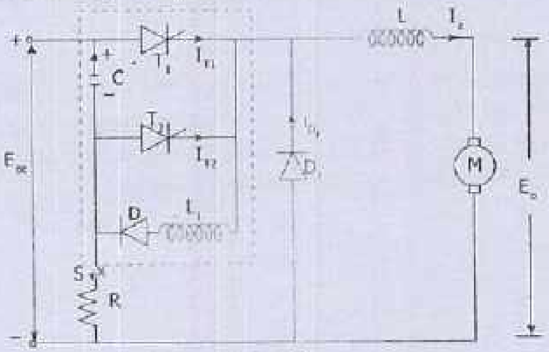


Figure 4.23(a)

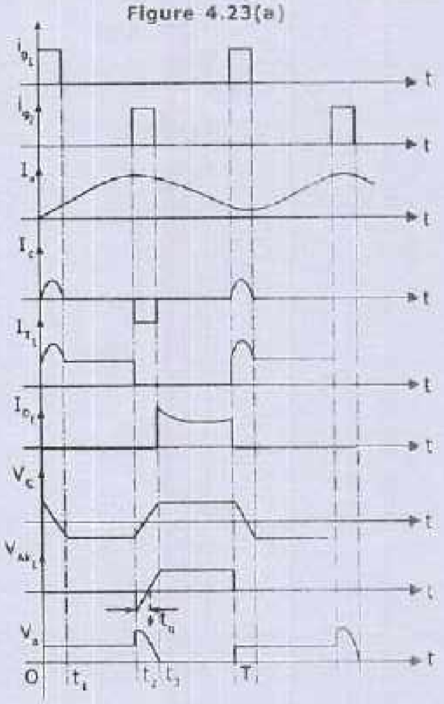


Figure 4.23(b)

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 ie., 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).

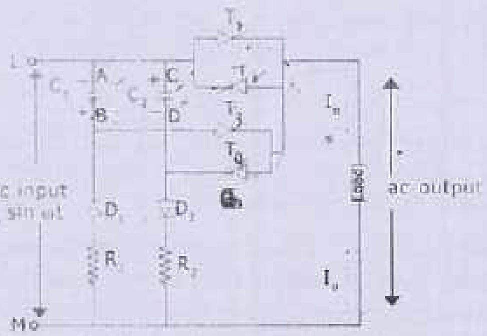


Figure 4.24(a) A.C chopper circuit diagram

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).

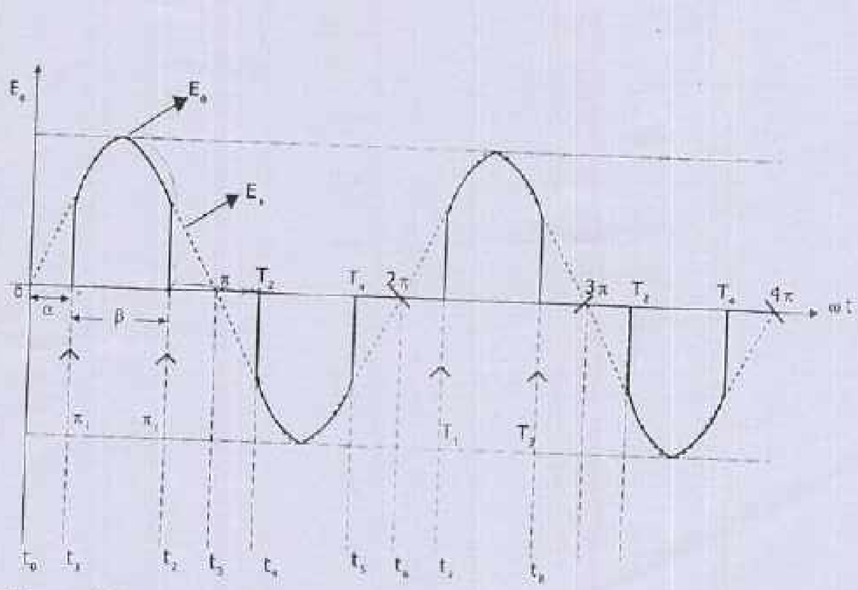


Figure 4.24(b) Supply voltage and output voltage waveforms in an A.C Chopper

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 μ sec

   T_{off} = 109.1 μsec

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 μ sec;

   $E_{o(new)}$ = 155.55v

3. For the basic chopper circuit, E_{dc} = 50volts, R = 80Ω, duty cycle α = 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} = 25μ 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 α = 0.6

   Ans: $E_{o(avg)}$ = 179.4 V; E_{orms} = 231.60v; η = 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

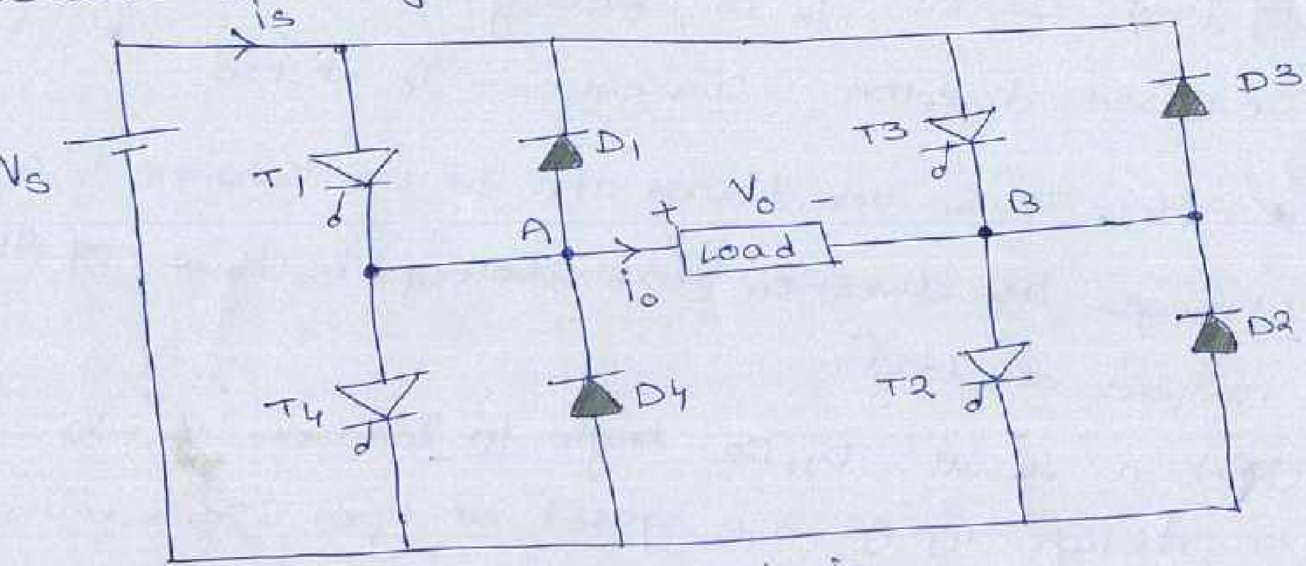
   T_{OFF} = 0.137 m sec

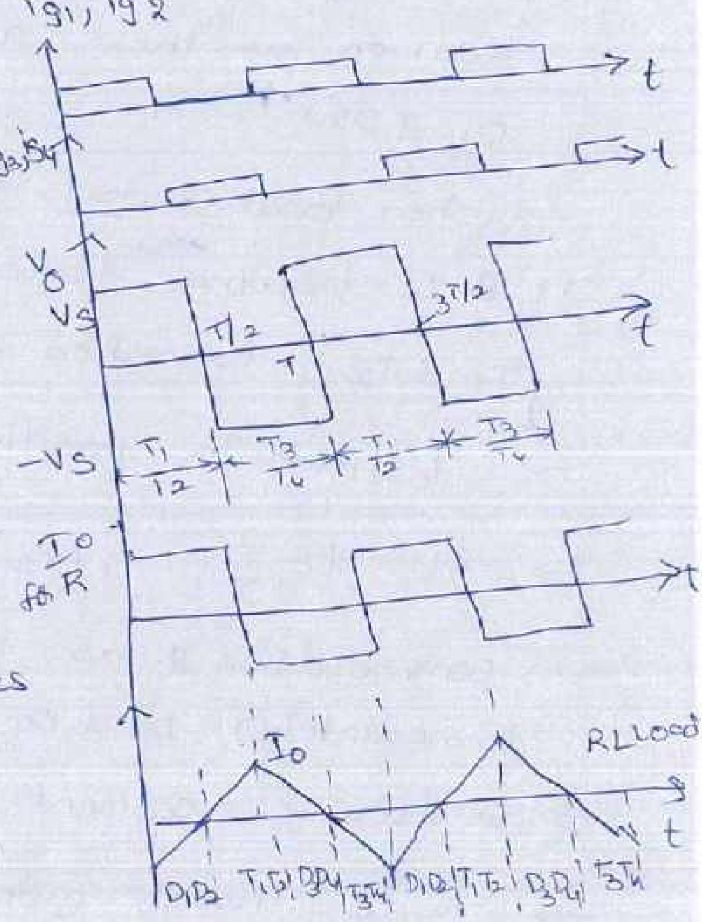
   α = 0.45

UNIT - V

INVERTERS

Single phase full bridge inverter :-





→ For Resistive load, SCRs would suffice because load current i_0 & V_0 would always be in phase with each other

→ For other than the resistive loads, current i_0 will not be inphase with voltage V_0 & 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 (D_1, D_2, D_3, D_4)

For <u>RL load</u>: Before $t=0$, SCRs T3 & T4 are conducting & load current i_0 is flowing from B to A i.e. in reversed direction. current $= -I_0$ at $t=0$.

→ After T3, T4 are turned off at $t=0$, current i_0 cannot change its direction immediately 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 D1, 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 $T/2$.

→ T3, T4 though gated, will not turn on as these are reverse biased by the voltage drop in diodes D3, D4

→ when current in diodes D3, D4 drops to zero, T3, T4 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

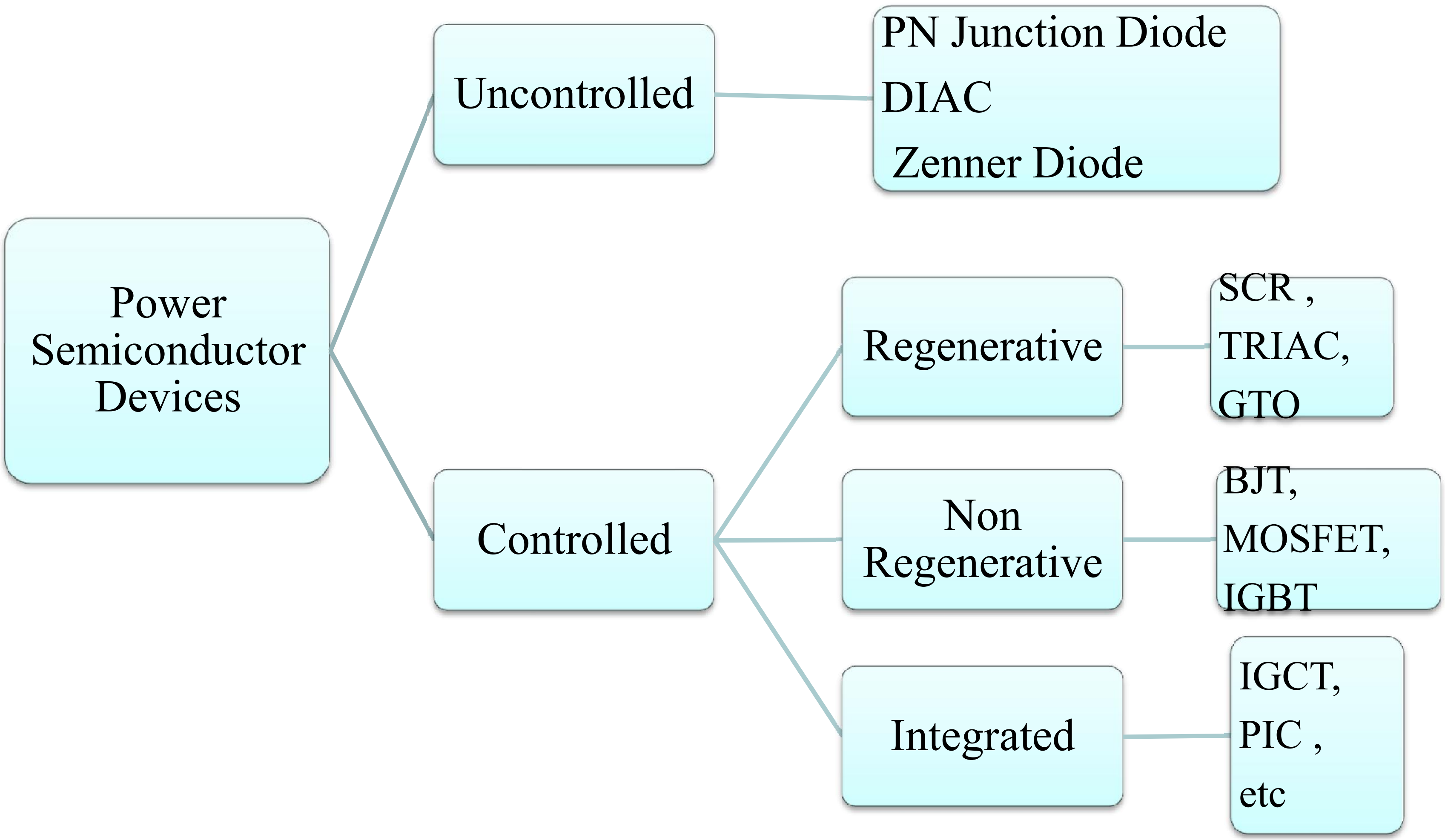
Topics to be covered:

- ❖ 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

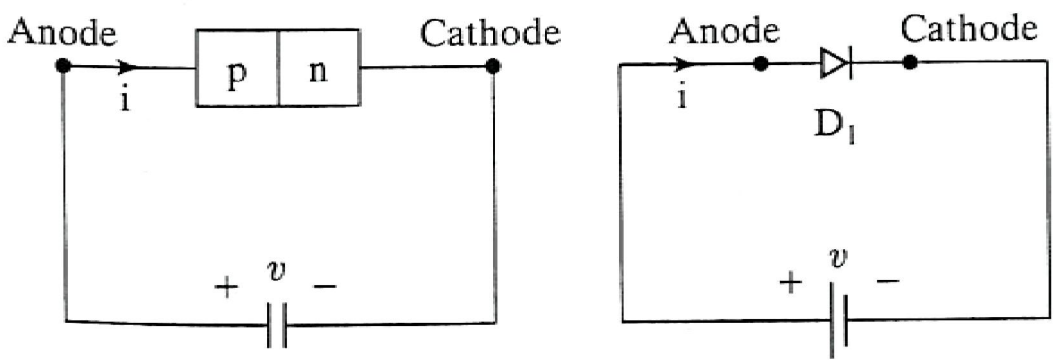
POWER DEVICES

- Voltage, current and power ratings are much higher than the conventional devises.
- Switching speed is also much higher than the conventional devices.

CLASSIFICATION



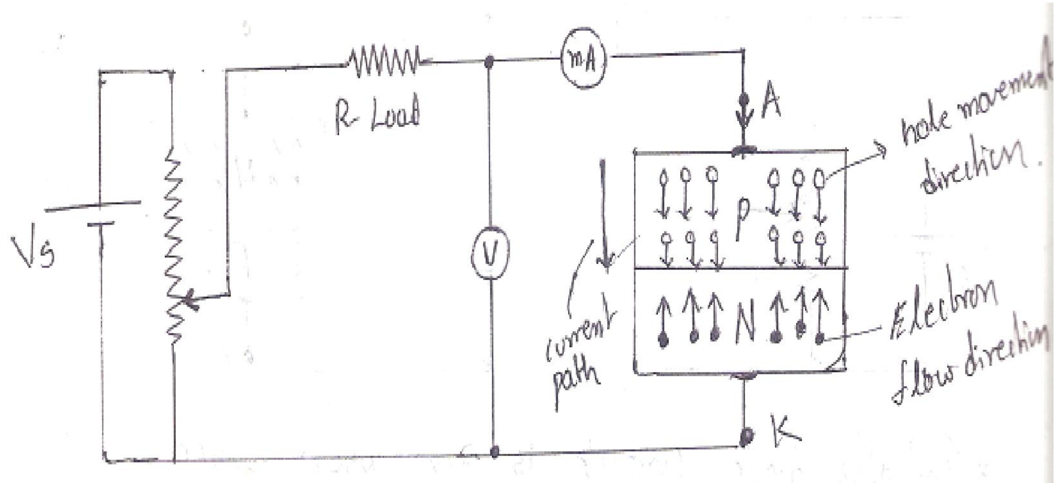
PN-JUNCTION DIODE

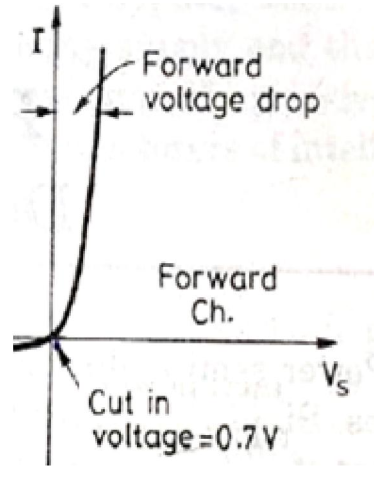


❖Forward Bias :- Diode Anode terminal is connected to more positive than the cathode terminal.

❖Reverse Bias :- Diode cathode terminal is connected to more positive than the anode terminal.

PN-JUNCTION DIODE V-I CHARACTERISTICS(FORWARD BIASED)





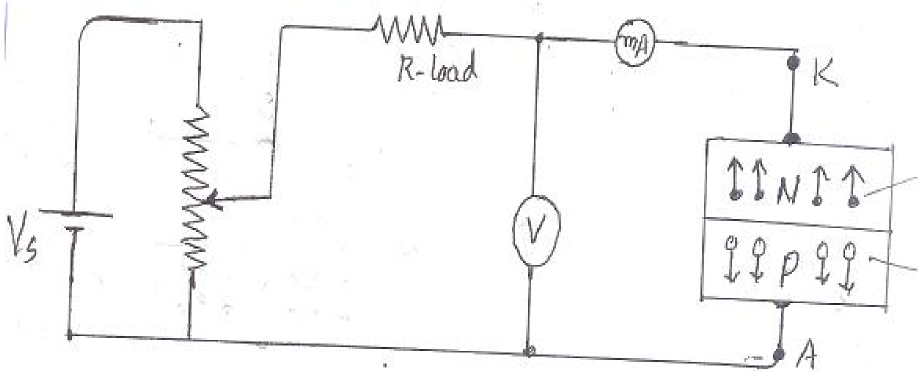
➢When source voltage greater than cut in or threshold or turn on voltage diode current rises rapidly .

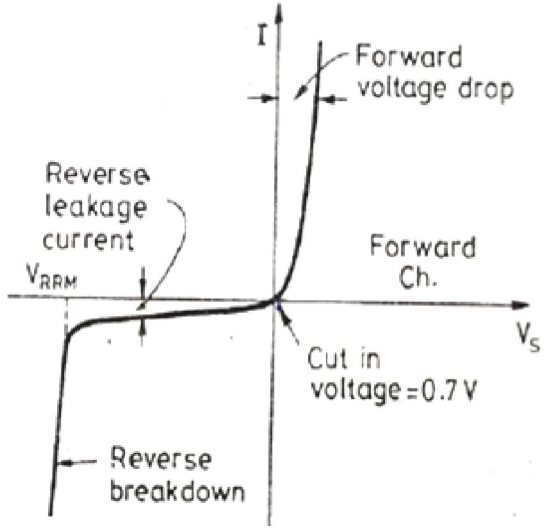
➢Diode offers less impedance in forward bias

➢Diode act as closed switch during forward bias.

➢Forward voltage drop across diode is typically 0.8v to 1v

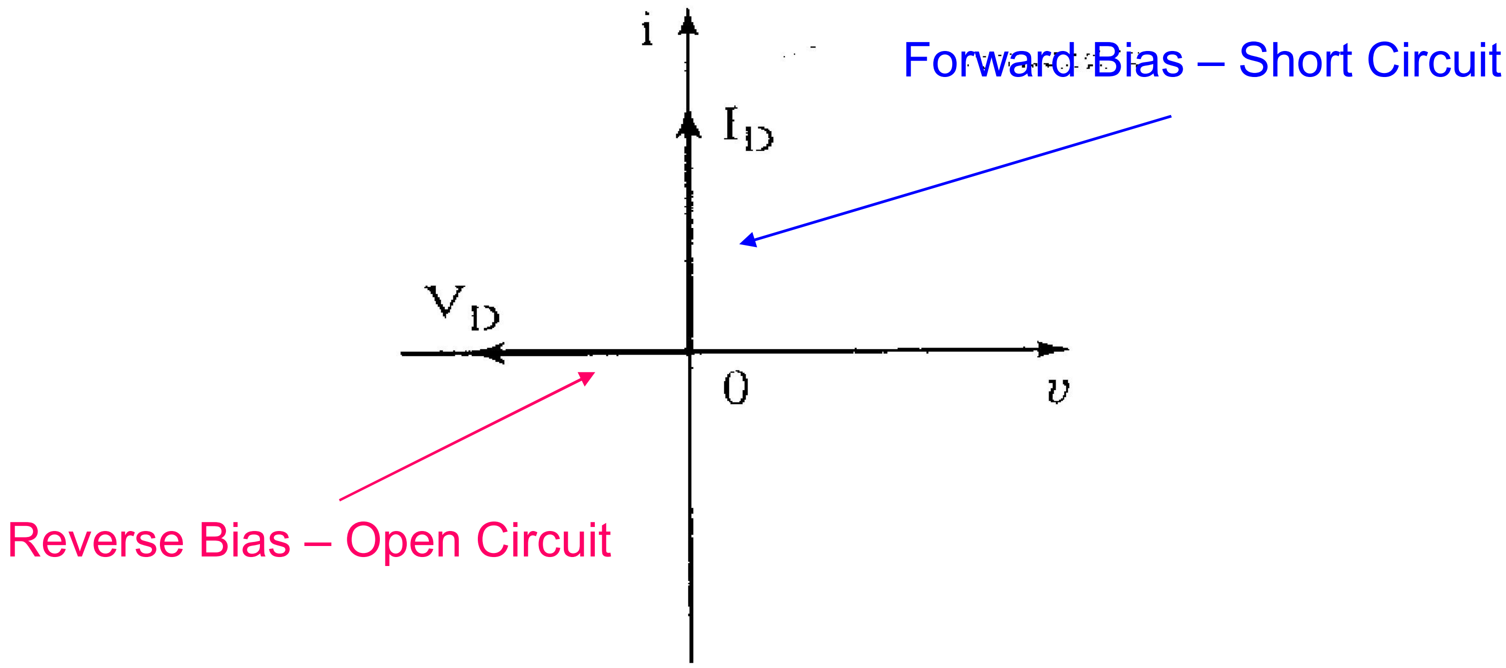
PN-JUNCTION DIODE V-I CHARACTERISTICS(REVERSE BIASED)





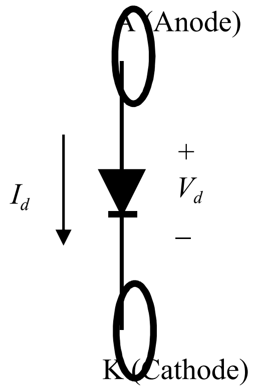
- By increasing reverse voltage across diode small amount of leakage current will flow from cathode to anode terminal.
- By keep on increasing reverse voltage at particular instant diode junction will break down and starts conduction and diode get damage.
- Diode offers high impedance in reverse bias ($V<V_{RRM}$)
- Diode act as open switch during reverse bias
- Diodes are available up to 3000A and 5KV

IDEAL DIODE V-I CHARACTERISTIC

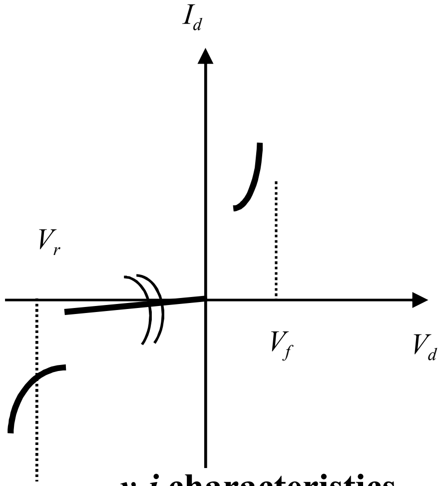


(b) Ideal

Power Diode



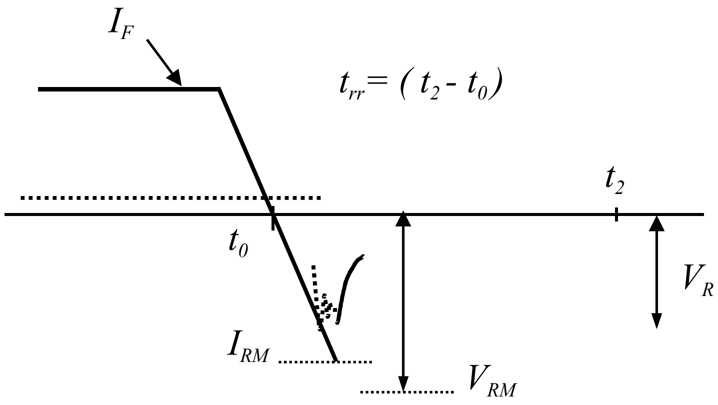
Diode: Symbol



***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

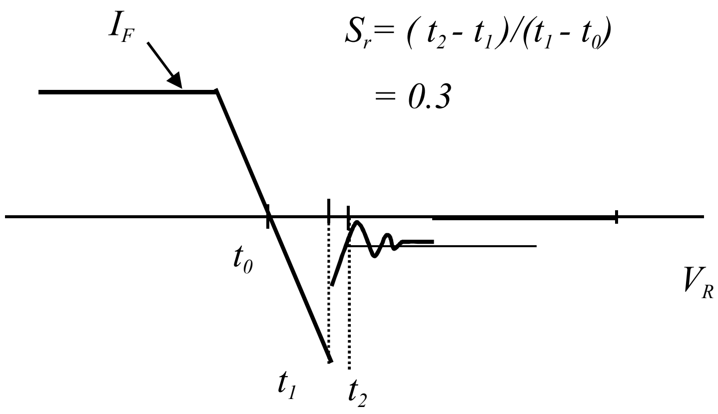
Reverse Recovery



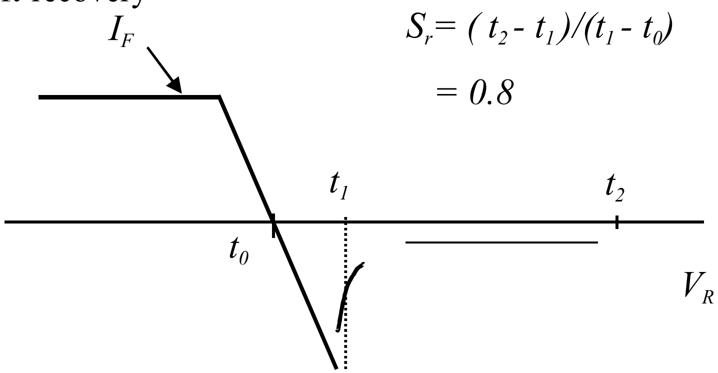
- When a diode is switched quickly from forward to reverse bias, it continues to conduct due to the *minority carriers* which remains in the p-n junction.
- The minority carriers require finite time, i.e, t_{rr} (reverse recovery time) to recombine with opposite charge and neutralise.
- Effects of reverse 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

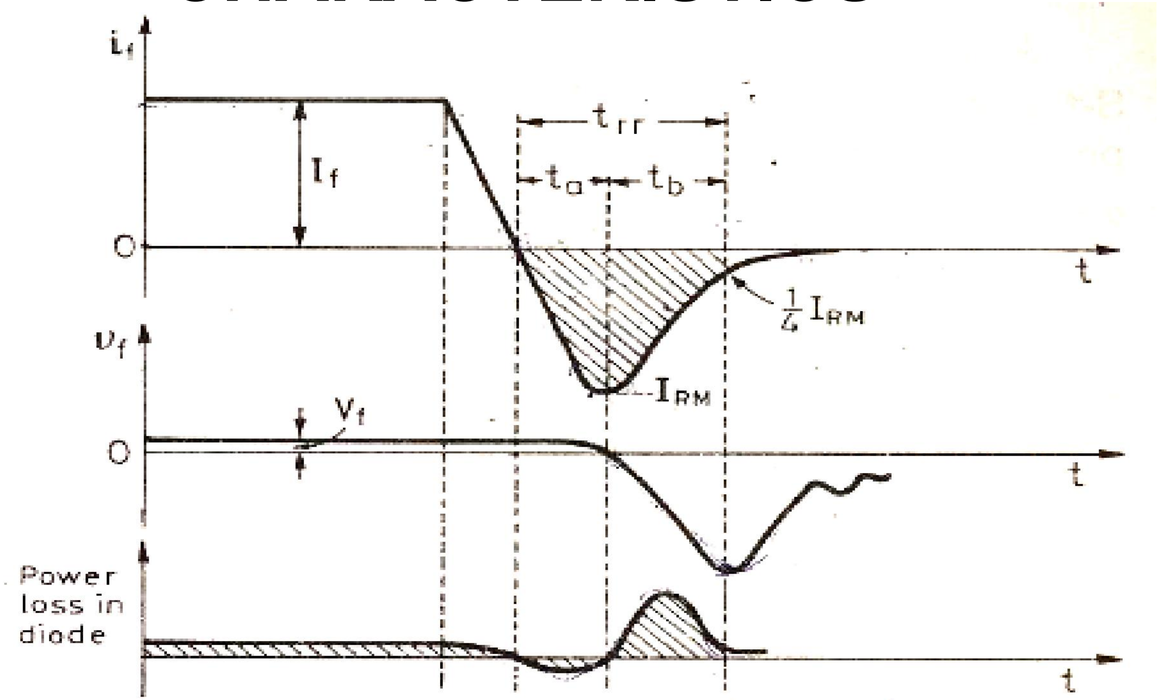
- **Fast recovery**
  - Very low t_{rr} (<1us).
  - Power levels at several hundred volts and several hundred amps
  - Normally used in high frequency circuits

- **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.

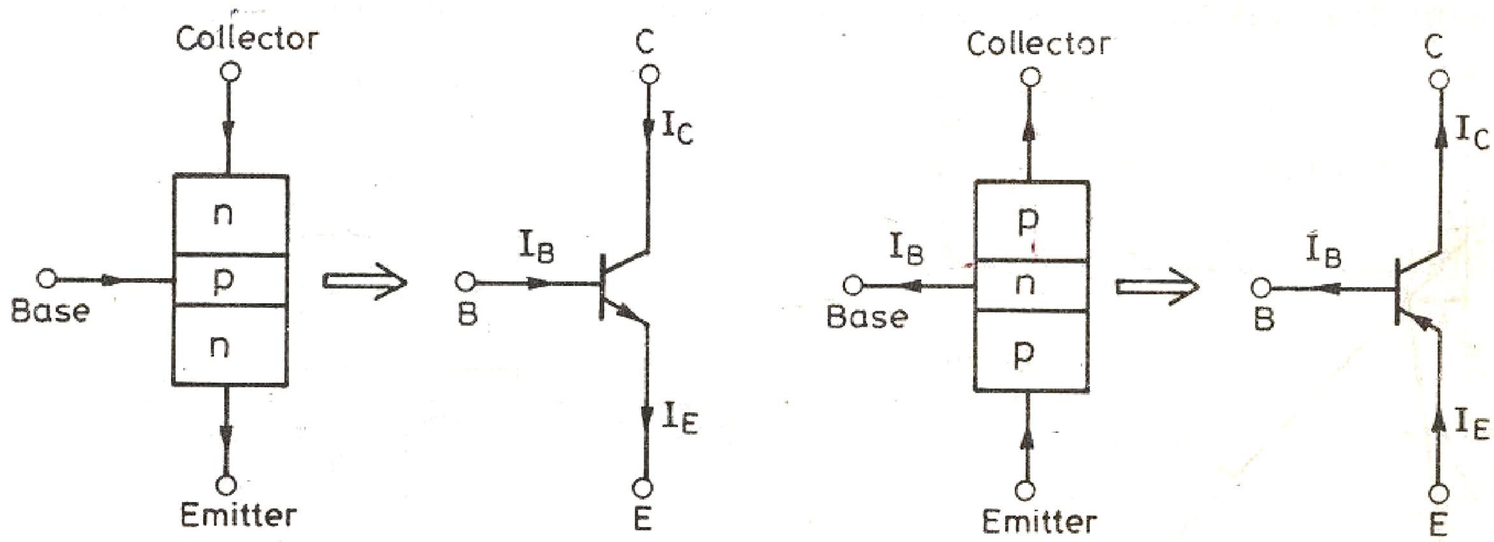
Fast Recovery Diode:-

- ✓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



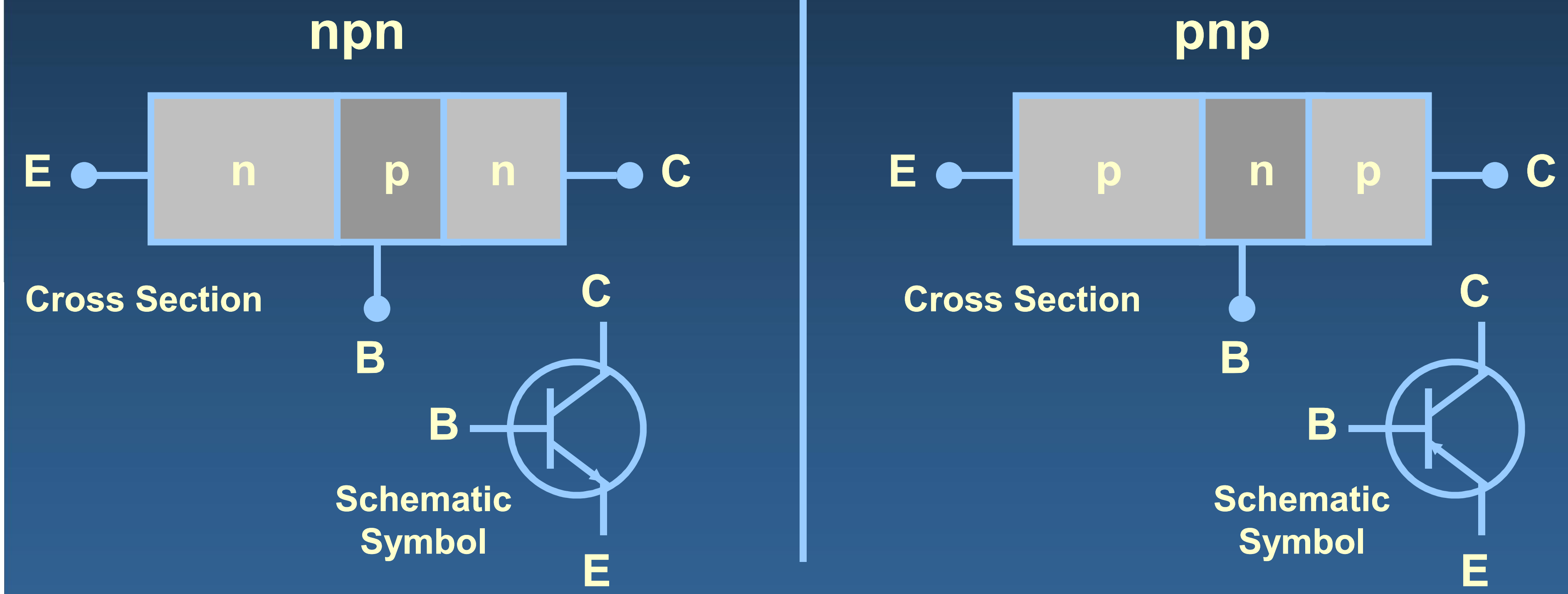
Collector
n
p
n
Base
Emitter
C
I_C
I_B
B
I_E
E
Collector
p
n
p
I_B
Base
Emitter
C
I_C
I_B
B
I_E
E

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

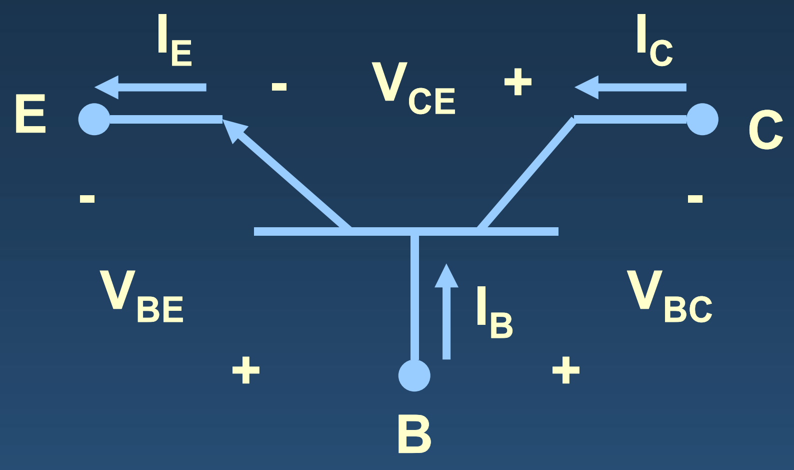
The Two Types of BJT Transistors:

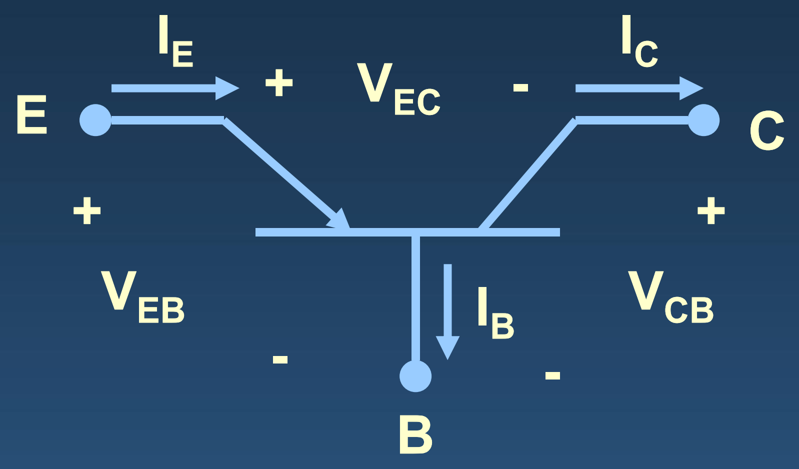


- Collector doping is usually ~ 10^6
- Base doping is slightly higher ~ $10^7 – 10^8$
- Emitter doping is much higher ~ 10^{15}

Kristin Ackerson, Virginia Tech EE
Spring 2002

BJT Relationships - Equations





npn

$$I_E = I_B + I_C$$

$$V_{CE} = -V_{BC} + V_{BE}$$

pnp

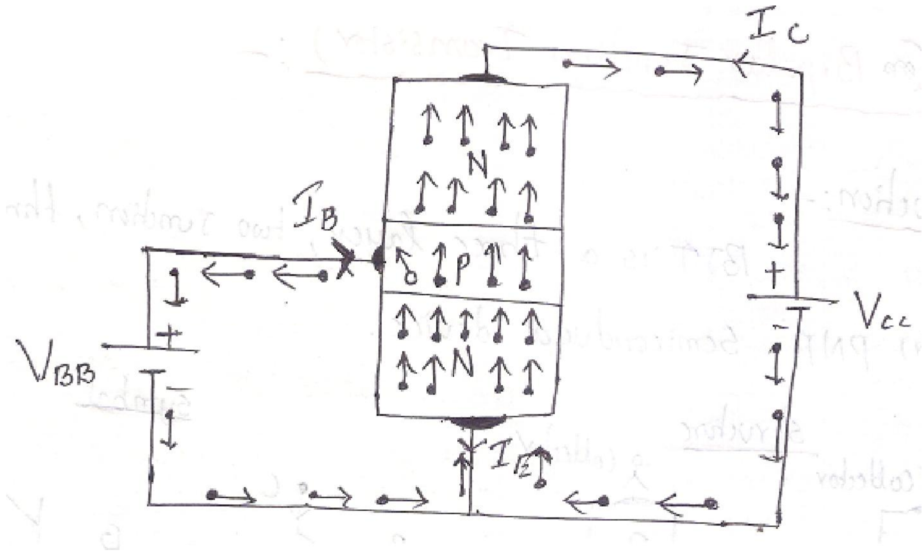
$$I_E = I_B + I_C$$

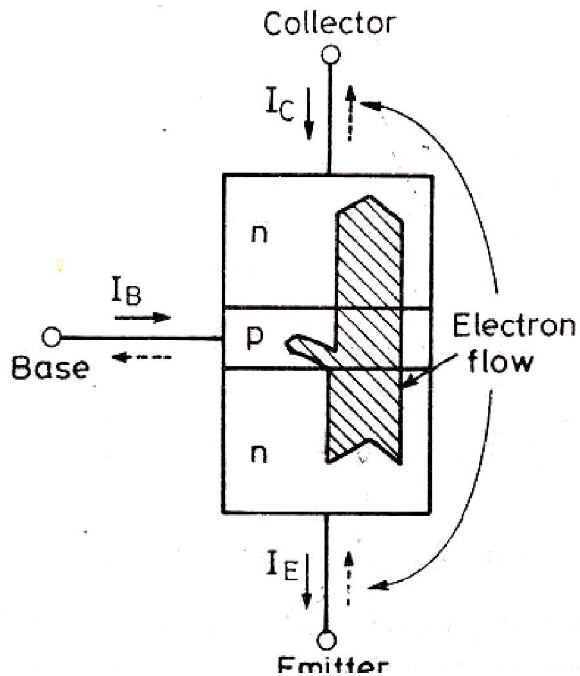
$$V_{EC} = V_{EB} - V_{CB}$$

Note: The equations seen above are for the transistor, not the circuit.

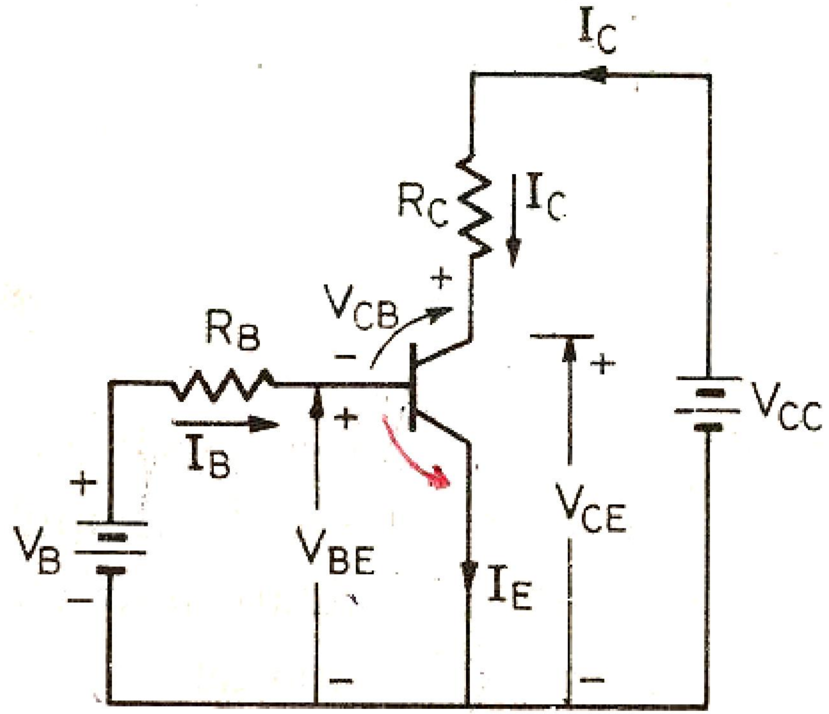
Kristin Ackerson, Virginia Tech EE
Spring 2002

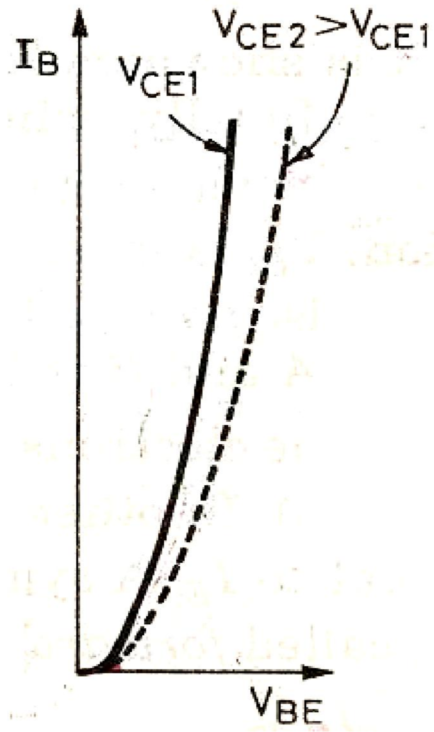
WORKING OPERATION OF BJT



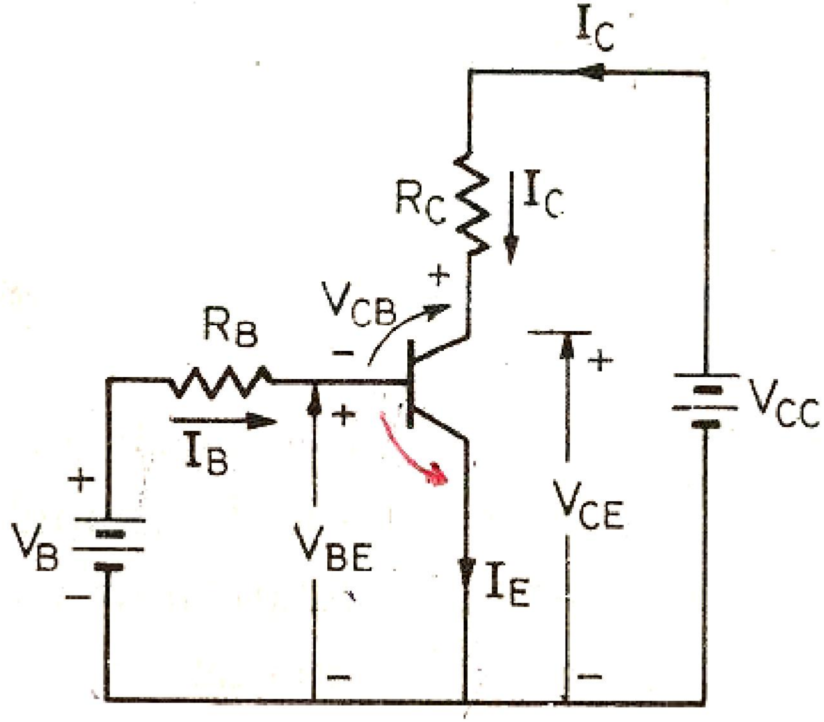


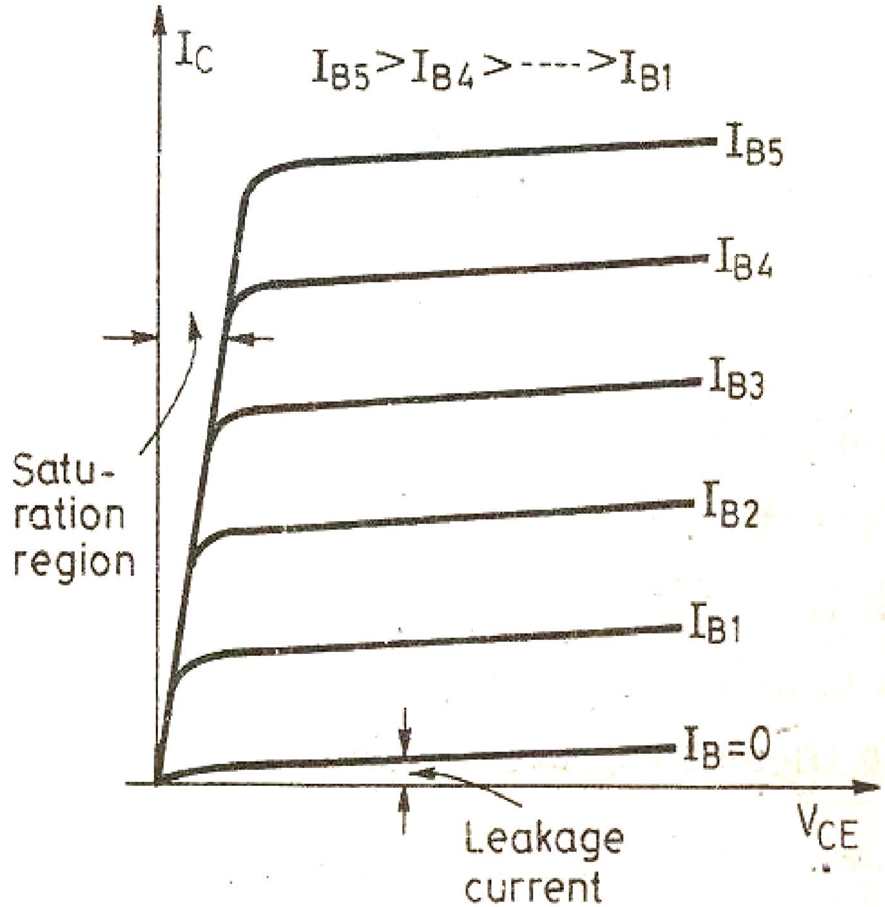
INPUT CHARACTERISTICS



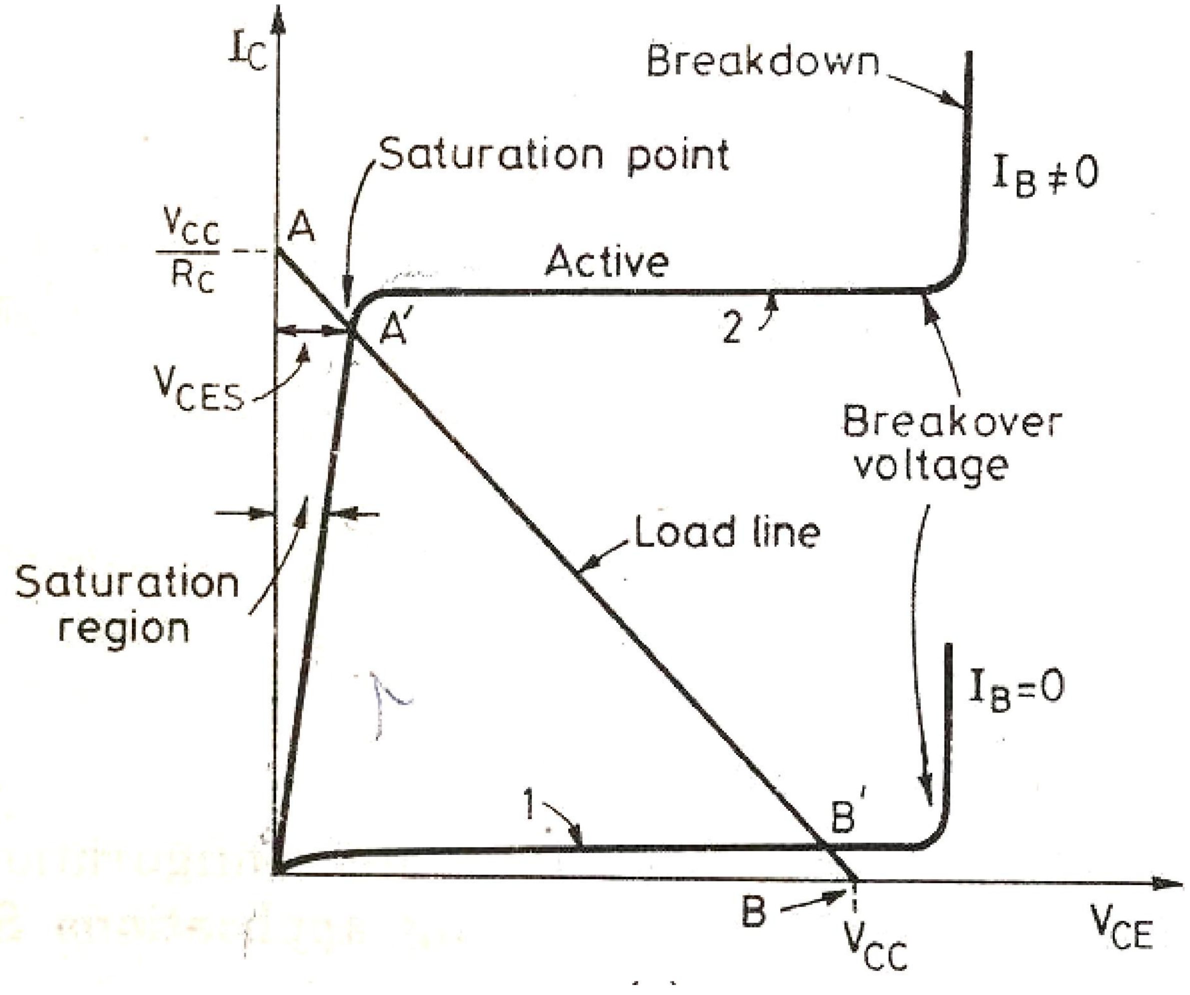


OUTPUT CHRACTRESTICS





TRANSISTOR ACT AS SWITCH



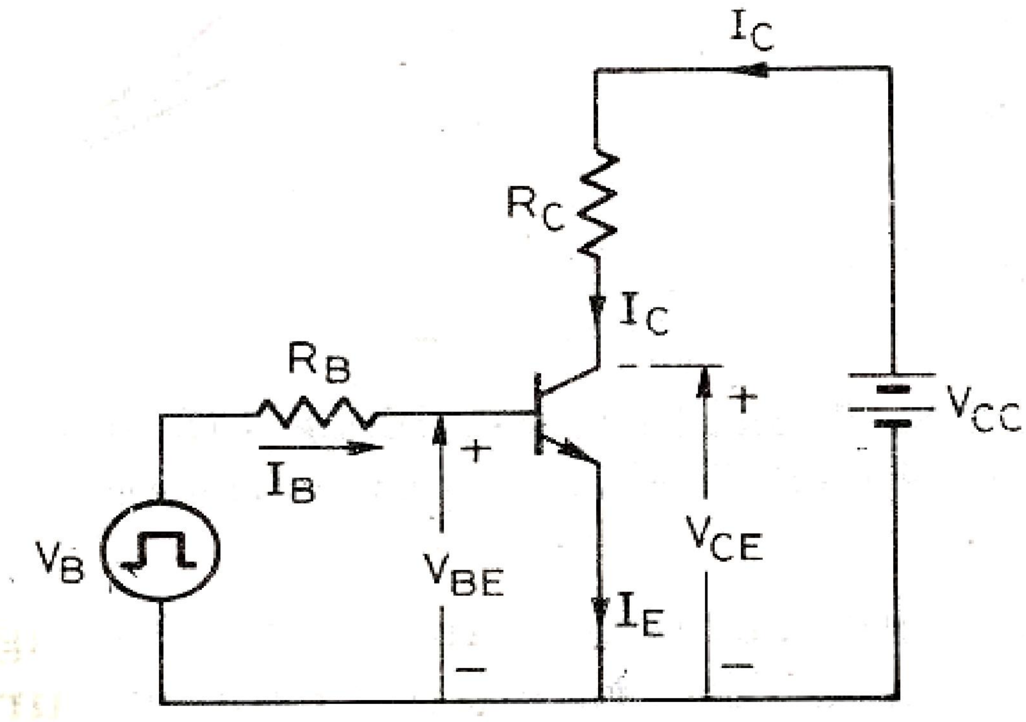
$$I_{CS} = \frac{V_{CC} - V_{CES}}{R_C}$$

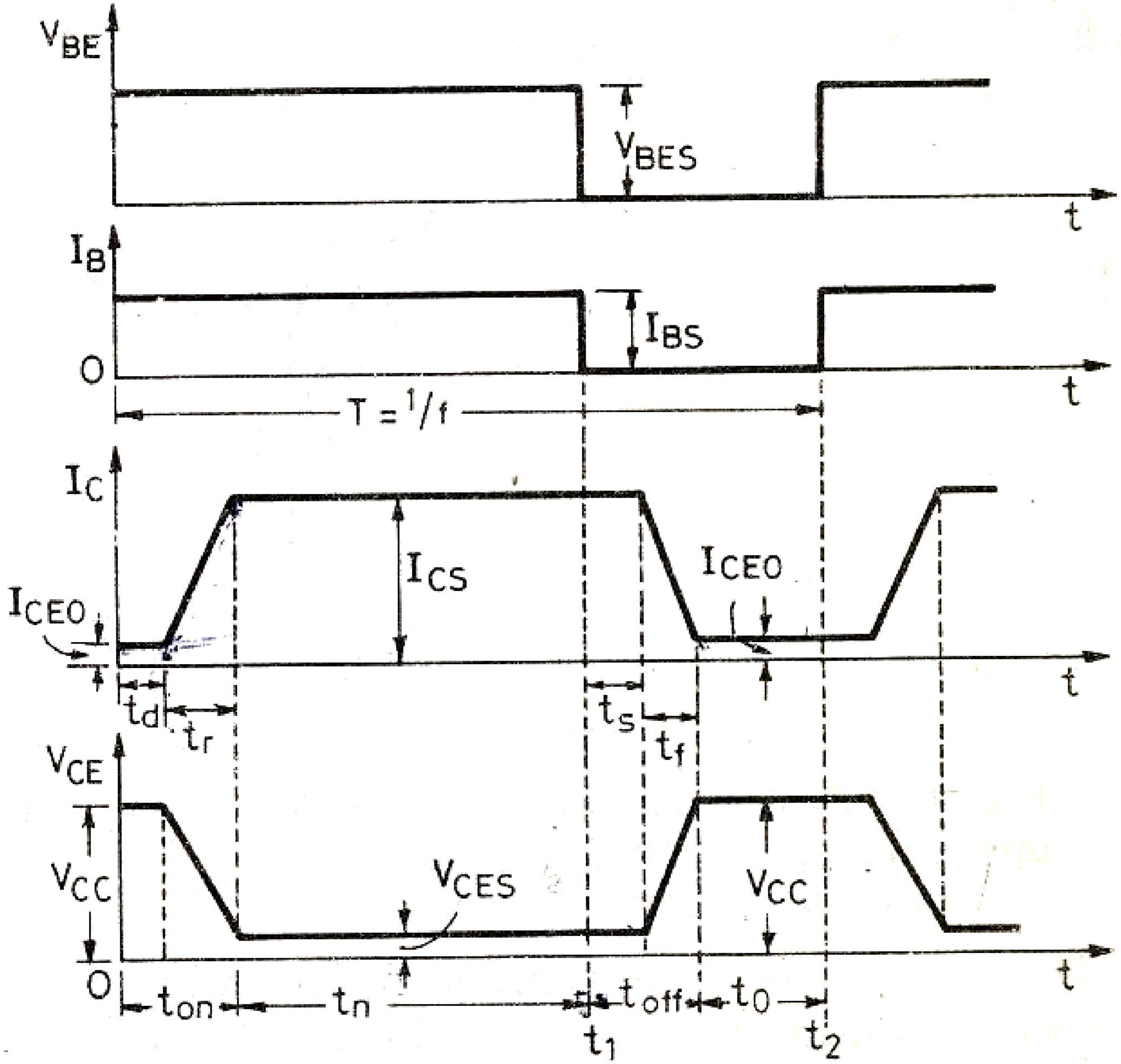
$$I_{BS} = \frac{I_{CS}}{\beta}$$

- 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





VBE
VBES
t
IB
IBS
O
t
T = 1/f
IC
ICS
ICEO
ICEO
t
td
tr
ts
tf
VCE
VCC
VCES
VCC
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tn
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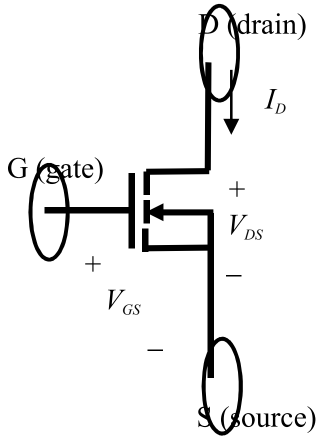
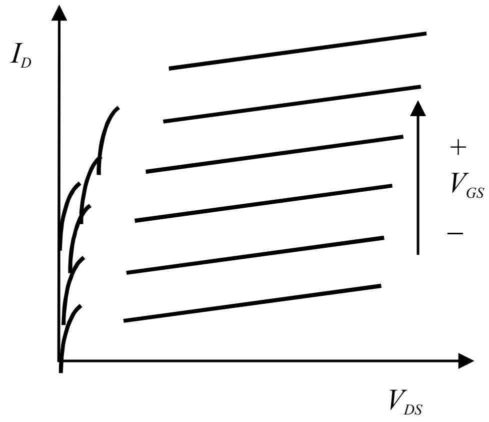
t0
t1
t2

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.

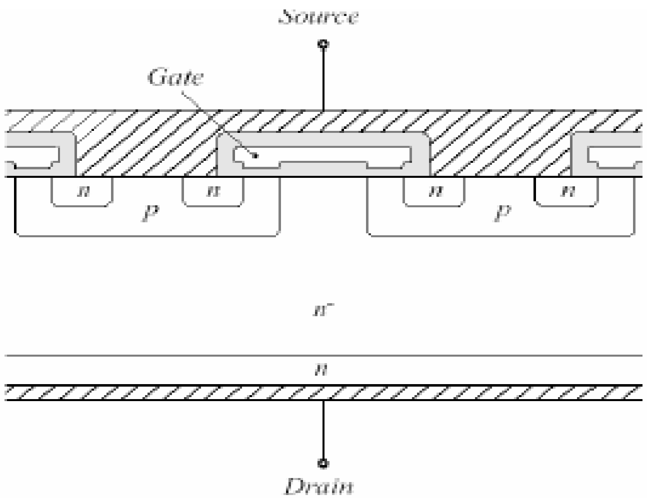
- Gate drive circuit is simple

1.4.3 Power metal- oxide- semiconductor field effect transistor—Power MOSFET

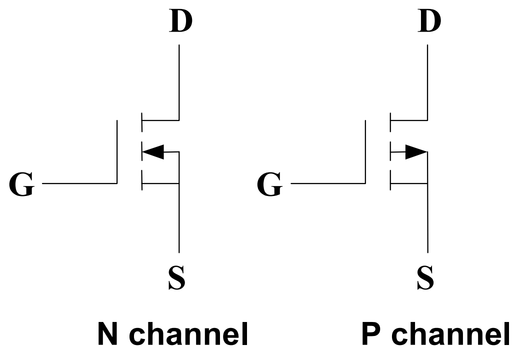
A classification

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



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

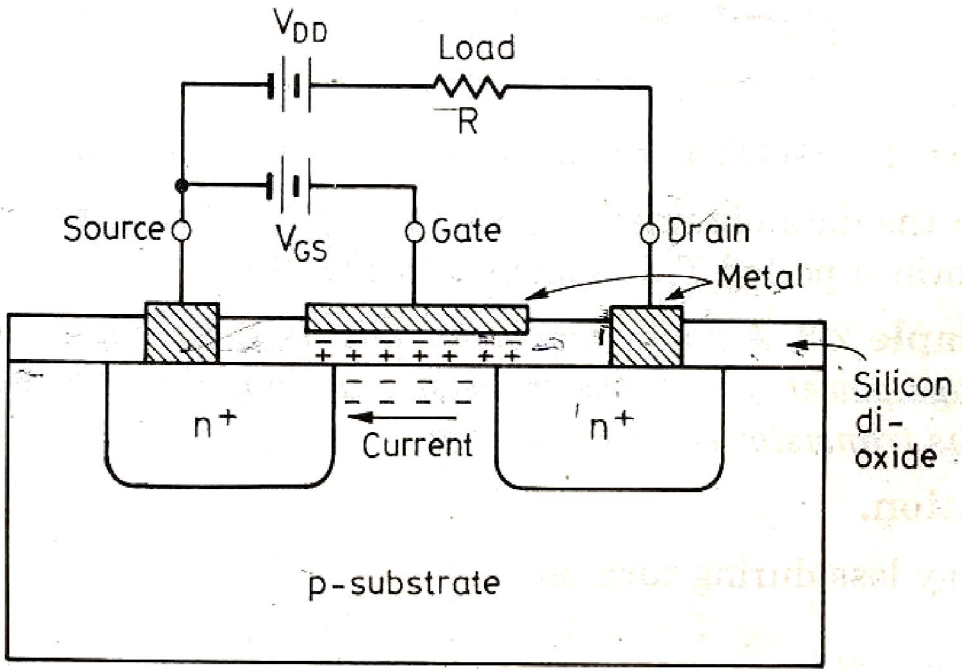
- The voltage applied to the GATE terminal determines whether current can flow between the SOURCE & DRAIN terminals.

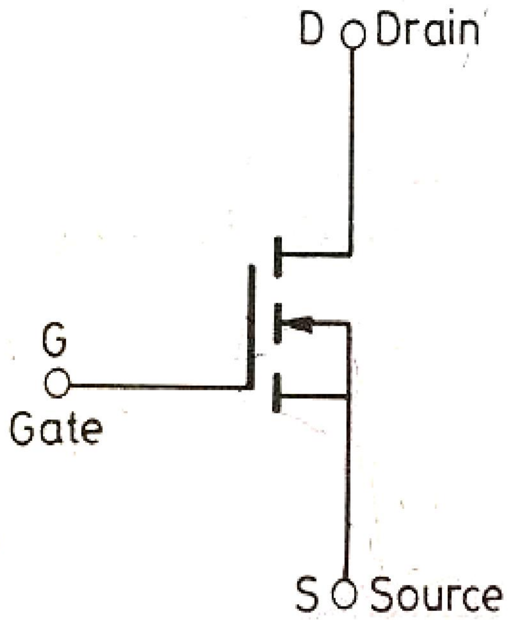
- For an n-channel MOSFET, the SOURCE is biased at a lower potential (often 0 V) than the DRAIN

(Electrons flow from SOURCE to DRAIN when VG > VT)

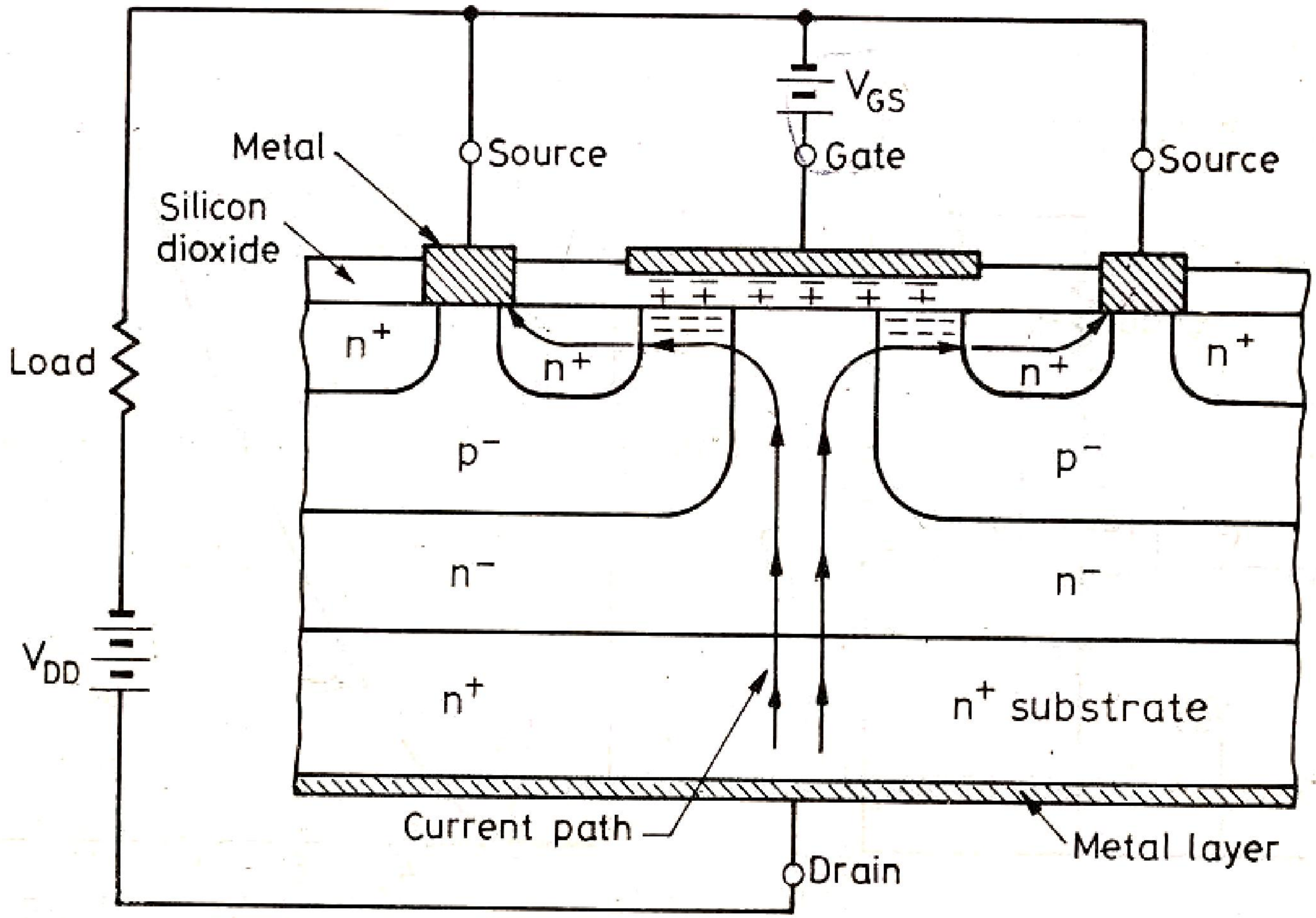
- For a p-channel MOSFET, the SOURCE is biased at a higher potential (often the supply voltage VDD) than the DRAIN (Holes flow from SOURCE to DRAIN when VG < VT)

MOSFET(LOW POWER)

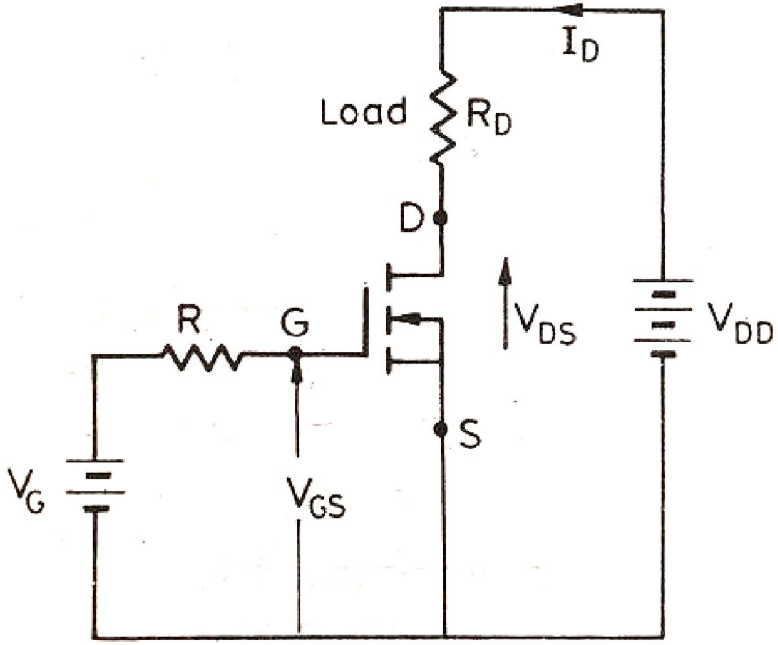


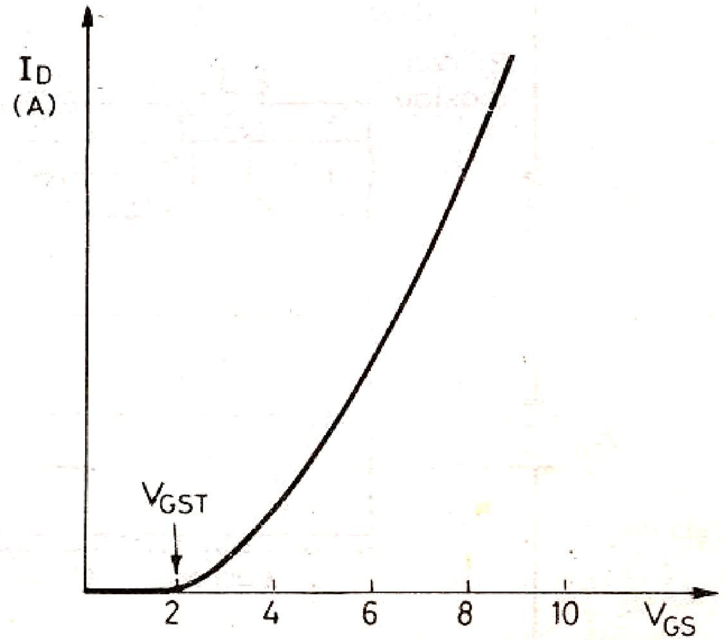


MOSFET(High Power)

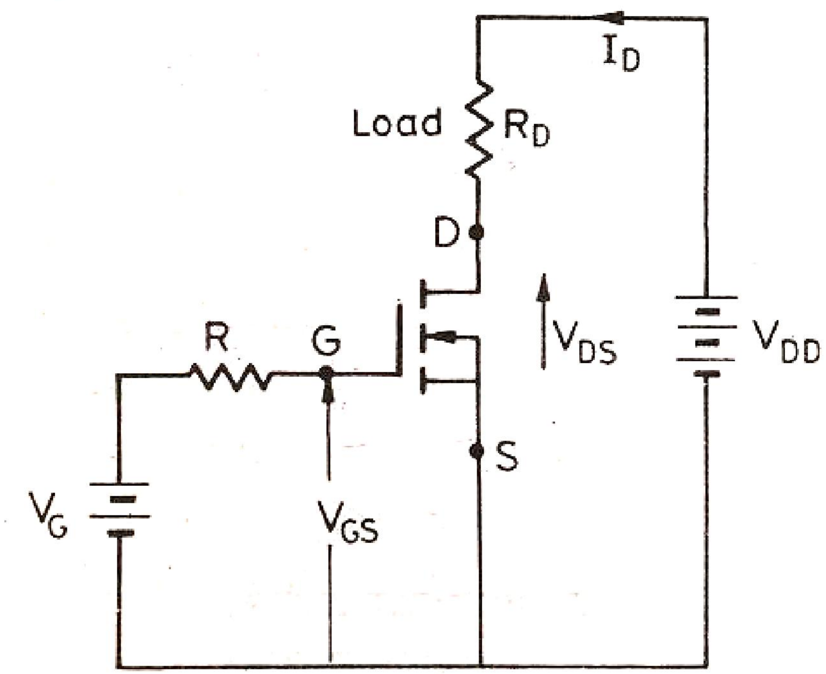


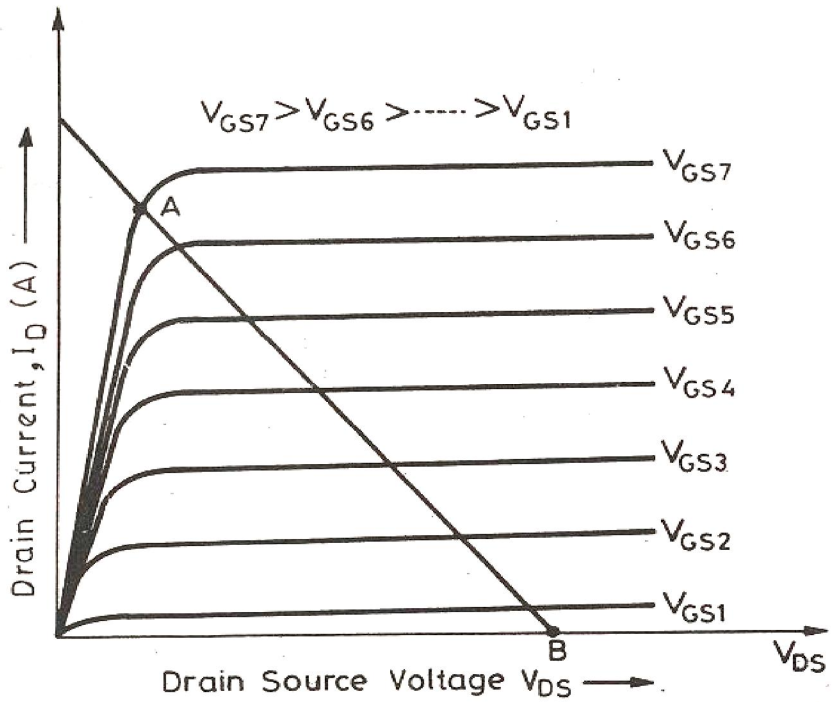
TRANSFER CHARACTERISTICS



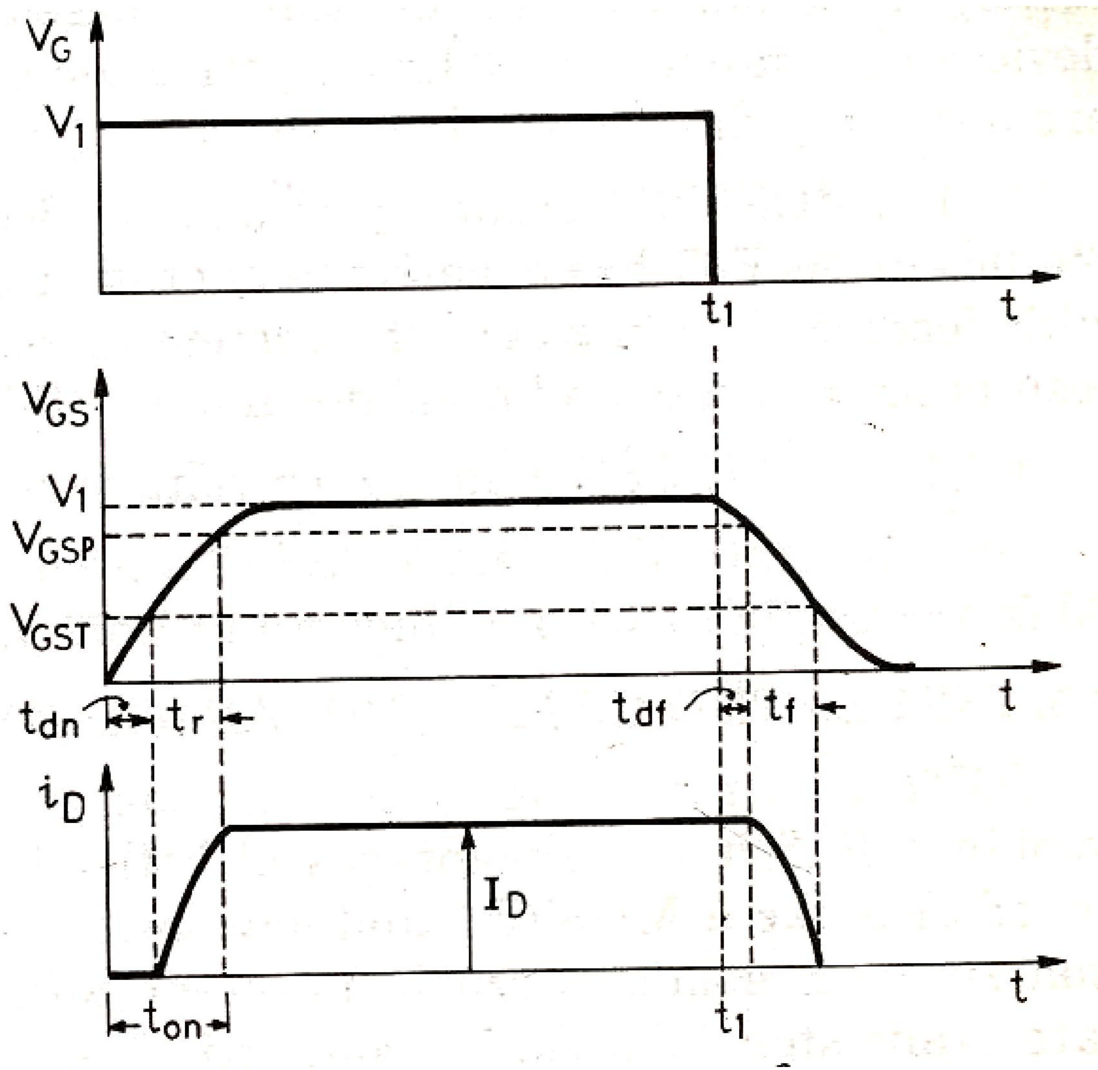


OUTPUT CHARACTERISTICS

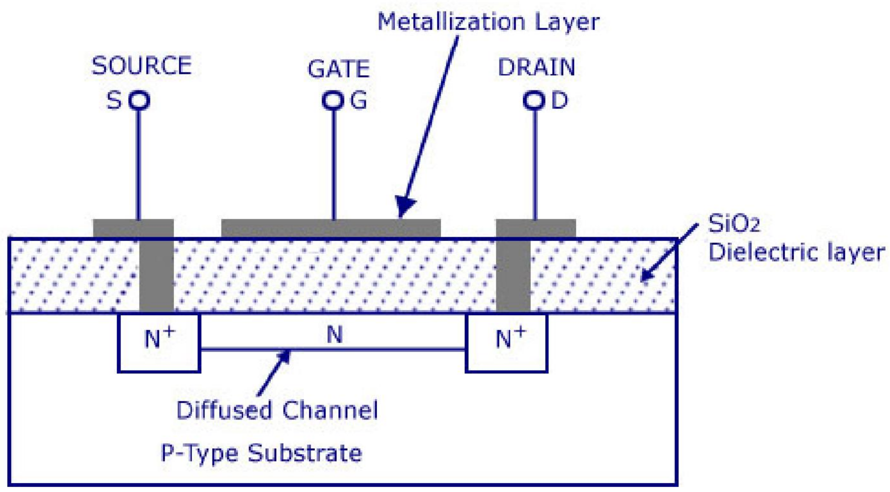




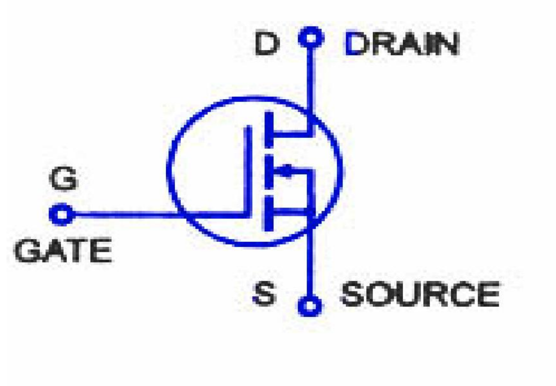
SWITCHING CHARACTERISTICS



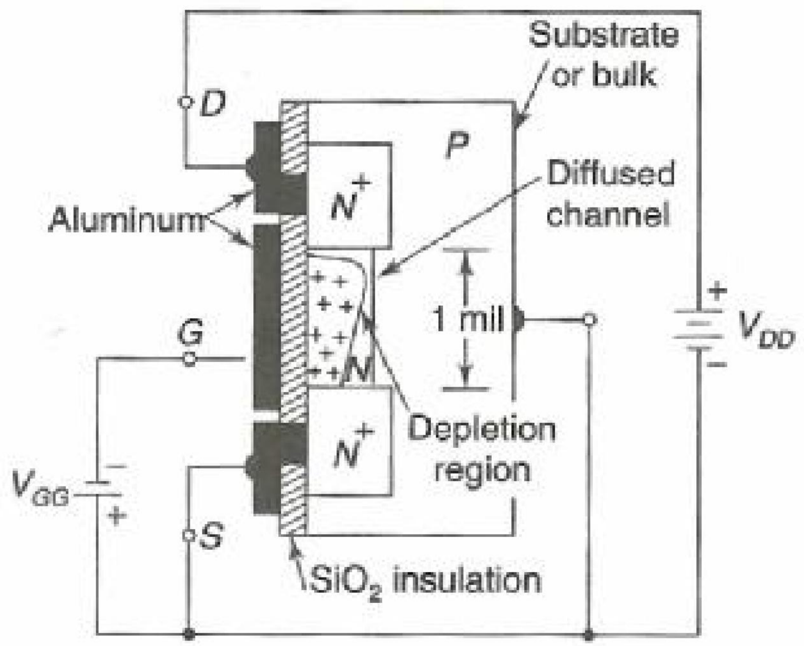
DE MOSFET

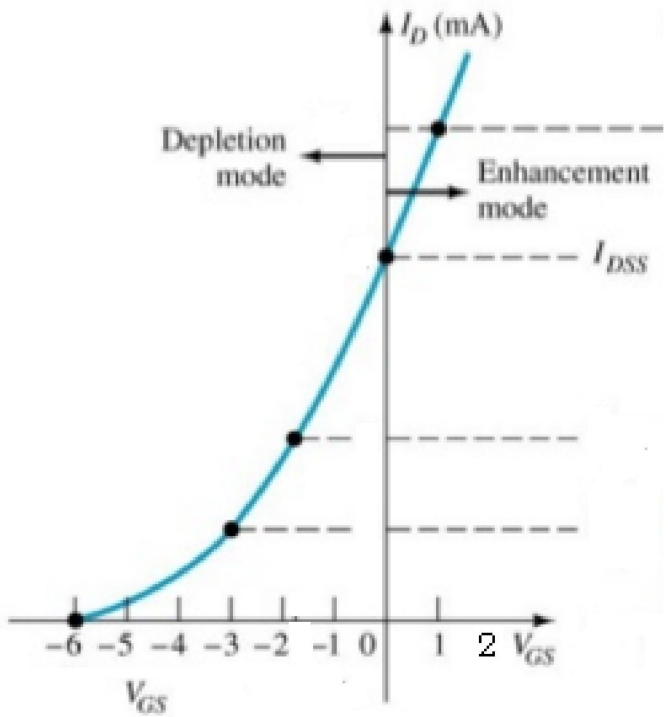


N-Channel DE-MOSFET Structure

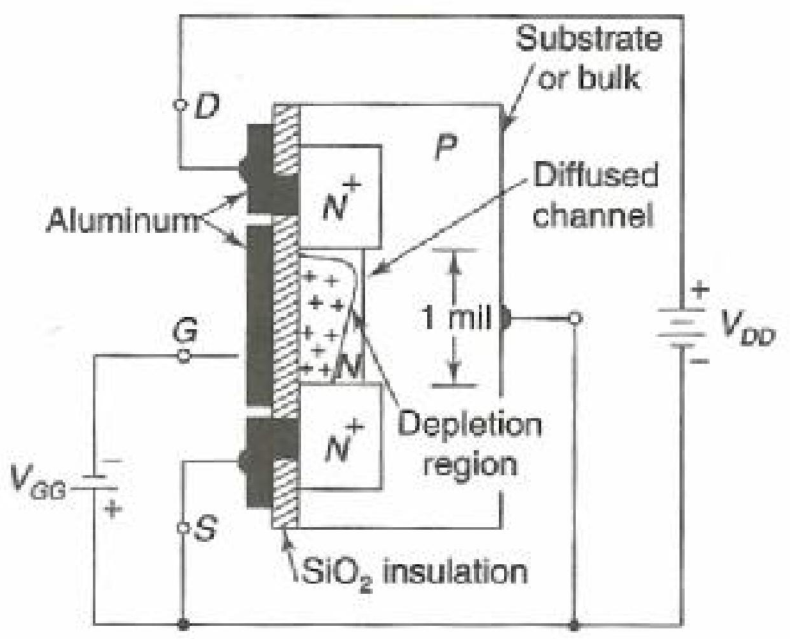


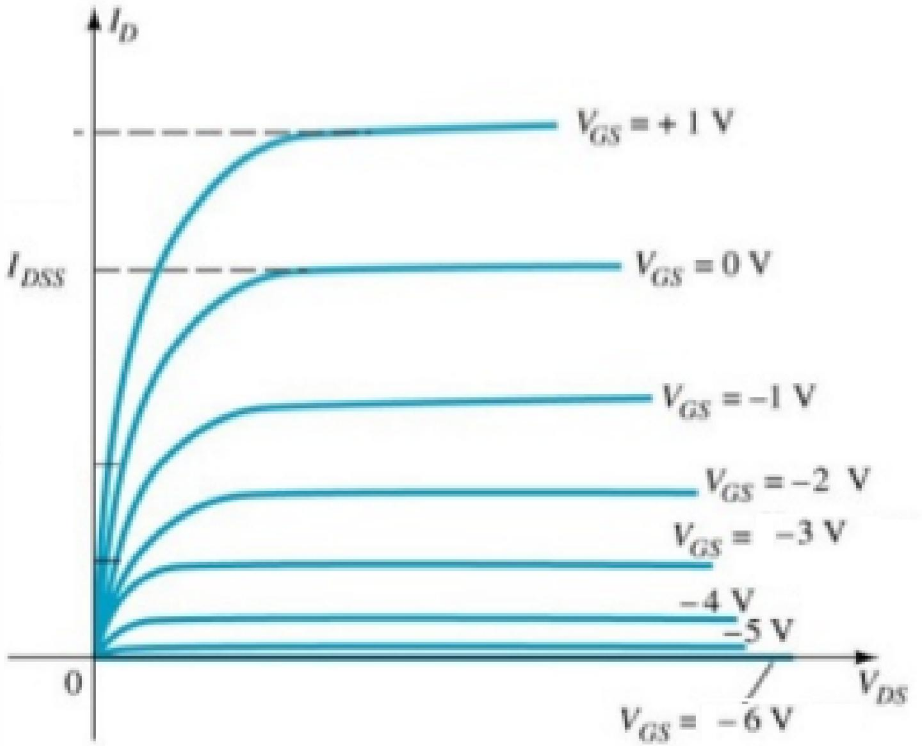
TRANSFER CHARACTERISTICS





OUTPUT CHARACTERISTICS





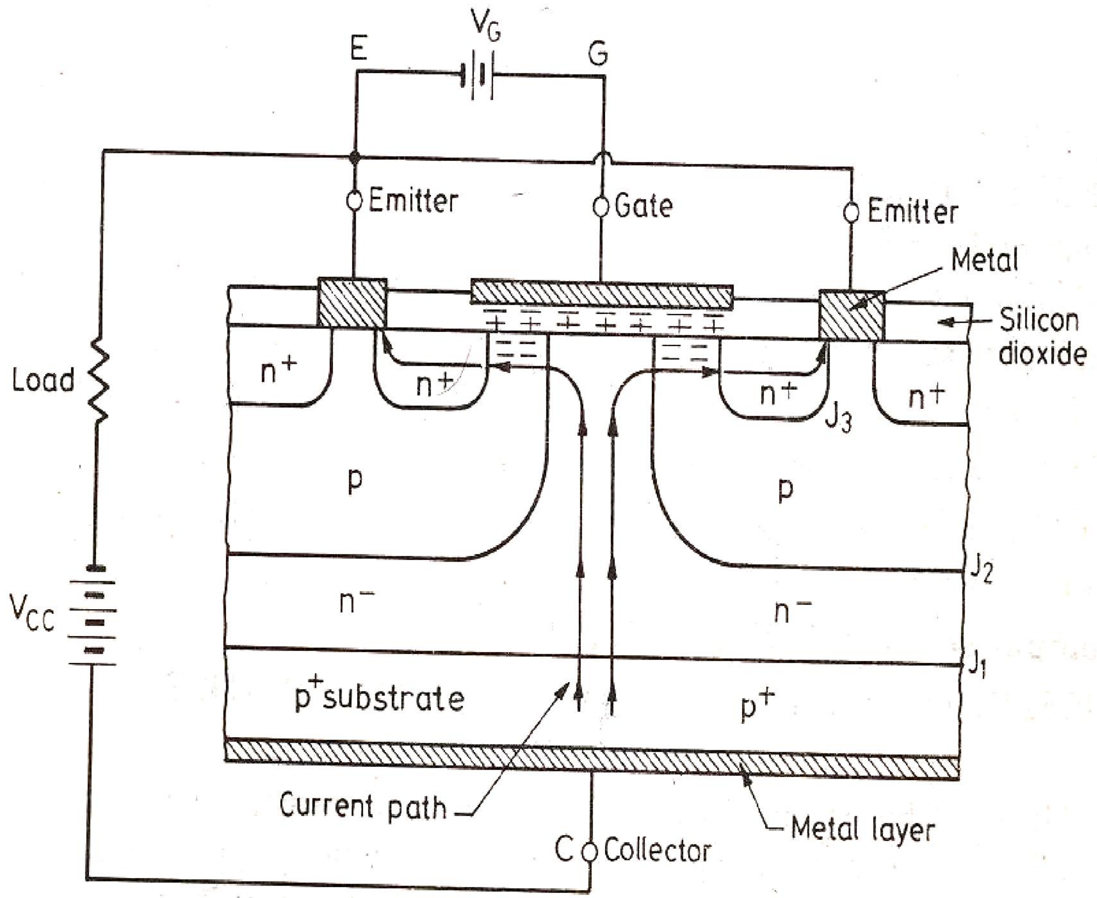
COMPARISON OF BJT AND MOSFET

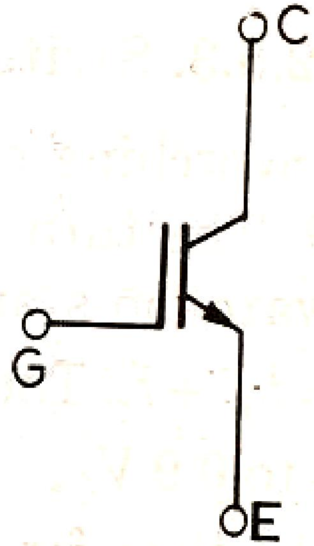
S.No	BJT	MOSFET
1	Bipolar Device	Unipolar Device
2	Low input impedance(kilo ohm)	High input impedance (mega ohm)
3	High switching losses but lower conduction losses	Lower switching losses but high on-resistance and conduction losses
4	Current controlled device	Voltage controlled device
5	Negative temperature 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



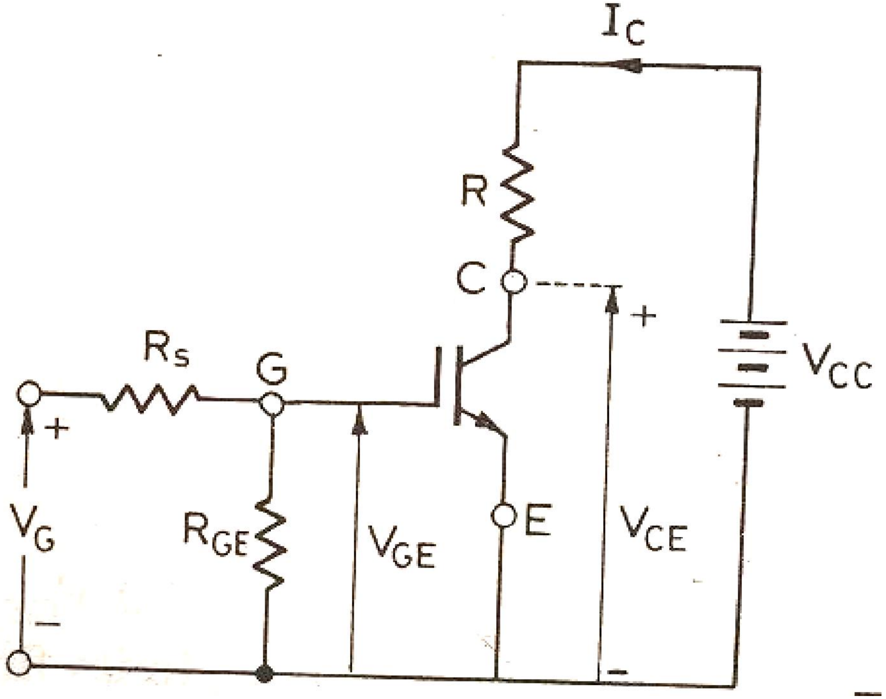


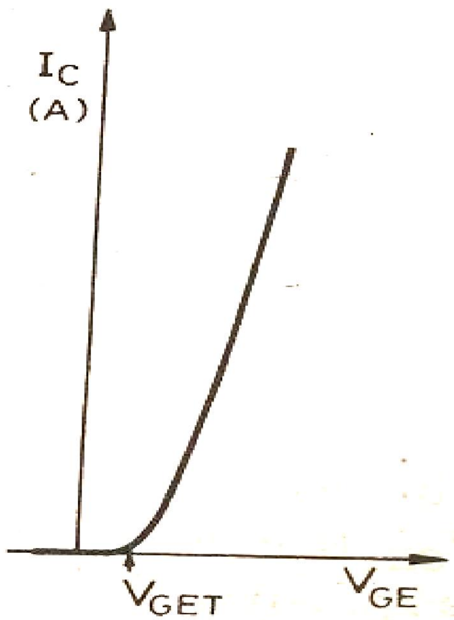
Insulated Gate Bipolar Transistor (IGBT)

- 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).

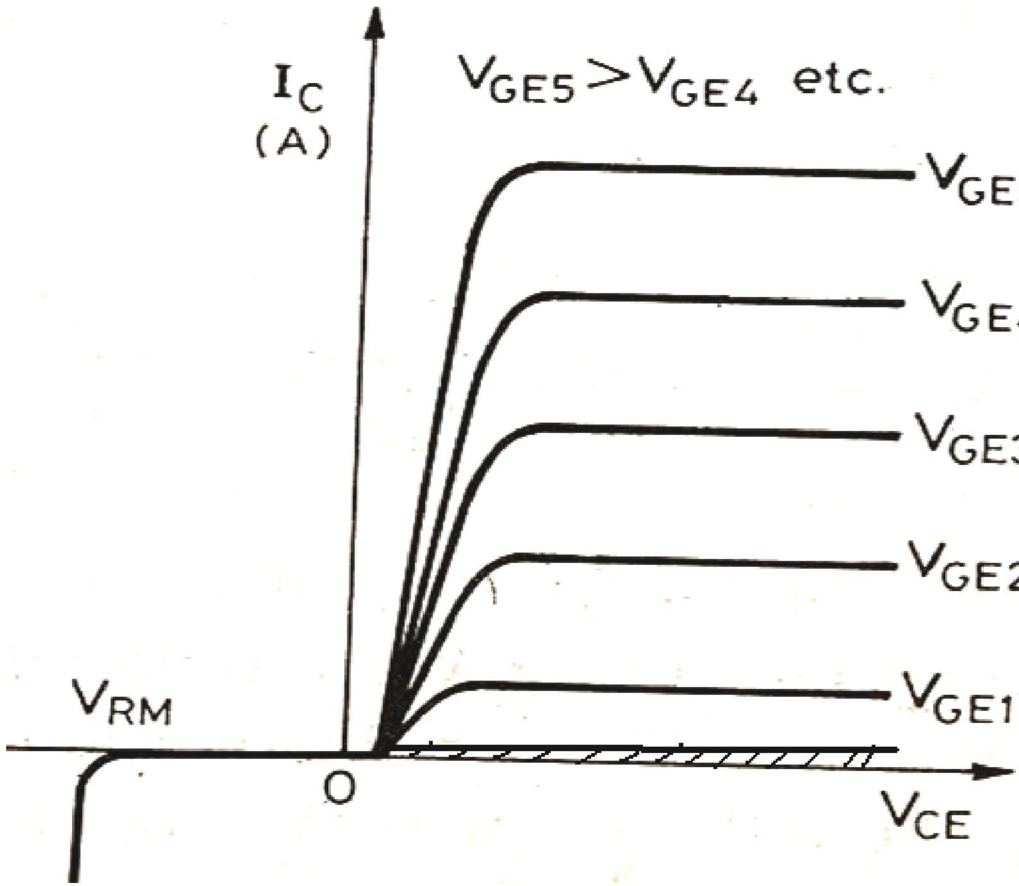
- **Ratings:** Voltage: V_{CE}<3.3kV, Current,: I_C<1.2kA currently available. Latest: HVIGBT 4.5kV/1.2kA.
- Switching frequency up to 100KHz. Typical applications: 20-50KHz.

TRANSFER CHARACTERISTICS

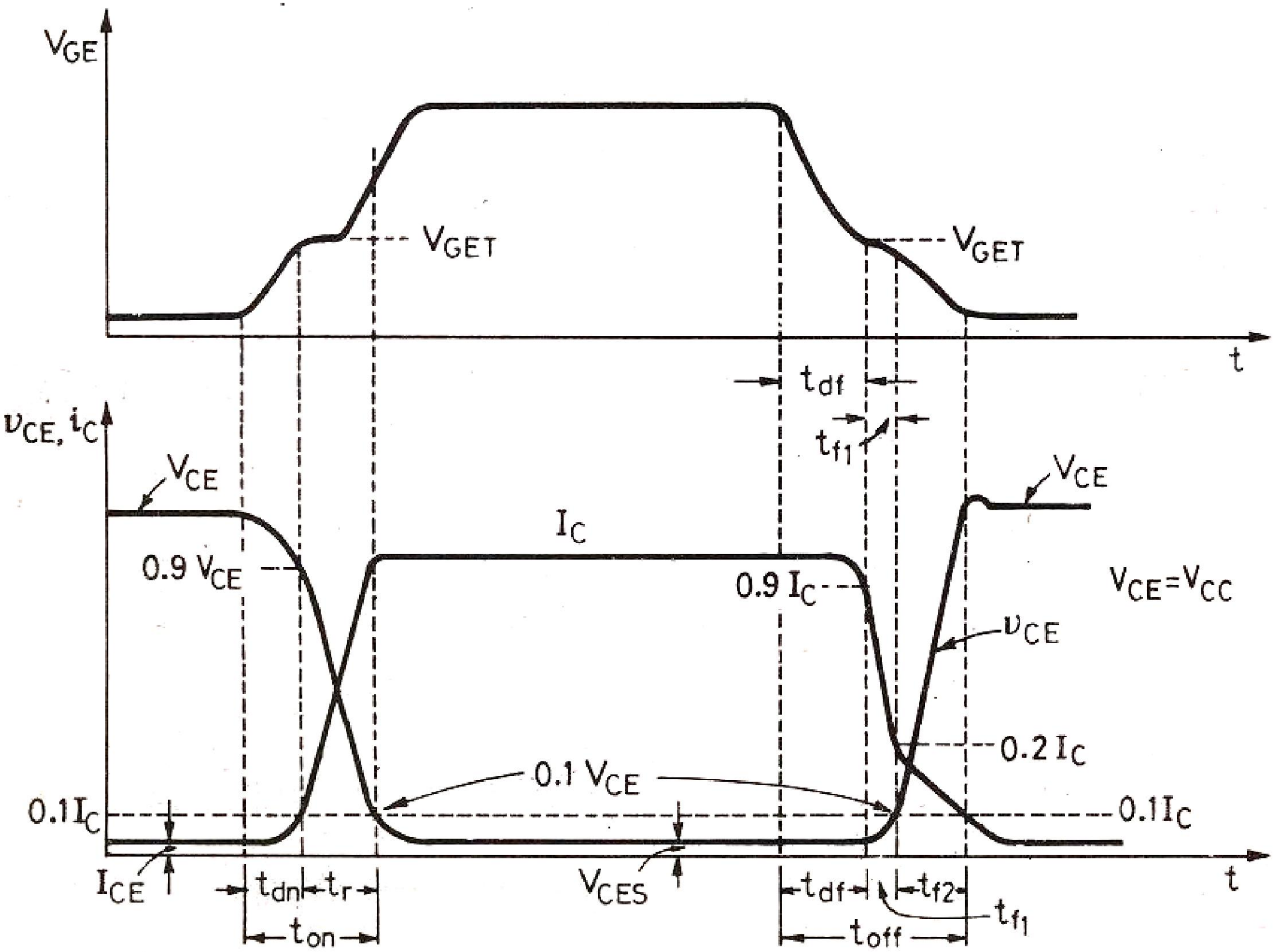




OUTPUT CHARACTERISTICS



DYNAMIC CHARACTERISTICS



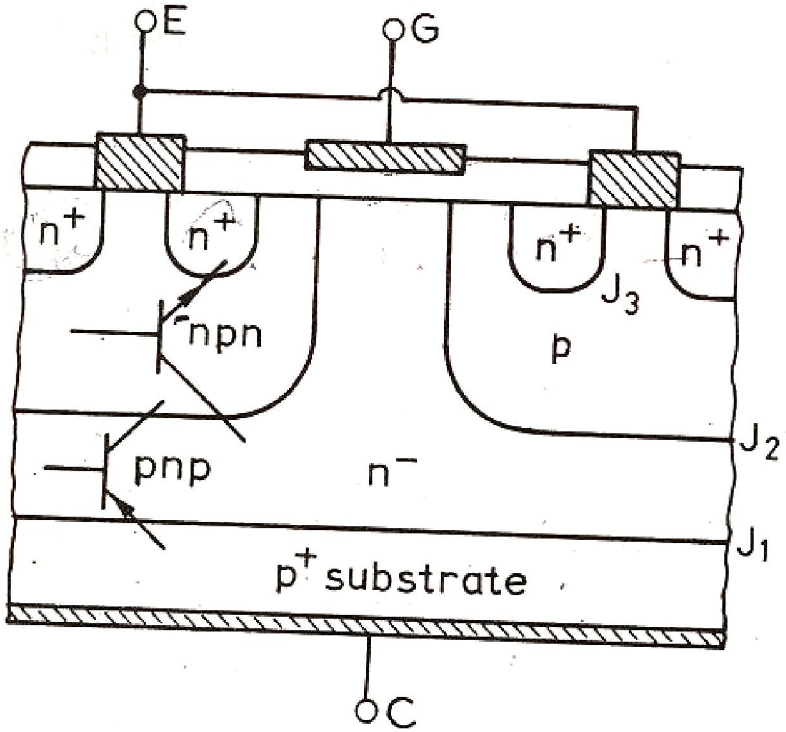
COMPARISON OF IGBT WITH MOSFET

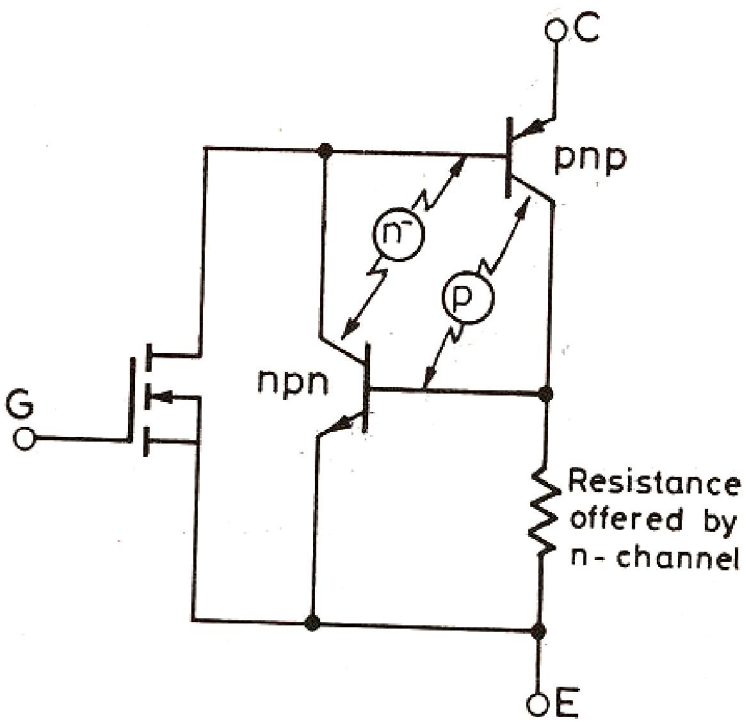
S.No	MOSFET	IGBT
1.	Three terminals are Gate, source and drain.	Three terminals are Gate, emitter and collecto
2.	High input impedance	High input impedance
3.	Voltage controlled device	Voltage controlled device
4.	Ratings available up to 500V,140A	Ratings available up to 1200V,500A
5.	Operating frequency 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

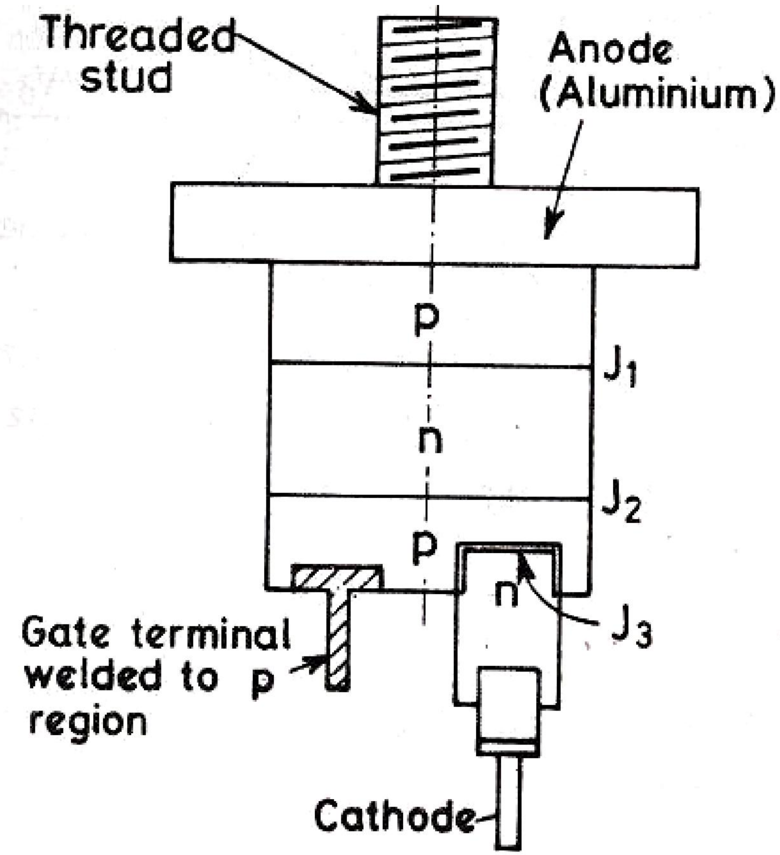




THYRISTOR FAMILY DEVISES

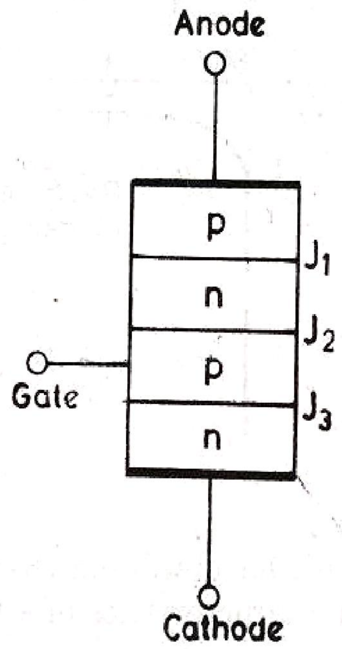
- SCR (Silicon Controlled Rectifier)
- TRIAC(Bidirectional thyristor)
- DIAC (Bidirectional thyristor)
- SUS (Silicon Unilateral Switch)
- SCS (Silicon Controlled Switch)
- LAT (Light Activated Thyristor)
- GTO (Gate turn off Thyristor)
- RCT (Reverse Conduction Thyristor)
- SITHS (Static Induction Thyristor)

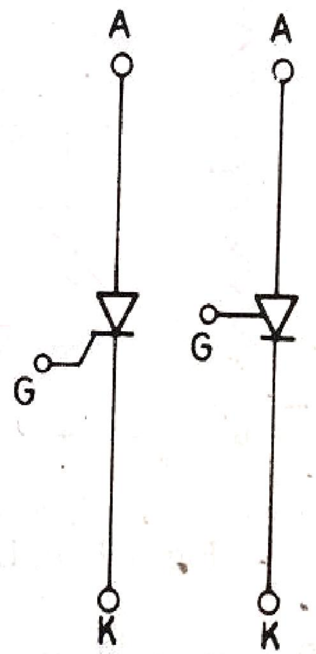
THYRISTOR



Threaded stud
Anode (Aluminium)
p
J_1
n
J_2
p
n
J_3
Gate terminal welded to p region
Cathode

THYRISTOR STRUCTURE AND SYMBOL





SILICON CONTROLLED RECTIFIER (SCR)

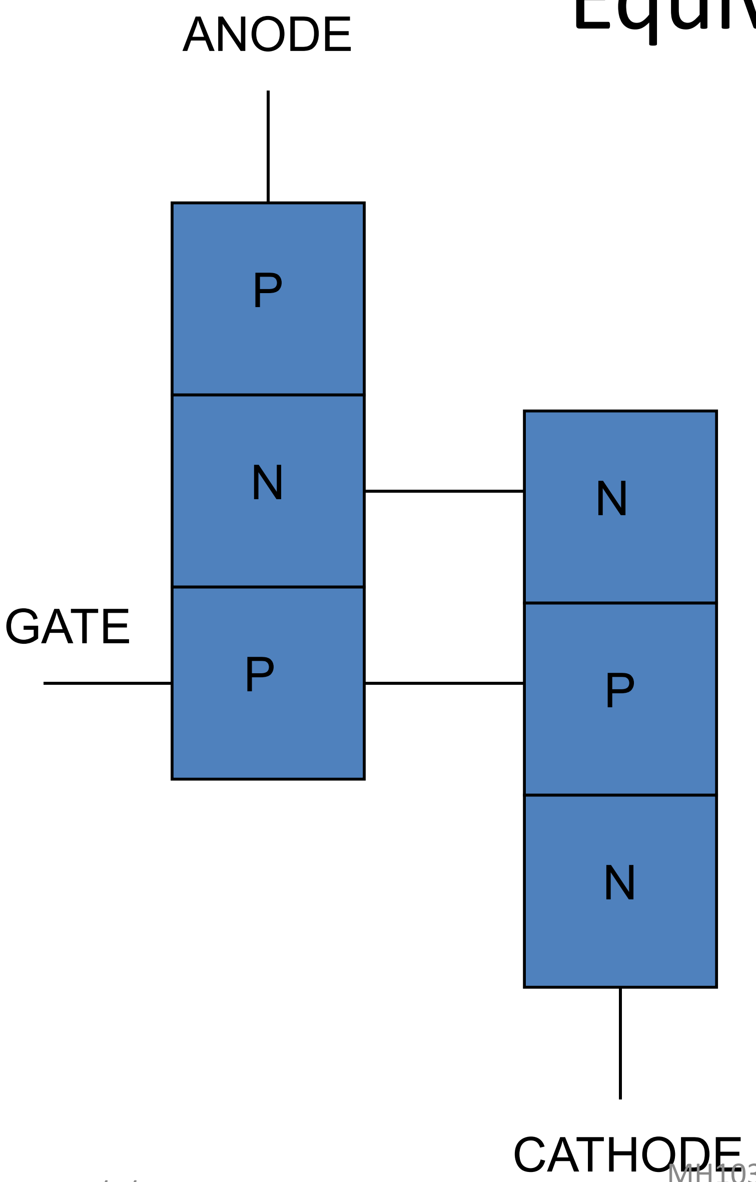
- Three terminal, four layers (P-N-P-N)
- Can handle high currents and high voltages, with better switching speed and improved breakdown voltage .
- Name 'Thyristor', is derived by a combination of the capital letters from **THYRatron** and **transISTOR**.
- Has characteristics similar to a thyratron tube

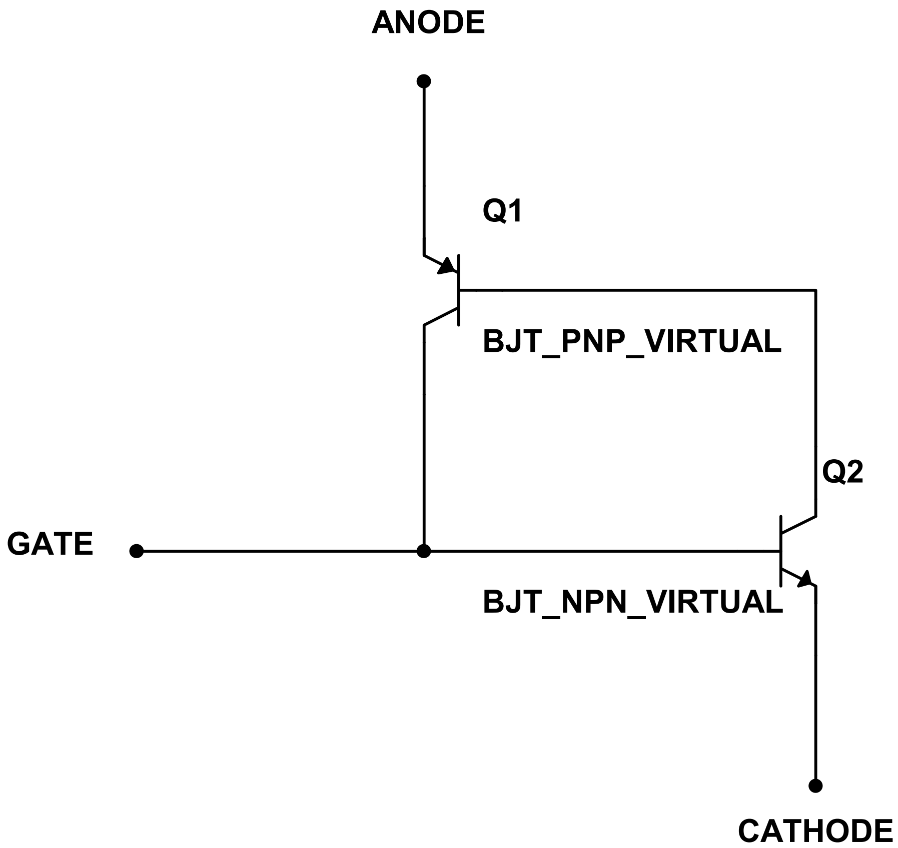
  But from the construction view point belongs to transistor (pnp or npn device) family.

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

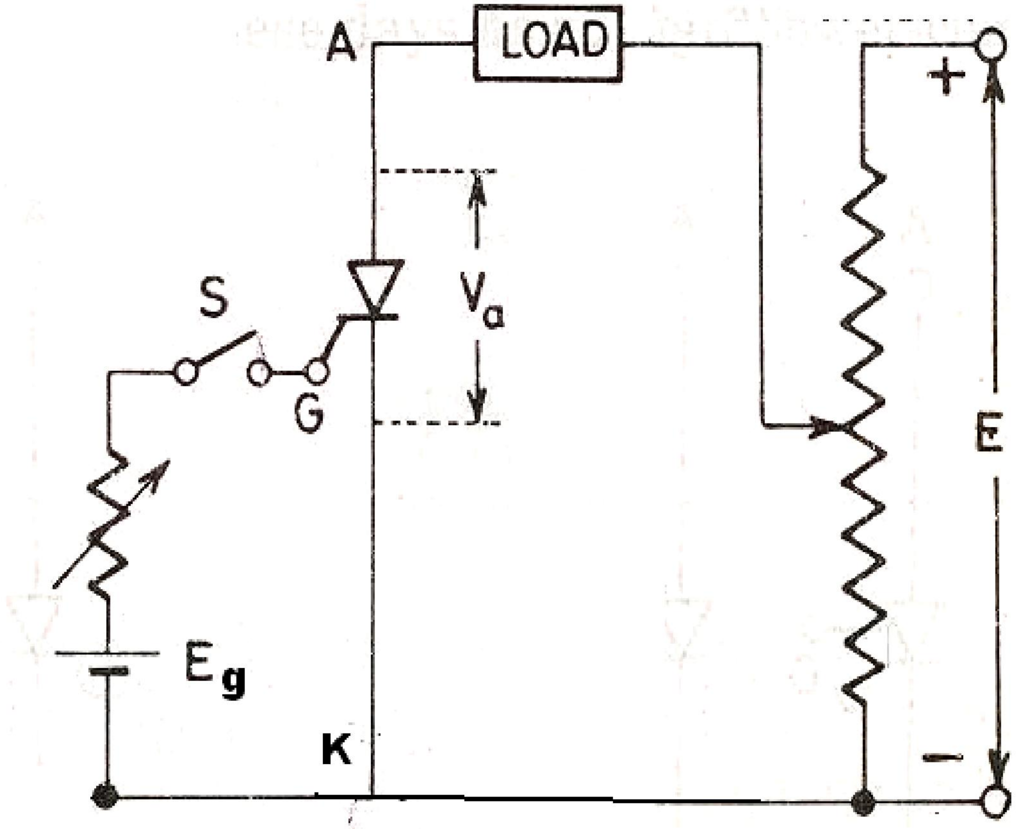




SCR OPERATING REGIONS

- Reverse blocking mode
- Forward blocking mode
- Forward conduction mode

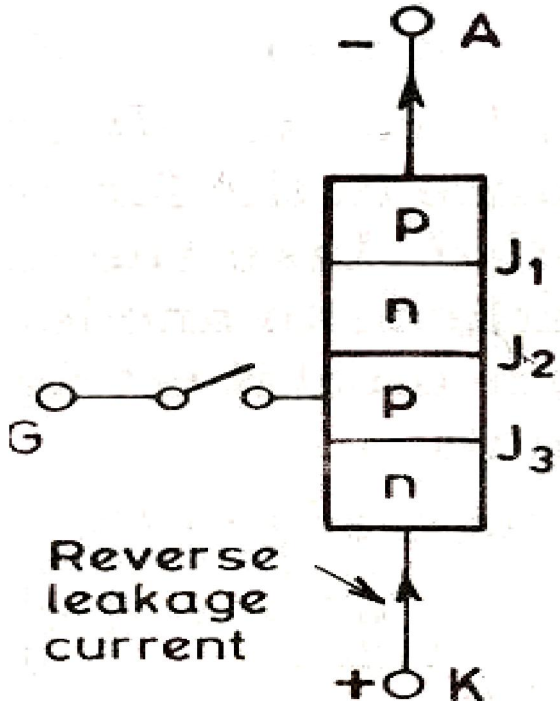
STATIC V-I CHARACTERISTICS

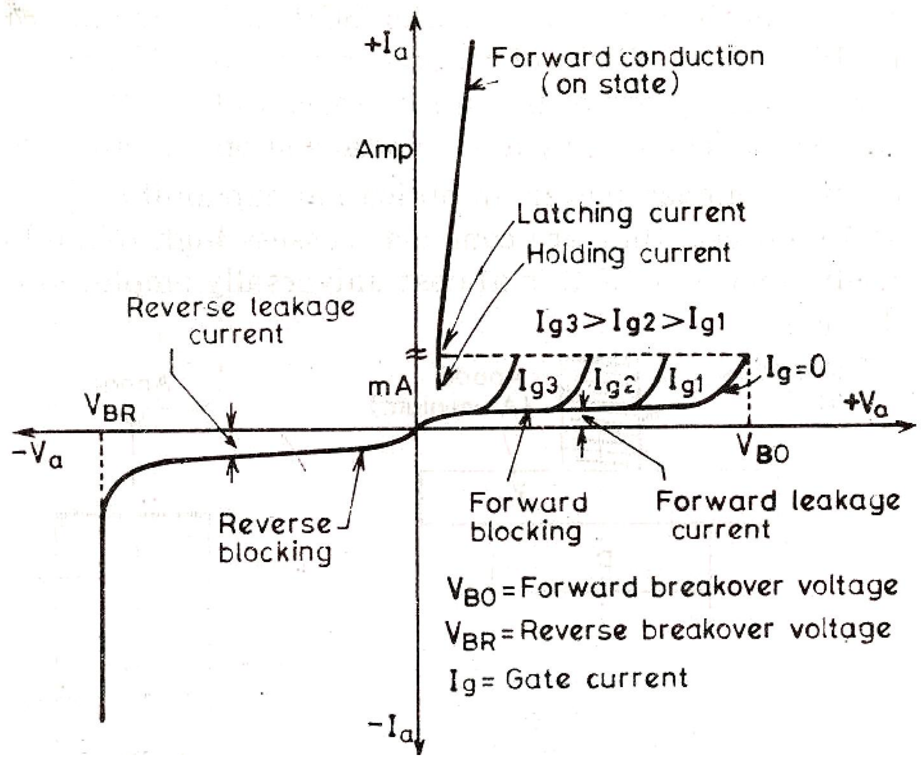


- Thyristors can only be turned on with three conditions:

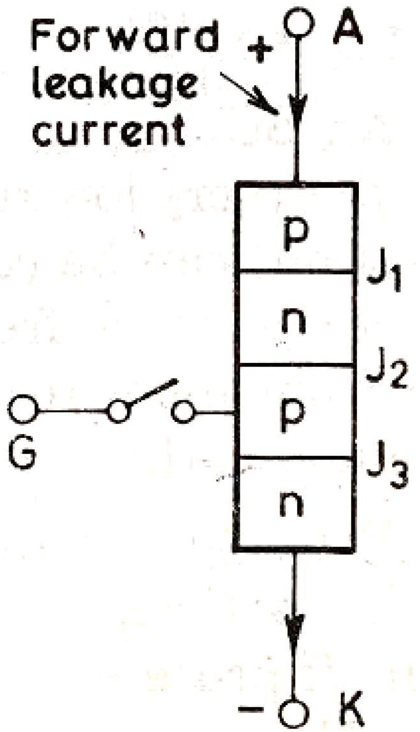
1. The device must be forward biased, i.e., the anode should be more positive than the cathode.
2. A positive gate current (Ig) should be applied at the gate.
3. The current through the thyristor should be more than the latching current. Once conducting ,the anode current is LATCHED (continuously flowing).

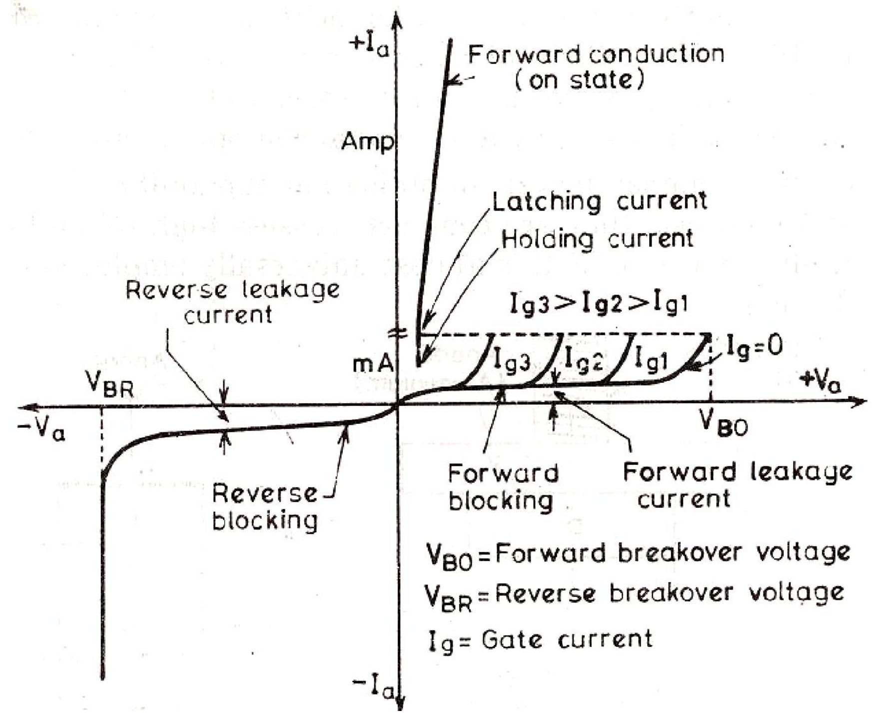
REVERSE BLOCKING MODE





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.

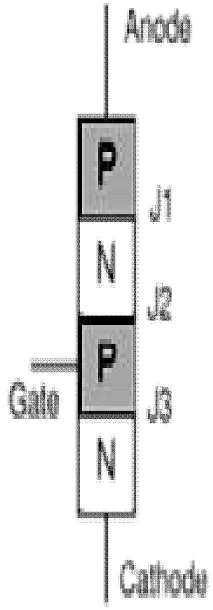
If the IG=IG1, thyristor can be turned ON even when anode voltage is less than VBO.

- 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.

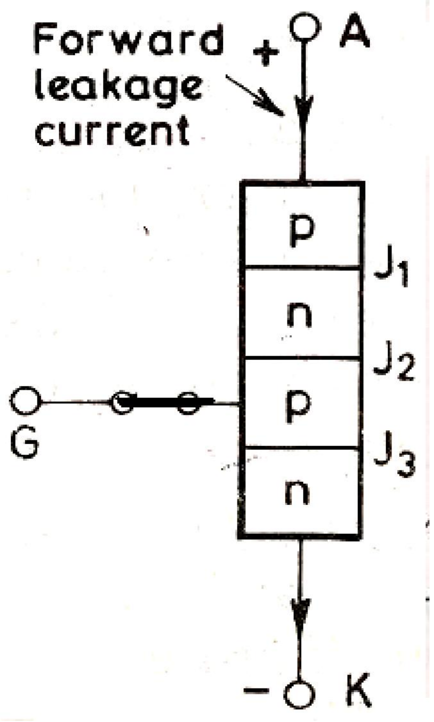
REVERSE BLOCKING MODE: When cathode is more positive than anode , small reverse leakage current flows. However if cathode voltage is increased to reverse breakdown voltage , Avalanche breakdown occurs and large current flows.

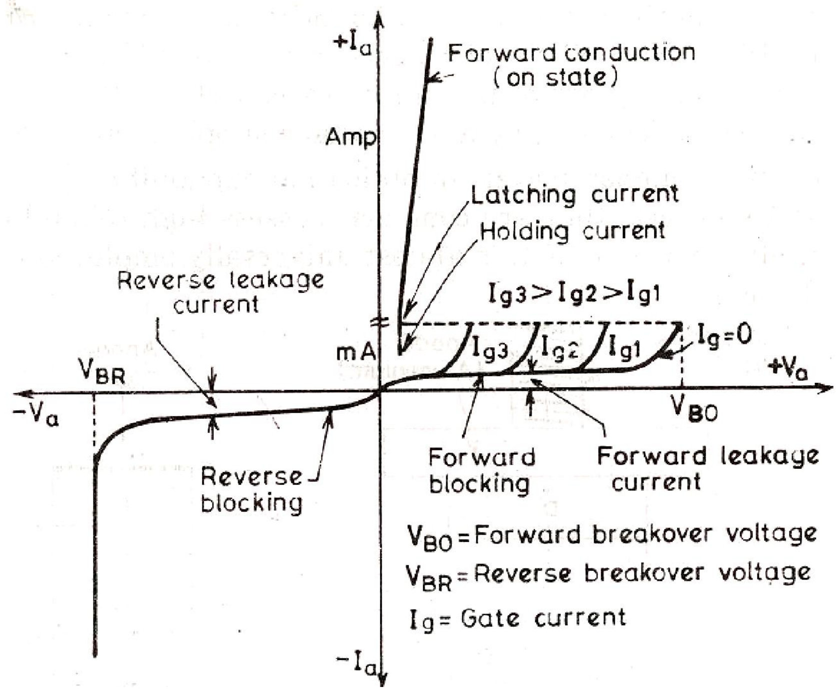
Thyristor- Operation Principle

- 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



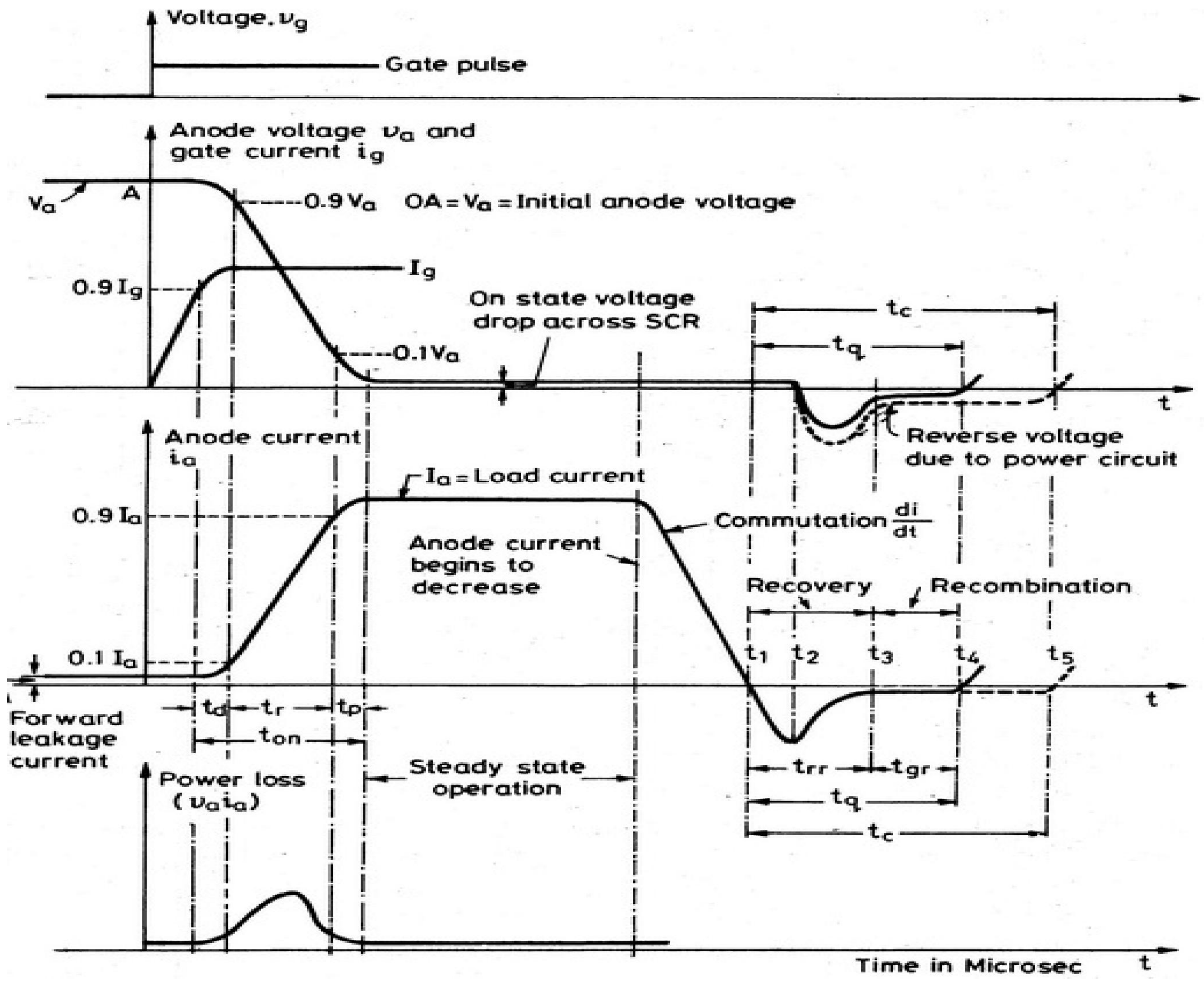
FORWARD CONDUCTION MODE





Once SCR is turned on it looses gate control.

SWITCHING CHARACTERISTICS OF SCR

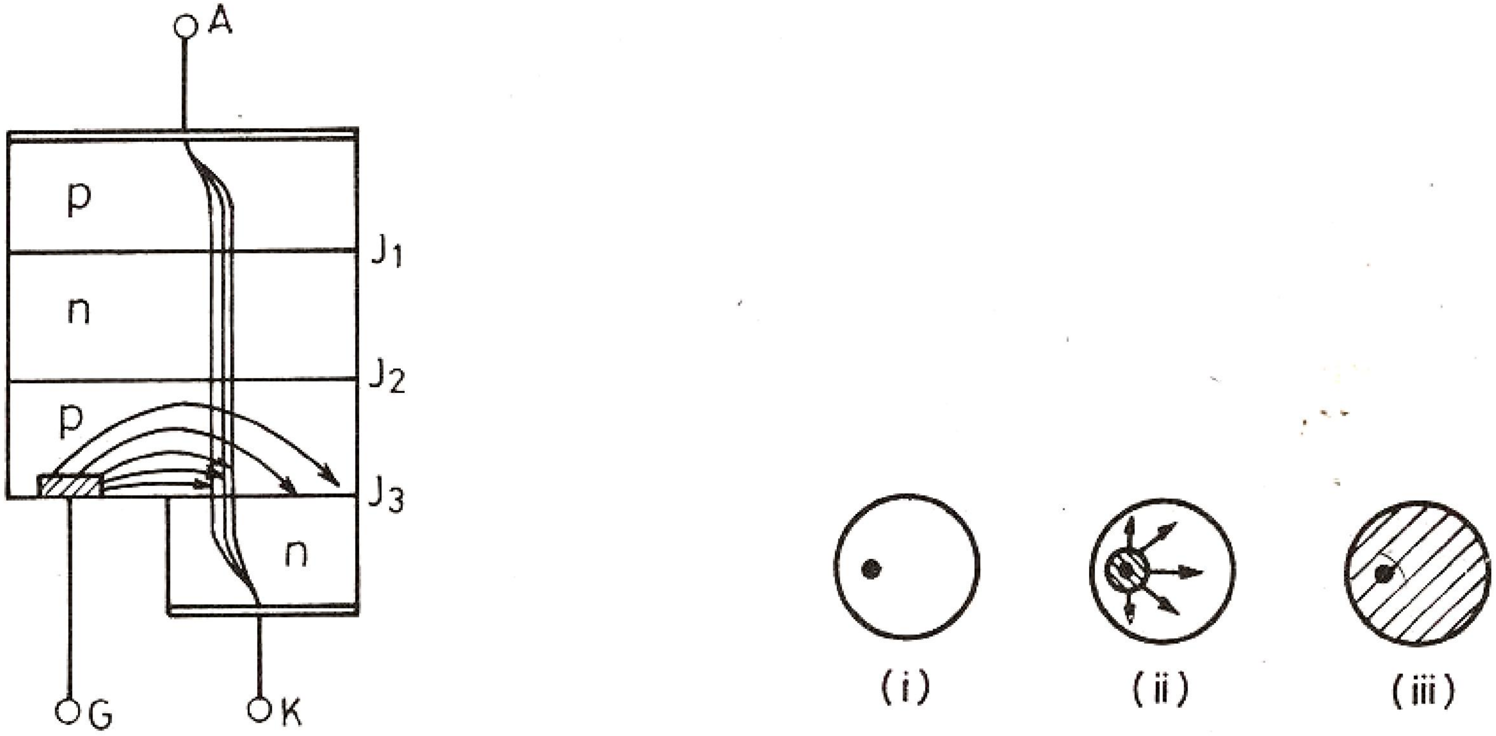


Turn on time(t_{on}):- (t_d +t_r+t_P)

- Delay time(t_d)
- Rise time(t_r)
- Spread time(t_P)

Turn off time(t_{off}):- (t_{rr} +t_{gr})

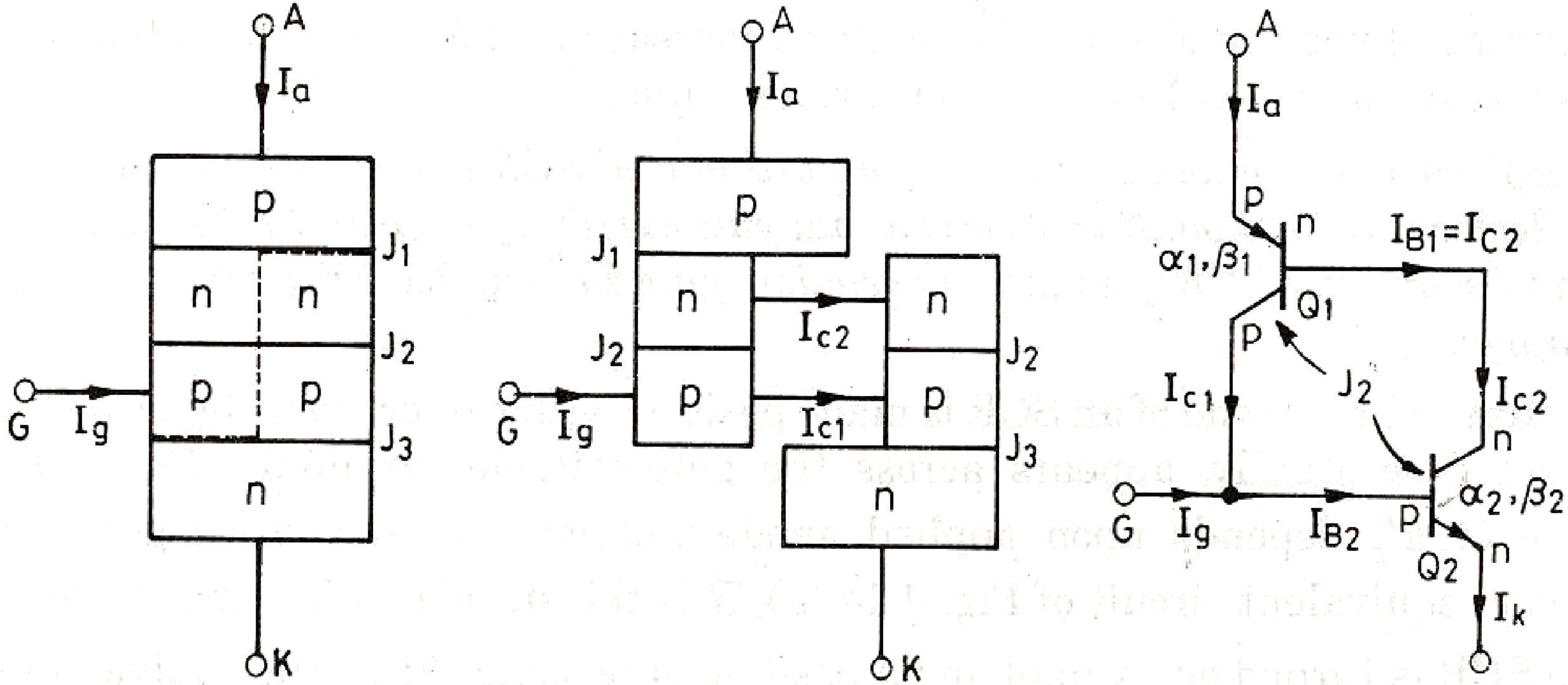
- Reverse recovery time(t_{rr})
- Reverse recovery time(t_{gr})



(*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

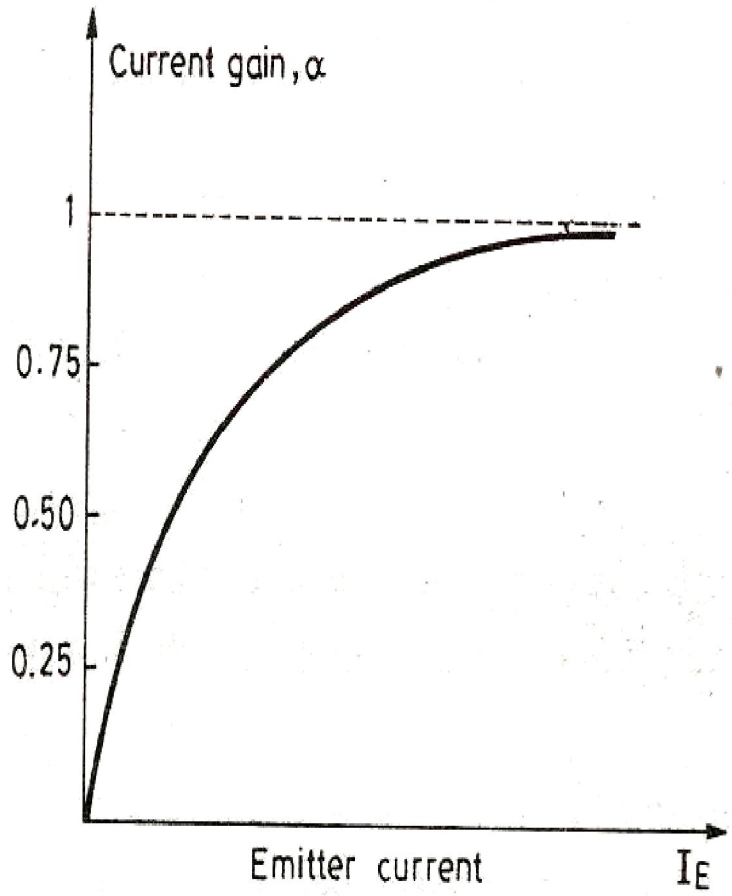
I_k = emitter current of Q_2.

$$\therefore \quad I_a = I_{C1} + I_{C2}$$

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2}$$

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

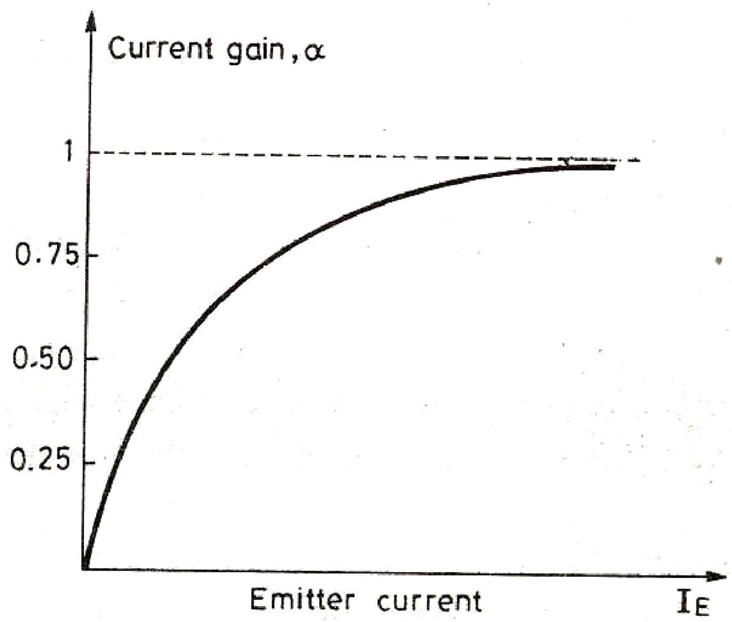
$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

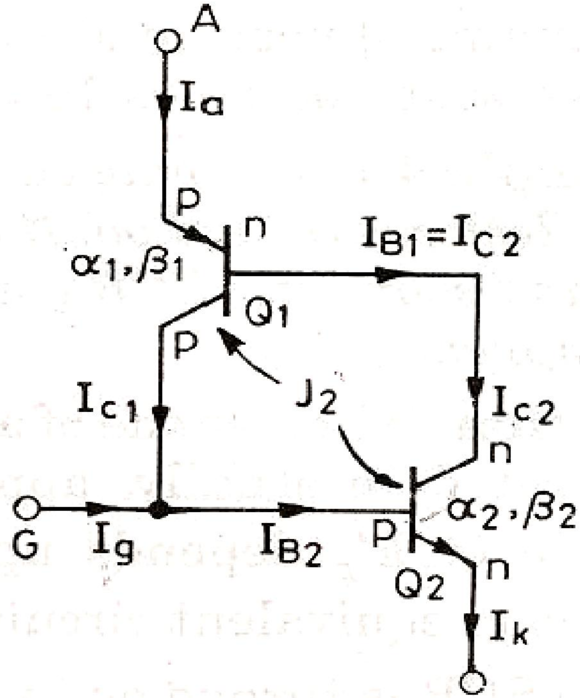


TURN ON METHODS OF SCR

- Gate triggering
- Forward voltage triggering
- dv/dt triggering
- Temperature triggering
- Light triggering

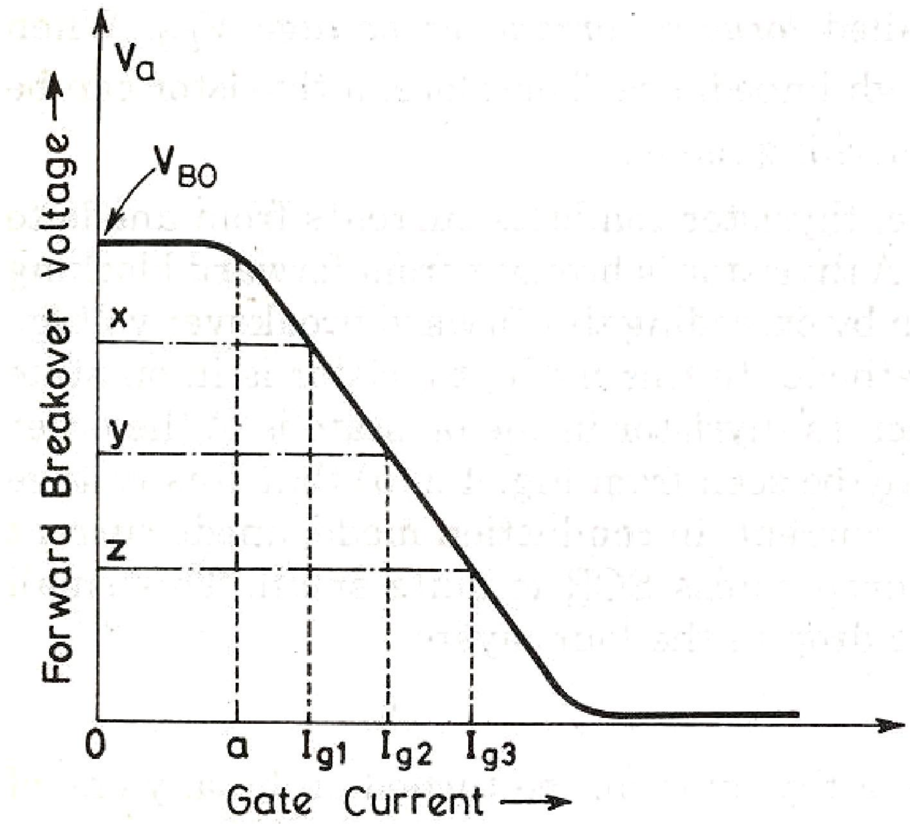
GATE TRIGGERING METHOD





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

GATE TRIGGERING



FORWARD VOLTAGE TRIGGERING

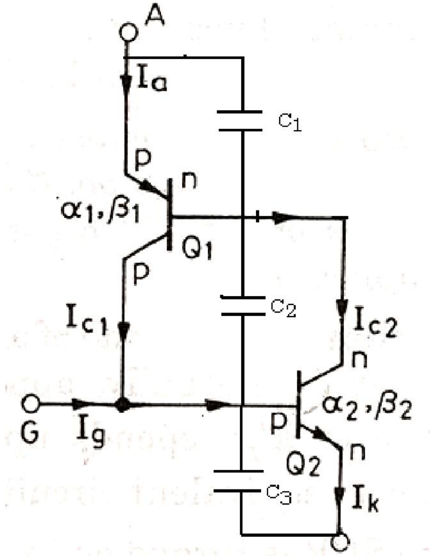
- In forward voltage triggering voltage is applied between anode and cathode with gate circuit open, junction j_2 is reverse biased.
- The width of depletion layer across junction j_2 decreases with an increase in anode cathode voltage
- If forward voltage across anode-cathode is gradually increases ,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:



$$i = C_j \frac{dv_a}{dt}$$

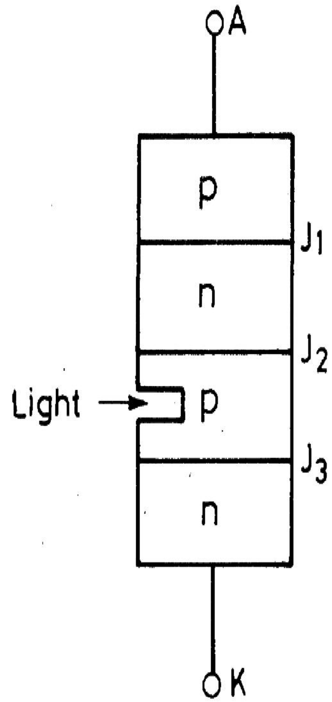
❖This method of triggering is not desirable because high charging current (Ic) may damage the thyristor.

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

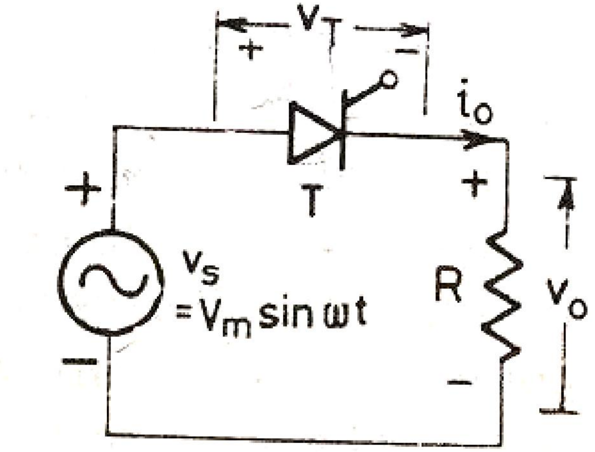
- Natural commutation
- Forced commutation

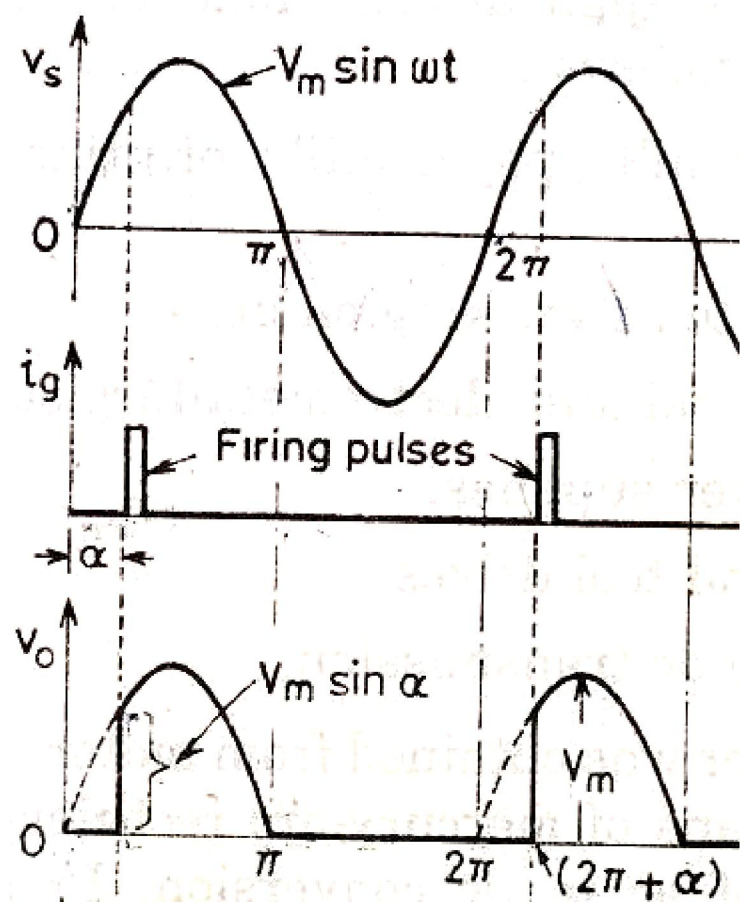
- The process of turning OFF SCR is defined as "Commutation".
- Thyristor cannot be turned off by applying negative gate current. It can only be turned off if the current *I* through it goes negative (reverse).
- In all commutation techniques, a reverse voltage is applied across the thyristor during 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





THANK YOU

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]

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Assignment Questions and Solutions

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.

Department of Electrical & Electronics Engineering

Previous University Question Papers

1(a) What is Holding Current?
(b) Define String Efficiency.
(c) Determine the average and RMS output voltages of single phase full conveter
(d) Define overlap angle.
(e) Express the advantages of freewheeling diode.
(f) What is the principle of operation of Inverters?
(g) Derive the expression for the Power dissipated in the load, for a single phase AC voltage controller feeding Resistive load.
(h) Determine the applications of Cycloconverter
(i) What are the different control strategies of Choppers?
(j) What is Duty Ratio?

2(a) Explain the working of Class-D commutation circuit with neat circuit diagram and waveforms.
(b) Draw the equivalent circuit of a UJT and explain its working. [5+5]

3(a) Describe the operation of a single phase two pulse midpoint converter with relevant waveforms. Derive an expression for average output voltage.
(b) Explain the effect of source inductance in full converter with relevant waveforms. [5+5]

4 (a) Explain the operation of three phase, half wave controlled converter with R load for $\alpha = 600$ with relevant waveforms.

(b)What are the different pulse width modulation techniques used for inverters.

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.
(b) Explain the operation of the single phase bridge type cycloconverter with RL load for Continuous conduction

6 (a) Explain the operation of DC Morgan's Chopper for resistive load with neat circuit diagram and output voltage and current waveforms.
(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.

7 (a) Explain the parallel operation of SCR's
(b) Draw and explain the simple SCR series inverter circuit employing class A type commutation with the help waveforms.

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.

(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 900, determine the rms load voltage, rms load current, rms thyristor current and input powerfactor for above two loads.

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INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE OBJECTIVES

Academic Year : 2018-2019

Semester : I

Name of the Program: EEE……… B.Tech …III/I……. Section: B

Course/Subject: Power Electronic ……Code: …GR15A3018

Name of the Faculty: D.Karunakumar Dept: …………..EEE…………
Designation: Assistant professor

On completion of this Subject/Course the student shall be able to:

S.No	Course Objectives
1.	Introduction to different switching devices and their characteristics
2.	Analysis of converters and voltage control techniques
3.	Visualization of different waveforms for converters.
4.	Understanding and deriving mathematical model for practical systems.
5.	Skill of applying Power electronic techniques to different machines and observing their characteristics

Signature of HOD Signature of faculty

Date: Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE OUTCOMES

Academic Year : 2018-2019

Semester : I

Name of the Program: EEE……… B.Tech …III/I……. Section: B

Course/Subject: Power Electronic…… Code:GR15A3018

Name of the Faculty: D.Karunakumar Dept: …………..EEE…………

Designation: Assistant professor

The expected outcomes of the Course/Subject are:

S.No	Course Outcomes
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.

Signature of HOD Signature of faculty

Date:

GUIDELINES TO STUDY THE COURSE / SUBJECT

Academic Year : 2018-2019

Semester : I

Name of the Program: B.Tech Year: III/I Section: B
Course/Subject: Power Electronic Course Code: GR15A3018

Name of the Faculty: D Karunakumar

Designation: ASST.PROFESSOR.

Guidelines to study the Course/ Subject: Power Electronic

CourseDesignandDeliverySystem(CDD):

- The Course syllabus is written into number of learning objectives and outcomes.
- These learning objectives and outcomes will be achieved through lectures, assessments, assignments, experiments in the laboratory, projects, seminars, presentations, etc.
- Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.
- The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, etc.

The faculty be able to –

Understand the principles of Learning

Understand the psychology of students

Develop instructional objectives for a given topic

Prepare course, unit and lesson plans

Understand different methods of teaching and learning

Use appropriate teaching and learning aids

Plan and deliver lectures effectively Provide feedback to students using various methods of Assessments and tools of Evaluation

Act as a guide, adviser, counselor, facilitator, and motivator and not just as a teacher alone

Signature of HOD   Signature of faculty

Date: Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE SCHEDULE

Academic Year : 2018-2019
Semester : I
Name of the Program: EEE……… B.Tech …III/I……. Section: B

Course/Subject: Power Electronic…… Code: GR15A3018

Name of the Faculty: D.Karunakumar Dept: …………..EEE…………

Designation: Assistant professor
The Schedule for the whole Course / Subject is:

Exp. No.	Description	Duration(Date)	Total No. of Periods
1.	Introduction to Power Semiconductor Devices	02-07-2018	2
2.	Thyristors, BJT, MOSFET and their characteristics	03-07-2018	2
3.	Basic theory of operation of Thyristors, Static V-I characteristics	04-07-2018	2
4.	Dynamic Characteristics,Thyristor Protection, Snubber circuit details	09-07-2018	2
5.	Turn-On & Off Methods,Two Transistor Analogy	10-07-2018	2
6.	Firing Circuit Model & UJT Triggering Circuit	11-07-2018	2
7	Series & Parallel operation ,Static Equalizing circuit	16-07-2018	2
8.	Dynamic Equalizing, Specifications and Ratings of SCR's	17-07-2018	2
9.	Line and Forced commutation circuit.	18-07-2018	2
10	Phase control technique, Single phase linecommutated converters	23-07-2018	2
11.	Half controlled converter with R-load,RL ,RLE load	24-07-2018	2
12.	Half controlled converter with RL and Free wheeling Diode	25-07-2018	2
13.	Numerical problems & Performance parameters	30-07-2018	2

14.	Fully controlled converter with R-load midpoint type, Bridge type	31-07-2018	2
15	Fully controlled converter with RL-load midpoint type, Bridge type	01-08-2018	2
16	Fully controlled converter with RL-load midpoint type,Mid Point type	02-08-2018	2
17	Full controlled converters with RLE load and free wheeling diode	07-08-2018	2
18	Active and Reactive power input, effect of source inductance	08-08-2018	2
19	Introduction to dual converter	13-08-2018	2
20	Three phase bridge type converter with R-Load, RL-Load	14-08-2018	2
21	Three phase bridge type converter with RLE-Load, Bridge point	20-08-2018	2
22	Three phase bridge type converter with RLE-Load Mid point	21-08-2018	2
23	Semi converter Effect of Source inductance Waveforms	27-08-2018	2
24	Inverters Single phase inverter Basic series inverter,	28-08-2018	2
25	Parallel Capacitor inverter, bridge inverter Waveforms,	29-08-2018	2
26	Voltage control techniques for inverters	10-09-2018	2
27	Pulse width modulation techniques Numerical problems.	11-09-2018	2
28	Basics of Resonant Inverters.	12-09-2018	2
29	AC voltage controllers Single phase two SCR's in antiparallel with R	17-09-2018	2
30	AC voltage controllers 1-phase two SCR's in antiparallel with RL loads	18-09-2018	2
31	AC voltage controllers 1-phase two SCR's in antiparallel with RL loads	19-09-2018	2

32	Triac with R and RL loads Derivation of RMS load voltage,current	24-09-2018	2
33	Triac with R and RL loads Derivation of RMS power factor- waveforms	25-09-2018	2
34	Cyclo converters Single phase mid point cyclo converters with R load	26-09-2018	2
35	Cyclo converters Single phase mid point cyclo converters with R& Load	01-10-2018	2
36	Choppers, Time ratio control and Current limit control strategies	03-10-2018	2
37	Step down choppers-Derivation of load voltage and currents with R Load	08-10-2018	2
38	Step down choppers-Derivation of load voltage and currents with R L Load	09-10-2018	2
39	Step down choppers-Derivation of load voltage and currents with RLE Load	10-10-2018	2
40	Morgan's chopper Jones chopper Oscillation choppers	15-10-2018	2
41	Waveforms AC Chopper Problems.	16-10-2018	2
42	Pulse Width Modulation Techniques	22-10-2018	2
43	Numerical problems	23-10-2018	2
44	Revision 5th Unit	24-10-2018	2

Total No. of Instructional periods available for the course: …. …….Hours / Periods

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INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONSCOURSEPLAN

Academic Year : 2018-2019

Semester : I

Name of the Program: EEE……… B.Tech …II/II……. Section: B

Course/Subject: Power Electronic…… Code:GR15A3018

Name of the Faculty: D.Karunakumar Dept: …………..EEE…………
Designation: Assistant professor

Exp. No	Topics	Objectives & Outcomes	References(TextBook,Journal…)
1.	Introduction to Power Semiconductor Devices	1,2,3 & 1,-	. P.S.Bhimbra
2.	Thyristors, BJT, MOSFET and their characteristics	1,2,3 & 1,2	. P.S.Bhimbra
3.	Basic theory of operation of Thyristors, Static V-I characteristics	1,2,3& 1,2	. P.S.Bhimbra
4.	Dynamic Characteristics,Thyristor Protection, Snubber circuit details	1,2,3,6& 1,2	. P.S.Bhimbra
5.	Turn-On & Off Methods,Two Transistor Analogy	1,2,3& 1,2	. P.S.Bhimbra
6.	Firing Circuit Model & UJT Triggering Circuit	1,2,3 & 1,2	. P.S.Bhimbra
7	Series & Parallel operation ,Static Equalizing circuit	1,2,3,4& 1,2	. P.S.Bhimbra

8.	Dynamic Equalizing, Specifications and Ratings of SCR's	1,2,3 & 2	. P.S.Bhimbra
9.	Line and Forced commutation circuit.	1,2,3 & 2	. P.S.Bhimbra
10	Phase control technique, Single phase linecommutated converters	1,2,3& 2	. P.S.Bhimbra
11.	Half controlled converter with R-load,RL ,RLE load	1,2,3,& 2	. P.S.Bhimbra
12.	Half controlled converter with RL and Free wheeling Diode	1,2,3,4 ,5,6 & 2	. P.S.Bhimbra
13.	Numerical problems & Performance parameters	1,2,3 & 1,2	. P.S.Bhimbra
14.	Fully controlled converter with R-load midpoint type, Bridge type	1,2,3 & 1,2	. P.S.Bhimbra
15	Fully controlled converter with RL-load midpoint type, Bridge type	1,2,3& 1,2	. P.S.Bhimbra
16	Fully controlled converter with RL-load midpoint type,Mid Point type	1,2,3,6& 1,2	. P.S.Bhimbra
17	Full controlled converters with RLE load and free wheeling diode	1,2,3& 1,2	. P.S.Bhimbra
18	Active and Reactive power input, effect of source inductance	1,2,3 & 1,2	. P.S.Bhimbra
19	Introduction to dual converter	1,2,3,4& 1,2	. P.S.Bhimbra
20	Three phase bridge type converter with R-Load, RL-Load	1,2,3 & 2	. P.S.Bhimbra
21	Three phase bridge type converter with RLE-Load, Bridge point	1,2,3 & 2	. P.S.Bhimbra
22	Three phase bridge type converter with RLE-Load Mid point	1,2,3& 2	. P.S.Bhimbra

23	Semi converter Effect of Source inductance Waveforms	1,2,3,& 2	. P.S.Bhimbra
24	Inverters Single phase inverter Basic series inverter,	1,2,3,4 ,5,6 & 2	. P.S.Bhimbra
25	Parallel Capacitor inverter, bridge inverter Waveforms,	1,2,3 & 1,2	. P.S.Bhimbra
26	Voltage control techniques for inverters	1,2,3 & 1,2	. P.S.Bhimbra
27	Pulse width modulation techniques Numerical problems.	1,2,3& 1,2	. P.S.Bhimbra
28	Basics of Resonant Inverters.	1,2,3,6& 1,2	. P.S.Bhimbra
29	AC voltage controllers Single phase two SCR's in antiparallel with R	1,2,3& 1,2	. P.S.Bhimbra
30	AC voltage controllers 1-phase two SCR's in antiparallel with RL loads	1,2,3 & 1,2	. P.S.Bhimbra
31	AC voltage controllers 1-phase two SCR's in antiparallel with RL loads	1,2,3,4& 1,2	. P.S.Bhimbra
32	Triac with R and RL loads Derivation of RMS load voltage,current	1,2,3 & 2	. P.S.Bhimbra
33	Triac with R and RL loads Derivation of RMS power factor- waveforms	1,2,3 & 2	. P.S.Bhimbra
34	Cyclo converters Single phase mid point cyclo converters with R load	1,2,3& 2	. P.S.Bhimbra
35	Cyclo converters Single phase mid point cyclo converters with R& Load	1,2,3,& 2	. P.S.Bhimbra
36	Choppers, Time ratio control and Current limit control strategies	1,2,3,4 ,5,6 & 2	. P.S.Bhimbra

37	Step down choppers-Derivation of load voltage and currents with R Load	1,2,3 & 1,2	. P.S.Bhimbra
38	Step down choppers-Derivation of load voltage and currents with R L Load	1,2,3 & 1,2	. P.S.Bhimbra
39	Step down choppers-Derivation of load voltage and currents with RLE Load	1,2,3& 1,2	. P.S.Bhimbra
40	Morgan's chopper Jones chopper Oscillation choppers	1,2,3,6& 1,2	. P.S.Bhimbra
41	Waveforms AC Chopper Problems.	1,2,3& 1,2	. P.S.Bhimbra
42	Pulse Width Modulation Techniques	1,2,3 & 1,2	. P.S.Bhimbra
43	Numerical problems	1,2,3,4& 1,2	. P.S.Bhimbra
44	Revision 5th Unit	1,2,3 & 2	. P.S.Bhimbra

Signature of HOD

Date:

Signature of faculty

Date:

COURSE OUTCOME AND PROGRAM OUTCOME MAPPING

PO's CO's	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	H	H	H	M		H		M	H	H	H	H
CO2		H	H	M		H			M	H	H	H
CO3	H	M		H		M	H		M			M
CO4	H		H	M		M	H	M	M		H	M
CO5	H	H	M	M		H	H	H			H	M
CO6		H	H	M		H	H	M	H	M	H	H
CO7	H	H	H	M		H		M	H		H	H

Assessment methods:

1. Operation skill and familiarization ofsoftware.
2. Experimental procedure, simulation results, internal observation, labrecord.
3. Internal examinations.
4. External examinations.
5. Viva-voce.

1. Course Objectives-Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark "X")

P-Outcomes / C-Objectives	A	B	c	d	e	F	g	h	i	j	k	l
1	X	X	X	X	X				X	X	X	X
2	X				X		X	X		X	X	
3	X	X	X			X	X	X	X		X	X
4				X	X	X		X	X	X	X	
5		X	X	X					X	X		
6				X	X	X		X		X	X	
7	X	X	X	X	X	X	X		X	X	X	

2. Course Outcomes-Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark"X")

P-Outcomes / C-Outcomes	a	b	c	d	e	f	g	h	i	J	K	l
1	X	X	X	X	X			X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	X	X	X	X
4	X	X	X							X	X	X
5	X	X	X							X	X	X
6	X	X	X							X	X	X
7	X	X	X							X	X	X

3. Courses (with title & code)-Program Outcomes (POs) Relationship Matrix
(Indicate the relationships by mark "X"

P-Outcomes / Courses	a	b	c	d	e	f	g	h	i	j	K	l
Electrical Networks Lab	X	X	X	X	X	X	X	X	X	X	X	X

4. **Program Educational Objectives (PEOs) –Vision/Mission Matrix** (Indicate therelationships by mark "X")

PEOs	Mission of department			
	Higher Learning	Contemporary Education	Technical knowledge	Research
Graduates will have a successful technical or professional careers, including supportive and leadership roles on multidisciplinary teams	X	X	X	X
Graduates will be able to acquire, use and develop skills as required for effective professional practices		X	X	
Graduates will be able to attain holistic education that is an essential prerequisite for being a responsible member of society	X		X	
Graduates will be engaged in life-long learning, to remain abreast in their profession and be leaders in our technologically vibrant society.	X		X	X

5. **Program Educational Objectives(PEOs)-Program Outcomes(POs) Relationship Matrix** (Indicate the relationships by m

P-Outcomes / PEOs	a	b	c	d	e	f
1	X	X	X	X	X	

2	X	X	X	X	X	
3		X	X	X		X
4				X		

6.**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	X	X	X	X
2	X	X	X	X	X	X	X
3	X	X					
4				X	X		
5			X	X	X	X	X
6			X	X	X	X	X
7	X		X	X	X	X	

Program Educational Objectives (PEOs)-Course Outcomes Relationship Matrix (Indicate the relationships by mark

P-Objectives(PEO) Course-Outcomes	1	2	3	4
1	X	X		X
2	X	X		X
3	X	X		X
4	X	X		X
5	X	X		X
6	X	X		X
7	X	X		X

8. Assignments & Assessments-Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark "X"

P-Outcomes Assessments	A	b	c	d	e	f
1	X	x		x		x
2	X	x	x			x

3	X	x	x			x
4	X	x	x			x

9. Assignments & Assessments-Program Educational Objectives (PEOs) Relationship Matrix (Indicate the relationships by

P-Objectives (PEOs) Assessments	1	2	3	4
1	X	X		
2		X		
3		X	X	X
4		X		
5		X		

<u>Assessment process and Relevant Surveys conducted:</u>

1. Constituencies -Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark "X").

Constituencies

1. **Alumni**
2. **Governmentemployers**
3. **Students**

P-Outcomes / Constituencies	a	b	c	d	e	f	G	h	i	j	k	l
1	X	X	X	X	X	X	X		X	X		X
2	X	X	X	X	X	X	X		X			X
3	X	X			X	X	X	X		X	X	X

9	CO-Cognitive Level Mapping

Subject :Power Electronic

CO	Cognitive Learning Level					
	1	2	3	4	5	6
1		X				
2			X			
3						X
4				X		

5		X				
6			X			
7		X				

Cognitive Learning Levels:

CLL1: Remembering

CLL2: Understanding

CLL3: Applying

CLL4: Analyzing

CLL5: Evaluating

CLL6: Creating

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

EVALUATION STRATEGY

Academic Year : 2018-2019

Semester : I

Name of the Program: EEE……… B.Tech …III/I……. Section: B

Course/Subject: Power Electronic…… Code: GR15A3018

Name of the Faculty: D.Karunakumar Dept: …………..EEE…………

Designation: Assistant professor

1. TARGET:

A) Percentage for pass: 100%

2. COURSE PLAN & CONTENT DELIVERY

- PPT presentation of the Lectures
- Solving exercise problems
- Model questions

3. METHOD OF EVALUATION

3.1 ☐ Daily Attendance

3.2 ☐ Lab records and observation

3.3 ☐ Mini Projects

3.4 ☐ Viva Voce

3.5 ☐ Internal Examination

3.6 ☐ Semester/End Examination

4. List out any new topic(s) or any innovation you would like to introduce in teaching the subjects in this Semester.

Signature of HOD Signature of faculty

Date: Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

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.	INDURI PAVANI (17241A0274)	**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.	
		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.	
		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	

		Listen to other team mates	Is always talking--never allows anyone else to speak.	Usually doing most of the talking--rarely allows others to	Listens, but sometimes talks too much.	Listens and speaks a fair amount.	
				speak.			
						Average score	
2.	PUDOTA ADITYA CECIL RAJ (16241A02A0)	**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.	
		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.	
		Share Equally	Always relies on others to do	Rarely does the assigned	Usually does the assigned	Always does the assigned	

			the work.	work--often needs reminding.	work--rarely needs reminding.	work without having to be reminded.	
		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.	
						Average score	
3	K VAISHNAVI (17245A0214)	**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 information--most relates to the topic.	Collects a great deal of information--all relates to the topic.	
		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.	

		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	
		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.	
						Average score	

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE COMPLETION STATUS

Academic Year : 2018-2019

Semester : I

Name of the Program: EEE……… B.Tech …III/I……. Section: B

Course/Subject: Power Electronic…… Code: GR15A3018

Name of the Faculty: D.Karunakumar Dept: …………..EEE…………

Designation: Assistant professor

Program	Remarks	No. of Objectives Achieved	No. of Outcomes Achieved
1	1st unit completed by 18/07/18	1,3	1,4
2	2nd unit completed by 13/08/18	2,3	3,4
3	3rd unit completed by 12/09/18	4,3	2,3
4	4th unit completed by 08/10/18	5,3	4,5
5	5th unit completed by 23/10/19	1,3	2,4

Signature of HOD

Date:

Signature of faculty

Date:

Note: After the completion of each unit mention the number of Objectives & Outcomes Achieved.

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

GUIDELINES TO STUDY THE COURSE/SUBJECT

Academic Year : 2018-2019

Semester : I

Name of the Program: EEE……… B.Tech …III/I……. Section: B

Course/Subject: Power Electronic…… Code: GR15A3018

Name of the Faculty: D.Karunakumar Dept: …………..EEE…………

Designation: Assistant professor

Course Design and Delivery System (CDD):

- The Course syllabus is written into number of learning objectives and outcomes.
- These learning objectives and outcomes will be achieved through lectures, assessments, assignments, experiments in the laboratory, projects, seminars, presentations, etc.
- Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.
- The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, etc.

The faculty be able to –

- Understand the principles of Learning
- Understand the psychology of students
- Develop instructional objectives for a given topic
- Prepare course, unit and lesson plans
- Understand different methods of teaching and learning
- Use appropriate teaching and learning aids
- Plan and deliver lectures effectively
- Provide feedback to students using various methods of Assessments and tools of Evaluation
- Act as a guide, advisor, counselor, facilitator, motivator and not just as a teacher alone

Signature of HOD
Date:

Signature of faculty
Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Result Analysis

B.Tech EEE III YEAR I SEM RESULT ANALYSIS OF 2016-2020 BATCH

ACADEMIC YEAR 2018-2019

TOTAL. NO. OF STUDENTS REGISTERED = 142

Subject	Total No. of students appeared	No. of students passed	No. of students failed	Grade Points							
				< 5	5	6	7	8	9	10	Pass percentage
MC	142	116	26	07	13	15	20	32	27	02	81.69%
MC Lab	142	141	01	00	01	00	00	09	26	105	99.29%
PTS	142	128	14	01	12	12	14	30	34	25	90.14%
EMI	142	128	14	08	11	08	12	32	31	26	90.14%
PE	142	135	07	03	08	11	08	27	37	41	95.07%
SMI Lab	142	140	02	06	10	02	04	12	17	89	98.59%
PE Lab	142	140	02	00	01	02	07	27	31	72	98.59%
SWE	142	125	17	06	11	16	09	44	29	10	88.02%

Overall pass (passed in all subjects) = 107/142 (75.35%)

Power Transmission System	V Vijaya Rama Raju, M Prashanth
Microcontrollers	P Prashanth Kumar
Electrical Measurements& Instrumentation	U Vijaya Lakshmi
Power Electronics	Dr T Suresh Kumar,D Karuna Kumar

Department of Electrical & Electronics Engineering

Solar and Wind Energy Systems	P Sri Vidya Devi /Dr J Praveen
Sensors/Measurements& Instrumentation Lab	P Srividya Devi/U Vijaya Lakshmi/P Sirisha
Power Electronics Lab	Dr T Suresh Kumar/Syed Sarfaraz Nawaz/M Rekha
Microcontrollers Lab	R Anil Kumar/MN Sandhya Rani

ARREARS POSITION – CURRENT YEAR

Description	All pass	One Arrear	Two Arrears	Three Arrears	More than Three Arrears	% of pass
142	107	10	16	03	06	75.35%

Performance overall Class Three Toppers

ROLL NO.	NAME	PERCENTAGE(SGPA)
16241A0259	VIPPARTHI SOWMYA	10
16241A0274 16241A0290 17245A0205 17245A0214 17245A0221	INDURI PAVANI MANGANAPALLY ROOPA CHILUKA PRANAVI K VAISHNAVI P SWATHI	9.84
16241A0257	UNDETY MOUNIKA	9.72

HOD,EEE

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 AND TECHNOLOGY

Department of Electrical & Electronics Engineering

CO Attainment for All Mids.

Gokaraju Rangaraju Institute of Engineering & Technology					
Dept: EEE III year MID-I Academic Year:2018-19 I Sem					
Subject Name: Power Electronics					
Date: 04.09.2018					
Course Attainment Analysis					
Roll Numbers	**Name**	**Q1 [5M] CO4**	**Q2 [5M] CO1**	**Q3 [5M] CO5**	**Q4 [5M] CO2**
16241A0261	A PRASHANTH	5	5	4	
16241A0262	ADEPU SOWMYA	5	5		5
16241A0263	AMGOTH RISHITHA PAMAAR	5	5		5
16241A0264	ARVIND NAIDU	4	2		
16241A0265	BOLISHETTI SAIJEEVAN	5			
16241A0266	BOLLUR YASHWANT	5		2	3
16241A0267	BOMRASPET PHANIDER	5	5		5
16241A0268	CHALLAGUNDLA SOWMYA	5	5		2
16241A0269	CHINTAPOOLA SWATHI	5	5	5	5
16241A0270	DESHPANDE PRAVALIKA	AB	AB	AB	AB
16241A0271	GONE SOWMYA	5		4	4
16241A0272	GOPIDI VENKAT REDDY	5	5	4	5
16241A0273	GORENKALA MEGHA SAIKRISHNA	2	2		3
16241A0274	INDURI PAVANI	5	5	5	5
16241A0275	JALAMANCHILI RAMA SURYAM	5	5	5	
16241A0276	JONNAVALASA DEVI PRASAD	5	5		4
16241A0277	K V S SANDEEP	3			1
16241A0278	KALYANAPU VENUGOPAL	5	4		5
16241A0279	KANNE SACHIN	2		3	
16241A0280	KARAM SANDHYARANI	5	5	5	4
16241A0281	KATTA MOUNIKA	5	5		4
16241A0282	KIDAMBI SREE GOVIND	5	5		5
16241A0283	KOLLIPARA CHAITANYA SAI	5	5		1
16241A0284	KONDA ANIL KUMAR	5		2	5

Department of Electrical & Electronics Engineering

16241A0285	KUNCHALA MOHANBABU	5		5	5
16241A0286	LANKA ROHITHA SRI	5	1	4	5
16241A0287	MADAPATHI SACHIN	5	2		
16241A0288	MALAKA UDAYASAGAR	4		1	
16241A0289	MALAVATH JAIPAL	4	4		5
16241A0290	MANGANAPALLY ROOPA	5	5		5
16241A0291	MOHAMMED KHALEEL	5	5		5
16241A0292	MUKKAMULA RAMYA SREE	5		4	4
16241A0293	MUNDRA SUBHASHINI	5			5
16241A0294	MYSA VINOD KUMAR	5			
16241A0295	NAGARAM VAMSHI	4		2	2
16241A0296	NAGARAPU PRADEEP		1		2
16241A0297	PATHAPATI DIVYA	5	2	2	4
16241A0298	POTTA SURYATEJA	3			4
16241A0299	PRODDUTUR MOHAN SAI	4			5
16241A02A0	PUDOTA ADITYA CECIL RAJ	2			5
16241A02A2	SADANAVENA RAHUL		4	4	5
16241A02A3	SAI TEJASWI NOOKA	5	5	3	
16241A02A4	SAKETH M	5	5		5
16241A02A5	SANGEM SOUJANYA	5	5	5	
16241A02A6	SANGISETTY RAKESH SAGAR		3	1	2
16241A02A7	SHASTRALA SRAVYA	5	5		5
16241A02A8	SURAM SHIRISHA	5	5		5
16241A02A9	SURYA SANJAY BANDARI	5	5		
16241A02B0	T LAKSHMI ASRITH	3	1		4
16241A02B1	TERATPALLY YESHWANTH	5	5		5
16241A02B2	THELLA SAI KRISHNA	5	2	3	
16241A02B3	THOTAKURI VISHAL	5	2		
16241A02B4	TUMMALACHARLA PRAVEEN	5		4	5
16241A02B5	VANGA RITHVIKA	5	5		
16241A02B6	VIDYA KANURI	5	5		4
16241A02B7	VINEESHA SRAVYA LAKSHMI . B	5	5		5
16241A02B8	VUJJINI HARSHITHA	5		4	5
16241A02B9	BHANU KAUSTUBA WALTATI	3		2	
17245A0213	K RAGHAVENDER	5		5	5

17245A0214	K VAISHNAVI	5		5	5
17245A0215	MANNELI KRANTHI KUMAR	5		3	5
17245A0216	MARTHA REVAN KUMAR	4			5
17245A0217	MASANNAGARI RAKESH REDDY	4		2	4
17245A0218	NARSING SHRAVANI	5	4	5	5
17245A0219	PONNAM ADITHYA	5		5	4
17245A0220	POOSALA NAVYARANI	5		5	5
17245A0221	P SWATHI	5		5	5
17245A0222	SABAVATH PARAMESH	5		5	5
17245A0223	SHAIK ASIF AHMED	5		4	5
17245A0224	SHAIK SOHEL	5		5	5
	Grand Total	**306**	**164**	**132**	**235**
	NSA	**66.0**	**40.0**	**35.0**	**54.0**
	Attempt %=(NSA/Total no of students)*100	**94.3**	**57.1**	**50.0**	**77.1**
	Average (attainment)= Total/NSA	**4.6**	**4.1**	**3.8**	**4.4**
	Attainment%= (Avg/max. Marks for question)*100	**92.73**	**82.00**	**75.43**	**87.04**
		CO4	CO1	CO5	CO2
		CO1	**81.5**		
		CO2	**86.6**		
		CO4	**92.73**		
		CO5	**74.86**		

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Gokaraju Rangaraju Institute of Engineering & Technology					
Dept: EEE III year MID-II Academic Year:2018-19 I Sem					
Subject Name: Power Electronics					
Date: 25.10.2018					
Course Attainment Analysis					
Roll Numbers	**Name**	**Q1 [5M] CO2**	**Q2 [5M] CO6**	**Q3 [5M] CO6**	**Q4 [5M] CO7**
16241A0261	A PRASHANTH	5	4		4
16241A0262	ADEPU SOWMYA	5	5	5	
16241A0263	AMGOTH RISHITHA PAMAAR	5	5	5	
16241A0264	ARVIND NAIDU	4	4		4
16241A0265	BOLISHETTI SAIJEEVAN	4	3	4	
16241A0266	BOLLUR YASHWANT	4	4		
16241A0267	BOMRASPET PHANIDER	5	5	4	
16241A0268	CHALLAGUNDLA SOWMYA	5	5	2	
16241A0269	CHINTAPOOLA SWATHI	5	5	5	5
16241A0270	DESHPANDE PRAVALIKA	4	5	5	
16241A0271	GONE SOWMYA	5	5	4	
16241A0272	GOPIDI VENKAT REDDY	5	5	5	
16241A0273	GORENKALA MEGHA SAIKRISHNA	3	3	4	
16241A0274	INDURI PAVANI	5	5	5	2
16241A0275	JALAMANCHILI RAMA SURYAM	5	5	5	
16241A0276	JONNAVALASA DEVI PRASAD	5	5	5	
16241A0277	K V S SANDEEP		5		
16241A0278	KALYANAPU VENUGOPAL	5	5	5	
16241A0279	KANNE SACHIN	4	5	2	
16241A0280	KARAM SANDHYARANI	5	5	5	
16241A0281	KATTA MOUNIKA	5	5	5	
16241A0282	KIDAMBI SREE GOVIND	5	5	5	
16241A0283	KOLLIPARA CHAITANYA SAI		4	3	
16241A0284	KONDA ANIL KUMAR	5	5	5	

16241A0285	KUNCHALA MOHANBABU	5	5	5	
16241A0286	LANKA ROHITHA SRI	4	5	4	
16241A0287	MADAPATHI SACHIN		5	5	
16241A0288	MALAKA UDAYASAGAR		5		
16241A0289	MALAVATH JAIPAL		5	5	5
16241A0290	MANGANAPALLY ROOPA		5	5	5
16241A0291	MOHAMMED KHALEEL	5	5	5	
16241A0292	MUKKAMULA RAMYA SREE	4	4	4	
16241A0293	MUNDRA SUBHASHINI	4	5	2	
16241A0294	MYSA VINOD KUMAR	4		4	
16241A0295	NAGARAM VAMSHI	3	3	4	
16241A0296	NAGARAPU PRADEEP	5	5	5	
16241A0297	PATHAPATI DIVYA	5	5	5	
16241A0298	POTTA SURYATEJA	3			
16241A0299	PRODDUTUR MOHAN SAI	5		5	5
16241A02A0	PUDOTA ADITYA CECIL RAJ		4		3
16241A02A2	SADANAVENA RAHUL	5	5		5
16241A02A3	SAI TEJASWI NOOKA	5	5		4
16241A02A4	SAKETH M	5	5	4	
16241A02A5	SANGEM SOUJANYA	5	5	5	
16241A02A6	SANGISETTY RAKESH SAGAR	4			
16241A02A7	SHASTRALA SRAVYA		5	5	5
16241A02A8	SURAM SHIRISHA	5	5		5
16241A02A9	SURYA SANJAY BANDARI		5	5	
16241A02B0	T LAKSHMI ASRITH	5	5	4	
16241A02B1	TERATPALLY YESHWANTH	5	5	5	
16241A02B2	THELLA SAI KRISHNA	5	5	5	
16241A02B3	THOTAKURI VISHAL	5		2	
16241A02B4	TUMMALACHARLA PRAVEEN	5	5	5	
16241A02B5	VANGA RITHVIKA	5	5	1	4
16241A02B6	VIDYA KANURI	5	5	3	
16241A02B7	VINEESHA SRAVYA LAKSHMI . B	5	5	5	
16241A02B8	VUJJINI HARSHITHA		5	5	5
16241A02B9	BHANU KAUSTUBA WALTATI	4	3		
17245A0213	K RAGHAVENDER	5	5	5	

17245A0214	K VAISHNAVI	5	5	5	
17245A0215	MANNELI KRANTHI KUMAR	5	5	5	
17245A0216	MARTHA REVAN KUMAR	5	4	4	
17245A0217	MASANNAGARI RAKESH REDDY	4	4	5	
17245A0218	NARSING SHRAVANI	5	4	5	5
17245A0219	PONNAM ADITHYA	5	5		5
17245A0220	POOSALA NAVYARANI	5	5	5	
17245A0221	P SWATHI	5	5	5	
17245A0222	SABAVATH PARAMESH	5	5	5	
17245A0223	SHAIK ASIF AHMED	5	5	4	
17245A0224	SHAIK SOHEL	5	5	4	
18248A0201	K ALHILA	4	4	4	5
	Grand Total	**282**	**308**	**252**	**71**
	NSA	**60.0**	**65.0**	**57.0**	**16.0**
	Attempt %=(NSA/Total no of students)*100	**84.5**	**91.5**	**80.3**	**22.5**
	Average (attainment)= Total/NSA	**4.7**	**4.7**	**4.4**	**4.4**
	Attainment%= (Avg/max. Marks for question)*100	**94.00**	**94.77**	**88.42**	**88.75**
		CO2	**94**		
		CO6	**91.60**		
		CO7	**88.75**		