Darbhanga College of Engineering

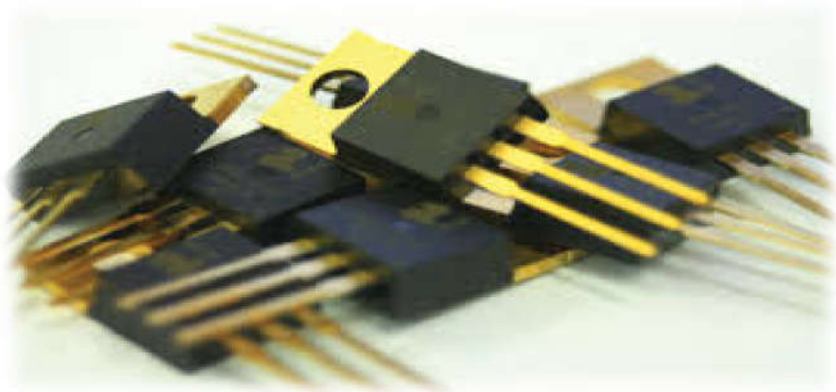
Darbhanga

Course File

of

Power Electronics

(031609)



Prepared by
Sweta Kumari
Assistant Professor
EEE Dept., DCE Darbhanga

Vision of the Institute

To produce young, dynamic, motivated and globally competent Engineering graduates with an aptitude for leadership and research, to face the challenges of modernization and globalization, who will be instrumental in societal development.

Mission of the Institute

1. To impart quality technical education, according to the need of the society.
2. To help the graduates to implement their acquired Engineering knowledge for society & community development.
3. To strengthen nation building through producing dedicated, disciplined, intellectual & motivated engineering graduates.
4. To expose our graduates to industries, campus connect programs & research institutions to enhance their career opportunities.
5. To encourage critical thinking and creativity through various academic programs.

Vision of the Department

To produce comprehensively trained, socially responsible, innovative electrical & electronics engineers and researchers of the highest quality to contribute to the nation's imprint on the world stage.

Mission of the Department

1. To provide world class teaching and mentoring to the students.
2. To create Engineering graduates well equipped with the skills of relevant simulation softwares required in the field of electrical and electronics engineering.
3. To motivate graduates towards innovations and research in the field of electrical & electronics engineering,relevant to the welfare of the society.
4. To create graduates well prepared to modern and global industry requirements.
5. To expose our graduates to the latest technology and research through industry and research institutes collaborations.

Program Educational Objectives:-

PEO 1. Graduates will excel in professional careers and/or higher education by acquiring knowledge in Mathematics, Science, Engineering principles and Computational skills.
PEO 2. Graduates will analyze real life problems, design Electrical systems appropriate to the requirement that are technically sound, economically feasible and socially acceptable.
PEO 3. Graduates will exhibit professionalism, ethical attitude, communication skills, team work in their profession, adapt to current trends by engaging in lifelong learning and participate in Research & Development.

Program Outcomes of B.Tech in Electrical and Electronics Engineering

1.Engineering knowledge: Apply the knowledge of mathematics, science, engineeringfundamentals, and an engineering specialization to the solution of complex engineering problems.

2.Problem analysis: Identify, formulate, review research literature, and analyze complexengineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3.Design/development of solutions: Design solutions for complex engineering problems anddesign system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4.Conduct investigations of complex problems: Use research-based knowledge and researchmethods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5.Modern tool usage: Create, select, and apply appropriate techniques, resources, and modernengineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.

6.The engineer and society: Apply reasoning informed by the contextual knowledge to assesssocietal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7.Environment and sustainability: Understand the impact of the professional engineering solutionsin societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8.Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms ofthe engineering practice.

9.Individual and team work: Function effectively as an individual, and as a member or leader indiverse teams, and in multidisciplinary settings.

10.Communication: Communicate effectively on complex engineering activities with the engineeringcommunity and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11.Project management and finance: Demonstrate knowledge and understanding of theengineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12.Life-long learning: Recognize the need and have the preparation and ability to engage in independent and life-long learning in the broadestcontext of technological change.

PSO 1. An ability to identify, formulate and solve problems in the areas of Electrical and Electronics Engineering.

PSO 2. An ability to use the techniques, skills and modern engineering tools necessary for innovation.

Scope and Objectives of the Course

The aim of the course is to provide the basic knowledge for the requirement of Power Electronics in the modern day life. In this regard, the course aims to equip the student with the basic understanding of the power semiconductor devices, their operating principles along with their control circuitry together with the review of electric and magnetic circuits. With this course, the student will be equipped with the knowledge in the wide range of power electronic converter circuits for AC-DC, DC-DC and DC-AC power conversion which are generally employed in various consumer and industrial electronic applications.

After the completion of this course the students will be able to:

CO 1: Enumerate the basic power electronic devices.

CO 2: Application of power electronic devices in power circuits in industrial drives.

CO 3: Design and control of power electronic converter circuits.

CO 4: Decision for the techniques to mitigate converter harmonics.

Mapping of CO’s with PO’s

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO 1	3	2	3	-	2	-	-	1	-	-	-	1	3	2
CO 2	3	3	3	2	-	-	2	1	3	3	1	3	-	2
CO 3	2	-	3	3	3	-	-	2	1	3	3	3	3	2
CO 4	3	2	3	2	3	2	-	1	-	-	-	3	3	1

Syllabus

Power Electronics

Course Code- 031609

L-T-P: 3-0-3 **Credit : 5**

1. Introduction to thyristor and control circuits : terminal characteristic, rating and protection.

2. Thyristor firing circuit : Triggering circuit suitable for 1 phase and 3 phase fully controlled converters.

3. Converters : Uncontrolled three phase power rectifiers, 1 phase & 3 phase line commutated A.C to D.C converters.

4. Inverters : Basic Bridge inverter circuit 1 phase & 3 phase phase McMurrayBedford method of communication, pulse width modulation inverters. Series inverter gating circuits.

5. Choppers : Types of choppers, steady state analysis of type A chopper, communication methods, chopper control of D.C. Motor.

6. Other applications A.C., voltage regulator, cyclo-converter.

7. Application of thyristors for industrial drives.

GATE Syllabus :

Characteristics of semiconductor power devices: Diode, Thyristor, Triac, GTO, MOSFET, IGBT; DC to DC conversion: Buck, Boost and Buck-Boost converters; Single and three phase configuration of uncontrolled rectifiers, Line commutated thyristor based converters, Bidirectional ac to dc voltage source converters, Issues of line current harmonics, Power factor, Distortion factor of ac to dc converters, Single phase and three phase inverters, Sinusoidal pulse width modulation.

DARBHANGA COLLEGE OF ENGINEERING, DARBHANGA **w.e.f. – 29-01-18**

EEE

Semester – 6th, Session (2015-19)

Day	1 (10am-10.50am)	2 (10.50am-11.40am)	3(11.40am-12.30pm)	4(12.30pm-1.20pm)	Lunch (1.20pm – 1.50pm)	5(1.50pm – 2.40pm)	6(2.40pm-3.30pm)	7(3.30pm-4.20pm)
Monday								
Tuesday				Power Electronics				
Wednesday								
Thursday				Power Electronics				
Friday								
Saturday				Power Electronics				

DARBHANGA COLLEGE OF ENGINEERING, DARBHANGA

6^{th} Sem. Branch:- EEE Batch- (2015-19)
Subject :- Power Electronics

S.No.	Name	Class Roll
01	Shashi Kant	15-EE-01
02	Md. Ashraf Ansari	15-EE-02
03	Abrar Ahamad	15-EE-03
04	Randhir Kumar	15-EE-04
05	Priti Kumari	15-EE-05
06	Rahul Kumar	15-EE-06
07	Shashank Kumar	15-EE-07
08	Puja Kumari	15-EE-08
09	Bipul Chandra	15-EE-09
10	Mukul Raj	15-EE-10
11	Sushil Kumar Paswan	15-EE-11
12	Vivek Kumar	15-EE-13
13	Rohit Kumar Mahto	15-EE-14
14	Ladly Kumari	15-EE-16
15	Ayesha Jahan	15-EE-17
16	Vikash Ranjan	15-EE-18
17	Tuhina Kumari	15-EE-19
18	Raushan Kumar	15-EE-20
19	Mukesh Kumar Pandit	15-EE-21
20	Anand Raj	15-EE-22
21	Ranjan Bharti	15-EE-23
22	Ranjan Kumar	15-EE-24
23	Deepak Kumar	15-EE-27
24	Nidhi	15-EE-28
25	Chandan Kumar Sah	15-EE-29
26	Rahul Kumar	15-EE-30
27	Sunny Kant Raj	15-EE-31
28	Ravi Ranjan Kumar	15-EE-32
29	Nishant Saurabh	15-EE-33
30	Ajeet Kumar Pandit	15-EE-34

31	Divakar Kumar	15-EE-35
32	Prince Kumar	15-EE-36
33	Vivek Kumar	15-EE-37
34	Hemant Kumar	15-EE-38
35	Jalandhar Kumar Nishad	15-EE-39
36	Avinash Kumar	15-EE-40
37	Rupa Kumari	15-EE-41
38	Hemant Kumar	15-EE-42
39	Alok Kumar	15-EE-43
40	Nitish Kumar	15-EE-44
41	Rahul Kumar	15-EE-45
42	Tarannum Parween	15-EE-46
43	Kranti Kumari	15-EE-47
44	Puja Kumari	15-EE-48
45	Rupesh Kumar Singh	15-EE-49
46	Amit Kumar	15-EE-50
47	Anshu Kumari	15-EE-51
48	Abhimanyu Kumar Sinha	15-EE-52
49	Gaurav Kharga	15-EE-53
50	Rituraj	15-EE-54
51	Priti Kumari	15-EE-55
52	Kanhaiya Kumar	15-EE-56
53	Sanjit Kumar Yadav	15-EE-57
54	Sanyam Kumar	15-EE-58
55	Kumari Shanu Raj	15-EE-59
56	Sunny Alok	15-EE-60
57	Shankar Kumar	15-EE-61
58	Pooja Roy	16(LE)EE-01
59	Rupak Kumari	16(LE)EE-02
60	Sumant Kumar Chouhan	16(LE)EE-03
61	Prabhakar Kumar	16(LE)EE-04

Institute / College Name :		**DARBHANGA COLLEGE OF ENGINEERING, DARBHANGA**	
Program Name		B.Tech., ELECTRICAL AND ELECTRONICS ENGINEERING	
Course Code		031609	
Course Name		POWER ELECTRONICS	
Lecture / Tutorial (per week):	3/0	**Course Credits**	3
Course Coordinator Name		Ms. SWETA KUMARI	

1. Scope and Objectives of the Course

The aim of the course is to provide the basic knowledge for the requirement of Power Electronics in the modern day life. In this regard, the course aims to equip the student with the basic understanding of the power semiconductor devices, their operating principles along with their control circuitry together with the review of electric and magnetic circuits. With this course, the student will be equipped with the knowledge in the wide range of power electronic converter circuits for AC-DC, DC-DC and DC-AC power conversion which are generally employed in various consumer and industrial electronic applications.

After the course the student should be able to:

- Understand the importance of Power Electronics and its applications in modern day life.
- Describe the modern power semiconductor devices such as Power Diodes, BJTs, MOSFETs, Thyristors, IGBT etc., their operation and control along with their protection schemes
- Calculate the power dissipation in the Power electronic component and design a cooling system.
- Select a suitable power converter topology depending on application.
- Design a power converter for a given application.
- Understand and analyze the quality of the input/output waveforms in different converter circuits which are a major concern with respect to its surroundings

2. Textbooks

TB1: ‘ Power Electronics Converters, Applications And Design’ By “Ned Mohan”, John Wiley & Sons

TB2: ‘ Power Electronics Circuits, Devices And Applications’ By Muhammad H. Rashid, PHI

3. Reference Books

RB1: ‘Power Electronics’ By “Dr. P.S. Bhimbhra”, Khanna Publication

RB2: ‘Thyristorised Power Controllers’ by “G.K dubey”, Wiley Eastern Ltd.

Other readings and relevant websites

S.No.	**Link of Journals, Magazines, websites and Research Papers**
1.	http://onlinelibrary.wiley.com/book/10.1002/9780470547113/homepage/AuthorBiography.html
2.	http://ieeexplore.ieee.org/abstract/document/1667898/
3.	https://books.google.co.in/books?hl=en&lr=&id=oxR8vB2XjgIC&oi=fnd&pg=PA1&dq=power+electronic+applications+converters&ots=KSiEoGq2Hn&sig=tKX5yfR03rBu26J

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4.	http://ieeexplore.ieee.org/search/searchresult.jsp?queryText=power%20electronics%20converters&newsearch=true
5.	https://www.sciencedirect.com/search?qs_cid=&qs=power+electronics&authors=&pub=&volume=&issue=&page=&origin=browse&zone=qSearch
6.	www.delnet.in

7. Course Plan

Lecture Number	Date of Lecture	Topics	Web Links for video lectures	Text Book / Reference Book / Other reading material	Page numbers of Text Book(s)
		Introduction to power electronics		RB1	
1-3		Introduction to signal semiconductor devices and power semiconductor devices like power diodes, BJT, MOSFETs and IGBTs.	https://www.youtube.com/watch?v=1Auay7ja2oY , https://www.youtube.com/watch?v=PEg0zb3cg2A		
Assignment I					
Power transistors, MOSFET's, SCR's, IGBT's, UJT's (power electronic devices) operation, structure and circuit analysis, design and control					
		Thyristors		TB1,TB2	596-610 (TB1), 304-312 and 338-340 (TB2)
4-6		Introduction to thyristor construction, gate control circuit, terminal characteristic, switching characteristics, gate characteristic, SCR rating and protection	https://www.youtube.com/watch?v=1Auay7ja2oY		
7-10		Thyristor firing circuit, Triggering circuit R, RC and UJT firing circuit.	https://www.youtube.com/watch?v=QqFIHhSkayw	TB2, RB1	195-213(RB1), 761-774(TB2)
11-12		Application of thyristors for industrial drives, control motor, power transmission applications	https://www.youtube.com/watch?v=r5TLR9uoQj8	TB1	449-454,460-479
Assignment II					
SCR structure control operation and terminal characteristics					
		AC to DC converter		TB1,TB2,RB1	121-152(TB1), 431-452 and 467-484(TB2)
13-24		Converters : Uncontrolled three phase power rectifiers, 1 phase & 3 phase line commutated A.C to D.C Controlled converters.	https://www.youtube.com/watch?v=fOZ8bUrFJGk		
Assignment III					

Single phase and three phase uncontrolled dc-dc converter circuit design and waveform analysis					
Mid semester exam (1- 24 lecture)					
		DC to AC converter		TB1,RB1	200-245
25-33		Introduction to Inverters single phase and three phase voltage source inverter, current source inverter, Pulse width modulation inverters. Series inverter	https://www.youtube.com/watch?v=7CReXeMAXHA		
Assignment IV					
Pulse width modulation control of inverters (DC-AC converters)					
		DC to DC converter		TB1,RB1	161-196
34-40		Introduction to Chopper circuits, step up and step down, steady state analysis of types of chopper, commutation methods, chopper control of D.C. Motor.	https://www.youtube.com/watch?v=7xyfMDDU-rw		
		Introduction to other useful power electronics devices		TB2,RB1	500-513, 526-535
40-44		Introduction to A.C. voltage regulator, cyclo-converter with different loads.	https://www.youtube.com/watch?v=Wr0NtKm6OyQ		

*All classes have home work with objective questions.

1. **Evaluation Scheme:**

Component 1	Mid Semester Exam	20
Component 2	Assignment Evaluation/Attendance/ Class Test	10
Component 3**	End Term Examination**	70
	Total	**100**

** The End Term Comprehensive examination will be held at the end of semester. The mandatory requirement of 75% attendance in all theory classes is to be met for being eligible to appear in this component.

SYLLABUS

Topics	No of lectures	Weightage
Introduction to thyristor and control circuits : terminal characteristic, rating and protection.	6	8%
Thyristor firing circuit : Triggering circuit suitable for 1 phase and 3 phase fully controlled converters.	4	10%
Converters : Uncontrolled three phase power rectifiers, 1 phase & 3 phase line commutated A.C to D.C converters.	12	35%
Inverters : Basic Bridge inverter circuit 1 phase & 3 phase phase McMurray-Bedford method of communication,pulse width modulation inverters. Series inverter gating circuits.	9	18%
Choppers : Types of choppers, steady state analysis of type A chopper, communication methods, chopper	7	15%

control of D.C. Motor.		
Other applications A.C., voltage regulator, cyclo-converter.	5	7%
Application of thyristors for industrial drives.	2	7%

Evaluation and Examination Blue Print:
Internal assessment is done through quiz tests, presentations, assignments and project work. Evaluation is a very transparent process and the answer sheets of sessional tests, internal assessment assignments are returned back to the students.
The components of evaluations along with their weightage followed by the University is given below
Mid sem 20%
Assignments/Quiz Tests/Seminars 10%
End term examination 70%

This Document is approved by:

Designation	**Name**	**Signature**
Course Coordinator	Ms. Sweta Kumari	
H.O.D	Mr. Santosh Kumar Gupta	
Principal	Dr. Aseem Kumar Thakur	
Date	15-02-2018	

DARBHANGA COLLEGE OF ENGINEERING

Department of Electrical and Electronics Engineering
Power Electronics (031609)

Assignment I

1. Explain structure and operating principal of power transistor.
2. Explain structure and operating principal of MOSFETs.
3. Explain structure and operating principal of SCR.
4. Explain structure and operating principal of IGBT.
5. Explain structure and operating principal of UJT.

DARBHANGA COLLEGE OF ENGINEERING

Department of Electrical and Electronics Engineering
Power Electronics (031609)

Assignment II

1. Explain structure and circuit symbol of SCR.
2. Explain operating principal of SCR.
3. Explain terminal characteristics of SCR and related terms of V-I characteristics.

Department of Electrical and Electronics Engineering
Power Electronics (031609)

Assignment III

Draw the V_o (output voltage) and I_o (output current) and other related waveforms for single phase full wave controlled rectifier, bridge connection (B-2), with R and RL load also explain the waveforms in SCRs conducting and non conducting states. Derive general expression for average and rms value of the output voltage waveform.

DARBHANGA COLLEGE OF ENGINEERING

Department of Electrical and Electronics Engineering
Power Electronics (031609)

Assignment IV

Explain different methods of Pulse width modulation control of inverters (DC-AC converters) with neat and clean diagram.

Darbhanga College of Engineering, Darbhanga

EEE Department

B.Tech, Semester VI (EEE)

Mid. Sem Exam

(Subject Code : 031609)

Power Electronics

Time: 2 Hours ***Max. Marks: 20***

Note: Attempt all four questions.

1. a) What is a diode? Explain i-v characteristics of ideal signal and power diode. [CO1] [3]

   b) Discuss how the power diodes are different from signal diodes. [CO1] [2]

   OR

   Enumerate the types of power transistors along with their circuit symbol. [CO1] [5]

2. Briefly explain the UJT firing circuit of a thyristor. [CO2] [5]
3. Discuss in detail three-phase 120 degree mode voltage source inverter. [CO3] [5]

   OR

   A single-phase full converter bridge is connected to RLE load. The source voltage is 230V, 50 Hz. The average load current of 10A is constant over the working range. For $R=0.4\Omega$ and $L= 2mH$, compute

   a) Firing angle delay for $E= 120$ V,

   b) Firing angle delay for $E= -120$ V.

   Indicate which source is delivering power to load in parts (a) and (b). Sketch the time variation of output voltage and load current for both the parts. [CO3] [5]

4. Briefly discuss the different types of PWM scheme available for voltage control in an inverter. [CO4] [5]

(iii) the r.m.s. and peak current of each thyristor;

(iv) the conduction time of thyristors and diodes if only fundamental component is considered.

9. (a) Sketch static *I-V* characteristics of a thyristor. Label the various voltages, currents and the operating modes on this sketch.

(b) SCR with a rating of 1000 V and 200 A are available to be used in a string to handle 6 kV and 1 kA. Calculate the no. of series and parallel units required in case derating factors are (i) 0·1 and (ii) 0·2.

* * *

Code : 031609

B.Tech. 6th Semester Exam., 2014

POWER ELECTRONICS

Time : 3 hours *Full Marks* : 70

Instructions :

(i) The questions are of equal value.

*(ii) There are **NINE** questions in this paper.*

*(iii) Attempt **FIVE** questions in all.*

(iv) Question No. 1 is compulsory.

1. Choose the correct answer (any *seven*) :

(a) Power electronic device with poor turn-off gain is

(i) symmetrical thyristor

(ii) conventional thyristor

(iii) power bipolar junction transistor

(iv) gate turn-off thyristor

(b) It is preferable to use a train of pulse of high frequency for gate triggering of SCR in order to reduce

(i) $\frac{dv}{dt}$ problem

(ii) $\frac{di}{dt}$ problem

(iii) the size of the pulse transformer

(iv) the complexity of the firing circuit

(c) In a fully-controlled converter, the load voltage is controlled by which of the following quantity?

(i) Extension angle

(ii) Firing angle

(iii) Conduction angle

(iv) None of the above

(d) In a single-phase full-wave controlled bridge rectifier, minimum output voltage and maximum output voltage are obtained at which conduction angle?

(i) 0°, 180° respectively

(ii) 180°, 0° respectively

(iii) 0°, 0° respectively

(iv) 180°, 180° respectively

(e) In the continuous conduction mode, the output voltage waveform does not depend on

(i) firing angle

(ii) conduction angle

(iii) supply

(iv) load

(f) A step-down chopper is operated in the continuous conduction mode in steady state with a constant duty ration D. If V_o is the magnitude of the d.c. output voltage and V_s is the magnitude of the d.c. input voltage, the ratio V_o / V_s is given by

(i) D (ii) $1 - D$

(iii) $\frac{1}{1-D}$ (iv) $\frac{D}{1-D}$

(g) In a single-pulse modulation PWM inverter, third harmonics can be eliminated if the pulse-width is made equal to

(i) 30° (ii) 150°

(iii) 60° (iv) 120°

(h) In case of voltage-source inverter, free-wheeling can be needed for the load of

(i) inductive nature

(ii) capacitive nature

(iii) resistive nature

(iv) back e.m.f. nature

(i) PWM switching is preferred in voltage-source inverters for the purpose of

(i) controlling output voltage

(ii) output harmonics

(iii) reducing filter size

(iv) controlling output voltage, output harmonic and reducing filter size

(j) Compared to a single-phase half-bridge inverter, the output power of a single-phase full-bridge inverter is higher by a factor of

(i) 12 (ii) 8

(iii) 4 (iv) 2

2. (a) Circuit of given Fig. 1, employing resonant-pulse commutation (or class-B commutation) has $C = 20\mu F$ and $L = 5\ \mu H$. Initial voltage across capacitor is $V_s = 230$ V, for a constant load current of 300 A, calculate—

(i) conduction time for the auxiliary thyristor;

(ii) voltage across the main thyristor when it gets commutated;

(iii) the circuit turn-off time for the main thyristor.

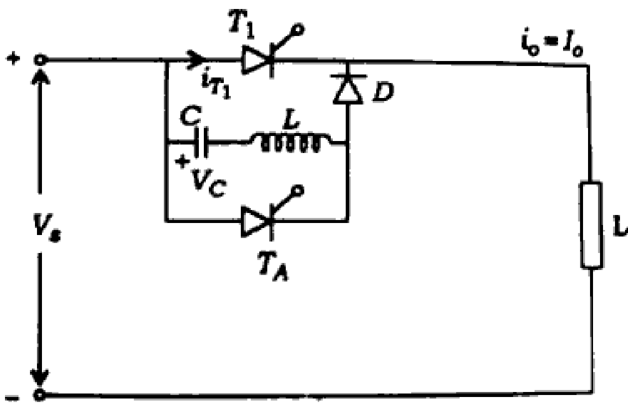

Fig. 1

(b) What is complementary impulse commutation?

3. A d.c. battery is charged through a resistor R as shown in Fig. 2. Derive an expression for the average value of charging current in terms of V_m, E, R, etc.

On the assumption that SCR is fired continuously—

(a) for an a.c. source voltage of 230 V, 50 Hz, find the value of average charging current for $R = 8\ \Omega$ and $E = 150$ V;

(b) find the power supplied to battery and that dissipated in the resistor;

(c) calculate the supply p.f.

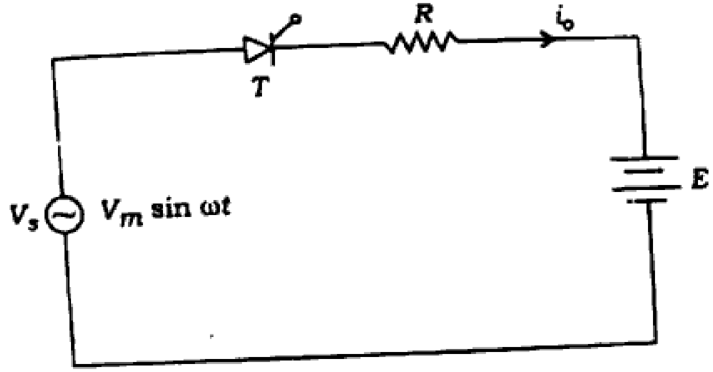

Fig. 2

4. A single-phase full-converter bridge is connected to RLE load. The source voltage is 230 V, 50 Hz. The average load current of 10 A is constant over the working range for $R = 0 \cdot 4\ \Omega$ and $L = 2$ mH.

(a) Compute the firing angle delay for $E = 120$ V.

(Turn Over)

(b) Compute the firing angle delay for $E = -120$ V.

Indicate which source is delivering power to load in parts (a) and (b). Sketch the time variations of output voltage and load current for both the parts.

(c) In case output current is assumed constant, find the input p.f. for both the parts (a) and (b).

5. (a) For type-A chopper of Fig. 3, DC source voltage = 230 V, load resistance = 10 Ω. Take a voltage drop of 2 V across chopper when it is on, for a duty cycle of 0·4, calculate—

(i) the average and r.m.s. values of output voltage;

(ii) the chopper efficiency.

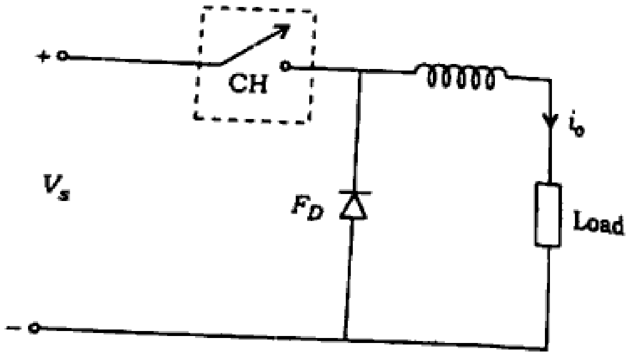

Fig. 3

(b) What is meant by step-up chopper? Explain its operation.

6. A step-down chopper, fed from 220 V d.c. is connected to RL load with $R = 10\,\Omega$ and $L = 150$ mH, chopper frequency is 1250 Hz and duty cycle is 0·5. Calculate—

(a) the minimum and maximum value of load current;

(b) the maximum value of ripple current;

(c) the average and r.m.s. values of load current;

(d) the r.m.s. value of chopper current.

7. With the help of equivalent circuit, obtain the nature of waveform of phase voltage of a star-connected resistive load fed from a three-phase DC to AC bridge-inverter operating in 180° conduction mode.

8. (a) Describe the working of single-phase full-bridge inverter.

(b) A single-phase full-bridge inverter has R-L-C load of $R = 4\,\Omega$, $L = 35$ mH and $C = 155\,\mu$F. The DC input voltage is 230 V and the output frequency is 50 Hz. Find an expression for load current up to fifth harmonic.

Also calculate—

(i) the r.m.s. value of fundamental load current;

(ii) the power absorbed by load and the fundamental power;

6. (a) Describe the principle of d.c. chopper operation.

   (b) Derive an expression for its average d.c. output voltage. 6+8=14

7. (a) Describe integral cycle control type a.c. voltage controller.

   (b) Enumerate the merits and demerits of a.c. voltage controller. 8+6=14

8. (a) Draw the basic integrated structure and the *V-I* characteristics of a TRIAC and briefly explain its principle of working.

   (b) Briefly explain the working of an oscillator employing a UJT. Derive the expressions for the frequency of triggering firing angle delay in terms of η, and the charging resistance values. 6+8=14

9. Write short notes on any *two* of the following : 7×2=14

   (a) Uninterrupted power supply

   (b) Regenerative braking control

   (c) Speed control of three-phase induction motor

   (d) HVDC transmission

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Code : 031609

B.Tech 6th Semester Exam., 2015

POWER ELECTRONICS

Time : 3 hours *Full Marks* : 70

Instructions :

(i) The marks are indicated in the right-hand margin.

*(ii) There are **NINE** questions in this paper.*

*(iii) Attempt **FIVE** questions in all.*

*(iv) Question No. **1** is compulsory.*

1. Choose the correct option (any *seven*) : 2×7=14

   (a) When an SCR is reverse biased

   (i) two junctions are reverse biased and one junction is forward biased

   (ii) all the three junctions are reverse biased

   (iii) one junction is reverse biased and two junctions are forward biased

   (iv) Any of the above depending on the magnitude of reverse bias

(b) An R-C snubber circuit is used to protect a thyristor against

(i) false triggering

(ii) failure to turn on

(iii) switching transients

(iv) failure to commutate

(c) A single-phase semiconverter is feeding a highly inductive load and has free-wheeling diode across the load. The waveshapes of output voltage and output current

(i) are similar

(ii) are not similar

(iii) may be similar or dissimilar

(iv) are similar only if firing angle is zero

(d) A single-phase half-wave rectifier is feeding a resistive load. Input voltage $v = V_m \sin \omega t$. The output d.c. voltage is $V_{d.c.}$ and output r.m.s. voltage is $V_{r.m.s.}$. If firing angle is 180°, $V_{d.c.}$ and $V_{r.m.s.}$ respectively are

(i) 0 and 0 (ii) $\frac{V_m}{\pi}$ and $\frac{V_m}{\sqrt{2}}$

(iii) 0 and $-V_m$ (iv) $-\frac{V_m}{\pi}$ and $-\frac{V_m}{2}$

(e) In a step-down chopper using pulse-width modulation $T_{on} = 3 \times 10^{-3}$ s and $T_{off} = 1 \times 10^{-3}$ s. The chopping frequency is

(i) 333.33 (ii) 250

(iii) 500 (iv) 1000

(f) In a three-phase full-wave regulator feeding a star-connected resistance load the input voltage is 400 V line to line. The firing angle is 160°. The line to line output voltage would be

(i) 400 V (ii) about 100 V

(iii) about 20 V (iv) zero

(g) Assertion (A) :

An inverter does not require forced commutation.

Reason (R) :

A series inverter is a forced commutation inverter.

(i) Both A and R are correct and R is correct explanation of A

(ii) Both A and R are correct but R is not correct explanation of A

(iii) A is correct but R is wrong

(iv) A is wrong but R is correct

(h) A three-phase bridge inverter is fed by 400 V battery. The load is star-connected and has a resistance of 10 Ω per phase. The peak value of load current is

(i) 8 A

(ii) 20 A

(iii) 10 A

(iv) 5 A

(i) The waveshape of output voltage of half-bridge inverter is

(i) sinusoidal

(ii) square

(iii) triangular

(iv) Either (i) or (ii)

(j) In dielectric heating, the thyristor circuits consist of

(i) rectifier-chopper combination

(ii) controlled rectifier

(iii) a.c. regulator

(iv) rectifier-inverter combination

2. (a) Discuss some of the advantages and disadvantages of power electronic converters.

(b) Define latching and holding currents as applicable to an SCR. Show these on the *V-I* characteristics. 6+8=14

3. (a) Why are dv/dt and di/dt protections in case of thyristor important?

(b) An SCR operating from a peak supply voltage of 400 V has the following specifications :

Repetitive peak current

$I_p = 200$ A

(di/dt) max $= 50$ A / us

(dv/dt) max $= 200$ V / us

Choosing a factor of safety of 2 for I_p, (di/dt) max and (dv/dt) max, design a suitable snubber circuit. The minimum value of load resistance is 10 ohms. 8+6=14

4. (a) Explain the principle of phase control with suitable diagram and waveform.

(b) Discuss in detail three-phase full converter with *R-L-E* load with suitable diagram and waveform. 7+7=14

5. (a) What is inverter? List a few industrial applications of inverter.

(b) Discuss in detail three-phase 120 degree mode voltage source inverter. 7+7=14

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B.Tech 6th Semester Exam., 2016

POWER ELECTRONICS

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1. Choose the correct option (any *seven*) : 2×7=14

(a) A single-phase one pulse diode rectifier is feeding an RL load with freewheeling diode across the load. For conduction angle β, the main diode and freewheeling diode would, respectively, conduct for

(i) π, $\pi - \beta$

(ii) π, $\beta - \pi$

(iii) β, π

(iv) $\beta - \pi$, π

(b) When a thyristor is forward biased, the number of blocked *p-n* junctions is

(i) 1

(ii) 2

(iii) 3

(iv) 4

(c) During forward blocking state, a thyristor is associated with

(i) large current, low voltage

(ii) low current, large voltage

(iii) medium current, large voltage

(iv) low current, medium voltage

(d) When a UJT is used for triggering an SCR, the wave shape of the voltage obtained from UJT circuit is a

(i) sine wave

(ii) sawtooth wave

(iii) trapezoidal wave

(iv) square wave

(e) In a commutation circuit employed to turn off an SCR, satisfactory turn-off is obtained when

(i) circuit turn-off time < device turn-off time

(ii) circuit turn-off time > device turn-off time

(iii) circuit time constant > device turn-off time

(iv) circuit time constant < device turn-off time

(f) A step-up chopper has V_s as the source voltage and α as the duty cycle. The output voltage for this chopper is given by

(i) $V_s(1+\alpha)$

(ii) $V_s/(1-\alpha)$

(iii) $V_s(1-\alpha)$

(iv) $V_s/(1+\alpha)$

(g) In an inverter with fundamental output frequency of 50 Hz, if third harmonic is eliminated, then the frequencies of other components in the output voltage wave, in Hz, would be

(i) 250, 350, 450, high frequencies

(ii) 50, 250, 350, 450

(iii) 50, 250, 350, 550

(iv) 50, 100, 200, 250

(h) A cycloconverter is a frequency converter from

1. higher to lower frequency with one-stage conversion
2. higher to lower frequency with two-stage conversion
3. lower to higher frequency with one-stage conversion
4. AC at one frequency to DC and then DC to AC at different frequencies

From these, the correct statement(s) is/are

(i) 2, 4

(ii) 1 only

(iii) 2, 3

(iv) 1, 3

(i) If, for a single-phase half-bridge inverter, the amplitude of output voltage is V_s and the output power is P, then their corresponding values for a single-phase full-bridge inverter are

(i) V_s, P

(ii) $2V_s$, P

(iii) $2V_s$, $2P$

(iv) $2V_s$, $4P$

(j) In DC choppers, the waveforms for input and output voltages are respectively

(i) discontinuous, continuous

(ii) both continuous

(iii) both discontinuous

(iv) continuous, discontinuous

2. (a) Briefly discuss the *V-I* characteristic of SCR. 6

(b) Explain the turn-on and turn-off characteristics of SCR with neat waveforms. 8

3. *(a)* Explain the operation of three-phase half-wave controlled converter for a firing angle less than 30° and feeding R load. Also derive the expression for its average output voltage. 8

(b) The specification sheet for an SCR gives maximum rms on-state current as 35 A. If this SCR is used in a resistive circuit, compute average on-state current rating for half sine wave current for conduction angle of 180°. 6

4. *(a)* Explain the effect of source inductance in the operation of single-phase fully controlled converter. 8

(b) With neat circuit diagram and waveform, explain the working principle of single-phase AC voltage controller with R-L load. 6

5. *(a)* Explain the principle of operation of three-phase inverter with 180° conduction mode with necessary waveforms and circuit. 8

(b) A step-up chopper has input voltage of 220 V and output voltage of 660 V. If the conducting time of thyristor-chopper is 100 μs, compute the pulse width of output voltage. In case output-voltage pulse width is halved for constant frequency operation, find the average value of new output voltage. 6

6. *(a)* Explain the two-transistor analogy of a thyristor. 7

(b) Discuss the various mechanisms that can be used to trigger thyristors. 7

7. *(a)* Discuss the operation of step-up chopper and prove that its output voltage is greater than input voltage. 8

(b) Snubber circuit for an SCR should primarily consist of capacitor only. But, in actual practice, a resistor is used in series with capacitor. Discuss. 6

8. *(a)* With neat circuit diagram and waveform, explain the operating principle of 1-ϕ to 1-ϕ step down mid-point type cycloconverter, with continuous load current. Assume the loads to be R and L in series. 8

(b) A single-phase half-wave AC voltage controller feeds a load of $R = 20\,\Omega$ with an input voltage of 230 V, 50 Hz. Firing angle of thyristor is 45°. Determine—

(i) rms value of output voltage;

(ii) average input current. 6

9. Briefly discuss the different types of PWM schemes available for voltage control in an inverter. 14

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POWER ELECTRONICS

6^{th} SEM EEE

Questions & Answers

UNIT – I

1. What is power electronics?

Power electronics is a subject that concerns the applications electronics principles into situations that are rated at power level rather than signal level. It may be defined as a subject deals with the apparatus and equipment working on the principle of electronics but at rated power level.

2. Give the applications of power electronics.

i. Aerospace
ii. Commercial
iii. Industrial
iv. Telecommunications

3. Classify power semiconductor devices give examples.

i. Diodes: power diodes
ii. Thyristors: SCR
iii. Control switches: BJT, MOSFET and IGBT

4. What are the types of power transistors?

a) Bipolar Junction Transistor (BJT)
b) Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
c) Insulated Gate Bipolar Transistor (IGBT)

5. Why IGBT is very popular nowadays?

a. Lower hate requirements
b. Lower switching losses
c. Smaller snubber circuit requirements

6. **What are the different methods to turn on the thyristor?**

a. Forward voltage triggering
b. Gate triggering
c. dv/dt triggering
d. Temperature triggering
e. Light triggering

7. What is the difference between power diode and signal diode?

S.No.	Power diode	Signal diode
1.	Constructed with n-layer, called drift region between p+ layer and n+ layer.	Drift region is not present.
2.	The voltage, current and power ratings are higher.	Lower

3.	Power diodes operate at high speeds.	Operates at higher switching speed.

8. IGBT is a voltage-controlled device. Why?
Because the controlling parameter is gate-emitter voltage.

9. Power MOSFET is a voltage-controlled device. Why?
Because the output (drain) current can be controlled by gate-source voltage.

10. Power BJT is a current controlled device. Why?
Because the output (collector) current can be controlled by base current.

11. What is the relation between α and β?
$\beta = \alpha / 1- \alpha$ or $\alpha = \beta / 1+ \beta$

12. What are the different types of power MOSFET?
a. N-channel MOSFET
b. P-channel MOSFET

13. How can a thyristor turned off?
A thyristor can be turned off by making the current flowing through it to a level below the holding current.

14. Define latching current.
The latching current is defined as the minimum value of anode current which it must attain during turn on process to maintain conduction when gate signal is removed.

15. Define holding current.
The holding current is defined as the minimum value of anode current below which it must fall to for turning off the thyristor.

16. What is a snubber circuit?
It consists of a series combination of a resistor and a capacitor in parallel with the thyristors. It is mainly used for dv / dt protection.

17. What losses occur in a thyristor during working conditions?
a. Forward conduction losses
b. Loss due to leakage current during forward and reverse blocking.
c. Switching losses at turn-on and turn-off.
d. Gate triggering loss.

18. Define hard-driving or over-driving.
When gate current is several times higher than the minimum gate current required, a thyristor is said to be hard-fired or over-driven. Hard-firing of a thyristor reduces its turn-on time and enhances its di/dt capability.

19. Define circuit turn off time.
It is defined as the time during which a reverse voltage is applied across the thyristor during its commutation process.

20. Why circuit turn off time should be greater than the thyristor turn-off time?
Circuit turn off time should be greater than the thyristor turn-off time for reliable turn-off, otherwise the device may turn-on at an undesired instant, a process called commutation failure.

21. What is meant by commutation?
It is the process of changing the direction of current flow in a particular path of the circuit. This process is used in thyristors for turning it off.

22. What are the types of commutation?
a. Natural commutation
b. Forced commutation

23. What is the turn-off time for converter grade SCRs and inverter grade SCRs?
Turn-off time for converter grade SCRs is 50 – 100 ms turn-off time for converter grade SCRs and inverter grade SCRs and for inverter grade SCRs is 3 – 50 ms.

24. What are the advantages of GTO over SCR?

i. Elimination of commutation of commutating components in forced commutation, resulting in reduction in cost, weight and volume.
ii. Reduction in acoustic noise and electromagnetic noise due to elimination of commutation chokes.
iii. Faster turn-off, permitting high switching frequencies. Improved efficiency of the converters.

25. Write down the applications of IGBT?
They are widely used for medium power applications.

a) AC and DC motor drives
b) UPS systems
c) Power supplies
d) Relays and Contactors

26.Compare Power MOSFET with BJT.

Power MOSFET	BJT
1. Lower Switching loss	Higher switching loss
2. high on state resistance so more conduction losses	lower conduction losses
3.Voltage controlled device	Current controlled device
4.It has positive temperature coefficient	It has negative temperature coefficient

27.Why IGBT is very popular now a days?

i. Lower gate drive requirement
ii. Lower switching losses

iii. Smaller snubber circuit requirements

28.What are the different methods to turn on the thyristor?
Forward voltage triggering, Gate triggering, dv/dt triggering, temperature triggering & light triggering

29. Define forward breakover voltage .
When anode is positive w.r.to cathode with gate current open, the junction J1 & J3 are forward biased but J2 is reverse biased. When the forward voltage is increased junction J2 will have an avalanche breakdown at a voltage. This voltage is called forward breakover voltage.

30. Define reverse breakover voltage .
When cathode is positive w.r.to anode with gate current open, the junction J1 & J3 are reverse biased but J2 is forward biased. When the reverse voltage is increased junctions J1 & J3 will have an avalanche breakdown at a voltage. This voltage is called as critical breakdown voltage Vbr.

31.IGBT is a voltage controlled device. Why?
IGBT is a voltage controlled device because the controlling parameter is gate emitter voltage V_{GE}

32.Power MOSFET is a voltage controlled device. Why?
Power MOSFET is a voltage controlled device because the output current can controlled by gate source voltage V_{GS}.

<u>16 MARK QUESTIONS:</u>

1. Explain special features of thyristor, triac and GTO. Draw relevant diagrams.

2. Explain the constructions and switches charactertics of power MOSFETs.

3. Discuss the circuit arrangements that are necessary for proper operation of parallel-connected thyristors.

4. Explain the various types of triggering methods of SCR.

5. What are the problems in series and parallel operation of SCRs?. How they are overcome.

6. Compare SCRs with power transistors and mention their fields of applications.

7. Draw the V-I charactertics of an SCR and explain its shape. How do these charactertics change with gate current variation?

8. Discuss the turn-on and turn-off charactertics of GTO and how it can be turned on and off.

9. Explain with neat diagrams, the four modes of operation of a triac.

10. Explain the dynamic charactertics of a thyristor during turn-off. What type of protection is needed for a thyristor**?**

UNIT – II – PHASE CONTRLLED CONVERTERS

1. What is meant by phase controlled rectifier?
It converts fixed ac voltage into variable dc voltage.

2. **Mention some of the applications of controlled rectifier**.

i. Steel rolling mills, printing press, textile mills and paper mills employing dc motor drives.
ii. DC traction
iii. Electro chemical and electro-metallurgical process
iv. Portable hand tool drives
v. Magnet power supplies
vi. HVDC

3. What is the function of freewheeling diodes in controlled rectifier?
It serves two process.
l. It prevents the output voltage from becoming negative.
2. The load current is transferred from the main thyristors to the freewheeling diode, thereby allowing all of its thyristors to regain their blocking states.

4. What are the advantages of freewheeling diodes in a controlled in a controlled rectifier?
a. Input power factor is improved.
b. Load current waveform is improved and thus the load performance is better.

5. What is meant by delay angle?
The delay angle is defined as the angle between the zero crossing of the input voltage and the instant the thyristor is fired.

6. What are the advantages of single phase bridge converter over single phase mid-point converter?
a. SCRs are subjected to a peak-inverse voltage of 2Vm in a fully controlled bridge rectifier. Hence for same voltage and current ratings of SCRs, power handled by mid-point configuration is about 2 times.
b. In mid-point converter, each secondary winding should be able to supply the load power. As such, the transformer rating in mid-point converter is double the load rating.

7. What is commutation angle or overlap angle?
The commutation period when outgoing and incoming thyristors are conducting is known as overlap period. The angular period, when both devices share conduction is known as the commutation angle or overlap angle.

8. What are the different methods of firing circuits for line commutated converter?
a.UJT firing circuit.

b. The cosine wave crossing pulse timing control.
c. Digital firing schemes.

9. Give an expression for average voltage of single-phase semiconverters.
Average output voltage $V_{dc} = (V_m / \pi)(1 + \cos \alpha)$.

10. What is meant by input power factor in controlled rectifier?
The input power factor is defined as the ratio of the total mean input power to the total RMS input volt-amperes.
$PF = (V_1 I_1 \cos \varphi_1) / (V_{rms} I_{rms})$
where V_1 = phase voltage, I_1 = fundamental component of the supply current, φ_1 = input displacement angle, I_{rms} = supply rms current.

11. What are the advantages of six-pulse converter?
a. Commutation is made simple.
b. Distortion on the ac side is reduced due to the reduction in lower order harmonics.
c.Inductance reduced in series is considerably reduced.

12. What does ac voltage controller mean?
It is device, which converts fixed alternating voltage into a variable voltage without change in frequency.

13. What are the applications of ac voltage controllers?
a. Domestic and industrial heating
b. Lighting control
c. Speed control of single phase and three phase ac motors
d. Transformer tap changing

14. What are the advantages of ac voltage controllers?
a. High efficiency
b. Flexibility in control
c. Less maintenance

15. What are the disadvantages of ac voltage controllers?
The main draw back is the introduction of harmonics in the supply current and the load voltage waveforms particularly at low output voltages.

16. What are the two methods of control in ac voltage controllers?
a. ON-OFF control
b. Phase control

17. What is the advantage of ON-OFF control?
Due to zero-voltage and zero current switching of thyristors, the harmonics generated by the switching action are reduced.

18. What is the difference between ON-OFF control and phase control?
ON-OFF control: In this method, the thyristors are employed as switches to connect the load circuit to the source for a few cycles of the load voltage and disconnect it for another few cycles. Phase control: In this method, thyristor switches connect the load to the ac source for a portion of each half cycle of input voltage.

19. **What is the disadvantage of ON-OFF control?**
This type of control is applicable in systems that have high mechanical inertia and high thermal time constant.

20. What is the duty cycle in ON-OFF control method?
Duty cycle K = n/ (n + m),
where n = no. of ON cycles, m = no. of OFF cycles.

21. What is meant by unidirectional or half-wave ac voltage controller?
Here the power flow is controlled only during the positive half-cycle of the input voltage.

22. What are the disadvantages of unidirectional or half-wave ac voltage controller?
a. Due to the presence of diode on the circuit, the control range is limited and the effective RMS output voltage can be varied between 70% to 100%.
b. The input current and output voltage are asymmetrical and contain a dc component. If there is an input transformer, saturation problem will occur
c. It is only used for low power resistive load.

23. What is meant by bidirectional or half-wave ac voltage controller?
Here the power flow is controlled during both cycles of the input voltage

24. **What is the control range of firing angle in ac voltage controller with RL load**?
The control range is < <180 , where = load power factor angle

25. What type of gating signal is used in single phase ac voltage controller with RL load?
High frequency carrier gating signal is used for single phase ac voltage controller with RL load.

26. What are the disadvantages of continuous gating signal?
a. More heating of the SCR gate.
b. Increases the size of pulse transformer.

27. What is meant by high frequency carrier gating?
Thyristor is turned on by using a train of pulses from to . This type of signal is called as high frequency carrier gating.

28. Define Displacement Factor.
The input displacement factor is defined as the cosine of the input displacement angle.

29. Define voltage ripple factor.
It is defined as the ratio of the net harmonic content of the output voltage to the average output voltage.

30. What is mean by uncontrolled rectifier?
The uncontrolled rectifier uses only diodes and it converts fixed ac voltage into fixed dc voltage.

31. How to classify rectifier circuits.
(i) Uncontrolled rectifier
(ii) Controlled rectifier

32. What is mean by full converter?
A fully controlled converter uses thyristors only and there is a wider control over the level of dc output voltage. It is also known as two quadrant converter.

33.What are the performance factors of line commutated converters?
Input displacement angle , input power factor, DC voltage ratio, Input harmonic factor, Voltage & current ripple factor.

34.What are the two configuration of single phase 2 pulse controlled rectifier?
i) Mid point converter
ii) Bridge Converter

35.What is meant by 2 pulse converter?
Two pulse converter is defined as two triggering pulses or two sets of triggering pulses are to be generated during every cycle of the supply to trigger the various SCRs.

36.What is meant by rectification mode in single phase fully controlled converter?
In single phase full converter $< 90^0$ the voltage at the dc terminal is positive. Therefore, power flows from source to load & the converter operates as a rectifier. Source voltage is Vs & Current is positive. This is known as rectification mode.

37.What is meant by inversion mode?
In single phase full converter $> 90^0$ the voltage at the dc terminal is negative. Therefore, power flows from load to source & the converter operates as line commutated inverter. Source voltage Vs is negative & Current is positive. This is known as inversion mode or synchronous mode.

38.What are the different types of controlled rectifier?
According to input supply – Single phase controlled rectifier & Three phase controlled rectifier
According to Quadrant operation – semiconverter , full converter, dual converter
According to no. pulses / cycle – one pulse, two pulse, three pulse , Six pulse & twelve pulse converter.

39.What are the difference between half controlled & fully controlled bridge rectifier?
Half Controlled Bridge Rectifier
1.Power circuit consists of mixture of diodes & SCRs
2.It is one quadrant Converter
3.The Dc output voltage has limited control level.
4.Input power factor is more.
Full Controlled Bridge Rectifier
1.Power circuit consists of SCRs only

2.It is 2 quadrant Converter
3.The Dc output voltage has wider control level.
4.Input power factor is less.

40.What is meant continuous current operation of thyristor converter?
When a free wheeling diode is connected across the output, load current continuous flow through the load. Whenever the load voltage tends to go to negative, free wheeling diode starts conduct. As a result load current is transferred from SCR to freewheeling diode. This is called continuous current operation as thyristor converter.

41. What is meant by sequence control of ac voltage regulators?
It means that the stages of voltage controllers in parallel triggered in a proper sequence one after the other so as to obtain a variable output with low harmonic content.

42. What are the advantages of sequence control of ac voltage regulators?
a. System power factor is improved.
b. Harmonics are reduced in the source current and the load voltage.

12 MARK QUESTIONS:

1. Describe the working of single-phase fully controlled bridge converter in the rectifying mode and inversion mode. Also sketch the following waveforms for delay angle load voltage, load current and thyristor voltage.

2. Explain the operation of 3phase, 6pulse bridge converter with resistive load. Draw the output voltage, voltage across T1 and current waveform of T2 for = 0. list the firing sequence of SCR.

3. Explain the method of phase control with relevant sketches derive an expression for r.m.s. Output voltage.

4. Explain the operation of dual converter with a neat circuit diagram.

5. Draw the circuit diagram of single-phase full wave fully controlled rectifier with inductive load. Explain the operation of circuit relevant sketches. Explain the operation of freewheeling diode on the performance of this circuit.

6. Explain the operation of a fully controlled thyristor bridge converter. Also, device expressions for the average load voltage and input power factor.

7. With a neat diagram and output waveforms explain the operation of 3-phase, 6pulse converter. Device expression for the d.c output voltage. When the source impedance effect is neglected and load is resistive.

8. Draw the power circuit diagram of a six pulse, two-quadrent converter circuit. Explain the operation of the circuit with necessary waveforms.

9. Explain the inverting operating and conditions for inversion of a fully controlled converter with relevant circuit diagram and waveforms.

10. Explain the clearly the effects of load inductance and source inductance on the performance of controlled rectifiers.

UNIT – III DC – DC CHOPPERS

1. **What is meant by commutation?**
It is the process of changing the direction of current flow in a particular path of the circuit. This process is used in thyristors for turning it off.

2. What are the types of commutation?
a. Natural commutation
b. Forced commutation

3. **What is meant by natural commutation?**
Here the current flowing through the thyristor goes through a natural zero and enable the thyristor to turn off.

4. **What is meant by forced commutation?**
In this commutation, the current flowing through the thyristor is forced to become zero by external circuitry.

5. **What is meant by dc chopper?**
A dc chopper is a high speed static switch used to obtain variable dc voltage from a constant dc voltage.

6. What are the applications of dc chopper?
a. Battery operated vehicles
b. Traction motor control in electric traction
c. Trolly cars
d. Marine hoists
e. Mine haulers
f. Electric braking.

7. What are the advantages of dc chopper?
Chopper provides
a. High efficiency
b. Smooth acceleration
c. Fast dynamic response
d. Regeneration

8. What is meant by step-up and step-down chopper?
In a step- down chopper or Buck converter, the average output voltage is less than the input voltage. In a step- up chopper or Boost converter, the average output voltage is more than the input voltage.

9. Write down the expression for average output voltage for step down chopper.
Average output voltage for step down chopper $V_0 = \alpha V_s$, α is the duty cycle

10. Write down the expression for average output voltage for step up chopper.
Average output voltage for step down chopper $V_0 = Vs$,
α is the duty cycle

11. **What is meant by duty-cycle**?
Duty cycle is defined as the ratio of the on time of the chopper to the total time period of the chopper. It is denoted by α.

12. What are the two types of control strategies?
a. Time Ratio Control (TRC)
b. Current Limit Control method (CLC)

13. **What is meant by TRC?**
In TRC, the value of T_{on} / T is varied in order to change the average output voltage.

14. What are the two types of TRC?
a. Constant frequency control

15. What is meant by FM control in a dc chopper?
In frequency modulation control, the chopping frequency f (or the chopping period T) is varied. Here two controls are possible.
a. On-time T_{on} is kept constant
b. Off period T_{off} is kept constant.

16. What is meant by PWM control in dc chopper?
In this control method, the on time Ton is varied but chopping frequency is kept constant. The width of the pulse is varied and hence this type of control is known as Pulse Width Modulation (PWM).

17. Write down the expression for the average output voltage for step down and step up chopper.
Average output voltage for step down chopper is $V_O = V_S$. Average output voltage for step up chopper is $V_O = V_S$ x [1/ (1-)].

18. What are the different types of chopper with respect to commutation process?
a. Voltage commutated chopper.
b. Current commutated chopper.
c. Load commutated chopper.

19. What is meant by voltage commutation?
In this process, a charged capacitor momentarily reverse biases the conducting thyristor and turn it off.

20. What is meant by current commutation?
In this process, a current pulse is made to flow in the reverse direction through the conducting thyristor and when the net thyristor current becomes zero, it is turned off

21. **What is meant by load commutation?**
In this process, the load current flowing through the thyristor either becomes zero or is transferred to another device from the conducting thyristor.

22. What are the advantages of current commutated chopper?
a. The capacitor always remains charged with the correct polarity.
b. Commutation is reliable as load current is less than the peak commutation current I_{CP}.
c. The auxiliary thyristor T_A is naturally commutated as its current passes through zero value.

23. What are the advantages of load commutated chopper?
a. Commutating inductor is not required.

b. It is capable of commutating any amount of load current.
c. It can work at high frequencies in the order of kHz.
d. Filtering requirements are minimal.

24. What are the disadvantages of load commutated chopper?
a) For high power applications, efficiency becomes very low because of high switching losses at high operating frequencies.
b) Freewheeling diode is subjected to twice the supply voltage.
c) Peak load voltage is equal to twice the supply voltage.
d) The commutating capacitor has to carry full load current at a frequency of half chopping frequency.
e) One thyristor pair should be turned-on only when the other pair is Commutated. This can be realized by sensing the capacitor current that is alternating.

25. How is the inverter circuit classified based on commutation circuitry?
a. Line commutated inverters.
b. Load commutated inverters.
c. Self commutated inverters.
d. Forced commutated inverters.

26.What are the different types of chopper configuration?
Depending upon the direction of current & voltages choppers can be classified into following types
1.Type A or First Quadrant chopper
2. Type B or Second Quadrant chopper
3. Type C or Two Quadrant type B chopper
4. Type D or Two Quadrant type C chopper
5. Type E or Four Quadrant chopper

27.What are the disadvantages of FM control?

The chopping frequency has to be varied over a wide range for the control of output voltage It generate harmonics at unpredictable frequencies

28. What are the disadvantages of voltage commutated chopper?

A starting circuit is required & the starting circuit should be switch that it triggers auxillary SCR TA first At the commutation occurs load voltage = 2Vs Turn off time is load dependent. It does not work at no load conditions

29.Write down the expression for average load current?
$I_o = (V_o - E) / R$
V_o = Avg. output voltage
E = Back emf & R = load resistance

30.Write down the expression for commutating elements L & C for voltage commutated chopper?
$L < C\,(V_s/I_o)^2$
$C = I_o\,(t_{off} + \Delta t) / V_s$

31.Differentiate between constant frequency & variable frequency control strategies of varying the duty cycle of DC chopper.

constant frequency control – Frequency of the chopper remains constant , but ON period is changed to vary the output. variable frequency control - Either Ton or Toff is kept constant & frequency is varied to change the output.

32. What is meant by commutation?
It is the process of changing the direction of current flow in a particular path of the circuit. This process is used in thyristors for turning it off.

33. What are the types of commutation?
a. Natural commutation
b. Forced commutation

34. What is meant by natural commutation?
Here the current flowing through the thyristor goes through a natural zero and enable the thyristor to turn off.

35. What is meant by forced commutation?
In this commutation, the current flowing through the thyristor is forced to become zero by external circuitry.

16 MARK QUESTIONS:

1. Describe the principle of step-up chopper. Derive an expression for the average output voltage in terms of input dc voltage and duty cycle. State the assumptions made.

2. For a type A chopper (first quadrant), express the following variables as a function of Vs, R and duty cycle in case the load is resistive average output voltage and current.

3. Explain the operation of a D.C chopper supplying power to a dc motor.

4. Derive an expression for load voltage and load current of a D.C chopper.

5. Compare ON-OFF control with Phase control and point out the relevant merits.

6. Explain the principle and operation of a Buk – Boost converter and relevant merits and demerits.

7. Explain the principle and operation of a Cuk converter and what are the merits and demerits of converter.

8. Explain the suitable waveforms the operation of a single quadrant kdc chopper with RL load.

9. With relevant diagram, explain two -quadrant operation of a DC chopper.

10. Show that Vout = Vin / 1- in step –up chopper. Explain the operation of the circuit.

11. What are the forced commutation circuits techniques used in chopper circuits? Explain.

UNIT – IV – INVERTERS

1. **What is meant by inverter?**
A device that converts dc power into ac power at desired output voltage and frequency is called an inverter.

2. What are the applications of an inverter?
a. Adjustable speed drives
b.Induction heating
c. Stand-by aircraft power supplies
d. UPS
e. HVDC transmission

3. **What are the main classification of inverter?**
a. Voltage Source Inverter
b. Current Source Inverter

4. **Why thyristors are not preferred for inverters?**
Thyristors require extra commutation circuits for turn off which results in decreased complexity of the circuit. For these reasons thyristors are not preferred for inverters.

5. **How output frequency is varied in case of a thyristor?**
The output frequency is varied by varying the turn off time of the thyristors in the inverter circuit, i.e. the delay angle of the thyristors is varied.

6. Give two advantages of CSI.
a. CSI does not require any feedback diodes.
b. Commutation circuit is simple as it involves only thyristors.

7. **What is the main drawback of a single phase half bridge inverter?**
It require a 3-wire dc supply.

8. **Why diodes should be connected in antiparallel with the thyristors in inverter circuits?**
For RL loads, load current will not be in phase with load voltage and the diodes connected in antiparallel will allow the current to flow when the main thyristors are turned off. These diodes are called feedback diodes.

9. **What types of inverters require feedback diodes?**
VSI with RL load.

10. **What is meant a series inverter?**
An inverter in which the commutating elements are connected in series with the load is called a series inverter.

11. **What is the condition to be satisfied in the selection of L and C in a series inverter?**

$$R^2 < \frac{4L}{C}$$

12. **What is meant a parallel inverter?**
An inverter in which the commutating elements are connected in parallel with the load is called a parallel inverter.

13. **What are the applications of a series inverter?**
The thyristorised series inverter produces an approximately sinusoidal waveform at a high output frequency, ranging from 200 Hz to 100kHz. It is commonly used for fixed output applications such as
a. Ultrasonic generator
b. Induction heating
c. Sonar Transmitter
d. Fluorescent lighting

14. How is the inverter circuit classified based on commutation circuitry?
a. Line commutated inverters.
b. Load commutated inverters.
c. Self commutated inverters.
d. Forced commutated inverters.

15. **What is meant by McMurray inverter?**
It is an impulse-commutated inverter, which relies on LC circuit and an auxiliary thyristor for commutation in the load circuit.

16. What are the applications of a CSI?
a. Induction heating
b. Lagging VAR compensation
c. Speed control of ac motors
d. Synchronous motor starting.

17. **What is meant by PWM control?**
In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the

most popular method of controlling the output voltage and this method is termed as PWM control.

18. **What are the advantages of PWM control?**
a. The output voltage can be obtained without any additional components.
b. Lower order harmonics can be eliminated or minimized along with its output voltage control. As the higher order harmonics can be filtered easily, the filtering requirements are minimized.

19. What are the disadvantages of the harmonics present in the inverter system?
a. Harmonic currents will lead to excessive heating in the induction motors. This will reduce the load carrying capacity of the motor.
b. If the control and the regulating circuits are not properly shielded, harmonics from power ride can affect their operation and malfunctioning can result.
c. Harmonic currents cause losses in the ac system and can even some time produce resonance in the system. Under resonant conditions, the instrumentation and metering can be affected.
d. On critical loads, torque pulsation produced by the harmonic current can be useful.

20. What are the methods of reduction of harmonic content?
a. Transformer connections
b. Sinusoidal PWM
c. Multiple commutation in each cycle
d. Stepped wave inverters

21. Compare CSI and VSI.

S. No.	VSI	CSI
1.	Input voltage is maintained constant	Input current is constant but adjustable
2.	The output voltage does not depend on the load	The output current does not depend on the load
3.	The magnitude of the output current and its waveform depends on the nature of the load impedance	The magnitude of the output voltage and its waveform depends on the nature of the load impedance
4.	It requires feedback diodes	It does not requires feedback diodes
5.	Commutation circuit is complicated i.e. it contains capacitors and inductors.	Commutation circuit is simple i.e. it contains only capacitors.

22. **What are the disadvantages of PWM control?**
SCRs are expensive as they must possess low turn-on and turn-off times.

23. **What is meant by cyclo-converter?**

It converts input power at one frequency to output power at another frequency with one-stage conversion. Cycloconverter is also known as frequency changer.

24. What are the two types of cyclo-converters?
a. Step-up cyclo-converters
b. Step-down cyclo-converters

25. **What is meant by step-up cyclo-converters?**
In these converters, the output frequency is less than the supply frequency.

26. **What is meant by step-down cyclo-converters?**
In these converters, the output frequency is more than the supply frequency.

27. **What are the applications of cyclo-converter?**
a. Induction heating
b. Speed control of high power ac drives
c. Static VAR generation
d. Power supply in aircraft or ship boards

28. **What is meant by positive converter group in a cycloconverter?**
The part of the cycloconverter circuit that permits the flow of current during positive half cycle of output current is called positive converter group.

29. **What is meant by negative converter group in a cycloconverter**?
The part of the cycloconverter circuit that permits the flow of current during negative half cycle of output current is called negative converter group.

30. **What is mean by VSI**?
A VSI is one which the dc source has small or negligible impedance. In other words aVSI has stiff dc voltage source at its input terminals.

31. **What is mean by VSI**?
A current fed inverter or CSI is fed with adjustable current from a dc source of high impedance is from a stiff dc current source.

32. **What are the different methods of forced commutation employed in inverter circuits?**
i) Auxillary commutation
ii) complementary commutation

33. **What are the methods of voltage control inverters**?
External control of ac output voltage
External control of dc input voltage
Internal control of inverter

34. **What is meant by feedback diodes or retun current diodes?**
For RL loads current io will not be in phase with voltage & diodes connected in antiparallel with SCR will allow the current to flow when the main SCRs are turnwed off. These diodes are called feedback diodes.

35. **What are the different types of PWM control**?
Single pulse width modulation
Multiple pulse width modulation
Sinusoidal pulse width modulation

36. **How the thyristor inverters are classified**?
According to the method of communal
i. Line commutated inveter
ii. Forced commutated inverter
According to the connection
iii. series inveter
iv. parallel inverter
v. Bridge inverter

16 MARK QUESTIONS:

1. Describe the different operation of series inverter. What are the advantages?

2. State different methods of voltage control inverters. Describe about PWM control in inverter.

3. Explain the operation of three- phase bridge inverter with neat circuit diagram and waveforms.

4. With a circuit diagram and relevant waveforms, describe the working of singlephase inverter.

5. What are techniques in PWM method and explain any one.

6. Explain the operation of current source inverter with different modes.

7. Draw a three-phase bridge inverter for 120 mode operation and explain its working. Give relevant waveforms also.

8. Write a basic parallel Inverter Bridge and explain its working with output voltage waveforms, for different load pfs.

9. Explain the operation of auxiliary commutated bridge inverter. Draw necessary waveforms.

10. Explain with neat sketch and waveforms PWM inverter.

11. Explain the operation of a complementary commutated bridge inverter circuit. Draw necessary waveforms.

12. Explain the PWM control of single –phase inverter.

13. Discuss in detail the operation of a single-phase bridge inverter with necessary waveforms. Hi light the role played by the return current diodes in such inverters.

UNIT – V – APPLICATIONS

1. What are the applications of power electronics?
Variable speed electric drives
Temperature and illumination controllers
Power supplies
HVDC transmission

2. What are parameters controlled using facts?
Series impedance, shunt impedance, current, voltage, phase angle and damping frequencies.

3. What are the types of facts controllers?
Series controllers
Shunt controllers
Combined series-series controllers
Combined series-shunt controllers

4. What are the types HVDC transmission lines?
Monopolar line
Bipolar line
Homopolar line

5. What are the types of ac power supplies in static var system?
Switched –mode ac power supplies
Resonant ac power supplies
Bidirectional ac power supplies

6. Define Voltage mode control.
The duty cycle is increased to cause a subsequent increase in output voltage in the mode control is called voltage mode control.

7. Define current mode control.
The current mode control uses the current as the feedback signal to achieve output voltage control.

8. What are the different modes of controlling in drives?
Motoring mode
Reverse motoring mode (Braking mode)
Generating mode
Reverse generating mode

9. **What are the types of ac power supplies in static var system?**
Resonant ac power supplies
Bidirectional dc power supplies.

10. What are the types of various faults?
Phase failure (PF)
Gate Pulse Failure (GPF)
Turn-on Failure of Thyristor (TFT)

Short Circuit across Thyristor (SCT)
Short Circuit across DC Terminals (SCD)

11. What is meant by SMPS?
SMPS means Switch Mode Power Supply. SMPS is based on the chopper principle. Varying the duty cycle of chopper by PWM techniques controls the output dc voltage.

12. What are the types of SMPS?
Fly back SMPS
Push pull SMPS
Half bridge SMPS
Full bridge SMPS

13. Advantages of SMPS.
For the same power rating,
SMPS is of smaller size,
Lighter in weight and processes,
Higher efficiency,
High frequency operation
Less sensitive to input voltage variations.

14. Disadvantages of SMPS.
It has higher output ripple and regulation is worse.
It is a source of both electromagnetic and ratio interference due to high frequency switching.
Control of ratio frequency noise requires the use of filters on both input and output.

15. Define thyristor valve.
The term of thyristor valve, used on HVDC systems, denotes a number of thyristors connected in series and parallel to get the required voltage and current ratings.

16. What are the advantages static switches over electromechanical switches.
On time of a static switch (SS) is of the order of 3microseconds, it has therefore very high switching speed.
SS has no moving parts; its maintance is therefore very low.
SS has no bouncing at the time of turning on.
SS has long operational life.

17. Define static circuit breakers.
Static circuit breakers are semi conductor-based circuits capable of providing a fast and reliable interruption to a continuous current.

18. Define resonant converters.
The converter circuits, which employ zero-voltage and or zero current switching, are called resonant converters.

19. What are the types of resonant converters?
Zero Voltage Switching (ZVS)
Zero Current Switching (ZCS)

20. What are the methods of reduction of harmonic content?

Transformer connections
Sinusoidal PWM
Multiple commutation in each cycle
Stepped wave inverters

21. What are the disadvantages of the harmonics present in the inverter system?
Harmonic currents will lead to excessive heating in the induction motors. This will reduce the load carrying capacity of the motor. If the control and the regulating circuits are not properly shielded, harmonics from power ride can affect their operation and malfunctioning can result. Harmonic currents cause losses in the ac system and can even some time produce resonance in the system. Under resonant conditions, the instrumentation and metering can be affected. On critical loads, torque pulsation produced by the harmonic current can be useful.

22. What is meant by PWM control in dc chopper?
In this control method, the on time Ton is varied but chopping frequency is kept constant. The width of the pulse is varied and hence this type of control is known as Pulse Width Modulation (PWM).

23. Mention some of the applications of controlled rectifier.
Steel rolling mills, printing press, textile mills and paper mills employing dc motor drives.
DC traction
Electro chemical and electro-metallurgical process
Portable hand tool drives
Magnet power supplies
HVDC

24. What is meant by sequence control of ac voltage regulators?
It means that the stages of voltage controllers in parallel triggered in a proper sequence one after the other so as to obtain a variable output with low harmonic content
.
25. What are the different methods to turn on the thyristor?
Forward voltage triggering
Gate triggering
dv/dt triggering
Temperature triggering
Light triggering

16 MARK QUESTIONS:

1. Draw the circuitry for a static circuit breaker and discuss its advantages and disadvantages.

2. What is the necessity for the UPS? Draw a block diagram for UPS and explain its operation.

3. Discuss the operation of the HVDC system and explain how the power flow can easily be controlled in both the directions. Also elaborate on its merits.

4. What is an SMPS? What are its advantages? Draw the circuit arrangement for SMPS and explain briefly its operation.

5. Give a short note on the Monopolar HVDC system.

6. State the advantages of HVDC over conventional ac transmission system. Draw the schematic diagram of dc bipolar transmission system and explain it briefly.

7. What are resonant converters? Give their advantages over PWM controlled converters.

8. Describe M-type ZCS resonant converter with relevant circuits and waveforms. Explain and draw the circuit diagram of shunt and series static var compensators? What are the advantages and disadvantages of static var compensators?

Introduction:

(1)

(1) Power electronic deals with control and conversion of high power applications.

(2) power semiconducter devices should be capable to withstand high power.

eg. (i) power diodes

(ii) SCR (↑P) (silicon control Rectifiers) P = Power

(iii) GTO (Gate tuen off)

(iv) ASCR (Assymetrical silicon control Reactifier)

(v) RCT (Reverse conducting thyristor

(6) LASCR

(7) TRIAC

(8) DIAC

power transistors

(i) power BJT

(ii) power MOSFET. (F↑) F = Frequency

(iii) IGBT (F)

(2) Signal Electronics

It deals with Control of low power applications.

(i) signal devices operate at low power and very high switching freq. when compared with power devices.

eg:

(1). Zener diodes

(2) LCD & LED's

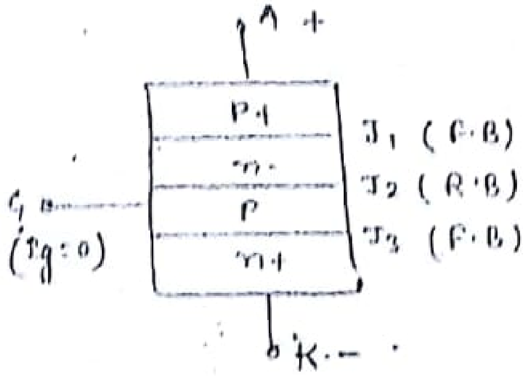
(3) Tunnel diode

(4) varactor diode

(1) Forward blocking Mode (FB)

A(+) w.r.t K, J_1 & J_3 are F.B, J_2 is R.B

Here the depletion layer at the junction J_2 is responsible for blocking the device



but a small leakage current flows in practical case.

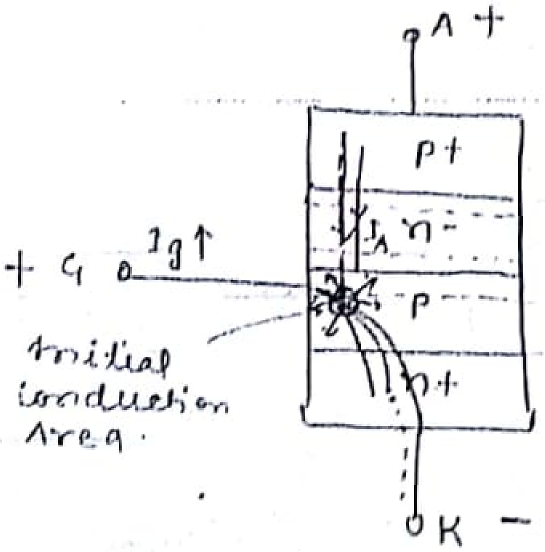
(2) Forward conduction mode

$V_{AK}\uparrow$ upto V_{BO}, break down occurs at J_2 and SCR starts conducting. But not used in practical case.

⊙ If SCR switched on if $I_g=0$ (without gate signal) power loss is more, SCR may get damaged.

[Not used with $I_g=0$]

Significance of gate signal :-



$I_g\uparrow$ or $\left(\frac{dI_g}{dt}\right)\uparrow$

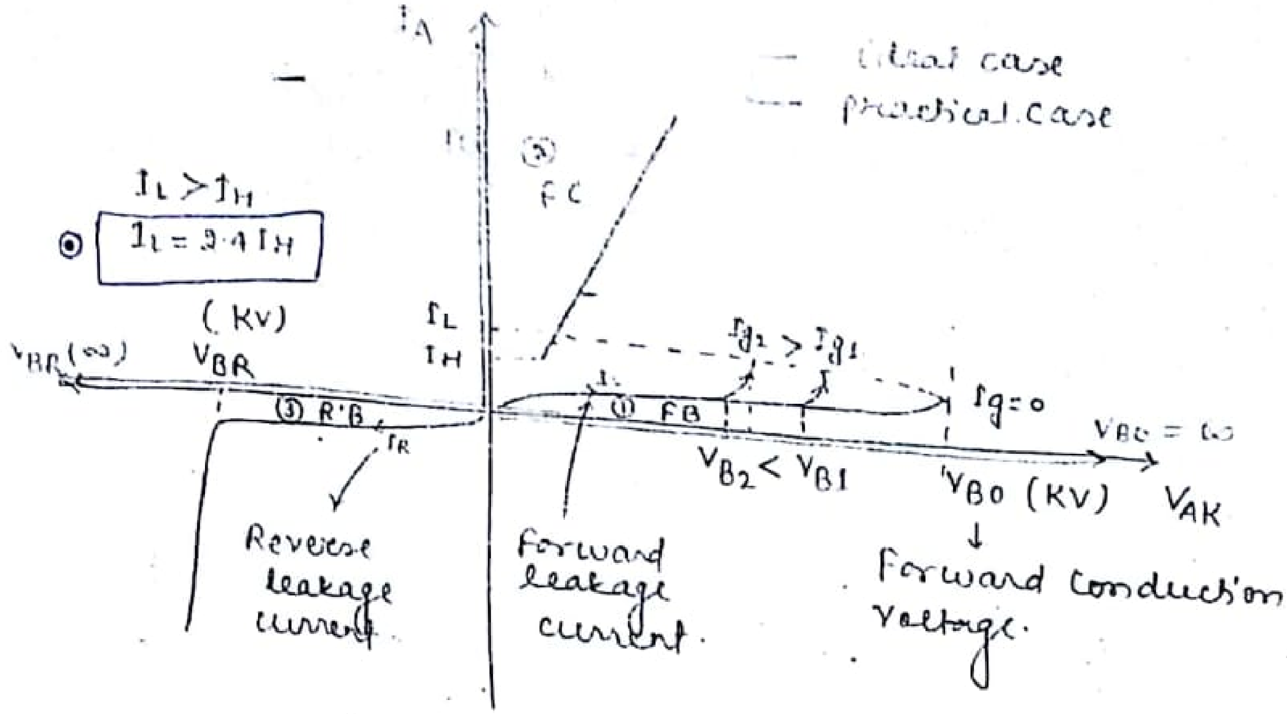
Initial conduction Area

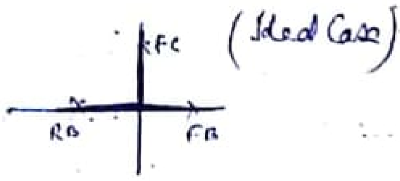
$\uparrow \left(\frac{dI_A}{dt}\right)\uparrow$ initial rate.

∴ $V_B\downarrow$ Break down voltage

i.e $\boxed{I_g\uparrow, V_B\downarrow}$

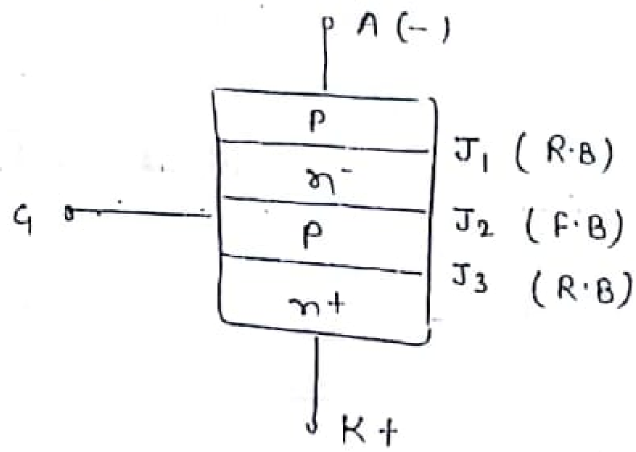
⊙ When SCR is in forward conducting mode all junction are F.B.





(3) Reverse blocking mode

A −, w.r.t, K.



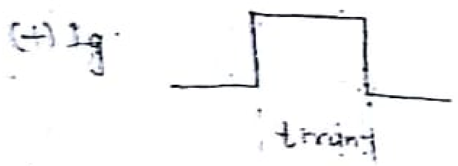
$J_1 \rightarrow$ R.B
$J_2 \rightarrow$ FB
$J_3 \rightarrow$ R.B

∴ SCR → OFF

But a small reverse leakage current flow in practical case.

Significance of latching current :- [At the time of Starting]
Latching current is related to turn-ON process.
Gate signal is required to initiate the turn-ON process when SCR is already in ON-state it get looses control on the device therefore we will remove the gate signal when it is ON state to avoid the continuous gate power loss.

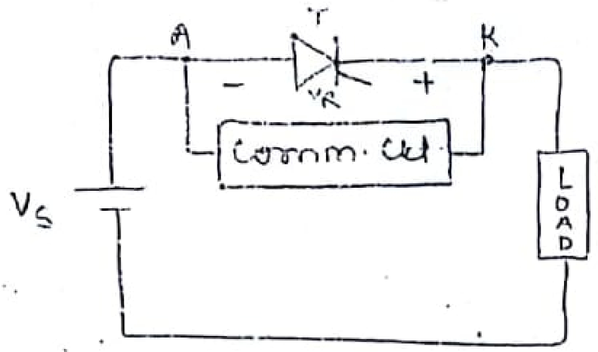
If gate signal is removed when $I_A < I_L$, then SCR fails to turn-ON. Therefore we must maintain the gate signal until anode current reaches just above certain minimum value. (latching current)



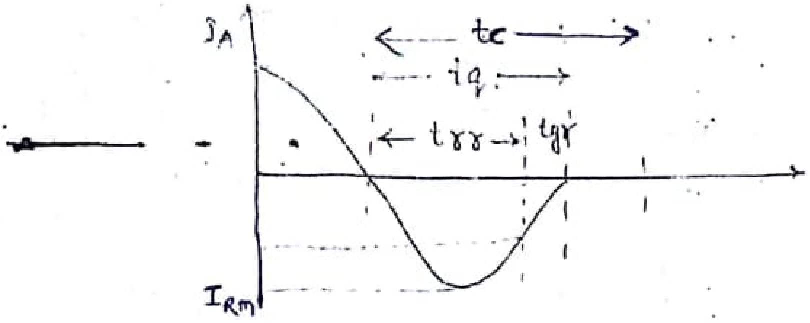
$\boxed{I_A \geq I_L}$

Significance of Holding current: [At the off time]

Holding current is related to turn-off process. gate has no control to turn-off the SCR. We require commutation circuit to turn off the SCR.



$\boxed{I_A \downarrow < I_H}$



t_c = Circuit turnoff time.

t_q = Device turn off time

t_{rr} = Reverse Recovery time.

t_{gr} = gate Recovery time

$$t_q = t_{rr} + t_{gr}$$

Procedure to turn-off SCR using comm. ckt:

The comm. ckt forced the anode current to reduce below a certain min^m value (I_H) and then applies a reverse voltage across SCR until it regains the blocking capability. i.e (until all carriers are removed).

Reverse voltage increases recombination process.

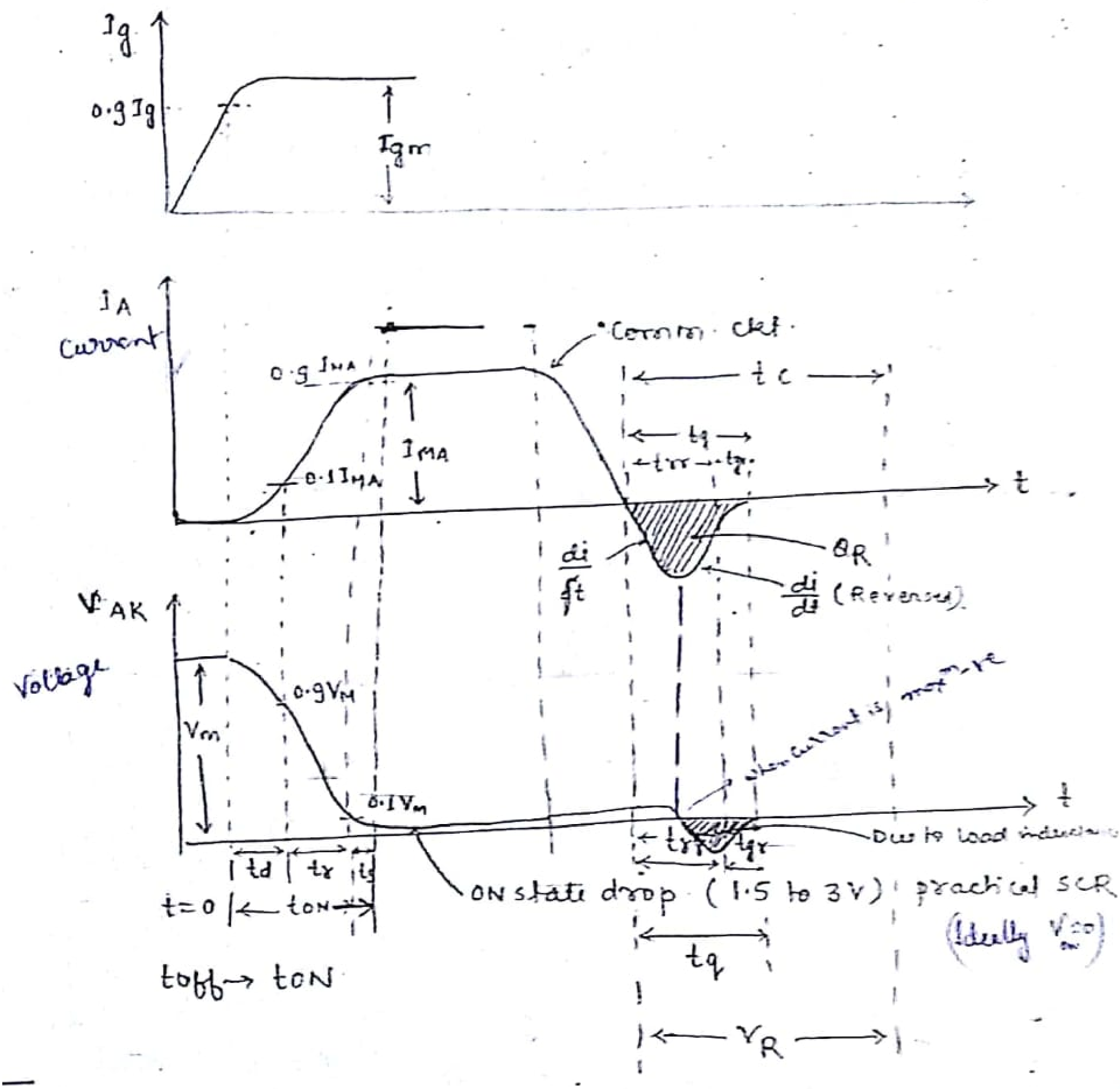
- Role of Commutation Ckt → to reduce I_A, below I_H

After the role of commutation ckt Reverse Voltage is applied

Holding current :

It is the minimum anode current below which the SCR becomes off and regains the blocking capability when a reverse voltage is applied across SCR at least for a period of device turn off time or greater than that

Switching characteristics of SCR.

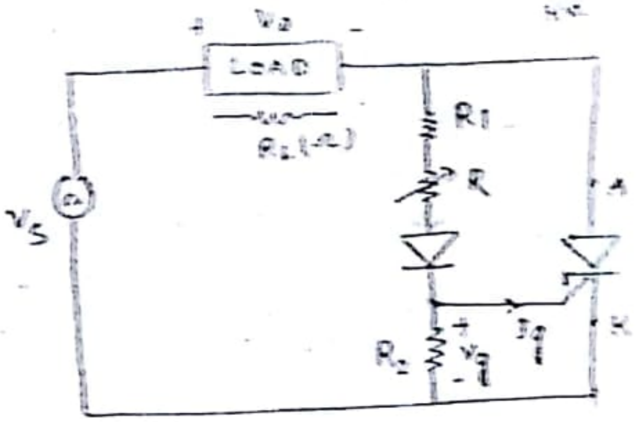


Firing circuits :-

Firing circuit gives the necessary gate pulse to turn on the SCR.

(i) R-firing circuit :-

$R_L << (R_1 + R + R_2)$
$k\Omega$



Main ckt → 1-φ half wave Rectifier.

Main signal required is gate pulse in mA

Gate specification

$$I_g\,min \le I_g \le I_g\,max$$
$$V_g\,min \le V_g \le V_g\,max.$$

R_1 → To limit gate current within $I_g\,max$

for worst condition $R = 0$, $R_L(\Omega) << R_1(k\Omega)$

$$\text{Max}^m \text{ possible gate current} = \frac{V_m}{R_1} \le I_g\,max.$$

$$\therefore R_1 \ge \frac{V_m}{I_g\,max}.$$

2) R_2 — R_2 is used to limit gate voltage within $V_{g\,max}$.

For worst condition, Max^m gate voltage

worst $V_{g\,max} = \frac{V_m}{R_1+R_2} \cdot R_2 \leq V_{g\,max}$.

From the above eq^n we can find the designed value of R_2

(3) **Diode**: Purpose of diode (Remove diode & find consequences).

Diode is used to avoid the negative gate pulse

(4) **R**: Used to varying the firing angle α.

(5) V_{gt}: Gate turn ON voltage: It is the gate voltage at which SCR will turn ON

when $V_g \to V_{gt}$, SCR $\to$ ON $\Rightarrow \omega t = \alpha$

$$V_g = \frac{V_m \sin\omega t}{R_1+R+R_2} \cdot R_2.$$

peak value of gate voltage.

$$V_{gm} = \frac{V_m R_2}{R_1+R+R_2}.$$

$$V_g = \frac{V_m R_2}{R_1+R+R_2} \cdot \sin\omega t$$

$$V_g = V_{gm} \sin\omega t \quad (T \to OFF).$$

when $V_g = V_{gt} \to$ SCR turn ON. at $\omega t = \alpha$.

$$\therefore V_{gm} \sin\alpha = V_{gt}$$

$$\sin\alpha = \frac{V_{gt}}{V_{gm}}$$

$$\boxed{\alpha = \sin^{-1}\left(\frac{V_{gt}}{V_{gm}}\right)}$$

$$\boxed{R\uparrow, V_{gm}\downarrow, \alpha\uparrow}$$

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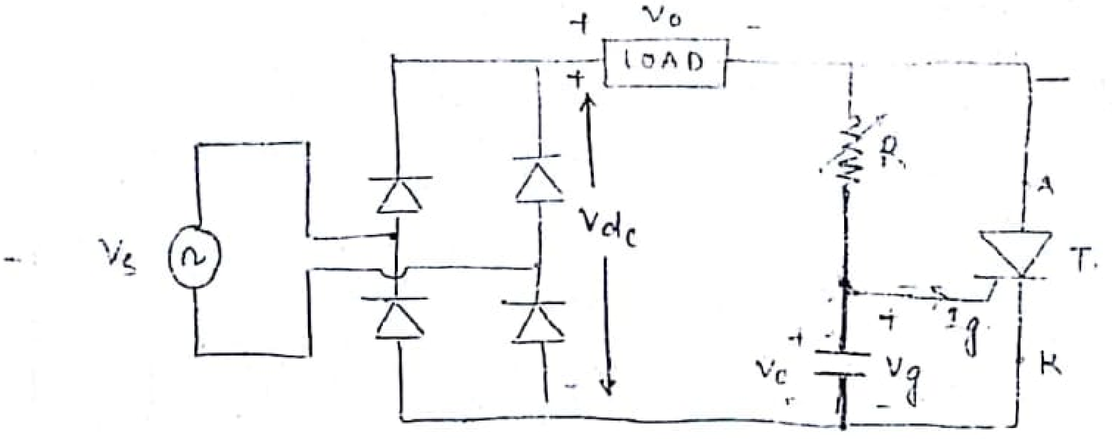
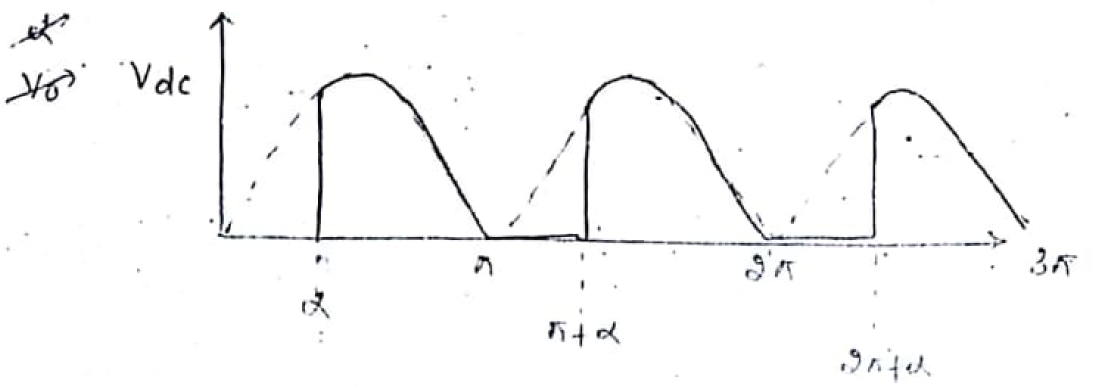
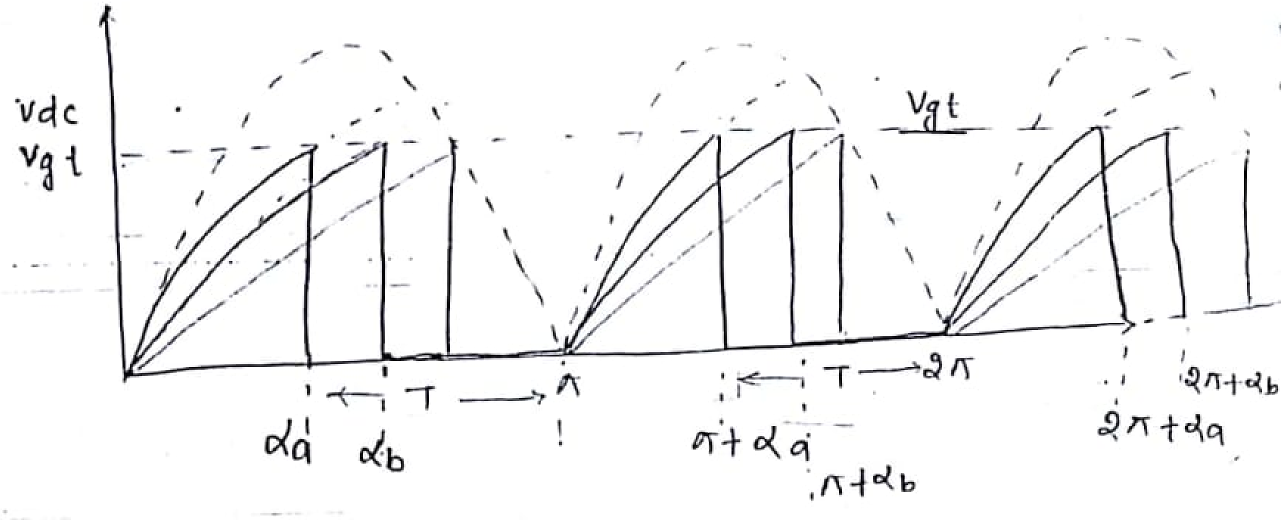
(4) RC firing circuit





(i) Here thyristor is used for getting variable pulsating dc by varying firing angle α. so avg. output is varied by varying α.

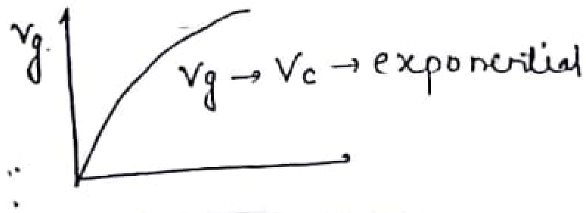


case I :

$R = R_a$

$\alpha = \alpha_a$

$T_a = R_a C$



$\boxed{R\uparrow \; T\uparrow \; \alpha\uparrow}$

case II

$R = R_b > R_a$

$\alpha = \alpha_b$

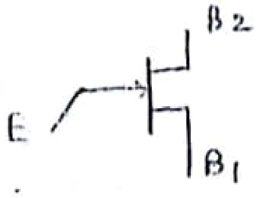
$T_b > T_a$

Ideally $V_g = 0$ and $\alpha \approx 180$ i.e. $\alpha_{max} = 180$

Ideally $\alpha \Rightarrow 0 < \alpha < 180$

Practicaly $(5-7) \; \alpha \lesssim (165-175)$

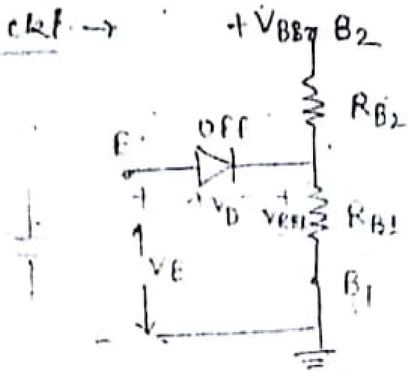
UJT :-



$B_1, B_2 \rightarrow$ Base terminals

$E \rightarrow$ Emitter terminals.

equivalent ckt $\rightarrow$



$$V_{RB1} = \frac{R_{B1}}{(R_{B1} + R_{B2})} \; V_{BB}$$

$$\boxed{V_{RB1} = \eta V_{BB}}$$

$$\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$$

η = intrinsic stand off Ratio (specification).

let $V_P = \eta V_{BB} + V_D$ $\qquad$ V_P = Peak point voltage.

$$V_E = V_{RB1} + V_D$$

$$V_E = \eta V_{BB} + V_D$$

- $\boxed{\uparrow V_E = V_P}$ ...... Condition to turn ON UJT.

UJT exhibits negative resistance characteristics.

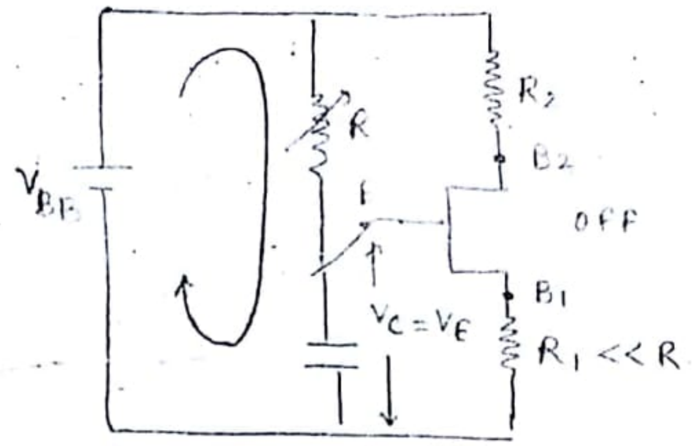
Diode or UJT $\rightarrow$ ON, $\quad R_{B1} \downarrow$

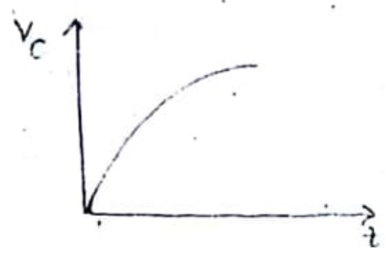
Diode or UJT $\rightarrow$ OFF, $\quad R_{B1} \uparrow$.

) When UJT becomes ON base resistance R_{B1} starts decrease because it exhibits negative Resistance behaviour. Therefore emitter voltage reduces after UJT becomes ON. When decrease in emitter voltage reaches value voltage UJT becomes OFF.

$\boxed{\downarrow V_E = V_V}$ ... condition to turn off UJT.

UJT as Relaxation oscillator

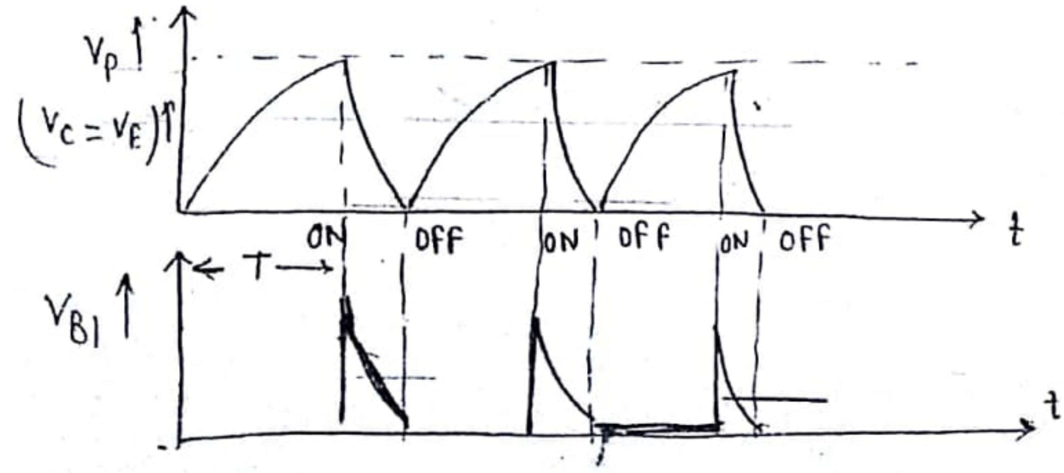




$V_P = \eta V_{BB} + V_D$

$R_1 << R$. i.e charging time of capacitor is high and discharging " " " " very low.

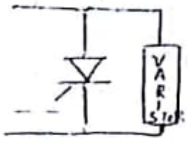
let $V_C = 0$ (say).



(2) Overvoltage Protection :-

for this ~~Magnets~~ Varistor are connected across SCR. Varistor is a non-linear Resistors. All metal oxides behaves as non-linear Resistors.

eg: Metal oxide Resistor (ZnO).



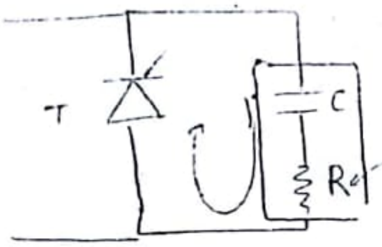
(3) dV/dt protection :-

Effect of high dV/dt

At high dV/dt the SCR will turn ON before the gate signal is given. This is known as false triggering. (unwanted turn ON).

i.e Gate loose control to turn ON the SCR due to high dV/dt.

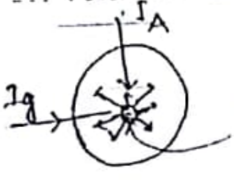
protection.



Protect SCR from High $\frac{dv}{dt}$ & high $\frac{di}{dt}$

(4) di/dt Protection.

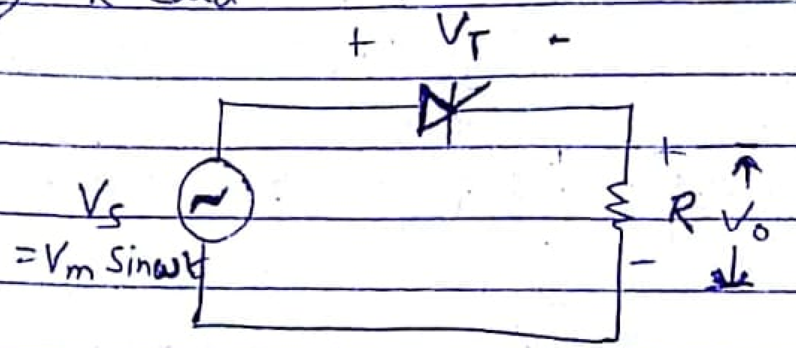
Effect of high di_A/dt.



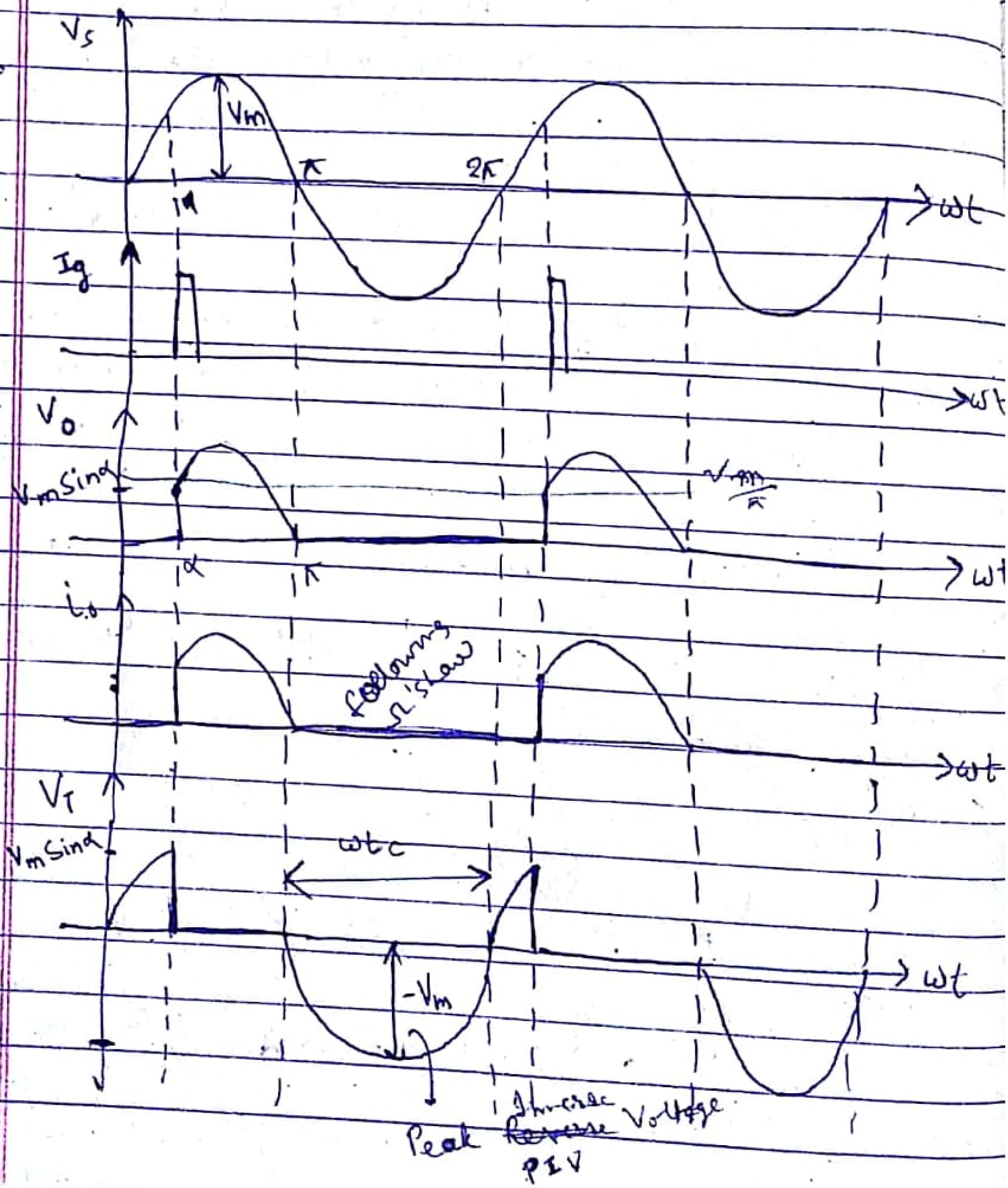
if $\frac{di}{dt}$ > spread velocity of charge carriers, then the accumulation of charge in a small conduction area increases and this leads to the formation of hot spots damaging the device.

Single phase half wave Rectifier.

(1) R-Load.



α = the angle at which diode starts conducting (firing angle)



Quality of Perfect DC —

(I) No ripple
(II) Rms output voltage & avg voltage are equal
(III) $FF = 1 = \frac{rms}{avg}$
(IV) $VRF = 0$

Avg. Voltage →

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

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

$$= \frac{-V_m}{2\pi}\Big[+\cos\pi - \cos\alpha\Big]$$

$$= \frac{-V_m}{2\pi}\Big[-1 - \cos\alpha\Big]$$

$$\boxed{V_0 = \frac{V_m}{2\pi}\left[\cos\alpha + 1\right]}$$

Avg. Current → $I_0 = V_0/R$

$$= \frac{V_m}{2\pi R}\left[1 + \cos\alpha\right]$$

Rms Voltage →

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \; d(\omega t)}$$

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

$$= \sqrt{\frac{1}{2\pi} V_m^2 \left\{\frac{1}{2}(\omega t) - \frac{\sin 2\omega t}{4}\right\}_{\alpha}^{\pi}}$$

$$= \sqrt{\frac{1}{4\pi} V_m^2 \left\{\pi - \alpha - \frac{\sin 2\pi}{2} + \frac{\sin 2\alpha}{2}\right\}}$$

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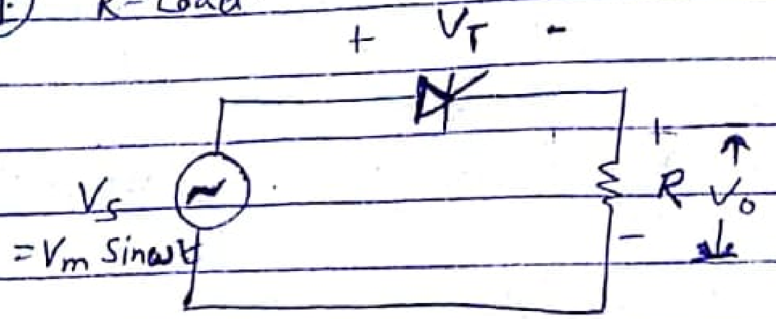
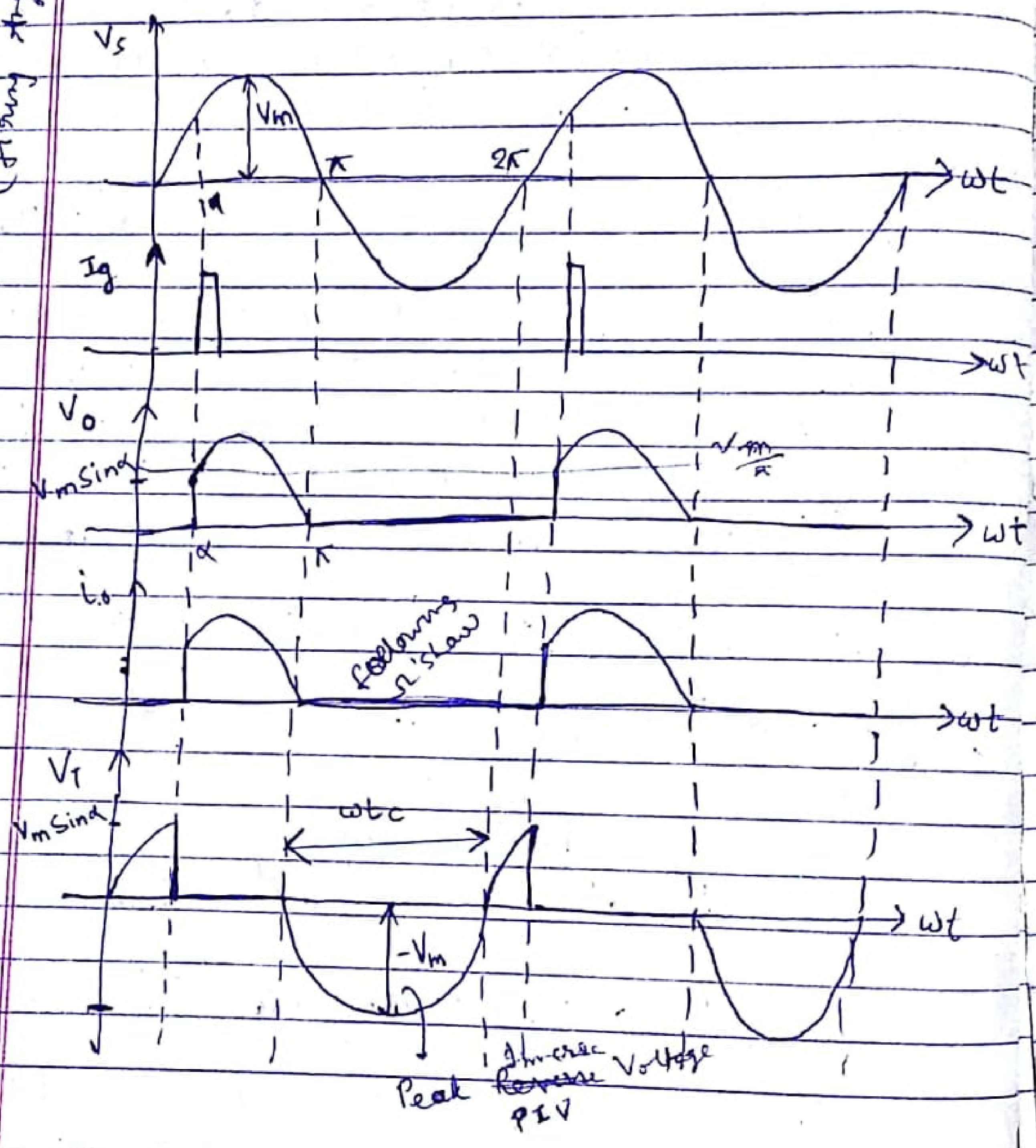
Single phase half wave Rectifier.

1. R-Load.



α = the angle at which diode starts conducting (firing angle)



quality of Perfect DC —

1. No ripple
2. Rms output voltage & avg voltage are equal
3. FF = 1 = $\frac{rms}{avg}$
4. VRF = 0

Avg. Voltage →

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

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

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

$$= \frac{-V_m}{2\pi}\left[-1 - \cos\alpha\right]$$

$$\boxed{V_0 = \frac{V_m}{2\pi}\left[\cos\alpha + 1\right]}$$

Avg. Current → $I_0 = V_0/R$

$$= \frac{V_m}{2\pi R}\left[1 + \cos\alpha\right]$$

Rms Voltage →

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

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

$$= \sqrt{\frac{1}{2\pi} V_m^2 \left\{\frac{1}{2}(\omega t) - \frac{\sin 2\omega t}{4}\right\}_{\alpha}^{\pi}}$$

$$= \sqrt{\frac{1}{4\pi} V_m^2 \left\{\pi - \alpha - \frac{\sin 2\pi}{2} + \frac{\sin 2\alpha}{2}\right\}}$$

If SCR is $\overset{30}{6}$A & 600V then it can carry 30A & blocks 600V.

$$= \sqrt{\frac{V_m^2}{4\pi}\left\{\pi - \alpha + \frac{\sin 2\alpha}{2}\right\}}$$

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

V_m at $\alpha = \alpha$

$$\boxed{I_{rms} = \frac{V_{rms}}{2R}}$$

→ ~~Single φ~~ Output voltage is not a const. dc it has an ac components [Perfect dc]

→ (The measure of AC components in the DC output voltage is known as to the ripple voltage)

$$V_{ripple} = \sqrt{V_{rms}^2 - V_{avg}^2}$$

$$\text{Ripple factor} = \frac{V_{ripple}}{V_0} = 1.21$$

→ Voltage Ripple factor — It is a measure of harmonics on dc side of converter for the output voltage waveforms.

$$V_{RF} = \frac{\sqrt{V_{rms}^2 - V_{avg}^2}}{V_{avg}}$$

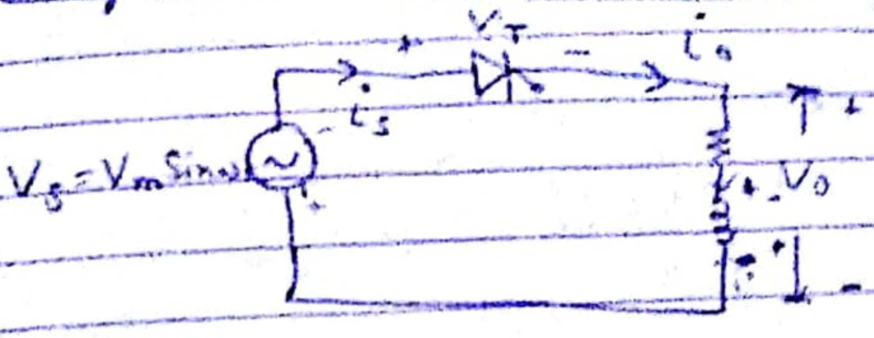
$$= \sqrt{\frac{V_{rms}^2}{V_{avg}^2} - 1}$$

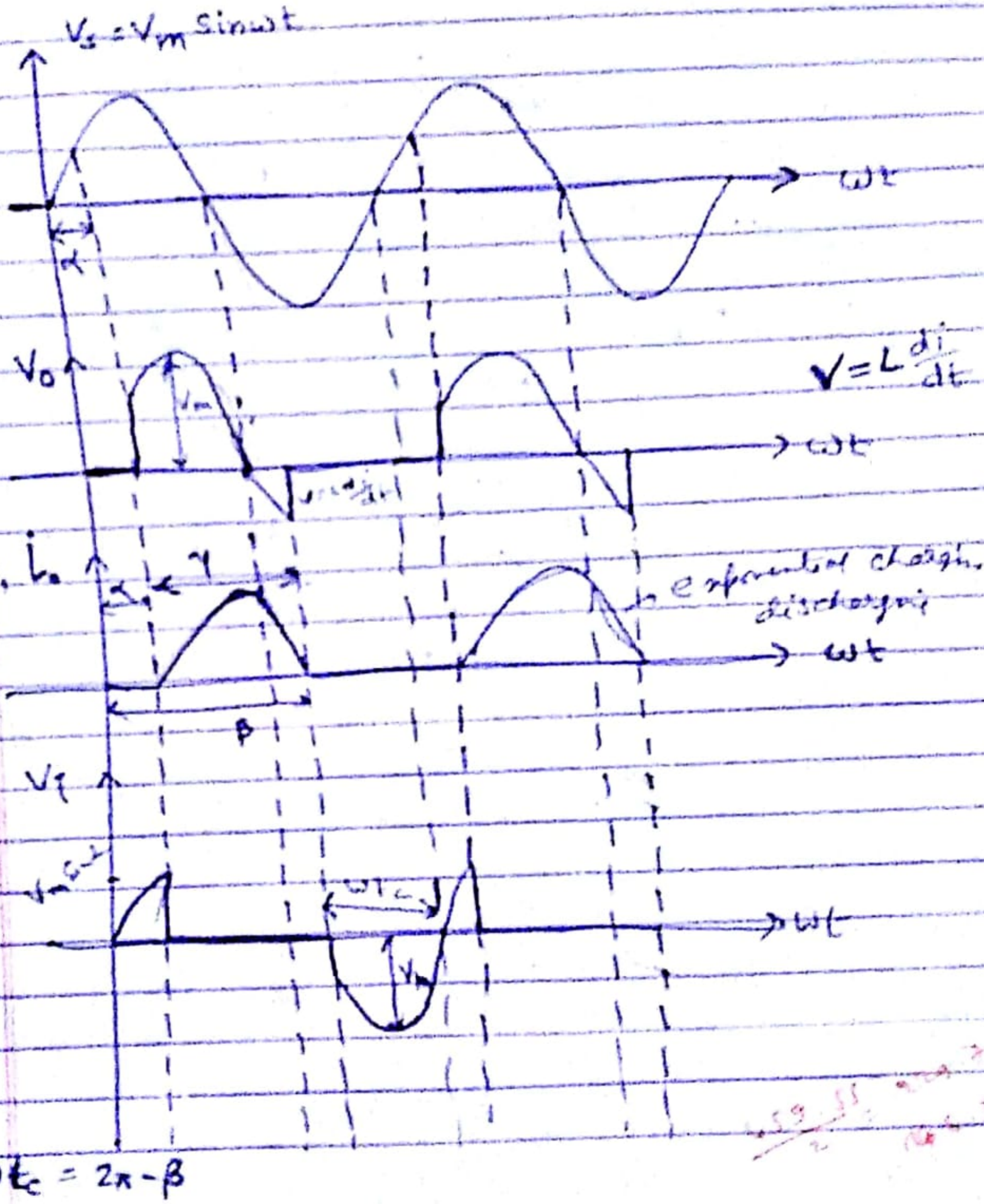
$$= \sqrt{(FF)^2 - 1}$$

$$FF = \frac{V_{rms}}{V_{avg}}$$

Drawback - The source current contains dc components and saturates suffers transformer core. Therefore half wave rectifier are not generally preffered for application.

Single phase Half wave circuit with RL Load -



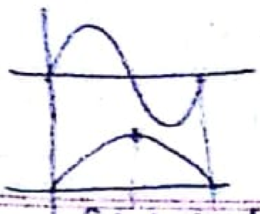


β = The angle at which diode stops conducting (extinction angle)

γ = Conduction Angle = $\beta - \alpha$

$\omega t_c = 2\pi - \beta$

NOTE →



for R L –

Peak of I_0 before π

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

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

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

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

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

[The avg voltage across ~~the~~ an ideal inductor is always zero]

avg current into an ideal capacitor is zero.

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

$$= \sqrt{\frac{1}{2\pi} \cdot V_m^2 \left\{\frac{1-\cos 2\omega t}{2}\right\}_{\alpha}^{\beta}}$$

$$= \sqrt{\frac{1}{2\pi} V_m^2 \left\{\frac{1}{2}\omega t - \frac{\sin 2\omega t}{4}\right\}_{\alpha}^{\beta}}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\left\{\frac{1}{2}\beta - \frac{1}{2}\alpha - \frac{\sin 2\beta}{4} + \frac{\sin 2\alpha}{4}\right\}}$$

... current for a capacitor it would ~~take~~ charge to infinite volts.
If it were not zero avg. volts for an inductor it would take infinite amps.

$$= \cancel{\frac{V_m}{\sqrt{2\pi}}} \{$$

$$= \sqrt{\frac{V_m^2}{4\pi}\left\{\beta - \alpha - \frac{\sin 2\beta}{2} + \frac{\sin 2\alpha}{2}\right\}}$$

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

Calculation of RMS Load Current —

output current $= i_0 = i_s + i_t$ —— (1)

$i_s \downarrow$ Steady State Component

$i_t \longrightarrow$ transient Component.

$Z = \sqrt{R^2 + X^2}$

Here, i_s is given by,

Source current $\Rightarrow i_s = \frac{V_m}{Z}\sin(\omega t - \phi)$ —— (2)

$\phi = \tan^{-1} X/R$

ϕ = phase diff. betn i_s & V_s due to R-L ckt nature.

$\omega t = 0$

$V = L\frac{di}{dt}$

& $Z = \sqrt{R^2 + X_L^2}$

Now, i_t can be Calculated by the eqn —

$$Ri_t + L\frac{di_t}{dt} = 0$$

By solving above eq^n —

$$i_t = A e^{-R/L\, t} \quad -(3)$$

Hence from (1) (2) & (3)

$$i_0 = \frac{V_m}{Z} \sin(\omega t - \phi) + A e^{-R/L\, t} \quad -(4)$$

Calculation of for the value of A —

when, $i_0 = 0$ $t = \alpha/\omega$ $(\omega t = \alpha)$

Then from (4) —

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

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

So, from (4)

$$i_0 = \frac{V_m}{Z} \left[\sin(\omega t - \phi) + \sin(\alpha - \phi) e^{-R/\omega L (\omega t - \alpha)} \right] \quad -(5)$$

Now at $\omega t = \beta$ $i_0 = 0$

from (5)

$$0 = \frac{V_m}{Z} \left[\sin(\beta - \phi) + \sin(\alpha - \phi) e^{-R/\omega L (\beta - \alpha)} \right] \quad -(6)$$

PWM INVERTERS —

The width of these pulses is modulated to obtain — 1) Inverter output voltage control
2) to reduce its harmonic content

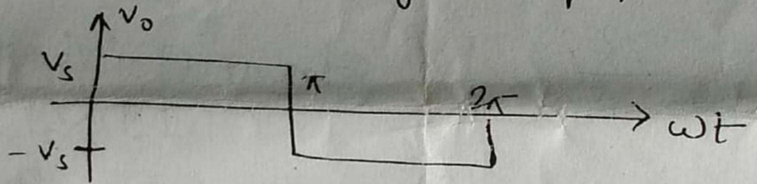
Different PWM techniques: —

a) SPM – Single pulse modulation
b) MPM – Multiple " "
c) Sinusoidal " " (SPWM)

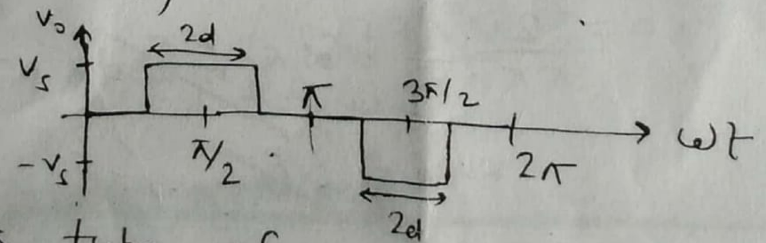
* Forced Commutation is essential.

SPM —

Full bridge Inverter Voltage Output —



Modulated wave (Let considered of a pulse of width 2d)



This type of waveform is called Quasi-Square wave.

Now, The fourier analysis of the modulated waveform.

Let, V_o = Output Voltage

$$V_o' = V_o' + \sum_{n=1}^{\infty} C_n \sin n(\omega t + \theta_n) \quad \text{—(1)}$$

Here,
$$V_o' = \frac{1}{2\pi}\left[\int_{(\pi/2-d)}^{(\pi/2+d)} V_s \, d(\omega t) + \int_{3\pi/2-d}^{3\pi/2+d} (-V_s)\, d(\omega t)\right]$$

$$V_o' = \frac{1}{2\pi} V_s [2d - 2d] = 0$$

Now, $a_n = 0$ [Symmetrical about Real Axis]

Also,
$$b_n = 2 \cdot \frac{1}{2\pi}\left[2\int_{\pi/2-d}^{\pi/2+d} V_s \sin n\omega t \; d(\omega t)\right]$$

$$= -\frac{2}{\pi} V_s \left[\frac{\cos n\omega t}{n}\right]_{\pi/2-d}^{\pi/2+d}$$

$$= -\frac{2}{\pi}\frac{V_s}{n}\left[\cos(\pi/2 + d)n - \cos(\pi/2 - d)n\right]$$

$$= \frac{2}{\pi}\frac{V_s}{n}\Big[\cancel{\cos \tfrac{\pi}{2}n \cos dn} + \sin \tfrac{\pi}{2}n \sin n$$
$$- \cancel{\cos \tfrac{\pi}{2}n \cos dn} + \sin \tfrac{\pi}{2}n \sin dn\Big]$$

$$= \frac{4V_s}{\pi n}\left[\sin \tfrac{\pi}{2}n \sin nd\right] \quad [=0 \text{ when } n = \text{ev}$$

where as, In (1) $\theta_n = \tan^{-1} a_n/b_n$ as $a_n = 0$ $\theta_n = 0$

Hence,
$$V_o = 0 + \sum_{n=1,3,5}^{\infty} \frac{4V_s}{\pi n} \sin \tfrac{\pi}{2}n \sin nd \sin n(\omega t + 0)$$

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$$V_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} \sin nd \sin n\omega t$$

or,

$$V_o = \frac{4V_s}{\pi}\left[\sin\frac{\pi}{2}\sin d \sin\omega t + \frac{1}{3}\sin\frac{3\pi}{2}\sin 3d \sin 3\omega t + \cdots\right]$$

or

$$V_o = \frac{4V_s}{\pi}\left[\sin d \sin\omega t + \frac{1}{3}\sin 3d \sin 3\omega t + \cdots\right]$$

$\left[\text{as, } \sin n\pi/2 = 1\right]$ $n = \text{odd}$.

If $2d = \pi$ [Unmodulated wave form]

$\omega t = \pi = 2d$, $d = \pi/2$

~~$V_{o1\,fund} = \frac{4V_s}{\pi}\sin\pi/2$~~

Then, $V_{o1\,\cancel{rms}\,max} = \frac{4V_s}{\pi}$ ($\sin\omega t = 1$) for max^m value

For pulse width $2d \neq \pi$ [modulated wave]

Then the peak value of fundamental Component is —

as, Fundamental Component $= \frac{4V_s}{\pi}\sin d \sin\omega t$

$(V_{o1})_{max}$ = Peak Value $= \frac{4V_s}{\pi}\sin d$ $[\sin\omega t = 1]$

Again, The peak value of n^{th} harmonic,

$$(V_{on})_{max} = \frac{4V_s}{n\pi}\sin nd.$$

Hence,

$$\frac{(V_{on})_{max}}{(V_{o1})_{max}} = \frac{\frac{4V_s}{n\pi}\sin nd}{\frac{4V_s}{\pi}\sin d} = \frac{\sin nd}{n}$$

Hence we can draw the graph as,

for cheking the graph

for $n = 1$

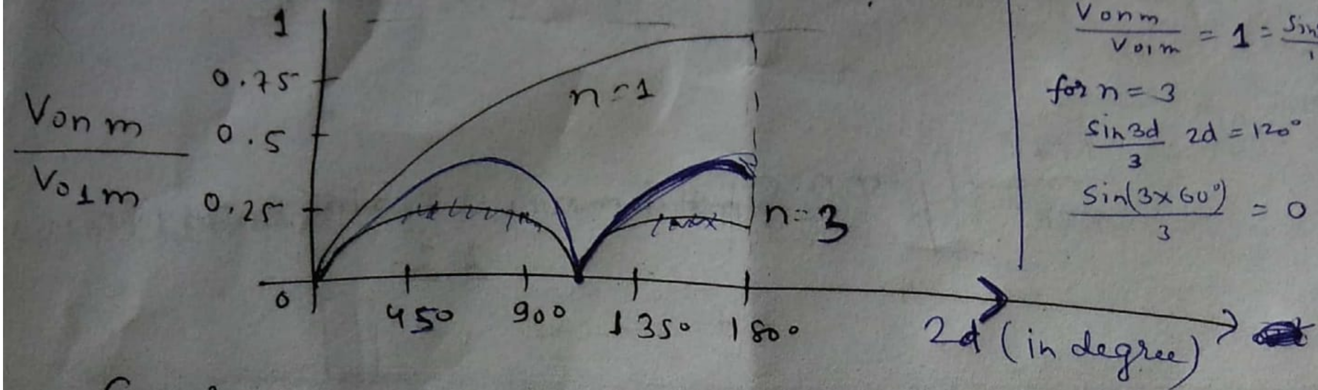
$2d = \pi \Rightarrow d = 90°$

$\frac{V_{onm}}{V_{o1m}} = 1 = \frac{\sin 90°}{1}$

for $n = 3$

$\frac{\sin 3d}{3}$ $2d = 120°$

$\frac{\sin(3 \times 60°)}{3} = 0$



Conclusion —

For eliminating n^{th} harmonic, pulse width $(2d)$ must be equal to $2\pi/n$.

Eg → for eliminating 3rd harmonic,

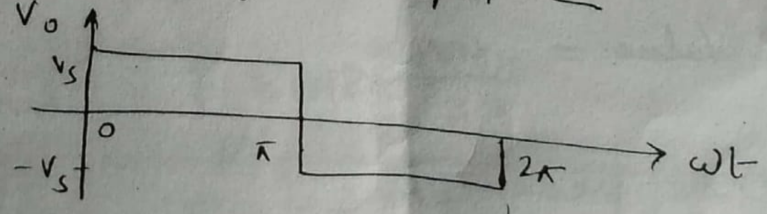
$$2d = 2\pi/n$$

or, $2d = 2\pi/3 = 120°$

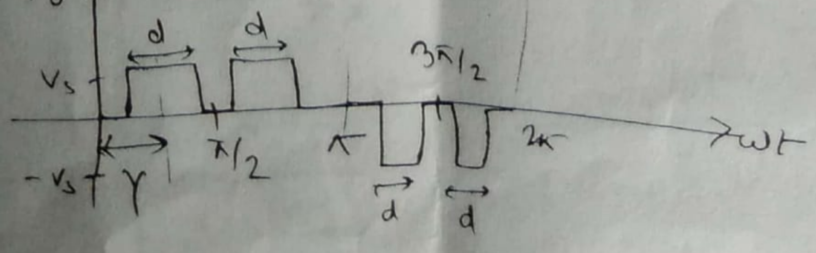
MPM —

In MPM, several equidistant pulses per half cycle are used.

Full inverter Voltage Output —



Modulated Wave —



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$a_n = 0$

$$b_n = \frac{2}{\pi}\int_{\gamma - d/2}^{\gamma + d/2} V_s \sin n\omega t \, d(\omega t)$$

$$b_n = \frac{4V_s}{n\pi} \sin \gamma n \sin \frac{nd}{2}$$

Therefore the waveform describe by Fourier Series as,

$$V_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi} \sin n\gamma \sin \frac{nd}{2} \sin n\omega t.$$

The peak value of fundamental voltage component is —

$$V_{o1\,max} = \frac{4V_s}{\pi} \sin \gamma \sin d/2$$

In general, $\gamma = \left[\frac{\pi - 2d}{N+1} + \frac{2d}{2N}\right]$

Here, N = No. of. pulse per half cycle.

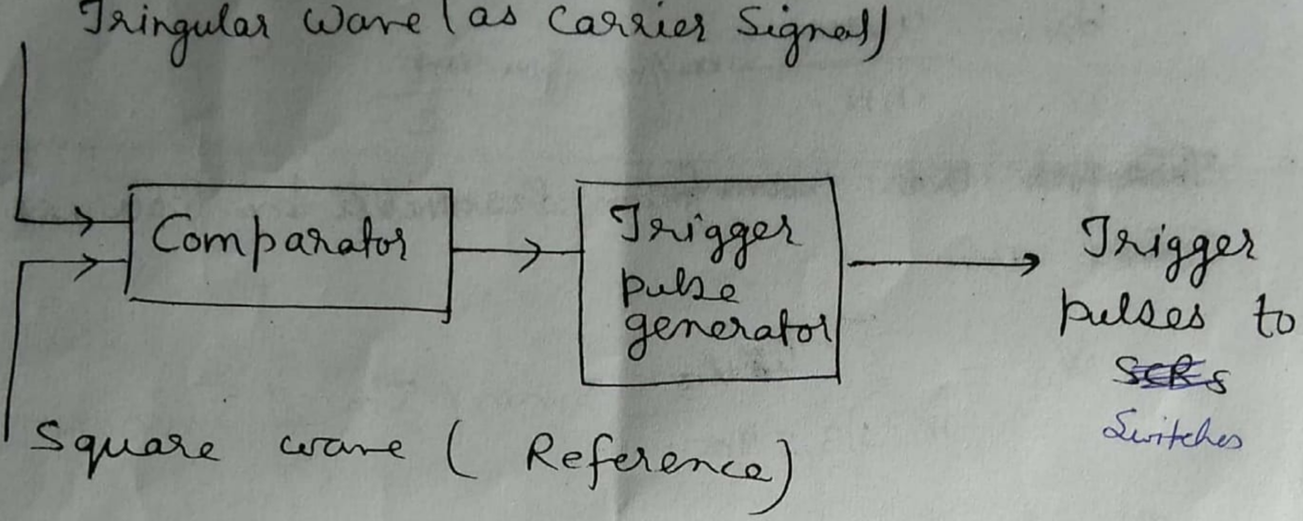
NOTES —

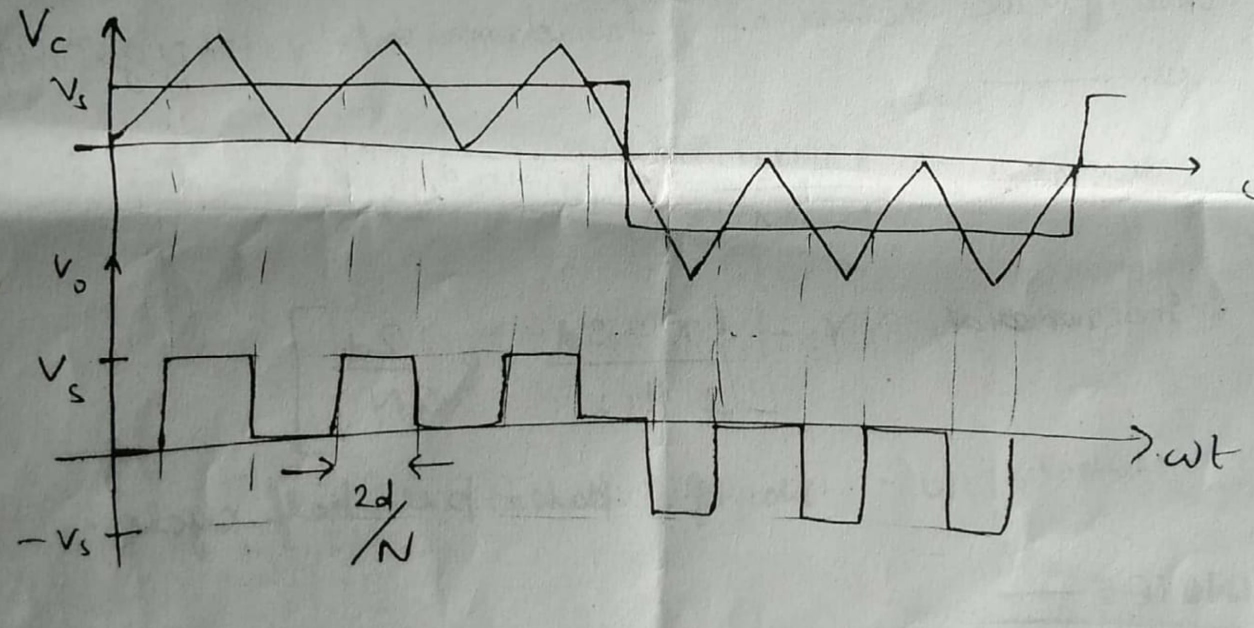
1) Fundamental component ($n=1$) of output voltage is lower for two pulse modulation than it is for single pulse modulation.

2) More no. of pulses per half cycle, the amplitude of lower harmonics are reduced but those of some higher harmonics are increased significantly.

But higher order harmonics can be filtered out easily.

Generation of MPM —





N = No. of hill tops per half cycle.

SPWM (Sinusoidal pulse width Modulation) —

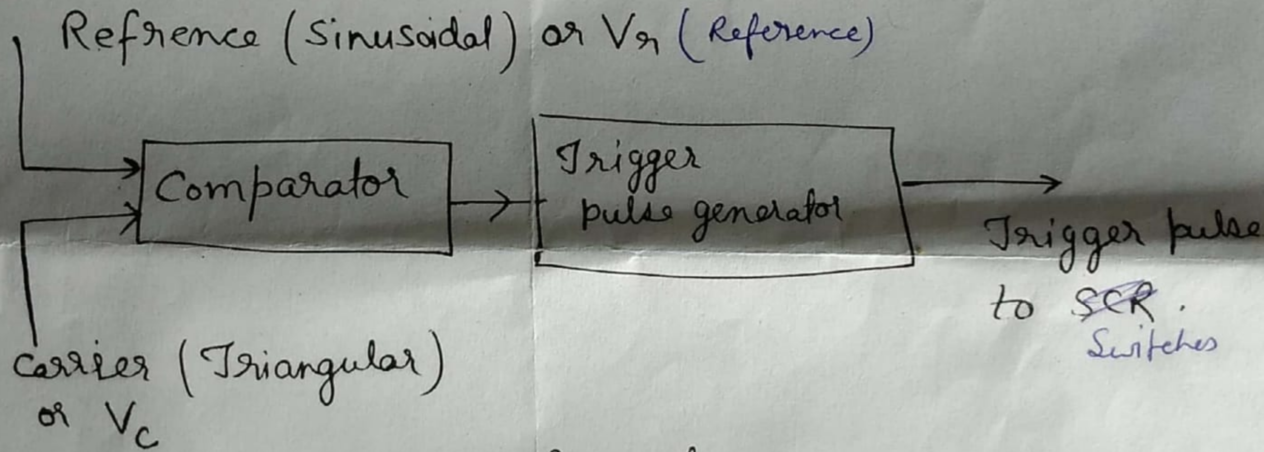
→ Several equidistant pulses per half cycle are used.

→ In MPM, the pulse width is equal for all the pulses. But in SPWM, the pulse width is a sinusoidal f^n of the angular position of pulse in a cycle.

For realizing SPWM, a high frequency triangular carrier wave V_c is compared with a sinusoidal reference wave V_r of the desired freq.

The intersection of V_c and V_r waves determines the switching instants and commutation of the modulated pulse.

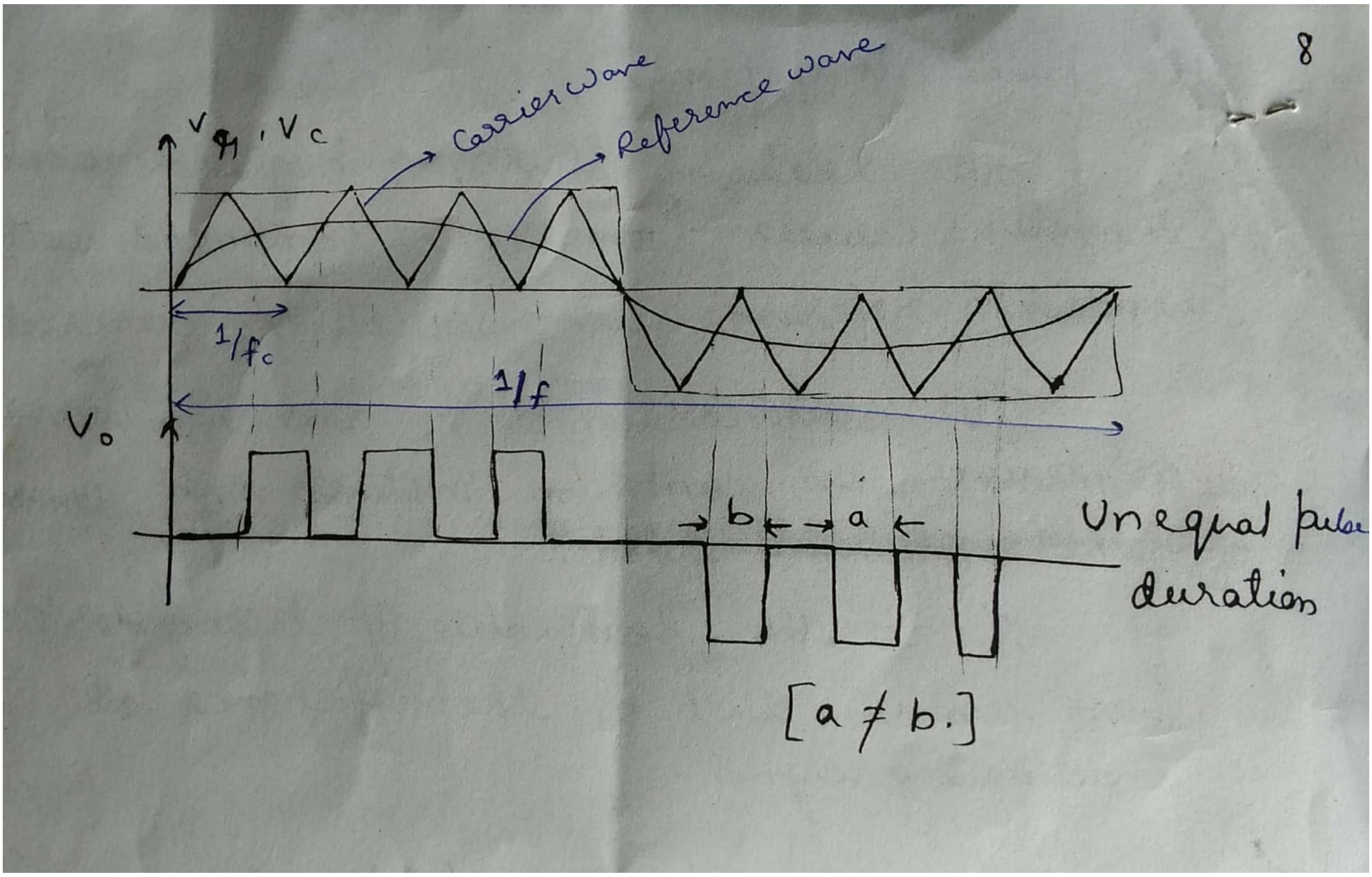
V_c is the peak value of triangular carrier wave and V_r that of the reference or modulating signal.



The carrier & reference waves are mixed in a comparator when sinusoidal wave has magnitude higher wave, the comparator output is high, otherwise it is low.

The comparator output is processed in a trigger pulse generator in such a manner the the output voltage wave of the inverter has a pulse width in agreement with the comparator output pulse width.

The ratio of V_r/V_c is called the modulation index. MI < 1 always.

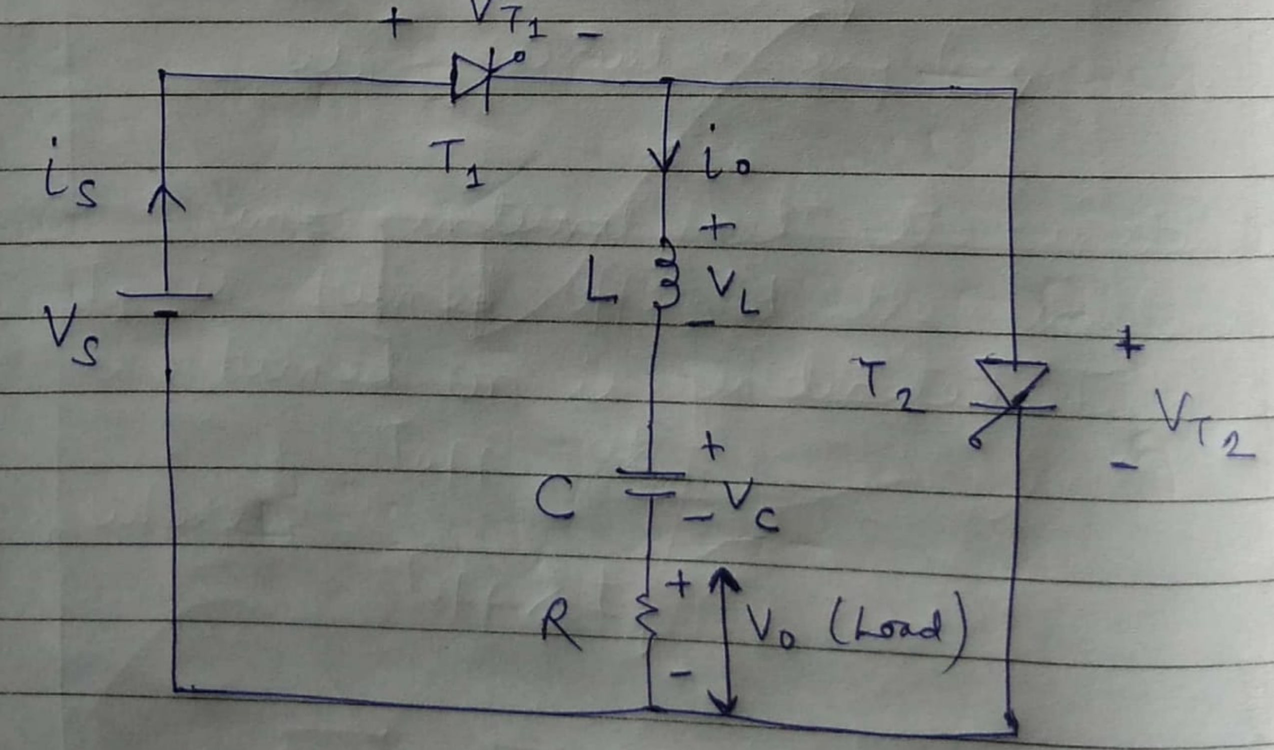

8
v_r, v_c
Carrier wave
Reference wave
$1/f_c$
$1/f$
V_o
b
a
Unequal pulse duration
[a ≠ b.]

Series Inverters

The Inverters in which commutating components are permanently connected in series with the load are called series Inverters.

- Series Circuit must be underdamped.
- Current attain zero value due to nature of series circuit. (RLC Series circuit)
- It operates at high frequency 200Hz to 100 KHz.

Construction of Series Inverter —



The basic circuit for a series inverter is shown in fig. It consists of a load resistance 'R' in series with commutating components L and C.

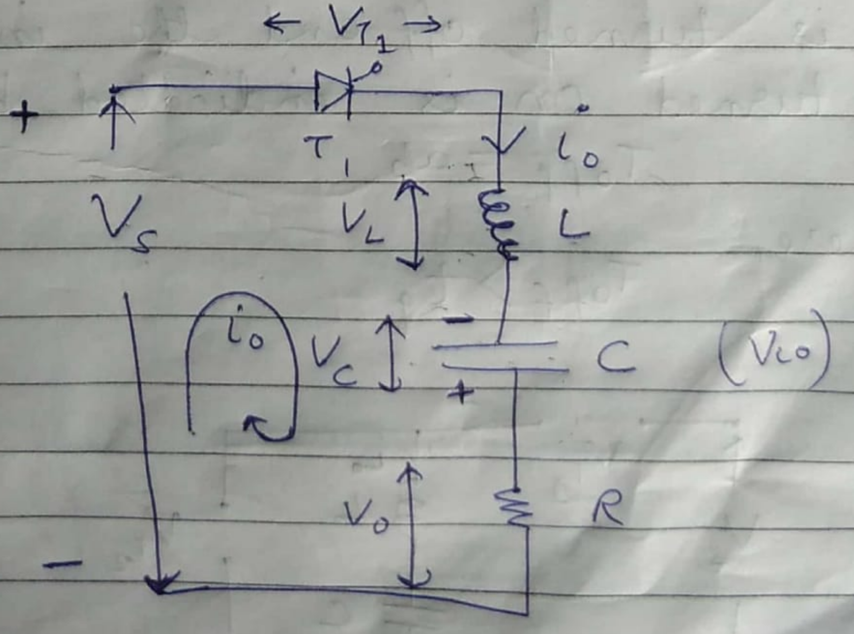
* The values of L & C are so chosen that the series RLC circuit forms an underdamped circuit.

Two thyristors T_1 & T_2 are turned on, ~~with T_2 off~~ appropriately so that output voltage of desired frequency can be obtained.

Operation —

MODE I :

When T_1 is turned on, with T_2 off, current i_o starts building up in the RLC circuit.



As the circuit is underdamped, the load current (i_o) after reaching some peak value, decays to zero at point 'a'. At point 'a', as the load current tends to reverse, thyristor T_1 turned off. After T_1 has commutated, upper plate of capacitor attains the polarity.

MODE II :

After instant a, some min^m time t_q must elapse for T_1 to regain its forward blocking capability. This min^m time is given by

$$t_q = \frac{\pi}{\omega_o} - \frac{\pi}{\omega_r} \quad \text{[Shown in graph]}$$

where,

ω_o = resonant freq.

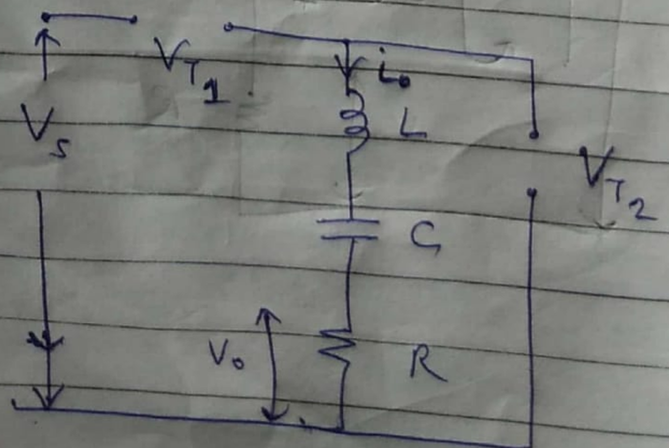
ω_r = circuit ringing freq.

Time interval bet^n the instant T_1 is turned off and the instant T_2 is turned on is indicated by

$$T_{off} = ab$$

where,

$$T_{off} > t_q$$



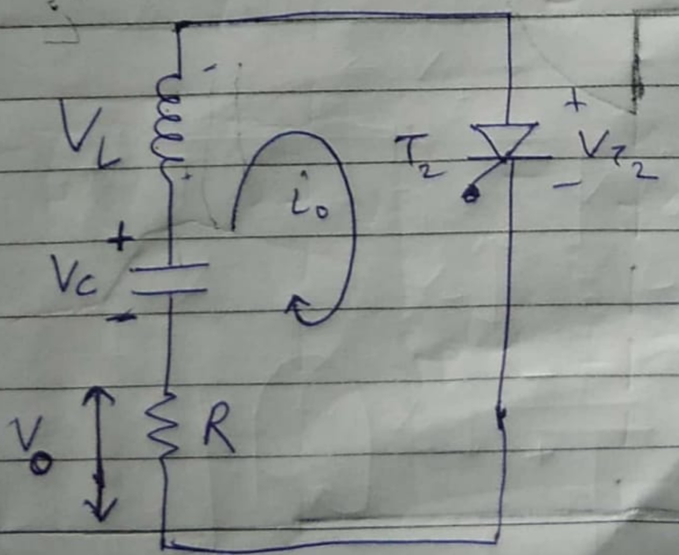
MODE III :

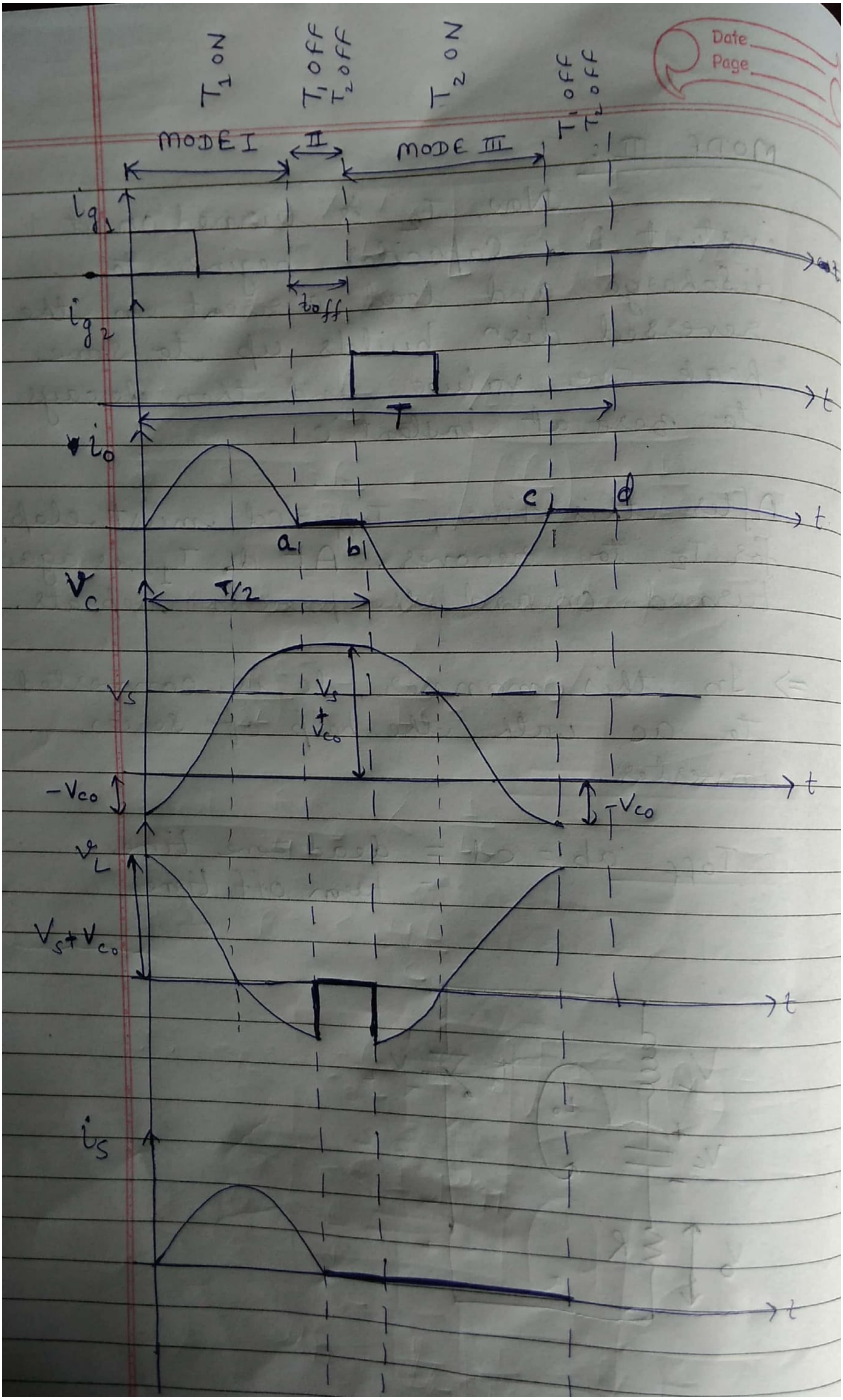
Now, T_2 is turned on at instant 'b', Capacitor begins to discharge and load current in the reversed dirn builds up to some peak -ve values and then decays to zero at instant 'C'.

After this time, $T_{off} = cd$ must elapse for T_2 to recover. At d, T_1 is again turned on and the process repeats.

=> In this manner, dc is converted to ac with the help of series inverter.

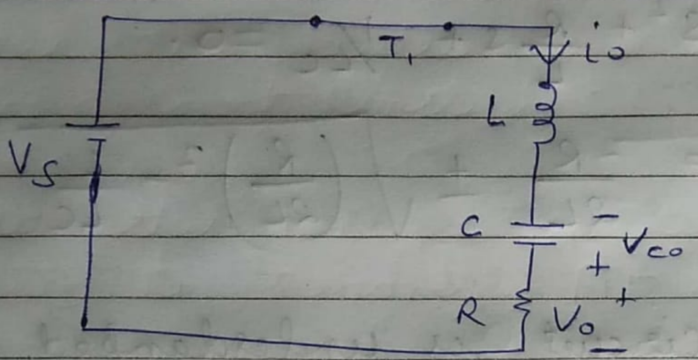
$T_{off} = ab = cd$ = dead zone time
= turn off time




T1 ON
T1 off T2 off
T2 ON
T1 off T2 off
MODE I
II
MODE III
ig1
t
toff
ig2
t
T
io
c
d
a
b
t
Vc
T/2
Vs
Vs + Vco
-Vco
-Vco
t
vL
Vs+Vco
t
is
t

Analysis :

MODE I: With T_2 off.



Here, the capacitor C is assumed to be initially charged to voltage V_{co} with lower plate +ve.

Mode I begins with turning on of T_1. Thus with T_1 on KVL for the closed crkt.

$$R i_0 + L\frac{di_0}{dt} + \frac{1}{C}\int i_0\,dt = V_s + V_{co}$$

$$R I_0(s) + LS\,I_0(s) + \frac{1}{CS}\,I_0(s) = \left(\frac{V_s + V_{co}}{S}\right)$$

$$\left[R + LS + \frac{1}{CS}\right] I_0(s) = \frac{V_s + V_{co}}{S}$$

$$I_0(s) = \frac{V_s + V_{co}}{S} \times \left[\frac{1}{R + LS + 1/CS}\right]$$

$$= \frac{V_s + V_{co}}{\cancel{S}} \times \left[\frac{C\cancel{S}}{RCS + CLS^2 + 1}\right]$$

$$I_o(s) = \frac{V_s + V_{co}}{L}\left[\frac{1}{s^2 + \frac{R}{L}s + 1/LC}\right] \quad \text{--- (1)}$$

$$\therefore \quad s^2 + \frac{R}{L}s + 1/LC = 0.$$

or $$s = \frac{-R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}$$

As the circuit is underdamped,

$$\left(\frac{R}{2L}\right)^2 - \frac{1}{LC} < 0.$$

or, $$\frac{R^2}{4L^{\cancel{2}}} < \frac{1}{\cancel{L}C}$$

or $$R^2 < \frac{4L}{C}$$

(as $\sqrt{-1} = j$)

$$\therefore \quad s = \frac{-R}{2L} \pm j\sqrt{\frac{1}{LC} - \left(R/2L\right)^2}$$

or. $s = -\xi \pm j\omega_{r}$

where,

$$\xi = \frac{R}{2L}$$

& $$\omega_{r} = \cancel{\frac{R}{2L}}\sqrt{\frac{1}{LC} - \left(R/2L\right)^2}$$

If $\omega_0 = 1/\sqrt{LC}$ = natural frequency.

Then,

$$\omega_r = \sqrt{\omega_0^2 - \xi^2}$$

Hence, from (1),

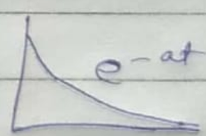
$$I_0(s) = \frac{V_s + V_{co}}{L}\left[\frac{1}{(s+\xi+j\omega_r)(s+\xi-j\omega_r)}\right]$$

or, $$I_0(s) = \frac{V_s + V_{co}}{L}\left[\frac{1}{s+\xi-j\omega_r} - \frac{1}{s+\xi+j\omega_r}\right]\frac{1}{2j\omega_r}$$

or, $$I_0(s) = \frac{V_s + V_{co}}{L}\left[\frac{\omega_r}{(s+\xi)^2 + \omega_r^2}\right] \cdot \frac{1}{\omega_r}$$

By taking inverse Laplace,

$$i_0(t) = \frac{V_s + V_{co}}{\omega_r L} \cdot e^{-\xi t} \sin\omega_r t$$



So current becomes zero after some time

P.T.O

Now, $v_L = L \frac{d i_o(t)}{dt}$

& $v_c = V_s - (V_R + V_L)$

MODE II :

T_1 & T_2 are off

$i_o = 0$

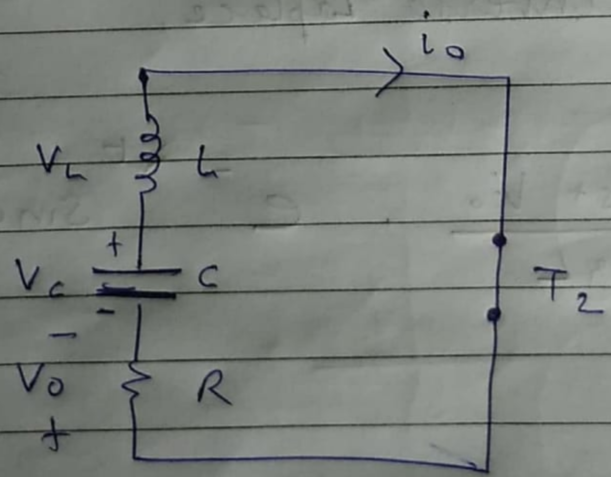
$V_L = 0$

$V_c = V_{c_1} = V_s + V_{co}$

MODE III :

T_2 is on

T_1 is off



Apply KVL —

$$R i_o + L\frac{d i_o}{dt} + \frac{1}{C}\int i_o\, dt = V_{c_1}$$

Initial voltage V_{C1} causes the capacitor to have upper plate +ve. Therefore when T_2 on, the current in load R is reverse as desired.

$$\therefore \quad i_o(t) = \frac{V_{C1}}{\omega_r L} e^{-\xi t} \sin \omega_r t .$$

Drawbacks of Series Inverter —

1) Harmonic Current ↑
2) Max^m operating frequency limited.
3) Load Voltage waveform is distorted.

Use —

Induction heating, fluorosent lighting.

CHOPPERS

A chopper is a static circuit that converts fixed dc input voltage to a variable dc output voltage directly.

A chopper may be thought of as dc equivalent of an ac X-former since they behave in an identical manner.

The power semiconductor devices as, force-commutated thyristors, used for a chopper circuit.

CONTROL STRATEGIES —

Time Ratio Control (TRC)

- → Const. freq. System ($1/T$)
- → Variable freq. System ($1/T$)

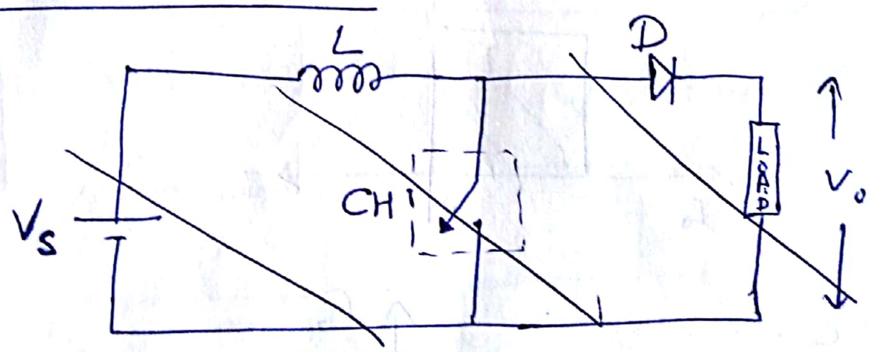
} See from the book.

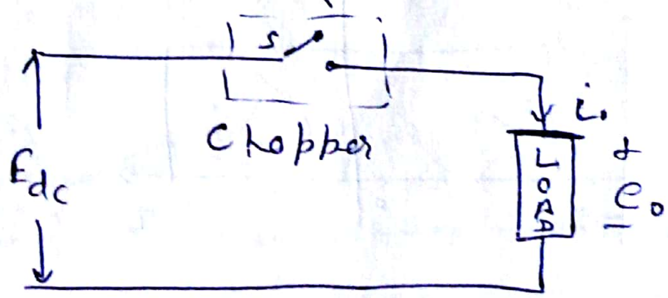
Const. freq. → It means T is Const., T_{ON} varied.

Variable freq. → It means T_{ON} is fixed, T is varied

$$[T = T_{ON} + T_{off}]$$

~~STEP-UP~~ CHOPPERS —





Basic Chopper Configuration

BASIC CHOPPER CLASSIFICATION

A) A/c to input / output Voltage Levels

a) Step up Chopper → $V_{out} > V_{in}$

b) Step down " → $V_{out} < V_{in}$

B) A/c to direction of output Voltage & Current.

a) Class A Chopper. [Classification based on quadrant operation]

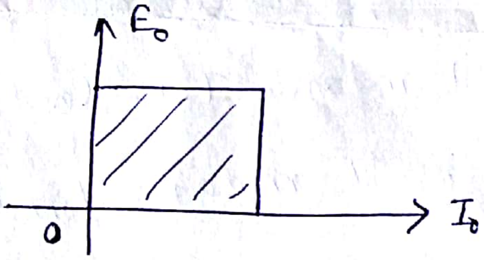
b) " B "

c) " C "

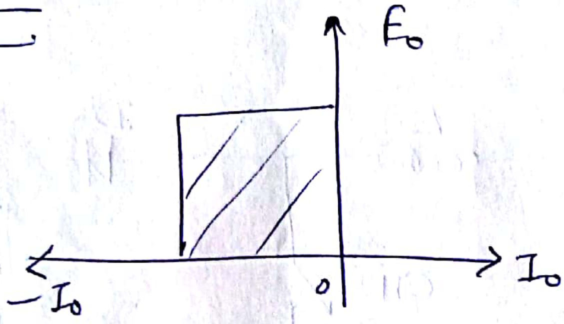
d) " D "

e) " E "

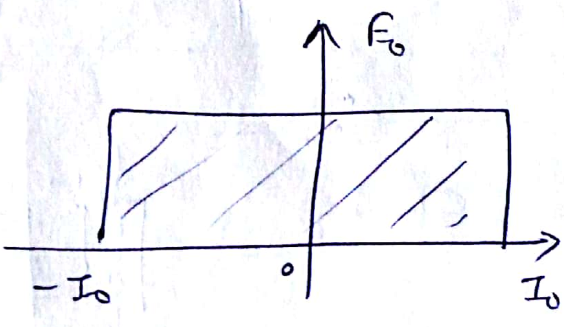
Class A —



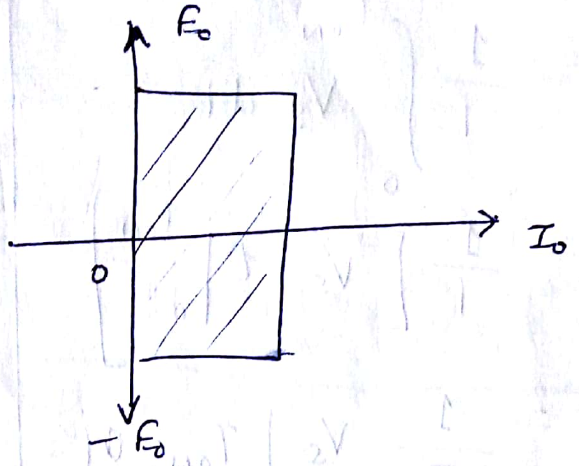
Class B —



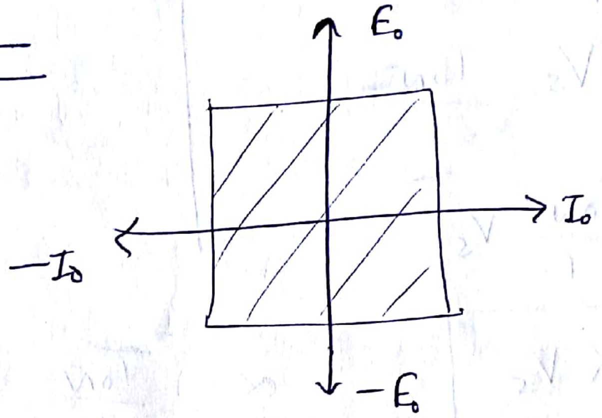
Class C —



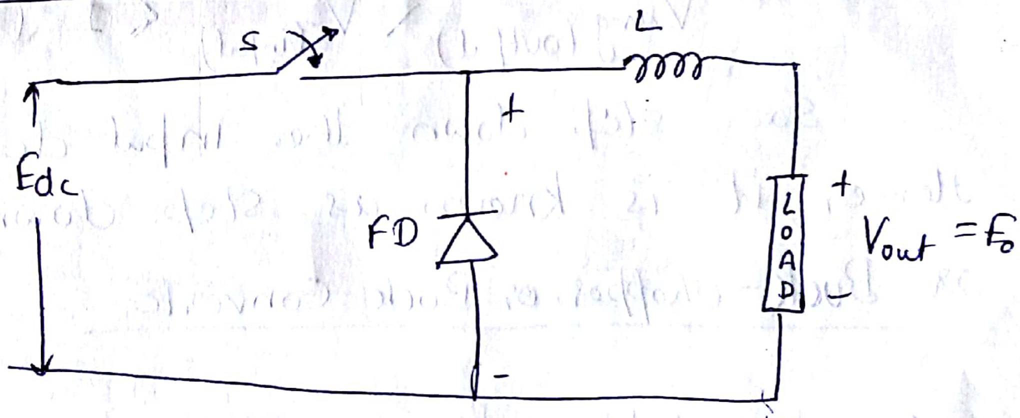
Class D —



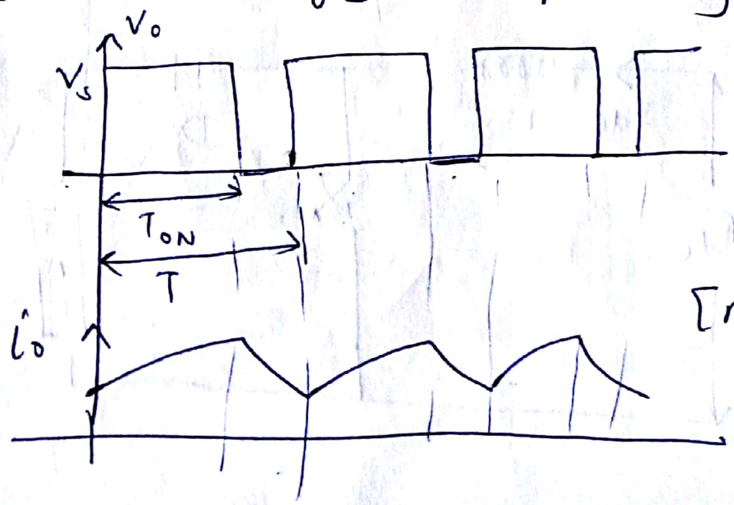
Class E —



* Step - down Chopper :



→ [Study its working [Ckt operation]]



[R-L Load]

Here,

$$V_{avg} = \frac{1}{T}\int_0^{T_{ON}} V_s \, dt$$

$$= \frac{1}{T}\left[V_s \cdot t \Big|_0^{T_{ON}} \right]$$

$$= \frac{1}{T} V_s \left[T_{ON} - 0 \right]$$

$$= V_s \frac{T_{ON}}{T}$$

or, $V_{avg} = \frac{T_{ON}}{T} V_s$

or $\boxed{V_{avg} = \alpha V_s}$

$\alpha = \frac{T_{ON}}{T}$ = duty Cycle

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^{T_{ON}} V_s^2 \ldots}$$

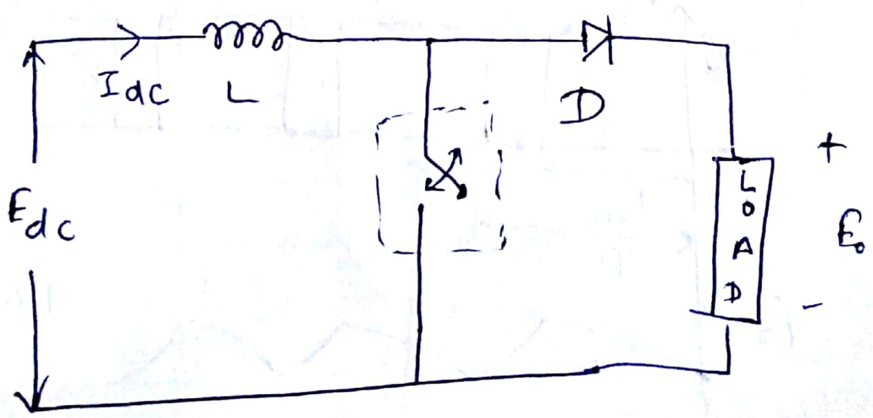
$$\boxed{V_{rms} = \sqrt{\alpha}\, V_s}$$

Hence, V_{avg} (output) $<$ V_s (input) <1 (always)

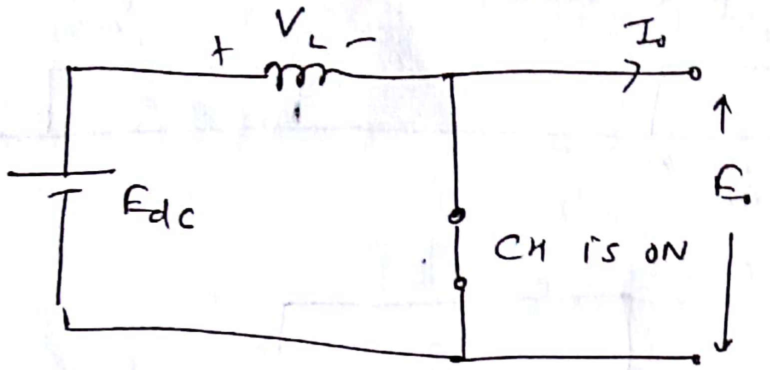
So step down the input dc.

Hence, it is known as step down chopper or Buck-Chopper. or Buck Converter.

Step-up Chopper [Boost Chopper]:



Mode I



$0 \leq t \leq T_{ON}$

CH → ON Diode − off

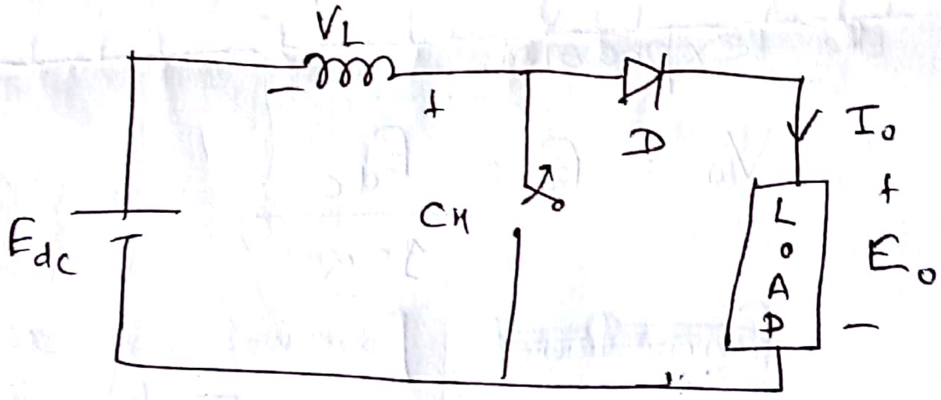
$E_o = 0$

$I_o = 0$

$V_L = E_{dc}$

L → Stores Energy

Mode II :

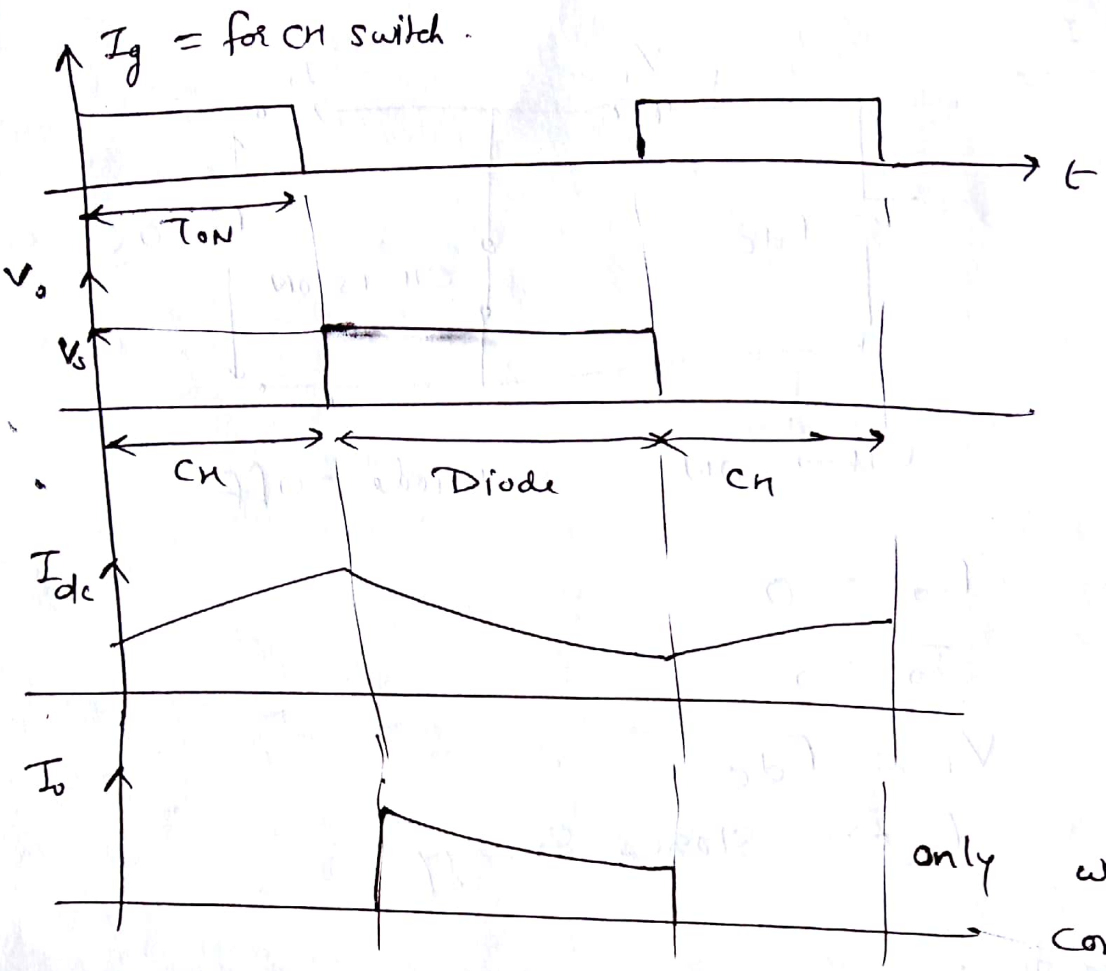


$T_{ON} \leq t \leq T$

CH = off D = ON

$V_{out} = E_o = E_{dc} + V_L$

$I_{dc} = I_o$



only when diode conducts.

Derive the expression,

$$V_o = E_o = \frac{E_{dc}}{1-\alpha}$$

~~from Book~~ [Derivation of this Expression — from page 9]

Que— A dc chopper ckt connected to a 100V dc source supplies an inductive load having 40mH in series with a resistance of 5Ω. A freewheeling diode is placed across the Load. The Load Current varies betn the limits of 10A & 12A. Determine the time Ratio of the Chopper.

Solⁿ: The avg value of the Load Current $= \dfrac{I_1 + I_2}{2}$

$$= \frac{10+12}{2} = 11A.$$

The maxm value of the Load Current

$$= \frac{100}{5} = 20A.$$

Now, the avg value of the Voltage $= E_{avg} = 100 \times \dfrac{11}{20} = 55V$

$$\left[E_{dc} \times \frac{I_{avg}}{I_{max}} \right]$$

Also,

$$E_{dc} \cdot \frac{T_{ON}}{T} = E_{avg}.$$

or,

$$\frac{E_{avg}}{E_{dc}} = \frac{T_{ON}}{T_{ON}+T_{off}} \quad [T = T_{ON} + T_{off}]$$

or,

$$\frac{55}{100} = \frac{T_{ON}}{T_{ON}+T_{off}} = 0.55$$

or

$$T_{ON} = 0.55\,(T_{ON}+T_{off})$$

or,

$$\frac{T_{ON}}{T_{off}} = \frac{0.55}{0.45} = 1.222 \quad \text{Ans.}$$

Que A, chopper ckt is operating on TRC principle at a (8) frequency of 2kHz on a 220V dc supply. If the Load voltage is 170V, compute the conduction and blocking period of thyristor in each cycle.

Soln: As we know,

$$E_o = E_{avg} = E_{dc} \cdot \alpha$$
$$= E_{dc} \cdot \frac{T_{ON}}{T}$$
$$= E_{dc} \cdot T_{ON}(f) \quad [f = 1/T]$$

Given, $f = 2kHz$.
$E_{dc} = 220$
$E_o = 170\ V$

Conduction period $= T_{ON} = \dfrac{E_{avg}}{E_{dc} \cdot f} = 0.386ms$

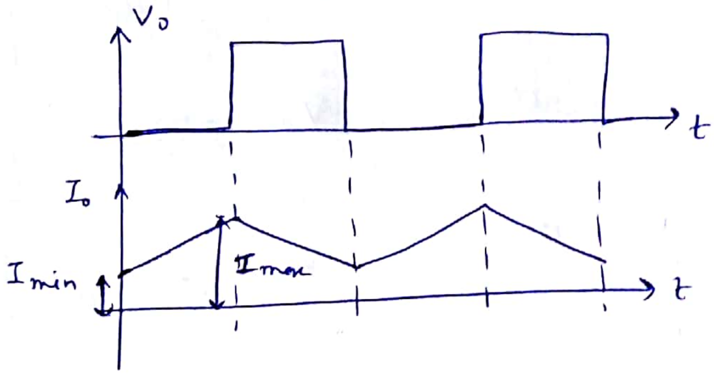
But chopping Period $= T = 1/f = 0.5ms$

$\therefore$ Blocking Period $= T_{off}$
$= T - T_{ON}$
$= 0.114ms$

Step - Up Chopper :

Calculation for 'V_o' (Load Voltage):

Now, during T_{ON},



$$\Delta i_{dc} = I_{min} - I_{max}$$

& $$V_L = E_{DC}$$

Also, $V_L = L\dfrac{di}{dt} = E_{DC}$

$$\Rightarrow L\left[\frac{I_{min} - I_{max}}{0 - T_{ON}}\right] = E_{DC}$$

or, $$-[I_{min} - I_{max}] = \frac{E_{DC} \cdot T_{ON}}{L}$$

or, $$I_{max} - I_{min} = \frac{E_{DC} \cdot T_{ON}}{L} \quad \text{--- (1)}$$

during T_{OFF},

$$L\frac{di}{dt} = V_o - E_{dc}$$

$$L \cdot \left[\frac{I_{max} - I_{min}}{T - T_{ON}}\right] = V_o - E_{dc}$$

$$I_{max} - I_{min} = \left(\frac{V_o - E_{dc}}{L}\right)(T_{OFF}) \quad \text{--- (2)}$$

[as, $T_{OFF} = T - T_{ON}$]

from (1) & (2) —

$$\frac{E_{dc}}{\cancel{L}} T_{ON} = \frac{V_o - E_{dc}}{\cancel{L}} T_{OFF}$$

or, $$E_{dc}[T_{ON} + T_{OFF}] = V_o \cdot T_{OFF}$$

or, $V_o = E_{dc} \cdot \frac{T}{T_{off}}$

or, $V_o = E_{dc} \cdot \left[\frac{T}{T - T_{ON}}\right]$

or, $V_o = E_{dc} \left[\frac{1}{1 - \frac{T_{ON}}{T}}\right]$

or $V_o = E_{dc} \left[\frac{1}{1 - \alpha}\right]$

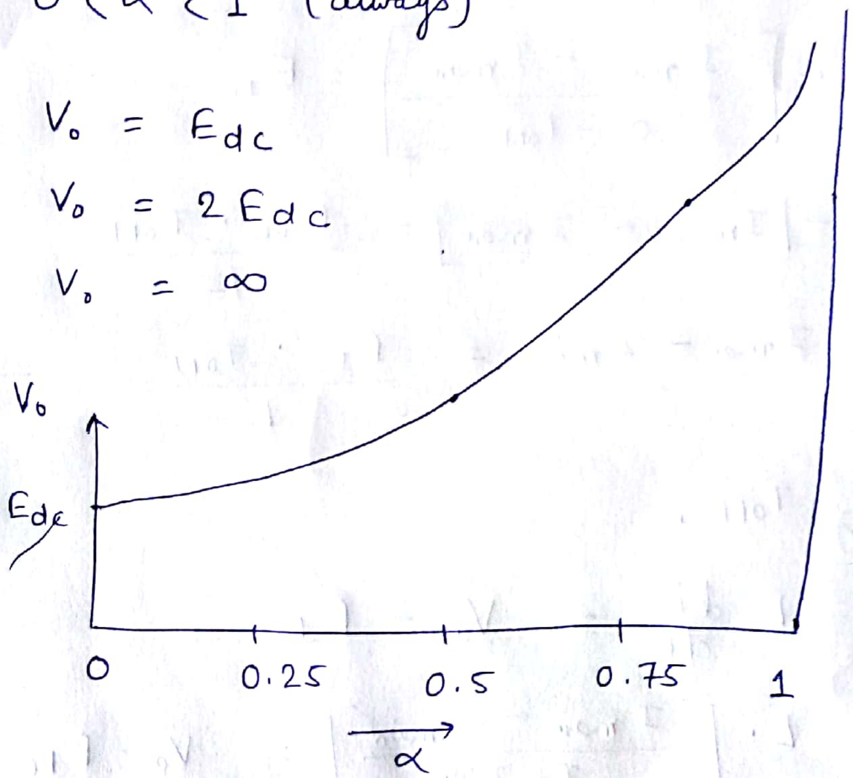
where, $0 < \alpha < 1$ (always)

for, $\alpha = 0$, $V_o = E_{dc}$

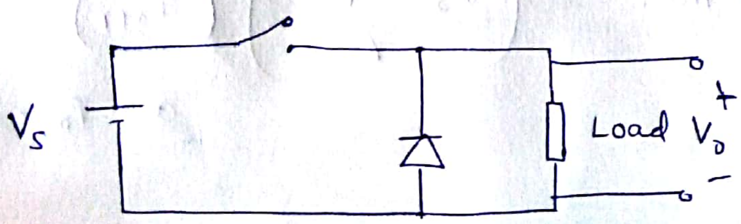
for, $\alpha = 0.5$ $V_o = 2E_{dc}$

for, $\alpha = 1$ $V_o = \infty$

for, $\alpha = 0.75$
$V_o = 4E_{dc}$

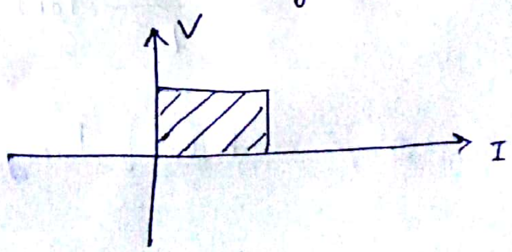


Type-A Chopper — [First Quadrant]



The power flow in type 'A' chopper is always from Source to load.

As, $V_o < V_s$ So, Step down.



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Que : 8 (b) / Que (9.1)

(1)

Sol^n :- Given that,

$V_s = 230\,V$ [Always rms Voltage is given for AC Source]

$R = 20\,\Omega$

$\alpha = 45° = \pi/4$

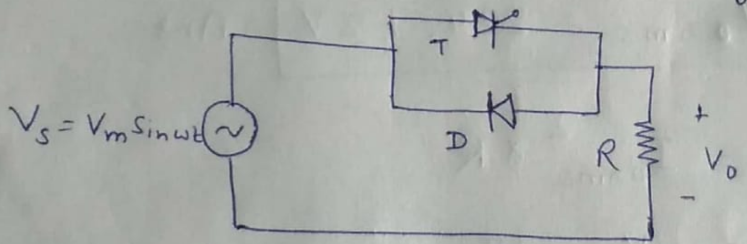
We have to find,

a) V_{rms} of output Voltage $= V_{o\,rms} = ?$

[b) Load Power $= P_o = ?$ & Input p.f. $= ?$]

c) Avg Input Current $= I_{s\,avg} = ?$

a) Single phase half wave ac voltage Controller.



fig(1): Circuit diagram

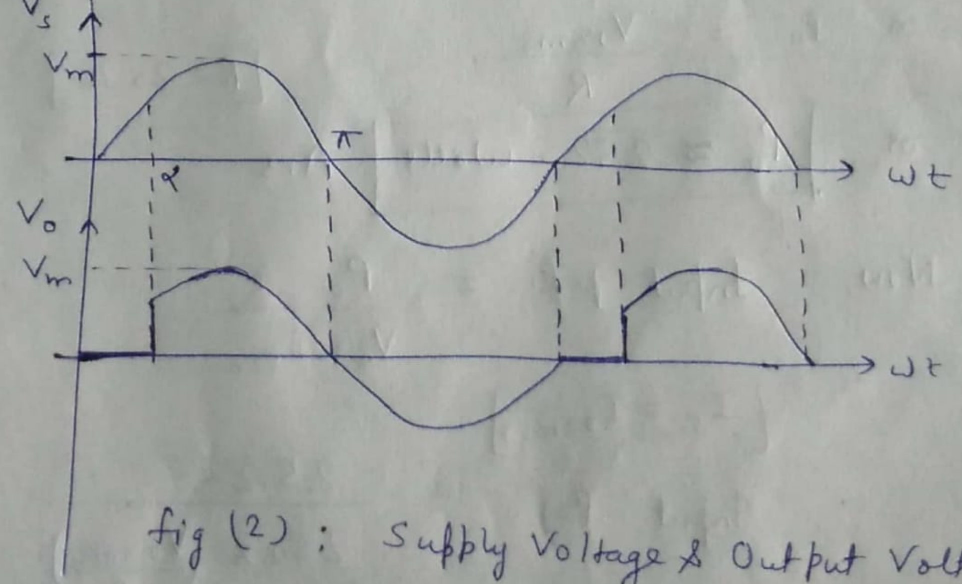


fig (2) : Supply Voltage & Output Voltage Waveform

Now, $V_{orms} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m^2 \sin^2\omega t \, d(\omega t)}$ By

or, $V_{orms} = \frac{V_m}{2}\left[\frac{1}{\pi}\left\{(2\pi-\alpha)+\frac{\sin 2\alpha}{2}\right\}\right]^{1/2}$ [Solve this Eqn]

As from question, $\alpha = \pi/4$.

So, $V_{orms} = \frac{V_m}{2}\left[\frac{1}{\pi}\left\{\left(2\pi - \frac{\pi}{4}\right) + \frac{\sin 2\left(\frac{\pi}{4}\right)}{2}\right\}\right]^{1/2}$

or $V_{orms} = \frac{\sqrt{2}V_s}{2}\left[\frac{1}{\pi}\left\{\frac{7\pi}{4}+\frac{1}{2}\right\}\right]^{1/2}$ $\left[\sin\pi/2 = 1, V_m = \sqrt{2}V_s\right]$

or, $V_{orms} = \frac{230}{\sqrt{2}}\left[\frac{1}{3.14}\left\{\frac{7\times 3.14}{4}+1/2\right\}\right]^{1/2}$ $[\pi = 3.14]$

$\boxed{V_{orms} = 224.72V}$ Ans.

b) As, $P_o = I_{orms}^2 \times R$

or, $P_o = \left(\frac{V_{orms}}{R}\right)^2 \times R$

or $P_o = \frac{V_{orms}^2}{R}$ $[R = 20\,\Omega]$

or, $\boxed{P_o \approx 2525 \text{ Watts}}$ Ans.

Now, $\text{Input p.f.} = \frac{P_o}{V_s \cdot I_{srms}}$

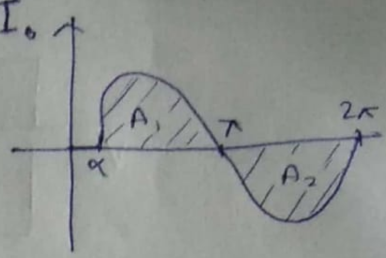
$[I_{srms} = I_{orms}]$

$\therefore$ $\text{Input P.f.} = \frac{2525}{230 \times \left(\frac{V_{orms}}{R}\right)}$

$\cos\phi_s = \frac{2525}{230 \times \left(\frac{224.72}{20}\right)}$

$\boxed{\cos\phi_s = 0.977}$ Ans

c) Avg. Input Current $= \dfrac{V_{o\,avg}}{R}$ — (1)



& $V_{o\,avg} = \dfrac{1}{2\pi}\displaystyle\int_{\alpha}^{2\pi} V_m \sin\omega t \; d(\omega t)$

$= \dfrac{-1}{2\pi} \cdot V_m \Big[\cos\omega t\Big]_{\alpha}^{2\pi}$

$= \dfrac{1}{2\pi} \cdot V_m \cdot \left[\cos\alpha - \cos 2\pi\right]$

$= \dfrac{1}{2\pi} \cdot V_m \left[\cos\dfrac{\pi}{4} - \cos 2\pi\right]$ $\quad [\alpha = \pi/4]$

$= \dfrac{1}{2\pi} \cdot V_m \left[\dfrac{1}{\sqrt{2}} - 1\right]$

$= \dfrac{1}{2\pi} \cdot 230\sqrt{2}\left[\dfrac{1}{\sqrt{2}} - 1\right]$

$= -15.17\ V$ [-ve Sign indicates that $A_2 > A_1$]

So, Avg. Input Current $= I_{s\,avg} = \dfrac{-15.17}{20}$

$\boxed{I_{s\,avg} = -0.7585\ A}$ Ans.

[-ve for $A_2 > A_1$].

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Que (5) (b) / Que (7.3)

Solⁿ: Given that, $V_s = 220\,V$

$V_o = 660\,V$

$T_{ON_1} = 100\,\mu s$

We have to find, $T_{OFF_1} = ?$

Also, If $T_{OFF\,2} = \dfrac{T_{OFF\,1}}{2}$ for $T = T_{ON} + T_{OFF} = $ Const.

Then, $V_{o\,avg} = ?$

Step up Chopper

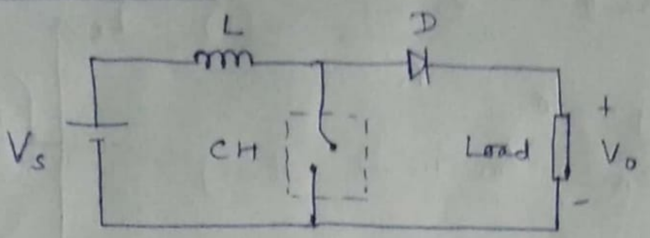
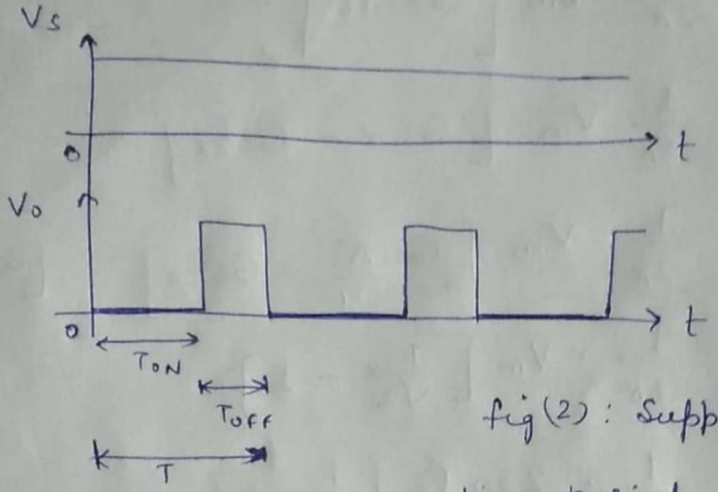


fig (1): Circuit diagram



[Pulse width of Output Voltage = T_{OFF}] (Shown in fig (2))

fig (2): Supply voltage & output voltage waveform

* T = Switching ~~(frequency)~~ time period of chopper = $T_{ON} + T_{OFF}$
* $\frac{1}{T} = f$ = Switching freq. of chopper

As we know for, Step up Chopper,

$$V_{o\,avg} = V_s \cdot \frac{1}{1-\alpha}$$

$\left[\alpha = \text{Duty Cycle} = \frac{T_{ON}}{T}\right]$

So, $660 = 220 \cdot \frac{1}{1-\alpha_1}$

or, $\alpha_1 = 2/3$

or, $\frac{T_{ON_1}}{T} = 2/3$

So, $T = \frac{3}{2} \cdot T_{ON_1}$

or $T = \frac{3}{2} \times 100 \times 10^{-6}$ sec.

or $T = 150\,\mu s$

Now, $T_{OFF_1} = T - T_{ON_1} = (150 - 100)\,\mu s$

or. $\boxed{T_{OFF_1} = 50\,\mu s}$ Ans.

Now, A/c to question,

$$T_{off_2} = \frac{T_{off_1}}{2}$$

or, $T_{off_2} = 25\mu s$

But $T = 150\mu s$.

So, $T_{ON_2} = T - T_{off_2}$ [As $T = T_{ON} + T_{off}$]

or $T_{ON_2} = (150 - 25)\mu s$

or $T_{ON_2} = 125\mu s$

Now, $\alpha_2 = \frac{T_{ON_2}}{T}$

$= \frac{125}{150}$

or $\alpha_2 = 5/6$

$\therefore V_{o\,avg} = V_s \cdot \frac{1}{1-\alpha_2}$

$= 220 \cdot \frac{1}{1-(5/6)}$

or $\boxed{V_{o\,avg} = 1320\,V}$ Ans.

Year 2015

Que 1 (e)

Solⁿ: Given that, $T_{ON} = 3\times10^{-3}\,s$

$T_{off} = 1\times10^{-3}\,s$

We have to find, $f = \frac{1}{T} = ?$

As, $T = T_{ON} + T_{off}$

So, $T = 4\times10^{-3}\,s$

& Chopping frequency $= \frac{1}{T} = 250\,Hz$

$\boxed{f = 250\,Hz}$

Year 2015 | P. S. Bimbhra
Que 3 (b) | Que (4.15)

Solⁿ: Given that, $V_s = 400V$

$$I_p = 200A$$

$$\left(\frac{di}{dt}\right)_{max} = 50 \ A/\mu s$$

$$\left(\frac{dv}{dt}\right)_{max} = 200 \ V/\mu s.$$

Safety factor = 2 for I_p, $\left(\frac{di}{dt}\right)_{max}$ & $\left(\frac{dv}{dt}\right)_{max}$

$$R_L = 10\,\Omega$$

We have to find, $R = ?$

$C = ?$

& $L = ?$

[As here di/dt limit is also considered so we add an inductor in series with a SCR to limit the current, So we have to find L also]

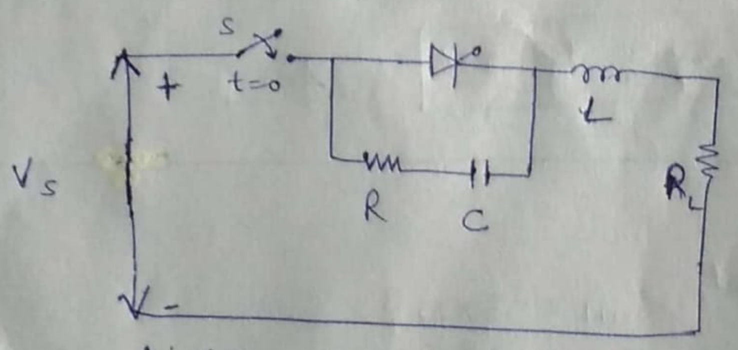
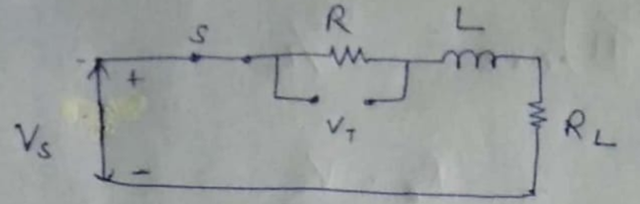


fig (1): SCR protection with R, C & L

at $t = 0^+$, soon after the instant of closing the switch 'S' is, (A/c KVL)

$$V_s = (R + R_L)\,i + L\frac{di}{dt} \quad \text{—(1)}$$

(from fig (2))



fig(2): at the instant Switch 's' is closed

Now, Solⁿ of Eqⁿ 1 is,

$$i = I\left(1 - e^{-t/\tau}\right) \quad -(2)$$

where, $I = \dfrac{V_s}{R+R_L}$ $\qquad (I = V/R)$

& τ = time Const. of Ckt $= \dfrac{L}{R+R_L}$ $\qquad (\tau = L/R)$

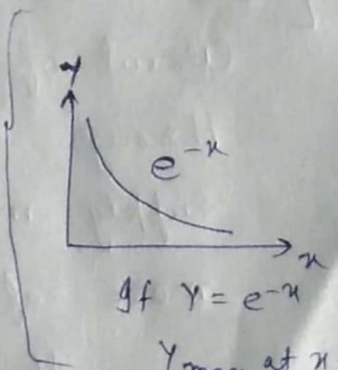
Now, differentiating eqⁿ 2 —

$$\frac{di}{dt} = \frac{I \cdot e^{-t/\tau}}{\tau}$$

$$= \left(\frac{V_s}{\cancel{R+R_L}}\right) \cdot e^{-t/\tau} \cdot \left(\frac{\cancel{R+R_L}}{L}\right)$$

or $\dfrac{di}{dt} = \dfrac{V_s}{L} e^{-t/\tau}$

or, $\left(\dfrac{di}{dt}\right)_{max} = \dfrac{V_s}{L}$, at $t=0$



If $Y = e^{-x}$

Y_{max} at $x=0$

So, $\boxed{L = \dfrac{V_s}{\left(di/dt\right)_{max}}}$ — (1)

Now, Voltage across the SCR is given by,

$$V_T = Ri$$

or, $\dfrac{dv_T}{dt} = R \cdot \dfrac{di}{dt}$

or, $\left(\dfrac{dv_T}{dt}\right)_{max} = R\left(\dfrac{di}{dt}\right)_{max}$ — (8)

from ①, $\left(\frac{di}{dt}\right)_{max} = V_s/L$

So, $\left(\frac{dv_T}{dt}\right)_{max} = R \cdot \frac{V_s}{L}$

or, $\boxed{R = \frac{L}{V_s} \cdot \left(\frac{dv_T}{dt}\right)_{max}}$ — ②

Also, from 2nd order Crkt Relation (RLC Crkt)

$$R = 2\xi\sqrt{L/C}$$

So, $\boxed{C = \left(\frac{2\xi}{R}\right)^2 L}$ — ③

Here, Safety factor = 2.

* [This means that 2 times Safety of by the protection circuit of SCR, means if max^m range for current through the SCR is Imax then we have to supply maximum $\frac{I_{max}}{2}$, ~~for~~ to provide 2 times more Safety.

If Safety factor is '1' then, max^m current (permissible current) through the SCR may be Imax.]

[More Safety ↑ Less Rating or Range ↓]

So, I_p becomes, $\frac{100}{2} = 100\,A$

& Also, $\left(\frac{di}{dt}\right)_{max} = \frac{50}{2} = 25\ A/\mu s$

and, $\left(\frac{dv}{dt}\right)_{max} = \left(\frac{dv_T}{dt}\right)_{max} = \frac{200}{2} = 100\,V/\mu s$

So, from Eqn ①

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

or $L = \frac{400\,V}{25\,A/\mu s}$

or $L = \frac{400\,V \times 10^{-6}\,Sec}{25\,A}$

or $\boxed{L = 16\,\mu H}$

Again from Eqn ②

$$R = \frac{L}{V_s} \cdot \left(\frac{dv}{dt}\right)_{max}$$

$$= \frac{16 \times 10^{-6}}{400} \cdot \frac{100\,V}{10^{-6}\,Sec}$$

or $\boxed{R = 4\,\Omega}$

when SCR is turned on, the peak current through the SCR is,

$$I_{P_{new}} = \frac{V_s}{R} + \frac{V_s}{R_L} \quad — \quad 4 \qquad (R \| R_L)$$

$$= \frac{400}{4} + \frac{400}{10}$$

$$\boxed{I_{P_{new}} = 140\ A}$$

Here, we see that, $I_{P_{new}} > I_P$

where, $I_P = 100A$ = max^m permissible value of Current through SCR.

So, we must have to vary any parameter in Eq^n 4 and in Eq^n 4 only 'R' can be varied,

So, If $I_{P_{new}}$ can be ↓

Then, $\frac{V_s}{R}$ ↓

So, 'R' can be ↑

Trail & Error

Let $R = 5\Omega$ $\quad I_{P\,new} = 120\,A$ (Not permissible)

$R = 6\,\Omega$ $\quad$ " $= 106.7A$ (")

$R = 7\Omega$ $\quad$ " $= 97.14\,A$ (permissible but very near to I_{pmax})

$R = 8\Omega$ $\quad$ " $= 90\ A$ (we can take this)

So, $\boxed{R = 8\Omega}$ Ans.

Also, $C = \left(\frac{2\xi}{R}\right)^2 \cdot L$

ξ (damping factor) may be in the range of 0.5 to 1 usually.

So, $C = \left(\frac{2 \times 0.65}{8}\right)^2 \times 16 \times 10^{-6}$

or $\boxed{C = 0.4225\ \mu F}$

* The value of C is reduced (whereas 'R' is increased) so that energy stored in C is small and the snubber discharge does not harm SCR when it is turned on.

So, $\boxed{C = 0.3\ \mu F}$ Ans. $(< 0.4\mu F)$

Now, we have to check, wheather the value of 'C' is acceptable so that $\left(\frac{dv}{dt}\right)_{max}$ ~~rating~~ value does not exceeded.

So, when SCR is open circuited and current through C is given by,

$$C\frac{dv}{dt} = \frac{V_s}{R + R_L}$$

or $$\frac{dv}{dt} = \frac{1}{C} \cdot \frac{V_s}{R + R_L}$$

$$\frac{dv}{dt} = \frac{1}{0.3 \times 10^{-6}} \times \frac{400}{10+8}$$

or $$\frac{dv}{dt} = 74.07 \text{ V}/\mu s \quad \left[< \left(\frac{dv}{dt}\right)_{max} \right]$$

Since designed value of $\left(\frac{dv}{dt}\right)$ is less than the specified max^m value of 100 V/μs, value of C chosen is correct.

So, we have to choose,

$$\left.\begin{aligned} L &= 11 \mu H \\ R &= 8 \Omega \\ \& \quad C &= 0.3 \mu F \end{aligned}\right\} \underline{\underline{\text{Ans.}}}$$

$\Bigg[$ as, $C = \left(\frac{2\xi}{R}\right)^2 L$

$C = 0.3$

$R = 8$

So, $L = 11.36 \mu H$

or $L \simeq 10$ or $11 \mu H$ (we can take) $\Bigg]$

Year 2014 / P. S. Bimbhra
Que : (3) / Que : 6. 2

Sol^n:

Given that,

$$V_s = 230\,V$$
$$R = 8\,\Omega$$
$$E = 150\,V$$

We have to find,

Expression for the average value of charging current, $I_{o\,avg} = ?$

a) $I_{o\,avg} = ?$

b) Power supplied to battery, $P_{oE} = ?$

~~c)~~ Power dissipated in R, $P_{oR} = ?$

c) Supply pf $= \cos\phi_s = ?$

The given Circuit is shown in fig (1) and its related waveforms in fig (2).

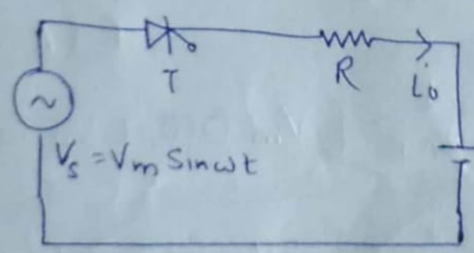
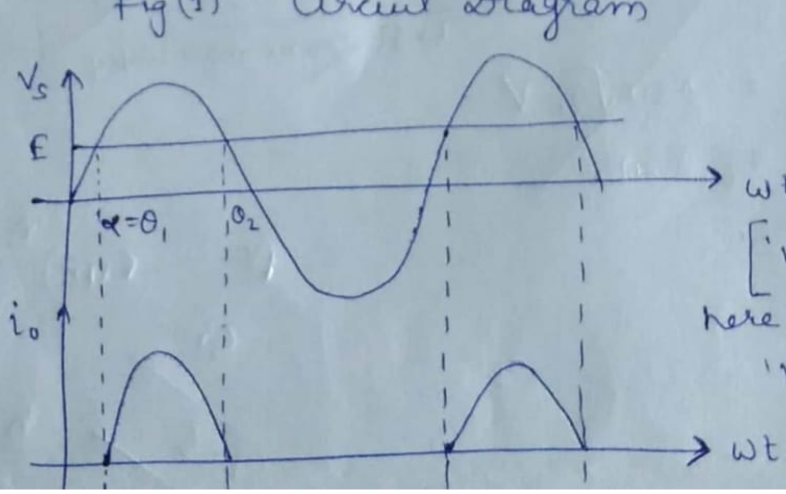


fig (1): Circuit Diagram



* The min^m possible $\alpha = \theta_1$

['V_o' is not drawn here as in given circuit 'V_o' is not mentioned]

Now, from the fig(1) :—

$$V_m \sin \omega t = E + i_o R$$

or, $$i_o = \frac{V_m \sin \omega t - E}{R}$$

So, $$I_{o\,avg} = \frac{1}{2\pi} \int_{\theta_1}^{\theta_2} \frac{V_m \sin \omega t - E}{R} \, d(\omega t)$$

or $$I_{o\,avg} = \frac{1}{2\pi R} \left[-V_m \cos \omega t \Big|_{\theta_1}^{\theta_2} - E \left(\omega t \Big|_{\theta_1}^{\theta_2} \right) \right]$$

$$= \frac{1}{2\pi R} \left[V_m \cos \theta_1 - V_m \cos \theta_2 - E(\theta_2 - \theta_1) \right]$$

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

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

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

or $I_{o\,avg} = \frac{1}{2\pi R}\left[2V_m \cos\theta_1 - E(\pi - 2\theta_1)\right]$ — (1)

Also,

The min^m firing angle for 'T' is Expressed as,

$$V_m \sin\theta_1 = E$$

$$\text{So,}\quad \theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$$

$$\text{So,}\quad \cos\theta_1 = \sqrt{1 - (E/V_m)^2}$$

$$\text{or}\quad \cos\theta_1 = \frac{\sqrt{V_m^2 - E^2}}{V_m}$$

So, from (1),

$$\boxed{I_{o\,avg} = \frac{1}{2\pi R}\left[2\sqrt{V_m^2 - E^2} - E\left\{\pi - 2\sin^{-1}(E/V_m)\right\}\right]} \text{ — (2)}$$

Ans.

Eq^n (2) is the expression for the average value of charging current in terms of V_m, E & R

[* Eq^n (1) may also be answer, as in question it is mention that the parameters are V_m, E, R etc.]

a) $V_m = 230\sqrt{2}$ V $\qquad E = 150$ V

$R = 8\ \Omega$

$$\theta_1 = \sin^{-1}(E/V_m) = \sin^{-1}\left(\frac{150}{230\sqrt{2}}\right)$$

$$\text{or}\quad \theta_1 = 27.46^\circ = 0.48 \text{ rad}$$

from Eq^n (1), $I_{o\,avg} = \frac{1}{2\pi \cdot 8}\left[2\cdot\sqrt{2}\cdot 230 \cos(27.46^\circ) - 150(\pi - 2\times 0.48)\right]$

$\boxed{I_{o\,avg} = 4.98\ A}$ Ans.

b) Power Supplied to battery $= E I_{o\,avg}$ [DC] (16)

or, $P_{oE} = 150 \times 4.98$

or, $\boxed{P_{oE} = 747 \text{ Watts}}$ Ans.

Now, Power dissipated in Resistor 'R' $= I_{o\,rms}^2 R$

$$I_{o\,rms} = \sqrt{\frac{1}{2\pi}\int_{\theta_1}^{\pi-\theta_1}\left(\frac{V_m \sin\omega t - E}{R}\right)^2 d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi R^2}\int_{\theta_1}^{\pi-\theta_1}\left(V_m^2 \sin^2\omega t + E^2 - 2V_m E \sin\omega t\right) d(\omega t)}$$

$$= \left[\frac{1}{2\pi R^2}\left\{(V_s^2 + E^2)(\pi - 2\theta_1) + V_s^2 \sin 2\theta_1 - 4V_m E \cos\theta_1\right\}\right]^{1/2} \longrightarrow (3)$$

(* You can derive this)

So, from Eq^n (3)

$I_{o\,rms} = 9.2955 A$

& Power dissipated in 'R' $= P_{oR} = (9.29)^2 \times 8$

or $\boxed{P_{oR} = 691.25 \text{ Watts}}$ Ans.

c) Power delivered $= P_{oR} + P_{oE}$

So, Supply Power factor, $\cos\phi_s = \dfrac{P_{oR} + P_{oE}}{V_s \cdot I_{o\,rms}}$

or $\cos\phi_s = \dfrac{691.25 + 747}{230 \times 9.2955}$

or, $\boxed{\cos\phi_s = 0.6727}$ Ans

Year 2014 Que (4) / P.S. Bimbhra Que 6.7

Soln:

Given that,

$V_s = 230\,V$

$f = 50\,Hz.$

$I_{o,avg} = 10\,A$

$R = 0.4\,\Omega$

$L = 2\,mH$

we have to find,

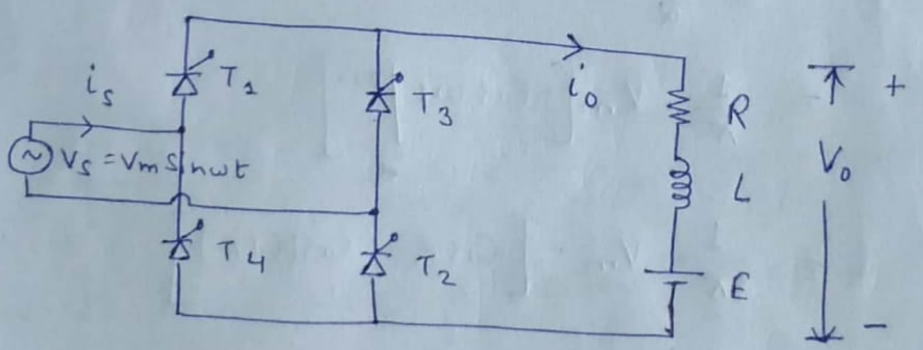
a) for $E = 120\,V$, $\alpha_1 = ?$

b) for $E = -120\,V$, $\alpha_2 = ?$

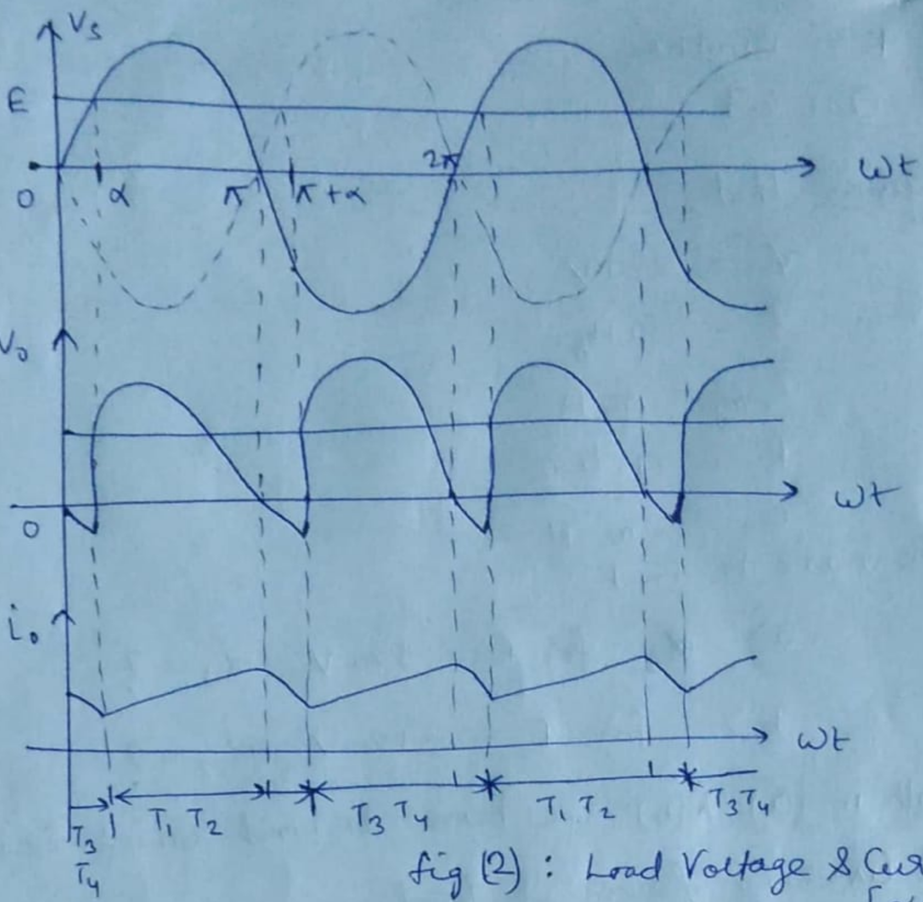
both in (a) & (b) we have to find which source is delivering power to load.

c) $\cos\phi_{s_1} = ?$ & $\cos\phi_{s_2} = ?$

a)



fig(1): Single phase full Converter bridge Circuit.



[* It is better to use Scale for drawing the waveforms]

fig (2) : Load Voltage & Current waveforms [$\alpha < 90°$]

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

$$= \frac{1}{\pi}\cdot V_m\left[-\cos\omega t\Big|_{\alpha}^{\pi+\alpha}\right]$$

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

$$V_{o\,avg} = \frac{2V_m}{\pi}\cos\alpha$$

from the circuit, we can write as.

$$V_{o\,avg} = E + I_{o\,avg}R$$

or, $$\frac{2V_m}{\pi}\cos\alpha_1 = E + I_{o\,avg}\cdot R$$

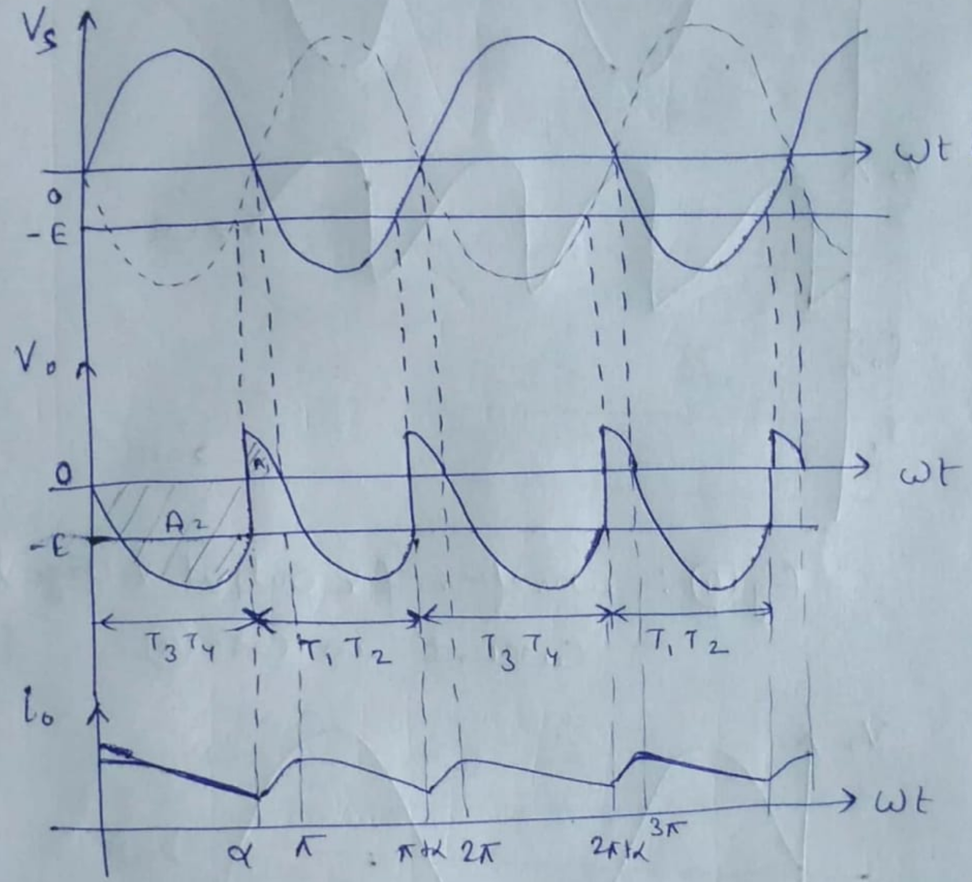
or, $$\frac{2\cdot\sqrt{2}\cdot 230}{\pi}\cos\alpha_1 = 120 + 10\times 0.4$$

or, $$\boxed{\alpha_1 = 53.208°}$$ Ans

Here for $\alpha = 53.21^\circ$

Power flows from AC Source to DC Load. [* graph or Waveforms make this things clear] fig (2)

b)



$\boxed{\alpha > 90^\circ}$

[* Use different Colours of ink]

fig (3): Load Voltage & Current waveform [$\alpha > 90^\circ$]

In this case,

$$\frac{2V_m}{\pi} \cos\alpha = E + I_{o_{avg}} R$$

or, $$\frac{2\sqrt{2} \cdot 230}{\pi} \cos\alpha_2 = -120 + 10 \times 0.4$$

or, $$\boxed{\alpha_2 = 124.075^\circ}$$ Ans.

[* $\alpha > 90^\circ$]

So, Power flows from DC Source to AC Load. [$A_1 < A_2$]

c) A/c question Modified waveform for both in case (a) $\alpha < 90°$ & in case (b) $\alpha > 90°$ is shown in fig ④ & fig ⑤

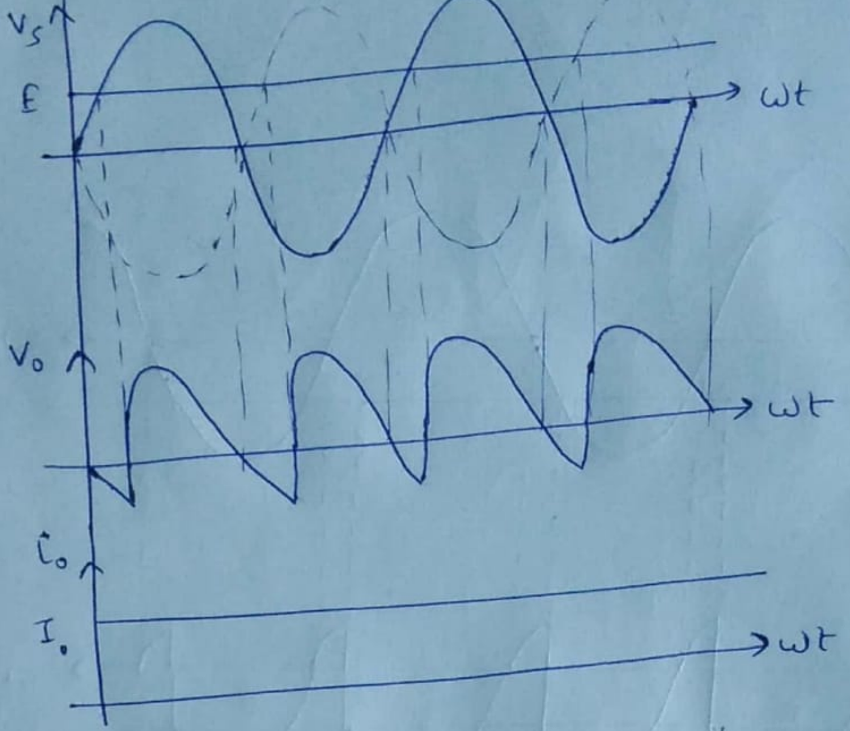


fig ④ : Waveform for output voltage & current in case ⓐ.

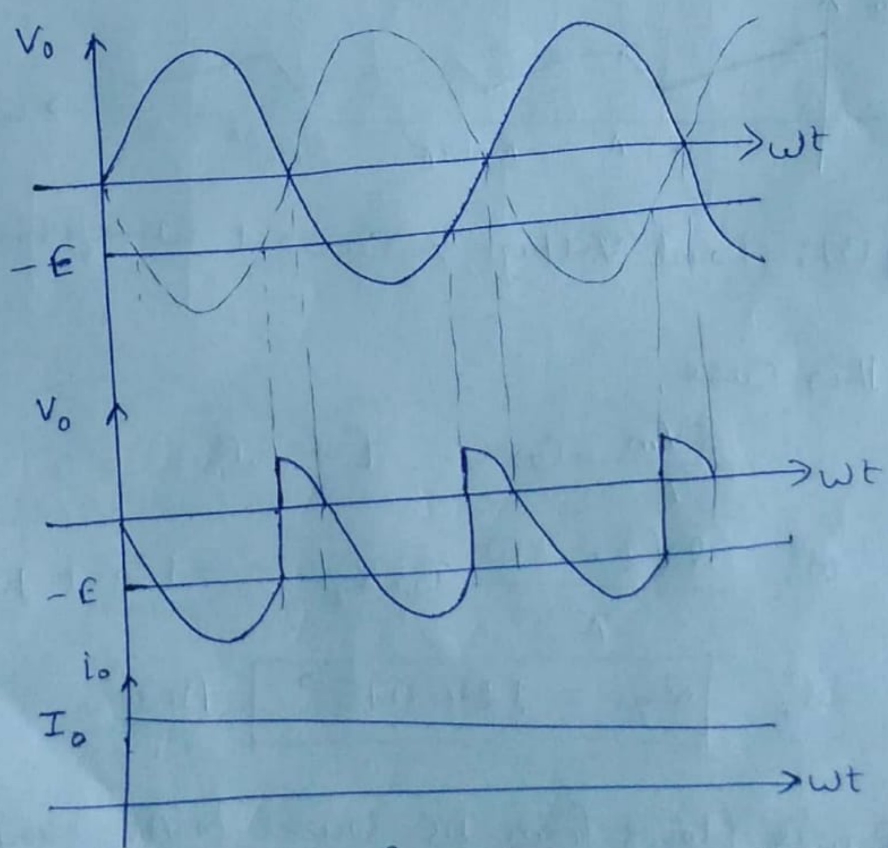


fig ⑤ : waveform for Output Voltage & Current in Case ⓑ

So, $I_{o\,rms} = I_{o\,avg} = 10\,A.$

& we can write as,

$$V_s I_{o\,rms} \cos\phi_s = E I_{o\,avg} + I_{o\,rms}^2 R$$

for $\alpha < 90°$ or $\alpha = 53.21°$

So, $$\cos\phi_{s1} = \frac{E I_{o\,avg} + I_{o\,rms}^2 R}{V_s I_{o\,rms}}$$

or. $$\cos\phi_{s1} = \frac{120 \times 10 + 10^2 \times 0.4}{230 \times 10}$$

or, $\boxed{\cos\phi_{s1} = 0.54}$ Ans

for $\alpha > 90°$. or $\alpha = 124.1°$

$$\cos\phi_{s2} = \frac{-120 \times 10 + 10^2 \times 0.4}{230 \times 10}$$

$\boxed{\cos\phi_{s2} = -0.5043}$ Ans.

Year 2014 | P.S. Bimbhra

Que 5 (a) | Que 7.2

Sol^n: Given that,

$V_s = 230\,V$

$R = 10\,\Omega$

$V_{CH} = 2\,V$

$\alpha = 0.4 = \frac{T_{ON}}{T}$

We have to find,

a) $V_{avg} = ?$ & $V_{rms} = ?$

b) $\eta = ?$

a)

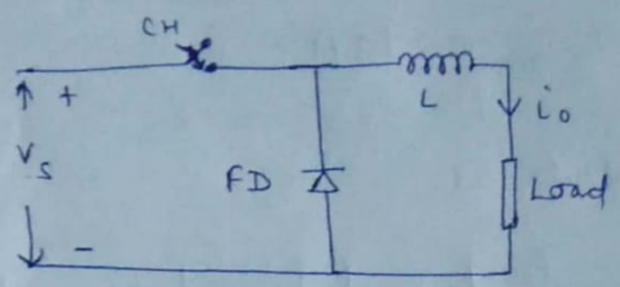


fig (1): Circuit diagram for type A Chopper

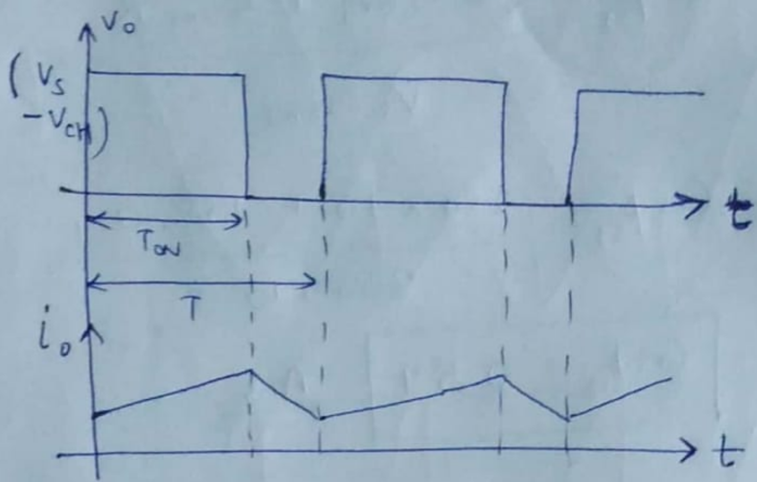


fig (2): Output Voltage & Current Waveform

when $0 < t < T_{ON}$, $V_o = V_s - V_{CH}$

or, $V_o = 230 - 2$

or, $V_o = 228\,V$

when $T_{ON} < t < T$, $V_o = 0\,V$

So, $V_{avg} = \frac{1}{T}\int_0^{T_{ON}} V_o\,dt$

$= \frac{1}{T} V_o [T_{ON} - 0]$

$= V_o \times \frac{T_{ON}}{T}$

or, $V_{avg} = 228 \times \alpha$

or $V_{avg} = 228 \times 0.4$

or $\boxed{V_{avg} = 91.2\,V}$ Ans

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^{T_{ON}} V_o^{\,2}\,dt}$$

$$= \sqrt{\frac{1}{T} \cdot V_o^{\,2} \cdot (T_{ON} - 0)}$$

$$= \sqrt{\frac{1}{T} \cdot V_o^{\,2} \cdot T_{ON}}$$

$$= V_o \cdot \sqrt{\frac{T_{ON}}{T}}$$

$$= V_o \sqrt{\alpha}$$

or $V_{rms} = 228 \times \sqrt{0.4}$

or $\boxed{V_{rms} = 144.2\,V}$ Ans.

b) $\% \eta = \dfrac{\text{Power Output, } P_o}{\text{Power Input, } P_i} \times 100\%$

$$P_o = \frac{V_{rms}^{\,2}}{R}$$

$$= \frac{144.2^2}{10}$$

or $P_o = 2079.36$ Watts

& $P_i = V_s\, I_{o\,avg}$

$$= 230 \times \frac{V_{o\,avg}}{R}$$

or $P_i = \dfrac{230 \times 91.2}{10} = 2097.6$ Watts.

So, $\eta = \dfrac{P_o}{P_i} = \dfrac{2079.36}{2097.6} = 0.9913$

or $\boxed{\% \eta = 99.13\%}$

Year 2014 / P.S. Bimbhra
Que (6) / Que 7.13

Based on Steady State Analysis of Type A Chopper

Year 2014 / P.S. Bimbhra
Que 2(a) / Que 5.2

Based on Thyristor Commutation techniques.

Year 2014 / P.S. Bimbhra
Que 9(b) / Que 4.22

Soln.

$$\text{String Efficiency (for Series/parallel)} = \frac{\text{Actual Voltage/Current Rating of whole String}}{[\text{Individual V/I rating of one SCR}][\text{Total No. of SCR in the String}]}$$

& DRF (Derating factor) = 1 − String Efficiency

[* You may Study String η in Power System. In the insulator Chapter]

Let, n_s = No. of Series Connected SCRs
& n_p = " " Parallel " "

Now, Given that, Rating of SCR, (1000 V & 200 A)
String Capacity is 6 kV & 1 kA

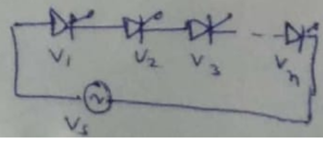
a) Now, DRF = 1 − String Efficiency

$$0.1 = 1 - \frac{\text{Whole String Capacity (V)}}{(\text{Individual SCR rating}) \times n_s}$$

[In Series we Consider Voltage]

$$= 1 - \frac{6000}{1000 \times n_s}$$

So, $n_s = 6.6$



As, n_s = No. of SCR in a string,

So, n_s must be an integer.

$\therefore \boxed{n_s \approx 7}$ Ans

Now, Number of parallel Connected SCRs,

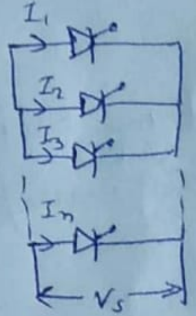
$$DRF = 1 - \text{String Efficiency}$$

$$0.1 = 1 - \frac{\text{Capacity of String (I)}}{\text{Individual SCR Rating (I)} \times n_p}$$

$$= 1 - \frac{1000}{200 \times n_p}$$

or $n_p = 5.5$

So, $\boxed{n_p \approx 6}$ Ans.



b) If $DRF = 0.2$

$$0.2 = 1 - \frac{\text{Capacity of String (V)}}{\text{Individual SCR Rating (V)} \times n_s}$$

$n_s = 7.5$

or $\boxed{n_s \approx 8}$ (No. of Series Connected SCRs)
Ans.

for n_p

$$0.2 = 1 - \frac{\text{Capacity of String (I)}}{\text{Individual SCR Rating (I)} \times n_p}$$

$n_p = 6.25$

or $\boxed{n_p \approx 7}$ (No. of parallel Connected SCR)
Ans.

Reference Materials For Power Electronics

1. **Textbooks**

   TB1: ' Power Electronics Converters, Applications And Design' By "Ned Mohan", John Wiley & Sons

   TB2: ' Power Electronics Circuits, Devices And Applications' By Muhammad H. Rashid, PHI

2. **Reference Books**

   RB1: 'Power Electronics' By "Dr. P.S. Bhimbhra", Khanna Publication

   RB2: 'Thyristorised Power Controllers' by "G.K dubey", Wiley Eastern Ltd.

Other readings and relevant websites

S.No.	Link of Journals, Magazines, websites and Research Papers
1.	http://onlinelibrary.wiley.com/book/10.1002/9780470547113/homepage/AuthorBiography.html
2.	http://ieeexplore.ieee.org/abstract/document/1667898/
3.	https://books.google.co.in/books?hl=en&lr=&id=oxR8vB2XjgIC&oi=fnd&pg=PA1&dq=power+electronic+applications+converters&ots=KSiEoGq2Hn&sig=tKX5yfR03rBu26JE2IKHJ4CyPjw#v=onepage&q=power%20electronic%20applications%20converters&f=false
4.	http://ieeexplore.ieee.org/search/searchresult.jsp?queryText=power%20electronics%20converters&newsearch=true
5.	https://www.sciencedirect.com/search?qs_cid=&qs=power+electronics&authors=&pub=&volume=&issue=&page=&origin=browse&zone=qSearch
6.	www.delnet.in

CO and PO attainment												
CO s	Assessment	Internal Test (50 %)			Continous Assessment (50 %)		DA	IDA		Co attainment	Target	Attained/Not Attained
		Avg. (%)	Attainment		Avg.(%)	Attainment		Course Exit Survey	Attainment	80 % DA+ 20% IDA		
CO 1		44.56140	2		85	3	2.5	4	3	2.6	2	Attained
CO 2		12.80702	0		85	3	1.5	5	3	1.8	2	Not Attained
CO 3		27.01754	0		85	3	1.5	3	3	1.8	2	Not Attained
CO 4		34.56140	1		85	3	2	4	3	2.2	2	Attained
				50%	3							
				40%	2							
				30%	1							

Institute / College Name :		**DARBHANGA COLLEGE OF ENGINEERING, DARBHANGA**	
Program Name		B.Tech., ELECTRICAL AND ELECTRONICS ENGINEERING	
Course Code		031609	
Course Name		POWER ELECTRONICS	
Lecture / Tutorial (per week):	3/0	**Course Credits**	3
Course Coordinator Name		Ms. SWETA KUMARI	

1. Scope and Objectives of the Course

The aim of the course is to provide the basic knowledge for the requirement of Power Electronics in the modern day life. In this regard, the course aims to equip the student with the basic understanding of the power semiconductor devices, their operating principles along with their control circuitry together with the review of electric and magnetic circuits. With this course, the student will be equipped with the knowledge in the wide range of power electronic converter circuits for AC-DC, DC-DC and DC-AC power conversion which are generally employed in various consumer and industrial electronic applications.

After the course the student should be able to:

- Understand the importance of Power Electronics and its applications in modern day life.
- Describe the modern power semiconductor devices such as Power Diodes, BJTs, MOSFETs, Thyristors, IGBT etc., their operation and control along with their protection schemes
- Calculate the power dissipation in the Power electronic component and design a cooling system.
- Select a suitable power converter topology depending on application.
- Design a power converter for a given application.
- Understand and analyze the quality of the input/output waveforms in different converter circuits which are a major concern with respect to its surroundings

2. Textbooks

TB1: ‘ Power Electronics Converters, Applications And Design’ By “Ned Mohan”, John Wiley & Sons

TB2: ‘ Power Electronics Circuits, Devices And Applications’ By Muhammad H. Rashid, PHI

3. Reference Books

RB1: ‘Power Electronics’ By “Dr. P.S. Bhimbhra”, Khanna Publication

RB2: ‘Thyristorised Power Controllers’ by “G.K dubey”, Wiley Eastern Ltd.

Other readings and relevant websites

S.No.	**Link of Journals, Magazines, websites and Research Papers**
1.	http://onlinelibrary.wiley.com/book/10.1002/9780470547113/homepage/AuthorBiography.html
2.	http://ieeexplore.ieee.org/abstract/document/1667898/
3.	https://books.google.co.in/books?hl=en&lr=&id=oxR8vB2XjgIC&oi=fnd&pg=PA1&dq=power+electronic+applications+converters&ots=KSiEoGq2Hn&sig=tKX5yfR03rBu26J

	E2IKHJ4CyPjw#v=onepage&q=power%20electronic%20applications%20converters&f=false
4.	http://ieeexplore.ieee.org/search/searchresult.jsp?queryText=power%20electronics%20converters&newsearch=true
5.	https://www.sciencedirect.com/search?qs_cid=&qs=power+electronics&authors=&pub=&volume=&issue=&page=&origin=browse&zone=qSearch
6.	www.delnet.in

7. **Course Plan**

Lecture Number	Date of Lecture	Topics	Web Links for video lectures	Text Book / Reference Book / Other reading material	Page numbers of Text Book(s)
		Introduction to power electronics		RB1	
1-3		Introduction to signal semiconductor devices and power semiconductor devices like power diodes, BJT, MOSFETs and IGBTs.	https://www.youtube.com/watch?v=1Auay7ja2oY , https://www.youtube.com/watch?v=PEg0zb3cg2A		
Assignment I					
Power transistors, MOSFET's, SCR's, IGBT's, UJT's (power electronic devices) operation, structure and circuit analysis, design and control					
		Thyristors		TB1,TB2	596-610 (TB1), 304-312 and 338-340 (TB2)
4-6		Introduction to thyristor construction, gate control circuit, terminal characteristic, switching characteristics, gate characteristic, SCR rating and protection	https://www.youtube.com/watch?v=1Auay7ja2oY		
7-10		Thyristor firing circuit, Triggering circuit R, RC and UJT firing circuit.	https://www.youtube.com/watch?v=QqFIHhSkayw	TB2, RB1	195-213(RB1), 761-774(TB2)
11-12		Application of thyristors for industrial drives, control motor, power transmission applications	https://www.youtube.com/watch?v=r5TLR9uoQj8	TB1	449-454,460-479
Assignment II					
SCR structure control operation and terminal characteristics					
		AC to DC converter		TB1,TB2,RB1	121-152(TB1), 431-452 and 467-484(TB2)
13-24		Converters : Uncontrolled three phase power rectifiers, 1 phase & 3 phase line commutated A.C to D.C Controlled converters.	https://www.youtube.com/watch?v=fOZ8bUrFJGk		
Assignment III					

Single phase and three phase uncontrolled dc-dc converter circuit design and waveform analysis					
Mid semester exam (1- 24 lecture)					
		DC to AC converter		TB1,RB1	200-245
25-33		Introduction to Inverters single phase and three phase voltage source inverter, current source inverter, Pulse width modulation inverters. Series inverter	https://www.youtube.com/watch?v=7CReXeMAXHA		
Assignment IV					
Pulse width modulation control of inverters (DC-AC converters)					
		DC to DC converter		TB1,RB1	161-196
34-40		Introduction to Chopper circuits, step up and step down, steady state analysis of types of chopper, commutation methods, chopper control of D.C. Motor.	https://www.youtube.com/watch?v=7xyfMDDU-rw		
		Introduction to other useful power electronics devices		TB2,RB1	500-513, 526-535
40-44		Introduction to A.C. voltage regulator, cyclo-converter with different loads.	https://www.youtube.com/watch?v=Wr0NtKm6OyQ		

*All classes have home work with objective questions.

1. **Evaluation Scheme:**

Component 1	Mid Semester Exam	20
Component 2	Assignment Evaluation/Attendance/ Class Test	10
Component 3**	End Term Examination**	70
	Total	**100**

** The End Term Comprehensive examination will be held at the end of semester. The mandatory requirement of 75% attendance in all theory classes is to be met for being eligible to appear in this component.

SYLLABUS

Topics	No of lectures	Weightage
Introduction to thyristor and control circuits : terminal characteristic, rating and protection.	6	8%
Thyristor firing circuit : Triggering circuit suitable for 1 phase and 3 phase fully controlled converters.	4	10%
Converters : Uncontrolled three phase power rectifiers, 1 phase & 3 phase line commutated A.C to D.C converters.	12	35%
Inverters : Basic Bridge inverter circuit 1 phase & 3 phase phase McMurray-Bedford method of communication,pulse width modulation inverters. Series inverter gating circuits.	9	18%
Choppers : Types of choppers, steady state analysis of type A chopper, communication methods, chopper	7	15%

control of D.C. Motor.		
Other applications A.C., voltage regulator, cyclo-converter.	5	7%
Application of thyristors for industrial drives.	2	7%

Evaluation and Examination Blue Print:
Internal assessment is done through quiz tests, presentations, assignments and project work. Evaluation is a very transparent process and the answer sheets of sessional tests, internal assessment assignments are returned back to the students.
The components of evaluations along with their weightage followed by the University is given below

Mid sem 20%
Assignments/Quiz Tests/Seminars 10%
End term examination 70%

This Document is approved by:

Designation	**Name**	**Signature**
Course Coordinator	Ms. Sweta Kumari	
H.O.D	Mr. Santosh Kumar Gupta	
Principal	Dr. Aseem Kumar Thakur	
Date	15-02-2018	