GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Course Title: ______HVDC Transmission___________

Following documents are available in Course File.

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

Course Instructor / Course Coordinator
(Name)

Course Instructor / Course Coordinator
(Signature)

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Department/Program-EEE

VISION OF THE INSTITUTE:

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

MISSION OF THE INSTITUTE:

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

MISSION OF THE PROGRAM:

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

Department of Electrical & Electronics Engineering

Programme Educational Objectives (B.Tech. – EEE)

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

Graduates will be able to

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

Programme Outcomes (B.Tech. – EEE)

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

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

PEOs & POs Mapping

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

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

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

ACADEMIC CALENDAR
Academic Year 2018-19

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

Dean of Academic Affairs

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SUBJECT ALLOCATION SHEET

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

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

AY: 2018-2019

TIME TABLE

GRIET/PRIN/06/G/01/18-19 wef: 02 July 2018
B.Tech - EEE - A IV Year - I Semester

Day/Hour	10:00-10:50	10:50-11:40	11:40-12:30	12:30-1:00	1:00-1:45	1:45-2:30	2:30-3:15	3:15-4:00
MONDAY	HVDCT	PSD	PSD	BREAK	PSS Lab / DSP Lab A1 /A2			
TUESDAY	SCT	SCT	EDS/HVE		PED Lab / PSS Lab A1 /A2			
WEDNESDAY	EDS/HVE	SCT	SCT		DSP Lab / PED Lab A1 /A2			
THURSDAY	EDS/HVE	PSOC	PSOC		PSD	PSD	HVDCT	HVDCT
FRIDAY	HVDCT	HVDCT	EDS/HVE		PSOC	PSOC	SCT	SCT
SATURDAY	HVDCT	EDS/HVE	EDS/HVE		PSOC	PSOC	PSD	PSD

Room No.	
Theory	4502
Lab	DSP Lab-4508 PSS Lab- 4504 PED Lab- 4407

Class Incharge:	P Praveen Kumar

Subject Code	Subject Name	Faculty Code	Faculty name	Almanac	
GR15A4022	Power Semiconductor Drives	YSV	Y Satya Vani	1st Spell of Instructions	02-07-2018 to 01-09-2018
GR15A4023	Power System Operation & Control	Dr JSD	Dr J Sridevi	1st Mid-term Examinations	03-09-2018 to 05-09-2018
GR15A4024	High Voltage DC Transmission Systems	MRE	M Rekha	2nd Spell of Instructions	06-09-2018 to 24-10-2018
GR15A4026	Electrical Distribution Systems	VVSM	VVS Madhuri	2nd Mid-term Examinations	25-10-2018 to 27-10-2018
GR15A4147	High Voltage Engineering	VUR	V Usharani	Preparation	29-10-2018 to 06-11-2018
GR15A4148	Soft Computing Techniques (OE-3)	RAK	R Anil Kumar	End Semester Examinations (Theory/ Practicals) Regular / Supplementary	08-11-2018 to 08-12-2018
GR15A4027	DSP based Electrical Lab	AVK/DKK	A Vinay Kumar / D Karuna Kumar	Commencement of Second Semester, A.Y	10/12/2018
GR15A4028	Power Systems Simulation Lab	GSR/VVSM	G Sandhya Rani/ VVS Madhuri		
GR15A4029	Power Electronic Drives Lab	MP/GBR	M Prashanth/ G Bhaskar Rao		

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

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

GRIET/PRIN/06/G/01/18-19 wef: 02 July 2018

B.Tech - EEE - B IV Year - I Semester

Day/Hour	10:00-10:50	10:50-11:40	11:40-12:30	12:30-1:00	1:00-1:45	1:45-2:30	2:30-3:15	3:15-4:00
MONDAY	SCT	SCT	PSOC	BREAK	HVDCT	HVDCT	PSD	PSD
TUESDAY	PSD	PSD	EDS/HVE		SCT	SCT	PSD	PSD
WEDNESDAY	EDS/HVE	HVDCT	HVDCT		PSOC	PSOC	SCT	SCT
THURSDAY	EDS/HVE	HVDCT	HVDCT		PSS Lab / DSP Lab B1 /B2			
FRIDAY	PSOC	PSOC	EDS/HVE		DSP Lab / PED Lab B1 /B2			
SATURDAY	PSOC	EDS/HVE	EDS/HVE		PED Lab / PSS Lab B1 /B2			

Room No.	
Theory	4512
Lab	DSP Lab-4508 PSS Lab- 4504 PED Lab- 4407
Class Incharge:	P Praveen Kumar

Subject Code	Subject Name	Faculty Code	Faculty name
GR15A4022	Power Semiconductor Drives	Dr DGP	Dr D G Padhan
GR15A4023	Power System Operation & Control	Dr JSD	Dr J Sridevi
GR15A4024	High Voltage DC Transmission Systems	Dr SVJK	Dr S V Jayaram Kumar
GR15A4026	Electrical Distribution Systems (PE)	VVSM	VVS Madhuri
GR15A4147	High Voltage Engineering (PE)	VUR	V Usharani
GR15A4148	Soft Computing Techniques (OE-3)	RAK	R Anil Kumar
GR15A4027	DSP based Electrical Lab	AVK/DKK	A Vinay Kumar / D Karuna Kumar
GR15A4028	Power Systems Simulation Lab	GSR/VVSM	G Sandhya Rani/ VVS Madhuri
GR15A4029	Power Electronic Drives Lab	MP/GBR	M Prashanth/ G Bhaskar Rao

Almanac	
1st Spell of Instructions	02-07-2018 to 01-09-2018
1st Mid-term Examinations	03-09-2018 to 05-09-2018
2nd Spell of Instructions	06-09-2018 to 24-10-2018
2nd Mid-term Examinations	25-10-2018 to 27-10-2018
Preparation	29-10-2018 to 06-11-2018
End Semester Examinations (Theory/ Practicals) Regular / Supplementary	08-11-2018 to 08-12-2018
Commencement of Second Semester, A.Y	10/12/2018

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

Department of Electrical & Electronics Engineering

Syllabus – HVDC TRANSMISSION

UNIT-I

HVDC TRANSMISSION: Introduction, equipment required for HVDC systems, Comparison of AC and DC Transmission, Limitations of HVDC transmission lines, reliability of HVDC systems, comparison of HVDC link with EHVAC link, HVDC convertors, HVDC –VSC transmission System: VSC system components, Control of Active and reactive power, Applications of VSC systems.

UNIT-II

HVDC CONVERTER OPERATION AND ANALYSIS: Thyristors and their characteristics, silicon rectifier, 6 pulse convertor configuration, ideal communication process without gate control, DC output voltage , gate control of valves, analysis of voltage wave forms with overlap angle, analysis of communication circuits , equivalent circuit of rectifier, Inverter operation with overlap, Equivalent circuit of inverter , complete equivalent circuit of HVDC link, power factor and reactive power of converters

UNIT-III

HVDC CONVERTER CONTROL :AC transmission and its control , necessary of dc link control, rectifier control , inverter control , constant beta control, constant gamma control, compounding of rectifiers, current compounding of inverter , complete HVDC system characteristics , power reversal in DC link, voltage dependent current order limit(VDCOL), system control hierarchy ,individual phase control, cosine control of phase delay, linear control phase delay , equidistance pulse control, pulse frequency control , constant current control

UNIT-IV

HARMONICS IN HVDC SYSTEM: Harmonics due to converter , characteristic current harmonics in the 12 pulse converter , harmonic model and equivalent circuit ,design of AC filters , single tune and double tuned high pass filters , second order filters and C-Type filter, Reactive power considerations of AC filters

UNIT-V

FAULTS ON AC SIDE OF CONVERTER STATION: 3-phase symmetrical fault and asymmetrical faults, commutation failure, DC circuit breaker, Ground Electrodes for HVDC system: Advantage and problems with ground return, HVDC system grounding , Resistance of electrodes- Electric current field, resistance of electrodes in uniform earth and non-uniform earth,distribution of current field between electrodes.

TEXT BOOKS:

1. HVDC transmission by S Kamakshaiah and V Kamaraju, Tata McGraw Hills Publications.

REFERENCE BOOKS:

1. K.R.Padiyar., HVDC Power Transmission System(English) 2nd edition. 2. Arillaga., High Voltage Direct Transmission,(London)Peter Peregrinus, 1981.

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

GUIDELINES TO STUDY THE COURSE/SUBJECT

Academic **Y**ear : 2018-2019

Semester : I

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

Course/Subject: …… HVDC……………… Code…GR15A4024……

Name of the Faculty: Dr.S.V.JAYARAM KUMAR, M.REKHA Dept.: ……EEE…………

Designation: Professor, Asst.Professor

Guidelines to study the Course/ Subject: HVDC TRANSMISSION

<u>Course Design and Delivery System (CDD):</u>

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

The faculty be able to –

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

Signature of HOD
Date:

Signature of faculty
Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE SCHEDULE

Academic **Y**ear : 2018-2019

Semester : I

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

Course/Subject: …HVDC TRANSMISSION……… ..Code:…GR15A4024………

Name of the Faculty: Dr.S.V.JAYARAM KUMAR
M.REKHA
Designation: Professor, Professor, Asst.Professor

The Schedule for the whole Course / Subject is:

UNIT	Description	Total No. of periods
1.	HVDC TRANSMISSION	10
2.	HVDC CONVERTER OPERATION AND ANALYSIS.	8
3.	HVDC CONVERTER CONTROL	8
4.	HARMONICS IN HVDC SYSTEM:	8
5.	FAULTS ON AC SIDE OF CONVERTER STATION.	10

Total No. of Instructional periods available for the course: ….42…….Hours / Periods

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS
COURSEPLAN

Academic **Y**ear : 2018-2019

Semester : I

Name of the program :……EEE**…**… B.Tech…**……** Section: A/B

Course/Subject: ……HVDC TRANSMISSION Code:…GR15A4024 Dept: EEE

TEXT BOOKS:
1. HVDC transmission by S Kamakshaiah and V Kamaraju, Tata McGraw Hills Publications.

REFERENCE BOOKS:
1. K.R.Padiyar., HVDC Power Transmission System(English) 2nd edition. 2. Arillaga., High Voltage Direct Transmission,(London)Peter Peregrinus, 1981.

Unit No.	Lesson No.	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Text Book, Journal…) Page Nos.: ____to ____
1	1.	1	Introduction	1&1	T1:1
1	2.	1	Equipment required for HVDC systems	1&1	T1:13
1	3.	1	Comparison of AC and DC Transmission	1&1	T1:17
1	4.	1	Limitations of HVDC transmission lines	1&1	T1:28
1	5.	1	Reliability of HVDC systems	1&1	T1:28
1	6	1	comparison of HVDC link with EHVAC link	1&2	T1:31
1	7.	1	HVDC convertors, HVDC –VSC transmission	1&2	T1:31
1	8.	1	System: VSC system components	2&2	T1:31
1	9.	1	Control of Active and reactive power, Applications of VSC systems	2&3	T1:34
2	10	2	Thyristors and their characteristics	2&3	T1:40
2	11.	1	Silicon rectifiers IGBT's ,HVDC voltage source converters principle and operation	2&3	T1:42

2	12.	1	6 pulse convertor configuration, ideal communication process without gate control	3&1	T1:62
2	13.	1	DC output voltage , gate control of valves	3&2	T1:71
2	15.	1	analysis of voltage wave forms with overlap angle, analysis of communication circuits	3&3	T1:81
2	16.	1	equivalent circuit of rectifier, Inverter operation with overlap	3&2	T1:94
2	17.	1	Equivalent circuit of inverter , complete equivalent circuit of HVDC link	1&3	T1:94
2	18.	1	power factor and reactive power of converters, analysis of 12 pulse converter	1&3	T1:97
2	19.	1	power flow in HVDC links, Power flow and current control , power loss in DC systems	1&3	T1:103
2	20	1	operation and analysis of VSC converters, VSC inverter operation , power flow in VSC-DC transmission	1&3	T1:106
2	21	2	comparison between CSC(classical HVDC) and NSC-HVDC system	2&3	T1:112
3	22	2	AC transmission and its control , necessary of dc link control,	2&3	T1:129
3	23	1	rectifier control , inverter control , constant beta control	2&3	T1:131
3	24	1	constant gamma control, compounding of rectifiers, current compounding of inverter	3&4	T1:134
3	25	1	complete HVDC system characteristics , power reversal in DC link, voltage dependent current order limit(VDCOL)	3&4	T1:135
3	26		system control hierarchy ,individual phase control, cosine control of phase delay, linear control phase delay	3 & 4	T1:142
3	27	2	equidistance pulse control, pulse frequency control , constant current control, inverter exhibition angle control	4&5	T1:147
3	28	2	Constant power control, control system for HVDC converter, inverter operation problem, control of VSC converters.	4&5	T1:152
4	29	2	Harmonics due to converter , characteristic current harmonics in the 12 pulse converter ,	4&4	T1:174

4	30	1	harmonics in VSC converter , harmonic model and equivalent circuit	4&5	T1:177
4	31	2	design of AC filters , single tuned and double tuned high pass filters , second order filters and C-Type filter	5&5	T1:200
4	32	1	Reactive power considerations of AC filters , Active filters and their applications, filters with VSC-HVDC schemes	5&5	T1:210
5	33	2	3-phase symmetrical fault and asymmetrical faults, commutation failure, DC circuit breaker	6&5	T1:263
5	34	3	Multi Terminal HVDC system: series and parallel MTDC systems and their operation and control, AC-DC system interaction short circuit rates and its effects	7&5	T1:306

Signature of HOD

Signature of faculty

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic **Y**ear : **2018-2019**

Semester : **II** UNIT NO.: ………**I**………….

Name of the Program: **B.Tech** ………..**Electrical**……….. Year: ……**IV**………. Section: A&B

Course/Subject: …**HVDC Transmission** Course Code: ..**GR15A4024.**

Name of the Faculty: …**Dr.S.V.Jayaram Kumar**, **M.Rekha**…………Dept.: …**EEE**………

Designation: PROFESSOR, ASST.PROFESSOR

Unit No.	Lesson No.	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Text Book, Journal…) Page Nos.: ____to ____
1	1.	1	Introduction	1&1	1: Pg.No1
1	2.	1	Equipment required for HVDC systems	1&1	1: Pg.No.13
1	3.	1	Comparison of AC and DC Transmission	1&1	1: Pg.No17
1	4.	1	Limitations of HVDC transmission lines	1&1	1: Pg.No28
1	5.	1	Reliability of HVDC systems	1&1	1: Pg.No28
1	6	1	comparison of HVDC link with EHVAC link	1&2	1: Pg.No31
1	7.	1	HVDC convertors, HVDC –VSC transmission	1&2	1: Pg.No31
1	8.	1	System: VSC system components	2&2	1: Pg.No131

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic Year : **2018-2019**

Semester : **II** UNIT NO.: ………**II**…………

Name of the Program: **B.Tech** ………..**Electrical**……….. Year: ……**IV**……… Section: A&B

Course/Subject: …**HVDC Transmission** Course Code: .. **GR15A4024.**

Name of the Faculty: …**Dr.S.V.Jayaram Kumar**, **M.Rekha**…………Dept.: …**EEE**………

Designation: PROFESSOR, ASST.PROFESSOR

Unit No	Lesson No	Periods	Topics/Subtopics	Objectives &Outcome Nos	(Text Book,Jouranal…) Page No.s
2	9	2	Choice Of Converter Configuration	1,2	2.Pg.no: 43-46
2	10	2	Analysis Of 6 pulse Graetz Circuit	1,2	1.Pg no. 84-97 2.Pg.no.46-61
2	11	2	Analysis Of 6 pulse Graetz Circuit	1,2	1.Pg no. 84-97 2.Pg.no.46-61
2	12	2	Analysis Of 6 pulse Graetz Circuit	1,2	1.Pg no. 84-97 2.Pg.no.46-61
2	13	2	Analysis Of 12 pulse Graetz Circuit	1,2	2.Pg.no.61-65
2	14	2	Principle Of DC link Control	1,2,3 2,3,4	1.Pg no. 66-68 2.Pg.no.76-79
2	15	2	Converter Control Characteristics	1,2,3 2,3,4	1.Pg no. 68-75 2.Pg.no.79-84
2	16	2	Converter Control Characteristics	1,2,3 2,3,4	1.Pg no. 68-75 2.Pg.no.79-84
2	17	2	Firing Angle Control	1,2,3 2,3,4	1.Pg no. 341-346 2.Pg.no.84-89
2	18	2	Current and extinction angle control	1,2,3 2,3,4	1.Pg no.346-350 2.Pg.no.8-90
2	19	2	Effect Of Source Inductance on the system,starting and stopping of DC link	1,2,3 2,3,4	2.Pg.no.90-94

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic Year : **2018-2019**

Semester : **II** UNIT NO.: ………**III**…………

Name of the Program: **B.Tech** ………..**Electrical**……….. Year: ……**IV**………. Section: A&B

Course/Subject: …**HVDC Transmission** Course Code: .. **GR15A4024.**

Name of the Faculty: …**Dr.S.V.Jayaram Kumar**, **M.Rekha**…………Dept.: …**EEE**………

Designation: PROFESSOR, ASST.PROFESSOR

Unit No	Lesson No	Periods	Topics/Subtopics	Objectives &Outcome Nos	(Text Book,Jouranal…) Page No.s
3	20	2	AC transmission and its control , necessary of dc link control,	2&3	1: Pg.no.129
3	21	2	AC transmission and its control , necessary of dc link control,	2&3	1: Pg.no.129
3	22	2	rectifier control , inverter control , constant beta control	2&3	1: Pg.no.131
3	23	2	constant gamma control, compounding of rectifiers, current compounding of inverter	3&4	1: Pg.no.134
3	24	2	complete HVDC system characteristics , power reversal in DC link, voltage dependent current order limit(VDCOL)	3&4	1: Pg.no.135
3	25	2	system control hierarchy ,individual phase control, cosine control of phase delay, linear control phase delay	3&4	1: Pg.no.135
3	26	2	equidistance pulse control, pulse frequency control , constant current control, inverter exhibition angle control	4&5	1: Pg.no.147
3	27	2	Constant power control, control system for HVDC converter, inverter operation problem, control of VSC converters.	4&5	1:Pg.no.152

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic Year : **2018-2019**

Semester : **II** UNIT NO.: ………**IV**…………

Name of the Program: **B.Tech** ………..**Electrical**……….. Year: ……**IV**………. Section: A&B

Course/Subject: …**HVDC Transmission** Course Code: .. **GR15A4024.**

Name of the Faculty: …**Dr.S.V.Jayaram Kumar**, **M.Rekha**…………Dept.: …**EEE**………

Designation: Professor, Asst.Professor

Unit No	Lesson No	Periods	Topics/Subtopics	Objectives &Outcome Nos	(Text Book,Jouranal…) Page No.s
4	28	2	Harmonics due to converter , characteristic current harmonics in the 12 pulse converter ,	3&4	1:Pg.No.174
4	29	1	harmonics in VSC converter , harmonic model and equivalent circuit	3&5	1: Pg.No 177
4	30	2	design of AC filters , single tuned and double tuned high pass filters , second order filters and C-Type filter	3&5	1: Pg.No 200
4	31	1	Reactive power considerations of AC filters ,Active filters and their applications, filters with VSC-HVDC schemes	3&5	1: Pg.No 210

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic Year : **2018-2019**

Semester : **II** UNIT NO.: ………**V**…………

Name of the Program: **B.Tech** ………..**Electrical**……….. Year: ……**IV**………. Section: A&B

Course/Subject: …**HVDC Transmission** Course Code: .. **GR15A4024.**

Name of the Faculty: …**Dr.S.V.Jayaram Kumar**, **M.Rekha**…………Dept.: …**EEE**………

Designation: PROFESSOR, ASST.PROFESSOR

Unit No	Lesson No	Periods	Topics/Subtopics	Objectives &Outcome Nos	(Text Book,Jouranal…) Page No.s
5	32	2	3-phase symmetrical fault and asymmetrical faults, commutation failure, DC circuit breaker	3&5	1:Pg.No263
5	33	2	Multi Terminal HVDC system: series and parallel MTDC systems and their operation and control, AC-DC system interaction short circuit rates and its effects	2&5	1:Pg.No306
5	34	2	3-phase symmetrical fault and asymmetrical faults, commutation failure, DC circuit breaker	3&5	1:Pg.No.263
5	35	2	Multi Terminal HVDC system: series and parallel MTDC systems and their operation and control, AC-DC system interaction short circuit rates and its effects	2&5	1:Pg No306

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 1 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Types of DC links

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about DC Links.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain briefly about different types of HVDC links. (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: Dr.S.V.Jayaram Kumar,
M.Rekha Dept.: EEE

Designation: Professor, Assistant professor..

Lesson No: 2 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Apparatus required for HVDC systems

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about the apparatus required for HVDC systems.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Draw a schematic diagram of typical HVDC converter station and describe the various components of the station. (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV Year**: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation Professor, Assistant professor.

Lesson No: 3 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Comparison of AC and DC Transmission

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about comparision of AC and DC Transmission.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is the need for interconnection of systems? Explain the merits of connecting HVAC systems by HVDC tie -lines (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section: A& B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant Professor.

Lesson No: 4 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Applications of DC Transmission System

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about the applications of HVDC systems.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain the economic advantages of HVDC system. (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section: A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor..

Lesson No: 5 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Choice of Converter Configuration

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Choice of Converter Configuration.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the factors which help in deciding the number of pulse converters used in a systems. Classify them as economic, technical and describe. (Obj: 1, 2/Out: 1, 2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor..

Lesson No: 6 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Analysis of 6 pulse Graetz Circuit

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Analysis of 6 pulse Graetz Circuit.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Obtain expression for the output voltage and direct current of a converter working as a rectifier with delay angle `**α**' and commutation angle `**γ**'. (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section: A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 7 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Analysis of 6 pulse Graetz Circuit

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Analysis of 6 pulse Graetz Circuit.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: With the help of neat sketches, analyze a six pulse rectifier bridge circuit with an overlap angle greater than 60^0. Deduce the relevant equations and draw the necessary graphs. (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 8 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Analysis of 6 pulse Graetz Circuit

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Analysis of 6 pulse Graetz Circuit.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Sketch a timing diagram for a 3phase Graetz's circuit considering with and without overlap angle less than 60^0. (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section: A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 9 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Analysis of 12 pulse Graetz Circuit

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Analysis of 12 pulse Graetz Circuit.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is the reason for using star-star and star-delta transformer configurations for 12 pulse converter. Derive an equation for primary current using fourier analysis. (Obj:1,2/Out:1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A& B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 10 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Principle of DC link Control

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Principle of DC link Control.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Derive the mathematical model of d.c. link controllers of a d.c. link. (Obj:1,2,3/Out:2,3,4)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 11 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Converter control characteristics

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Converter control characteristics.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the basic characteristics of converter control? With the aid of V-I characteristics, explain how power ow control is achieved? (Obj:1,2,3/Out:2,3,4)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 12 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Converter control characteristics

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Principle of Converter control characteristics.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the desired features of control? Explain in detail. (Obj:1,2,3/Out:2,3,4)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 13 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Firing angle control

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Firing angle control.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is equivalent pulse control? What are the advantages of equivalent pulse contur over individual phase control? (Obj:1,2,3/Out:2,3,4)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV Y**ear: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 14 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Current and extinction angle control

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Current and extinction angle control.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is the necessity of having constant ignition angle, constant current and constant extinction angle controllers at each converter station? (Obj:1,2,3/Out:2,3,4)

Signature of faculty

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA

Dept.: EEE Designation: Professor, Assistant professor..

Lesson No: 15 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Effect of source inductance on the system, Starting and stopping of DC link

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Effect of source inductance on the system, Starting and stopping of DC link.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain the working of working basic power controller using VDCOL (Voltage Dependent Current Order Limiter). (Obj:1,2,3/Out:2,3,4)

Signature of faculty

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic Year : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA

Dept.: EEE Designation: Professor, Assistant professor.

Lesson No: 16 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Reactive power requirements in steady state, Conventional Control Strategies

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with firing angle of HVDC System.
2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Reactive power requirements in steady state, Conventional Control Strategies.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is meant by Reactive power control and also give different sources of reactive power. (Obj:3,4/Out:4,5)

Signature of faculty

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 17 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Alternate Control Strategies

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with firing angle of HVDC System.

2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Alternate Control Strategies
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Write a note on Alternate control strategies. (Obj:3,4/Out:4,5)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor..

Lesson No: 18 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Sources of Reactive power

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with firing angle of HVDC System.

2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Sources of Reactive power
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Give different sources of reactive power. (Obj:3,4/Out:4,5)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 19 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Modelling of DC link

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with firing angle of HVDC System.
2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Modelling of DC link.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain by means of a schematic diagram and with theortical expression, how power ow through HVDC link, is controlled? (Obj:3,4/Out:4,5)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 20 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: P.U system for d.c quantities

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with firing angle of HVDC System.

2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about P.U system for d.c quantities.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Write a short notes on:

(a) Modeling of H.V.D.C. links
(b) P.U. system for d.c. quantities. (Obj:3,4/Out:4,5)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 21 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Solution of AC- DC load flow

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with firing angle of HVDC System.

2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Solution of AC- DC load flow.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What do you understand by a load flow? Is the load flow chart different for a DC Load flow as compared to AC load flow? (Obj:3,4/Out:4,5)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 22 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Protection against over current and overvoltage in converter station

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the protection of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Protection against over current and overvoltage in converter station.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the basic principles of over current protection. (Obj:6/Out:7)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 23 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Surge arrestors, Smoothing Reactors

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with the protection of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Surge arrestors, Smoothing Reactors.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Give the necessity of smoothing reactor in a HVDC system and list out main functions of it. (Obj:6/Out:7)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 24 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: DC Breakers, Corona effects on DC lines

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with the protection of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about DC Breakers, Corona effects on DC lines
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: How is the effect of corona neglected in a HVDC system? Compare this with corona effect of a HVDC system. (Obj:6/Out:7)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic Year : 2018-19

Semester : I

Name of the Program: B.Tech IV Year: **………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty:
DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor,
Assistant professor.

PROFESSOR. Lesson No: 25 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Generation of Harmonics, Characteristic harmonics

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Generation of Harmonics, Characteristic harmonics
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Why are harmonics generated in HVDC converter and what are the problems associated with the harmonics. Suggest some remedial measures. (Obj:5/Out:6, 7)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV Year **: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor..

Lesson No: 26 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Calculation of AC Harmonics, Non Characteristics harmonics

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Calculation of AC Harmonics, Non Characteristics harmonics
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: How is Total Harmonic Distortion estimated in a circuit? Explain the relevance of THD to a HVDC system. (Obj:5/Out:6, 7)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.: EEE

Designation: Professor, Assistant professor.

Lesson No: 27 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Types of AC filters

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Types of AC filters
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the various types of _lters that are employed in HVDC converter station? Discuss them in detail. (Obj:5/Out:6, 7)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV **Year: ………………..** Section:A&B

Course/Subject: HVDC Transmission Course Code: GR15A4024

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation: Professor, Assistant professor..

Lesson No: 28 Duration of Lesson: 1hr 30 Minutes

[redacted]

Lesson Title: Design of Single tuned filters, High pass filters

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Design of Single tuned filters, High pass filters
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Compare the schematics of a low pass filter and a high pass filter. What are the key elements common features and the dissimilarities. (Obj:5/Out:6, 7)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 1

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV Year Section:A&B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation : Professor, Assistant professor.

This Assignment corresponds to Unit No. I

Q1. Explain briefly about different types of HVDC links

Q2. What is the need for interconnection of systems? Explain the merits of connecting HVAC systems by HVDC tie -lines

Q3. Explain the economic advantages of HVDC system

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2

Outcome Nos.: 1,2

Signature of HOD Signature of faculty

Date: Date:

Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 2

Academic Year : 2018-19 Date: 07.07.16

Semester : I

Name of the Program: B.Tech IV Year: Section:A&B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation : Professor, Assistant professor.

This Assignment corresponds to Unit No. II

Q1. Draw a schematic of a 6 pulse converter circuit and derive from fundamentals, the expression for voltage and currents for the operation of converter as a rectifier and inverter with relevant waveforms.

Q2. Sketch a timing diagram for a 3phase Graetz's circuit considering with and without overlap angle less than 60^0.

Q3. Draw the equivalent circuits of both recti_er and inverter.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2.

Outcome Nos.: 1,2

Signature of HOD Signature of faculty

Date: Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 3

Academic **Y**ear : 2018-19

Semester :I

Name of the Program: B.Tech **………IV Year: ………………..** Section: A&B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation : Professor, Assistant professor.

This Assignment corresponds to Unit No. III

Q1. What are the alternate reactive power control strategies?

Q2.Discus s the various sources of reactive power for HVDC converters.

Q3. Explain in detail , the concept of reactive power requirement in HVDC converters.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.:.3,4

Outcome Nos.: 4,5

Signature of HOD Signature of faculty

Date: Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 4

Academic **Y**ear : 2018-19 Date: 22.09.16.

Semester : I

Name of the Program: B.Tech **………IV Year: ………………..** Section:A&B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR,
M.REKHA Dept.:EEE

Designation : Professor, Assistant professor.

This Assignment corresponds to Unit No. IV

Q1. Classify the faults on a converter

Q2. Write a brief note on short circuits in a converter.

Q3. Explain the difference between the A.C. circuit breaker and H.V.D.C. circuit breaker.

Q4. Explain the causes of over voltages on D.C. side of H.V.D.C converter.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 5

Outcome Nos.: 7

Signature of HOD

Signature of faculty

Date:

Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 5

Academic **Y**ear : 2018-19

Semester :I

Name of the Program: B.Tech IV **Year: ………IV……….** Section:A&B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.:EEE.

Designation :Professor, Assistant professor.

This Assignment corresponds to Unit No. V

Q1. Derive the expression for a total harmonic distortion in a 12 pulse converter.

Q2. How the voltage and current harmonics are calculated.

Q3. Explain in detail the non characteristic harmonics

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 5

Outcome Nos.: 6,7

Signature of HOD Signature of faculty

Date: Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

TUTORIAL SHEET - 1

Academic Year : 2018-19 Date: 30.06.16.

Semester : I

Name ofthe Program: B.Tech IV Year: Section:A &B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation : Professor, Assistant professor.

This Tutorial corresponds to Unit No. I

Q1. What is the need of interconnection of systems?

Q2. Explain the merits of connecting HVAC systems by HVDC tie-lines?

Q3. Discuss the relative merits and demerits of using E.H.V.A.C transmission and HVDC transmission for bulk power transmission over long distances.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2

Outcome Nos.: 1,2

Signature of HOD

Signature of faculty

Date:

Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

TUTORIAL SHEET - 2

Academic **Y**ear : 2018-19

Semester :I

Name of the Program : B.Tech IV Year Section:A&B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation : Professor, Assistant professor.

This Tutorial corresponds to Unit No. II

Q1. With the help of neat sketches, analyze a six pulse recti_er bridge circuit with

an overlap angle greater than 600. Deduce the relevant equations and draw the necessary graphs.

Q2 . With the help of neat sketches, analyze a six pulse recti_er bridge circuit with an overlap angle less than 600. Deduce the relevant equations and draw the necessary graphs.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2

Outcome Nos.: 1,2

Signature of HOD

Signature of faculty

Date:

Date:

TUTORIAL SHEET - 3

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech IV Year: Section:A &B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA

Dept.: EEE

Designation : Professor, Assistant professor.

This Tutorial corresponds to Unit No. III

Q1. Write a short notes on:

(a) Modeling of H.V.D.C. links
(b) P.U. system for d.c. quantities.

Q2. Compare simultaneous and sequential methods of power flow analysis.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.:.3,4

Outcome Nos.: 4,5

Signature of HOD

Signature of faculty

TUTORIAL SHEET - 4

Academic Year : 2018-19 Date: 22.09.16.

Semester : I

Name of the Program: B.Tech IV Year: Section:A &B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation : Professor, Assistant professor.

This Tutorial corresponds to Unit No. IV

Q1. Explain the effects of single commutation failure in converter.

Q2. Explain briefly the factors on which recovery from a commutation failure depends.

Q3. Explain the fault clearing process in H.V.D.C. poles. Explain how are the H.V.D.C.equipment protected against prolonged short circuit currents though there is no H.V.D.C. circuit breaker on H.V.D.C. pole side.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 6

Outcome Nos.: 7

Signature of HOD Signature of faculty

Date: Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

TUTORIAL SHEET - 5

Academic **Y**ear : 2018-19 Date: 04.10.16.

Semester :I

Name of the Program: B.Tech IV Year: Section:A &B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.: EEE

Designation : Professor, Assistant professor.

This Tutorial corresponds to Unit No. V

Q1. What are the various sources of harmonics generation in a HVDC line? Describe how a double tuned filter can be designed for a HVDC system.

Q2. How is Total Harmonic Distortion estimated in a circuit? Explain the relevance of THD to a HVDC system.

Q3. Explain the effect of firing angle errors on non characteristic harmonics.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 5

Outcome Nos.: 6,7

Signature of HOD

Signature of faculty

Date:

Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

EVALUATION STRATEGY

Academic **Y**ear : 2018-19

Semester : I

Name of the Program: B.Tech **IV Year: ……………….. Section:A&B**

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: DR.S.V.JAYARAM KUMAR, M.REKHA Dept.:EEE

Designation :Professor, Assistant professor.

1. TARGET:

A) Percentage for pass: 100

b) Percentage of class: 95

2. COURSE PLAN & CONTENT DELIVERY

- PPT presentation of the Lectures
-

3. METHOD OF EVALUATION

3.1 ☑ Continuous Assessment Examinations (CAE-I, CAE-II)

3.2 ☑ Assignments/Seminars

3.3 ☐ Mini Projects

3.4 ☐ Quiz

3.5 ☑ Semester/End Examination

3.6 ☐ Others

Signature of HOD Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Academic Year: **2018-19**
Year: **IV**
Semester: **I**

MID Exam – I (Descriptive)
HVDC TRANSMISSION
Code: GR15A4024

Date: /09/2018
Duration: **90 min**
Max Marks: **20**

Answer any four questions. All questions carry equal marks

1.Discuss the advantages and disadvantages of HVDC transmission

2.Draw twelve pulse diagram of HVDC station and discuss various components related to the system**.**

3.Derive the rectifier output voltage equation as a function of delay angle and overlap angle.

4.Draw the equivalent circuit of rectifier and inverter with relevant equations.

5.What is meant by commutation failure?

6.Why control is necessary for HVDC system? Explain.

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INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Academic Year: **2018-19**
Year: **IV**
Semester: **I**

MID Exam – I (Objective)
HVDC Transmission
Code: GR15A4024

Date: /09/2018
Duration: **30 min**
Max Marks: **05**

Roll No.

Note: Answer all the questions. All questions carry equal marks.

1.In a monopolar system usually the pole is

(a)Positive and Negative (b)Positive (c)Negative (d)Alternatively positive and negative

2.The break-even distance is the distance beyond which

(a)DC transmission is economical (b)AC transmission is economical (c) cost of both systems are the same (d) both(b) and (c).

3.The first HVDC scheme in India is

(a)Vidhyachal back-to-back system (b)Delhi-Rihand 500kV system(c)Chandrapur-Padghe scheme(d)Sileru-Barsoor system.

4.12-pulse converters are used in modern converters because of

(a)reduced current (b)reduced ripple (c)increased voltage and reduced harmonics (d)both(b) and (c)

5.The output voltage of a converter is changed by varying

(a) α (b)μ (c) γ (d)any one α,μ,γ

Fill in the blanks

1.HVDC transmission line commercially began in the year-------------------.

2.Modern HVDC system are all----------pulse converters.

3.Coolant used in thyristor/IGBT valves is-------------------.

4.In a bipolar system one conductor is----------------and the other is ------------------.

5.IGBT converters operate on the principle of ------------------ source converter.

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Department of Electrical & Electronics Engineering

MID Exam – II (Descriptive)

HVDC TRANSMISSION

Code: GR15A4024

Academic Year: **2018-19**
Year: **IV**
Semester: **I**

Date: /10/2018
Duration: **90 min**
Max Marks: **15**

Answer any three questions. All questions carry equal marks

1.Obtain the equation for harmonics for 12-pulse converter. Also discuss the impact of harmonics on the system. (CO5)

2.What is meant by individual phase control used for firing the HVDC valves. Explain with neat diagram. (CO4)

3. Explain the significance of earthing in HVDC system. (CO6)

4.Discuss the various faults exist in Converter Station. (CO7)

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Academic Year: **2018-19**
Year: **IV**
Semester: **I**

MID Exam – II(Objective)
HVDC Transmission
Code: GR15A4024

Date: /10/2018
Duration: **30 min**
Max Marks: **05**

Roll No.

Note: Answer all the questions. All questions carry equal marks.

1.Commutation failure occurs usually in [ ]

(a)Rectifiers (b)Inverters (c)Both inverters and rectifiers (d)controllers

2.In HVDC-VSC schemes filters are used [ ]

(a)only on the AC side (b) only on the DC side (c)both AC and DC side (d)no filter is needed.

3.During commutation in a converter [ ]

(a)voltage is exchanged (b)current is transformed from one valve to the other(c)DC voltage is blocked(d)none of the above.

4. Power transfer in DC line depends on [ ]

(a)sending and receiving end voltages (b)number of pulses in the rectifier(c)line resistance(d)none of the above

5. VDCOL controlling is done and is necessary when [ ]

(a)low voltage due to faults (b) to regulate DC current depending on DC voltage due to fault on AC side (c)to regulate DC current when DC voltage dips (d) to regulate AC current under fault

6.In a 12-pulse converter, the phase difference between the two 6-pulse bridges is------------

7. If pulse number =p and k is an integer, voltage harmonic generated on the DC side is------

8. Most frequent type of faults in DC system is ---------------------------

9. Increase in pulse number has the effect of increasing the lowest harmonic number (True/False)

10. Advantage of DC link for power transfer is more economical(True/False)

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

IV B.Tech-(HVDC) I Sem I Mid Marks(2018-19)

S.NO	1 (CO1)	2 (CO3)	3 (CO2)	4 (CO1)
15241A0261	4	3		5
15241A0262				
15241A0263	3			
15241A0264	4	2		2
15241A0265	4	4	4	
15241A0266	5	1		4
15241A0267	5	2		4
15241A0268	5	2		3
15241A0269	2	4		1
15241A0270	4	2		
15241A0271	5	5		5
15241A0272	5	5		5
15241A0273	5	2		5
15241A0274	0	0	0	0
15241A0275	5	2		4
15241A0276	3	2		
15241A0277	5		5	4
15241A0278	3	1	2	
15241A0279	3	3		2
15241A0280	4	4		
15241A0281	4	3		3
15241A0282	4	3	5	4
15241A0283	3	2		
15241A0284	4	2		5
15241A0285	5	2		4
15241A0286	4	3		
15241A0287	4	4		
15241A0288	3	1	2	
15241A0289	4	2		5
15241A0290				
15241A0291	3	2		
15241A0292	5		5	5
15241A0293	5	4	2	
15241A0294	3	3		
15241A0295	5	2		5
15241A0296		2		4
15241A0297	5	2		4
15241A0298	4	2		
15241A0299	2		3	3
15241A02A0	2			1

15241A02A1	2	2		2
15241A02A2		3		
15241A02A3	3	2		3
15241A02A5	3		3	3
15241A02A6	3			2
15241A02A7	3	3		4
15241A02A8				
15241A02A9	4	2		3
15241A02B0	3	2		1
15241A02B1	5	2		4
15241A02B2	3			
15241A02B3	5		5	5
15241A02B4	5	2		
15241A02B5	3	2		4
15241A02B6	5	5		5
15241A02B7	5	2		5
15241A02B8	5		5	4
15241A02B9		5		5
15241A02C0	4	2		5
16245A0213	5	1		5
16245A0214	3	5		3
16245A0215	2	2		1
16245A0216	4	2		
16245A0217	5	5		5
16245A0218	3	2		
16245A0219	4	2		3
16245A0220	2	2		1
16245A0221	5	4		2
16245A0222	4	2		2
16245A0223		2	3	
16245A0224	4	2		1
Total	245	148	44	165
No of students attempted(NSA)	64	58	13	48
Attempt %=(NSA/Total no of students)*100	90.14	81.69	18.31	67.61
Average (attainment)= Total/NSA	3.83	2.55	3.38	3.44
Attainment % = (Total/no.of max marks*no.of students attempted)*100	76.56	51.03	67.69	68.75
	1	**2**	**3**	**4**
	1 (CO1)	**2 (CO3)**	**3 (CO2)**	**4 (CO1)**

CO1	72.65
CO2	67.69
CO3	51.03
CO4	
CO5	
CO6	
CO7	

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INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

IV B.Tech-(HVDC) I Sem II Mid Marks(2018-19)

S.NO	1 (CO5)	2 (CO4)	3 (CO6)	4 (CO7)
15241A0261		5		2
15241A0262				
15241A0263				
15241A0264	5			2
15241A0265		4	3	1
15241A0266	5		1	2
15241A0267	5	5		5
15241A0268	4	5		3
15241A0269	2	1		1
15241A0270	5	5	1	
15241A0271	1			3
15241A0272	5	5		1
15241A0273	5	5		3
15241A0274	5			1
15241A0275	5	5		5
15241A0276	1	5		3
15241A0277		5	1	5
15241A0278	2		1	1
15241A0279		5	1	
15241A0280	5		1	3
15241A0281	5	5		4
15241A0282	5	5		5
15241A0283	5		1	3
15241A0284	5	5		5
15241A0285	5	5	5	
15241A0286	2		1	1
15241A0287	1		1	2
15241A0288			1	2
15241A0289		5	1	2
15241A0290	2			2
15241A0291		3	1	
15241A0292	5	5		5
15241A0293	3	5		5
15241A0294	1	3		
15241A0295	4	5		
15241A0296	1	5		
15241A0297	5	5		5
15241A0298	3	5		4
15241A0299	2		2	
15241A02A0			1	3
15241A02A1	5	5		3
15241A02A2	5			4

15241A02A4	5	3		4
15241A02A5	3		1	
15241A02A6		5		2
15241A02A7	5	5		4
15241A02A8	5	5		4
15241A02A9		5	3	
15241A02B0		3	2	3
15241A02B1	5	5		2
15241A02B2		5		5
15241A02B3	5	5		5
15241A02B4	5	5	3	
15241A02B5	5	5		4
15241A02B6	5	5	5	
15241A02B7	5	5		5
15241A02B8	5	5		3
15241A02B9	5			3
16245A02C0	5			4
16245A0213			1	4
16245A0214		5	5	3
16245A0215	5	5	1	
16245A0216	5	4		
16245A0217	5	5		3
16245A0218			2	1
16245A0219	5		5	4
16245A0220			1	4
16245A0221	5	4		1
16245A0222		2	1	3
16245A0223	4		1	4
16245A0224	5		1	4
Total	216	212	55	175
No of students attempted(NSA)	52	46	30	55
Attempt %=(NSA/Total no of students)*100	73.24	64.79	42.25	77.46
Average (attainment)= Total/NSA	4.15	4.61	1.83	3.18
Attainment % = (Total/no.of max marks*no.of students attempted)*100	83.08	92.17	36.67	63.64
	1	**2**	**3**	**4**
	1 (CO5)	**2 (CO4)**	**3 (CO6)**	**4 (CO7)**

CO1	
CO2	
CO3	
CO4	92.17
CO5	83.08
CO6	36.67
CO7	63.64

Cognitive Level Mapping

Co's	Cognitive level learning					
	1	2	3	4	5	6
1		√				
2			√			
3				√		
4						√
5				√		
6		√				
7					√	

Cognitive Learning Levels

CLL 1: Remembering

CLL 2: Understanding

CLL 3: Applying

CLL 4: Analyzing

CLL 5: Evaluating

CLL 6: Creating

DE: GR11A4049 | GR 11 | SET - 2

IV B. Tech I Semester Supplementary Examinations, Feb/Mar 2017
High Voltage DC Transmission Systems
(Electrical and Electronics Engineering)

Time: 3 hours | **Max Marks: 75**

Answer any FIVE questions
All questions carry equal marks

*****

1). a What are the different applications of D.C Transmission System? Explain them in detail. [8]

b With neat sketches explain the different kinds of D.C Links available. [7]

2). a Draw the schematic circuit diagram of a 6-Pulse GREATZ Circuit and explain its principle of operation. [8]

b Explain in detail, with the help of neat diagrams [7]
i) Firing Angle Control ii) Current and Extinction Angle Control

3). a Explain the merits of Constant Current Control over Constant Voltage Control. [8]

b Write the Mathematical Model of a D.C Converter. [7]

4). a Broadly classify the HVDC Faults and explain all possible Converter Faults with their causes and effects on its operation. [8]

b What are the basic principles of Over Current Protection? [7]

5). a What do you understand by "characteristic harmonics" in HVDC System? Using Fourier Analysis, obtain an expression for nth harmonic voltage on the D.C side of the Converter System. [8]

b What are the various types of Filters that are employed in HVDC Converter Station? Discuss them in detail. [7]

6). a Briefly explain the following sources of Reactive Power: [8]
i) Shunt Capacitors ii) Synchronous Condensers

b Explain the effect of Source Inductance on HVDC System. [7]

7) a Write short notes on [8]
i) Corona effects on D.C Line ii) Radio Interference

b Discuss the Design of Single Tuned Filters. [7]

*****

GR11A4049 | GR 11 | SET - 3

IV B. Tech I Semester Regular Examinations, Nov/Dec 2016
High Voltage DC Transmission Systems
(Electrical and Electronics Engineering)

Time: 3 hours | Max Marks: 75

Answer any FIVE questions
All questions carry equal marks

*****

1) a Discuss the economical factors that favor HVDC Transmission. [8]
b What are the demerits of HVDC Power Transmission? [7]

2) a Explain the 6-pulse Graetz Circuit and derive the expressions for average DC voltage with delay angle (α). [10]
b Distinguish between firing angle delay and extinction angle of an HVDC Converter [5]

3) a Explain the causes of reactive power absorbed by HVDC Converter Substation. [8]
b Classify the solution methodology for AC-DC load flow and explain. [7]

4) a What are the reasons to DC and AC System Faults? [8]
b Explain in detail about the surge arresters used in HVDC Transmission System. [7]

5) a List out problems associated with the injection of harmonics both on AC and DC side of HVDC Link. [8]
b Discuss the Design of High Pass Filters for HVDC System. [7]

6) a Explain the various apparatus required for HVDC Station and explain the purpose of each. [8]
b Explain the firing angle control scheme for HVDC System. [7]

7) a Explain the per unit system for DC Quantities. [8]
b Mention the configurations and impedance characteristics of various types of Filters. [7]

*****

FEEDBACK FROM STUDENTS

Summation of Teacher Appraisal by Student
Academic Year 2018-19

Name of the Instructor	M Rekha
Faculty ID	933
Branch	EEE
Class and Semester/Section	IV / I / A
Academic Year	2018-19
Subject Title	HVDCT
Total No. of Responses/class strength	33/69

Average rating on a scale of 4 for the responses considered:

S. No	Questions of Feedback	Average
1	How do the teacher explain the subject?	3.2000000000000002
2	The teacher pays attention to	3.1400000000000001
3	The Language and communication skills of the teacher is	3.1400000000000001
4	Is the session Interactive?	3.2200000000000002
5	Rate your teacher's explanation in clearing the doubts	3.1000000000000001
6	Rate your teachers commitment in completing the syllabus	3.2599999999999998
7	Rate your teachers punctuality	3.3199999999999998
8	Rate your teachers use of teaching aids	3.1200000000000001
9	Rate your teacher's guidance in other activities like NPTEL, Moodle, Swayam, Projects.	3.0800000000000001
10	What is your overall opinion about the teacher?	3.1800000000000002

Net Feedback on a scale of 1 to 4: 3.1760000000000006

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Gokaraju Rangaraju Institute of Engineering & Technology
(Autonomous)

Summation of Teacher Appraisal by Student
Academic Year 2018-19

Name of the Instructor	Dr S V Jayaram Kumar
Faculty ID	1291
Branch	EEE
Class and Semester/Section	IV / I / B
Academic Year	2018-19
Subject Title	HVDCT
Total No. of Responses/class strength	28/71

Average rating on a scale of 4 for the responses considered:

S. No	Questions of Feedback	Average
1	How do the teacher explain the subject?	3.0277777777777777
2	The teacher pays attention to	3.0555555555555554
3	The Language and communication skills of the teacher is	3.1111111111111112
4	Is the session Interactive?	2.9444444444444446
5	Rate your teacher's explanation in clearing the doubts	3.0277777777777777
6	Rate your teachers commitment in completing the syllabus	3.0555555555555554
7	Rate your teachers punctuality	3.2400000000000002
8	Rate your teachers use of teaching aids	3.1200000000000001
9	Rate your teacher's guidance in other activities like NPTEL, Moodle, Swayam, Projects	2.9166666666666665
10	What is your overall opinion about the teacher?	3

Net Feedback on a scale of 1 to 4: 3.0498888888888893

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INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

RESULT ANALYSIS

Year	Total No. Of Students appeared	Total No. of Students Passed	No. of Students Failed	GRADE =10	GRADE =9	GRADE= 8	GRADE= 7	GRADE= 6	GRADE= 5	GRADE= 4	PASS PERCENTAGE(%)
2018-19	140	132	08	16	18	16	17	38	22	05	94.28
2017-18	124	121	03	35 (<60%)	32 (60-70%)	54 (>70%)					97.58
2016-17	140	130	10	31 (<60%)	42 (60-70%)	57 (>70%)					92.85

- The network of transmission and distribution lines is formed by three phase alternating current system.
- For longer lines and higher power transfer, higher transmission voltages are necessary.
- The Electrical Power System (Network) is formed by a 3 phase, 50 Hz, AC System with several AC voltage levels for generation, transmission, distribution and utilisation.
- Choice of transmission voltage depends on power and distance.

•AC power transformers are installed in various transmission and distribution substations and near load points to step-up or step down AC Voltages to required levels.

•The entire AC Network operates synchronously at common prevailing frequency (50 Hz, ± 3%).

•3 Phase AC System has a tendency to operate naturally in synchronism and the operation and control is very easy.

•Power transfer through an AC transmission link is given by

$$Pac = \frac{|V_1| \cdot |V_2|}{X} \sin \delta$$

In an AC Network AC Power transfer through a particular AC line cannot be controlled easily, quickly and accurately.

- The sin **δ** causes transient stability limit which is almost 50% of steady state limit.
- Reactive power flow causes additional ($I^2 Rt$) transmission losses and voltage regulation problems.

•For very long, high power transmission lines (> 800km;> 1000 MW), for System Interconnections between two or more independently controlled AC Networks (Regional Grids) and for long submarine cables.

•

•High Voltage Direct Current Transmission (HVDC) links are preferred due to technical and economic superiority over equivalent EHV AC transmission links for same power/distance.
•Nominal Power transfer through an HVDC Link is given by:

$$P_{dc} = U_d \cdot I_d = [(U_{d1} - U_{d2})/R]\, U_d$$

•The H VDC power transfer can be controlled quickly and accurately by thyristor control and tap changer control.
•There are no problems of reactive power flow, voltage fluctuations and high transmission losses.
•However HVDC voltages cannot be easily stepped up or stepped down.
• HVDC requires costly and complex substations, high
technology, complex controls.
•The Modern TransmissionNetwork continues to be of3 phase 50 Hz, AC System with a few specific HVDC links integrated with the 3 phase AC Network.
•HVDC links are considered only for specific projects such as :

- A few long high power, point to point, 2 terminal HVDC Transmission Systems. (e.g. ± 500 kV, 1500

  MW, 820 km, Rihand-Deihi Bipolar 2T HVDC System (UP, India, 1992): ± 500 MW 1500 MW, 850 km Chandrapur-Padaghe Bipolar 2T HVPC System (Maharashtra, India, 1997)

- Back to Back Interconnecting HVDC Coupling Systems between Regional Grids (e.g. Vindhyachal sack-to-Back, 500 MW Link between Western Region and Northern Region, India (1989); Chandrapur Back-to-Back, 1000 MW Link between Western Region and Southern Region, India, 1996)
- Multi-terminal HVDC Interconnecting Systems (e.g. 5-Terminal Hydro-Quebeck : New England, USA/Canada, 1987-96)
- High Voltage long high power Cable transmission. (e.g. UK? France submarine Link, 2000 MW, 65 km).

- First commercial High Voltage Direct Current transmission system (HVDC) was introduced during 1953.

- With the successfully development of high power thyristor valves in early 1970**'s,** the HVDC transmission systems have become a technically and commercially viable alternative to EHVAC transmission particularly for (1) long distance bulk power transmission; (2) Submarine cable transmission and (3) system interconnection.

- For these three applications HVDC transmission systems have a distinct superiority over EHVAC and are being increasingly preferred.

Choice of a Transmission System

- The choice of the voltage is made from HVAC, EHV-AC, HVDC on the basis of the following economical and technical considerations.

Economic Considerations

- Capital cost of transmission systems:
    - Cost of line conductors, towers, insulators, installation land/right of way.
    - Capital cost of substations, intermediate substations, compensating substations, conversion substations, substation equipment like transformers, switchgear; substation area, buildings.
    - Cost of energy losses, maintenance.
- Needs of future expansion and associated cost.
- Economic aspects telated with availability, reliability.
- Economic strategy for Energy Transmission.

Technical Considerations

- Length of the transmission line and total power to be transferred

- Control over Power Transfer, magnitude, rate of change.
- Existing network and long term plans.
- Choice of voltage considering power flow.
- Stability considerations related with power flow and frequency disturbances.
- Reliability and security of power flew. Availability of transmission link.

- Reactive power compensation and voltage control.
- Switching requirement.
- Right of way for transmission lines.
- Radial or Mesh.
- **21’ or 31’ or MT.**
- Type of line :

  Overhead/underground/submarjne cables.

- Network configuration, parallel lines, T-offs, multi-terminals etc.

Application of EHV-AC Transmission

- Voltage can be stepped-up or stepped-down in transformer substations to have economical transmission voltage.
- Lines can be tapped easily, extended easily.
- Parallel lines can be easily added.
- Control of Power flow in the Network is simple and natural.
- Power flow in a particular line cannot be controlled easily and quickly.
- Equipments are simple and reliable without need of high- tech.
- Operation is simple and adopts naturally to the synchronously operating AC systems.
- Generation and distribution is by AC.

Special Features and Technical Consideration for EHVAC Lines

- The most important requirement of an EHV-AC transmission line is power transfer ability based on transient stability limit.

$$Pac = \frac{|V_1| \cdot |V_2|}{X} \sin \delta$$

at $\delta = 30°$, sin $\delta = 0.5$. Hence AC line can transfer only 50% of its steady state power limit.

- EHV-AC line needs compensation of reactive power. This is provided by SVS ; shunt reactors, Shunt capacitors, etc. installed in sub-stations. Intermediate substations are necessary at interval of 250 km to 400 km.
- Power transfer ability of EHV lines may be increased by using series capacitors or adding a parallel line. For high power lines several parallel circuits may be necessary.
- The line design is based on limits of corona, radio interference, TV interference, electrical field at ground level, etc.
- For EHV-AC lines the voltage stress at conductor surface should be kept below critical voltage. For achieving this, the use of bundled conductors is essential. Bundle conductors reduce the corona losses, Radio Interference, TV Interference.
- Switching surges occur during opening and closing f unloaded lines. Line insulation is designed on the basis of switching overvoltages. Appropriate circuit-breakers and compensation is necessary to limit switching surges. Insulation co-ordination is achieved with the use of suitable surge arresters.
- EHV-AC lines and Network have high short-circuit levels and associated protection problems. HVDC interconnection limits the short-circuit levels of both the AC networks.
- EHV-AC lines experience power swings during system disturbances, switching and faults. Protection of EHV-AC lines is designed to block during low power swings.
- EHV-AC lines transmit bulk power. Outage of a line causes stability problems in the network. Hence alternative transmission paths should be plannèd along with the protection system design. For each radial line, at least two three phase circuits are, necessary.
- In large interconnected networks, the effect of a major fault in one of the networks can result in cascade tripping and a large scale blackout To prevent this the Network Segregation is carried out. HVDC interconnection eliminates the problem of cascade tripping.

Applications of HVDC transmission

- Long distance high Power transmission by overhead lines.
- Medium and long high power submarine or underground cables.
- System interconnection by means of overhead lines or underground/submarine cables or back to back HVDC coupling stations.
- Multi-Terminal HVDC System for interconnecting three or more 3 phase AC systems.
- Frequency conversion (6O Hz —50 Hz ; 50 Hz —25 **'Hz)**
- Incoming lines in megacities.

Schematic diagram of an HVDC Transmission System

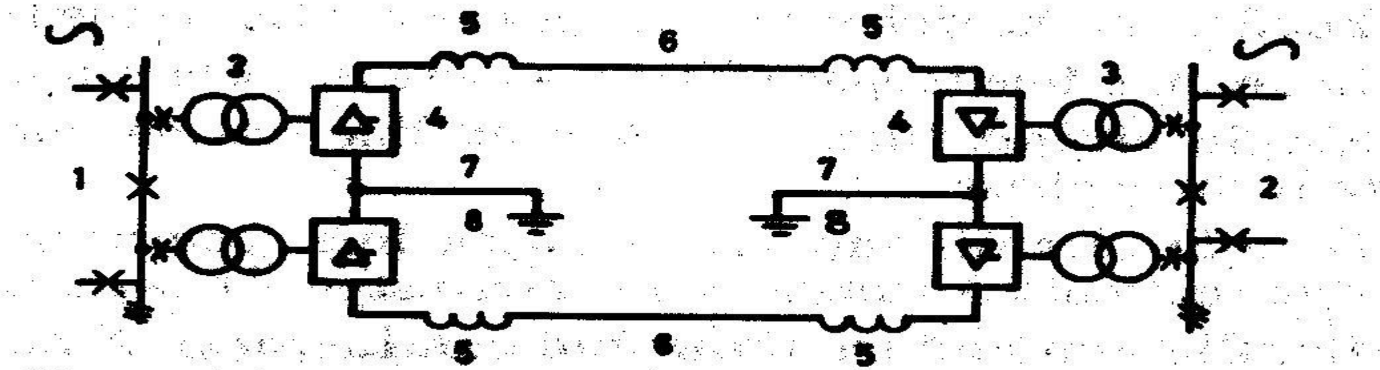


Fig. 1·6. Schematic diagram of an HVDC Transmission System.
1, 2. AC systems at terminals, terminal AC substations
3. Convertor transformers
4. Thyristor valves of convertor
5. Smoothing reactor (HVDC)
6. HVDC transmission line (Bipolar)
7. Electrode line
8. Earth electrodes.

- An HVDC link has an AC system at each end.
- The AC power is converted by thyristor-convertor valves into DC power.
- The energy is transmitted in HVDC form to the other end.

•At the other end the DC power is inverted in thyristor-convertor valves and fed into the receiving system.

•An 2-Terminal HVDC transmission system has an HVDC convertor substation at each end and an HVDC transmission line in between.

- In case of back-to-back coupling station, the rectifier and inverter are at the same place and there is no HVDC line.

•A back-to-back HVDC station provides an asynchronous tie between two adjacent AC Networks.

Choice of HVDC Transmission
System

- **Long, high power transmission**

  - For long distance, high power transmission lines HVDC transmission systems are preferred due to their economic advantage and exact, fast and easy control of power flow from generating station to load centre.
  - Though HVDC system needs costly terminal substations, the line cost is lower than that of equivalent AC line.
  - Power flow can be controlled.
  - Line losses are low.
- The per km cost of HVDC line is lesser than that of an equivalent 3 phase double circuit AC line.
- For equal power transfer, the number of conductors for 3 phase AC line is 6 to 24 as against only 2 numbers required for Bipolar HVDC line.

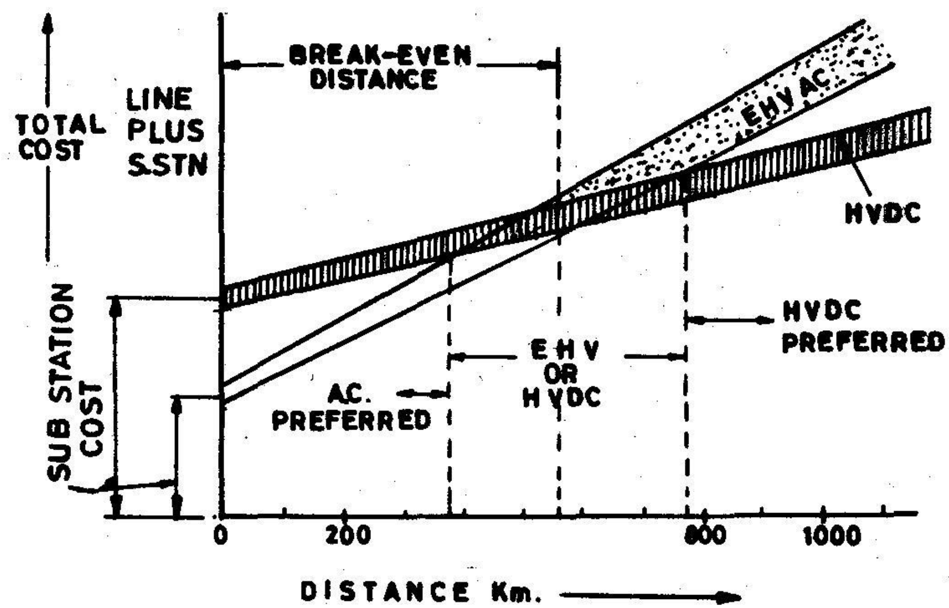


Fig. 1·12. Economic comparison of long distance high power HVDC transmission and EHV-AC transmission.

•System Interconnections

- Neighbouring independently controlled AC Networks are interconnected by system interconnections.
- System interconnection is either by EHV-AC/HVAC or HVDC.
- The basic function of an **interconnection** is to transfer energy from surplus zone to deficit zone.
- When neighbouring AC Networks are connected by and AC interconnection they start operate synchronously at the same frequency. AC interconnection is called synchronous tie.
- When neighbouring AC Networks are interconnected by HVDC interconnection, they can continue to have their independent load frequency control.(Asynchronous tie)
- System interconnection has following major advantages.

  - Lesser overall installed capacity to meet the peak demand.
  - Lesser spinning reserves.
  - Overall economic generation by optimum use of high capacity economical generating plants.
  - Better use of energy reserves such as hydro, thermal, nuclear.
  - Better system support to week network.
  - Better system support to network having emergency due to outage of a plant or a line.
  - Stronger grid with stable frequency.

EHV-AC interconnection:

- It is simple.
- Power flow adapts naturally to the needs and prevailing surplus deficit between interconnected networks.
- Voltages and connections can be made suitably by using transformer connection.

The limitations of EHV-AC interconnections include:

- It is synchronous tie.
- Frequency disturbance in one zone is quickly transferred to the other.
- Power swings in one network affect the other network. A weak tie link gets tripped due to such power swings.
- Large interconnected networks suffer from cascade tripping. and overall black-outs in the event of major faults in any of the network.

HVDC interconnections:

It is an asynchronous tie.

Frequency disturbance from one AC Network is not transferred to the other.

Direction and magnitude of power flow can be changed quickly and accurately by controlling the characteristics of rectifier/ inverter.

Power swings and frequency disturbances in connected AC Network can be quickly dampened by modulating the power flow through the HVDC interconnection.

HVDC link can be used for interconnecting

HVDC link can be used for interconnection between two networks separated by sea or lake by using submarine cables.systemshavingdifferentfrequencies.

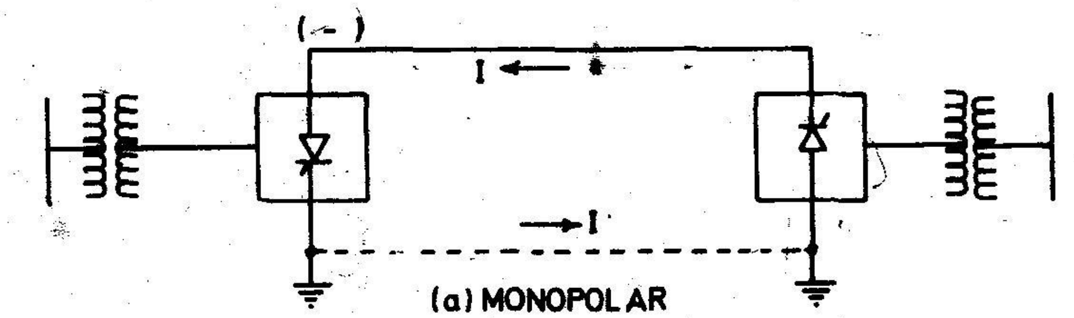
- **Back-to-back asynchronous tie sub-stations**
  - In back-to- back HVDC coupling stations the interconnection is by a converter- substation without any transmission line.
  - The HVDC inverter and rectifier are installed

  in the same station.
  - Such a tie-link gives an asynchronous interconnection between two adjacent independently controlled AC networks.
- **Multi-terminal HVDC Interconnection**
  - Three or more AC networks can be interconnected asynchronously by means of a multi-terminal HVDC system.
  - Power flow from each connected AC Network can be controlled suitably.
  - Large power can be transferred.
  - Overall stability can be improved.
- **Cable Transmission**
  - HVDC is preferred for underground or submarine-cable transmission over long distance at high voltage.
  - The submarine cables are necessary to transfer power across oceans, lakes etc.
  - In case of AC cables, the temperature rise due to charging currents forms a limit for loading.
  - For each voltage rating there is a limit of length beyond which an AC cable cannot be used to transfer load current due to thermal limit.

• HVDC cables have no continuous charging currents and can transfer bulk power over long distances.

Types of HVDC Systems

Monopolar HVDC system



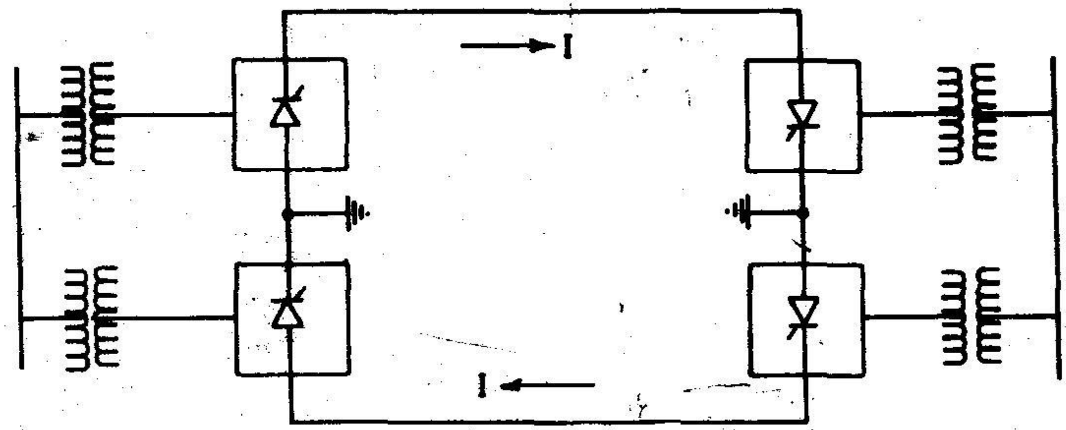
- This system has, only one pole and the return path is provided by permanent earth or sea.
- The pole generally has negative polarity with respect to the earth.
- In monopolar HVDC system the full power and current is transmitted through a line conductor with earth or sea as a return conductor.
- The earth electrodes are designed for continuous full- current operation and for any overload capacity required in the specific case.
- The sea or ground return is permanent and of continuous rating.
- Monopolar HVDC systems are used only for low power rated links and mainly for cable transmission.

Bipolar HVDC Transmission

•This is most widely used of overhead long distance HVDC systems, for point-to-point power transfer.

•The HVDC substation and HVDC line has two poles, one positive and the other negative with respect to earth.

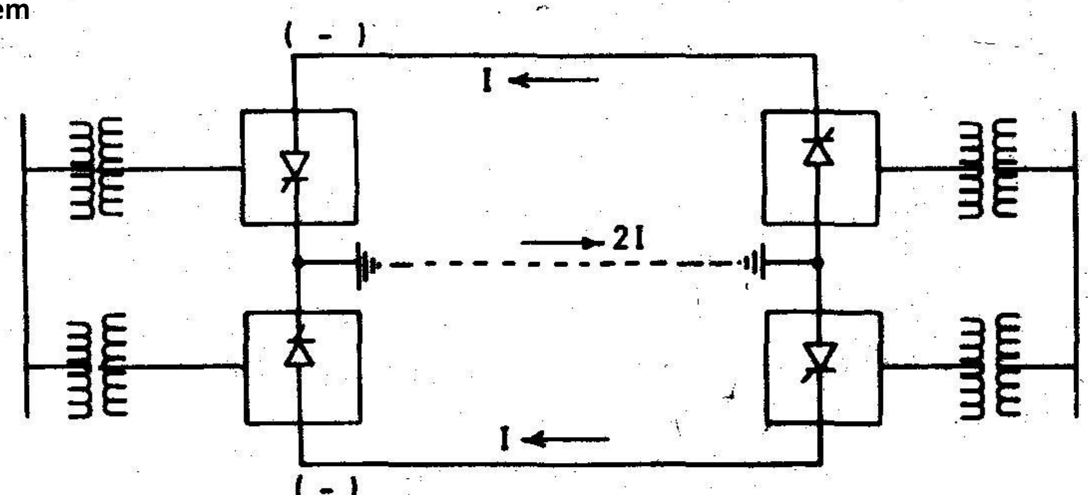
- The mid points of convertors at each terminal station are earthed via electrode line and earth electrode.
- Power rating of one pole is about half of bipole power rating.



(b) BIPOLAR

•During fault or trouble on one of the poles, the bipolar HVDC system is switched over automatically to monopolar mode.
•Thereby, the service continuity is maintained.

Homopolar HVDC System



(c) HOMOPOLAR

- In such a system two transmission poles are of the same polarity and the return is through permanent earth.
- Two homopolar overhead lines feeding to a common monopolar cable termination.
- One overhead transmission tower carrying insulator strings supporting two homopolar transmission line conductors.
- Applications of homopolar transmission are limited.

Limitations of HVDC
Transmission Systems

- HVDC system does not have step-up and step-down transformers.
- HVDC system does not have suitable HVDC circuit breakers.
- HVDC Transmission cannot be used economically for main transmission, subtransmission, distribution. It is used only for specific long distance/cable/interconnection projects.
- Cost of HVDC terminal substations is very high.
- Operation of HVDC transmission required continuous firing of thyristor valves. Controls of HVDC are complex. Several additional abnormal conditions are possible on DC side and in controls.
- HVDC substation require additional harmonic filters and shunt capacitors.

Converter station

- The major components of a HVDC transmission system are converter stations where conversions from AC to DC (Rectifier station) and from DC to AC (Inverter station) are performed.
- A point to point transmission requires two converter stations.
- The role of rectifier and inverter stations can be reyersed (resulting in power reversals) by suitable converter control.
- The various components of a converter station are discussed below.

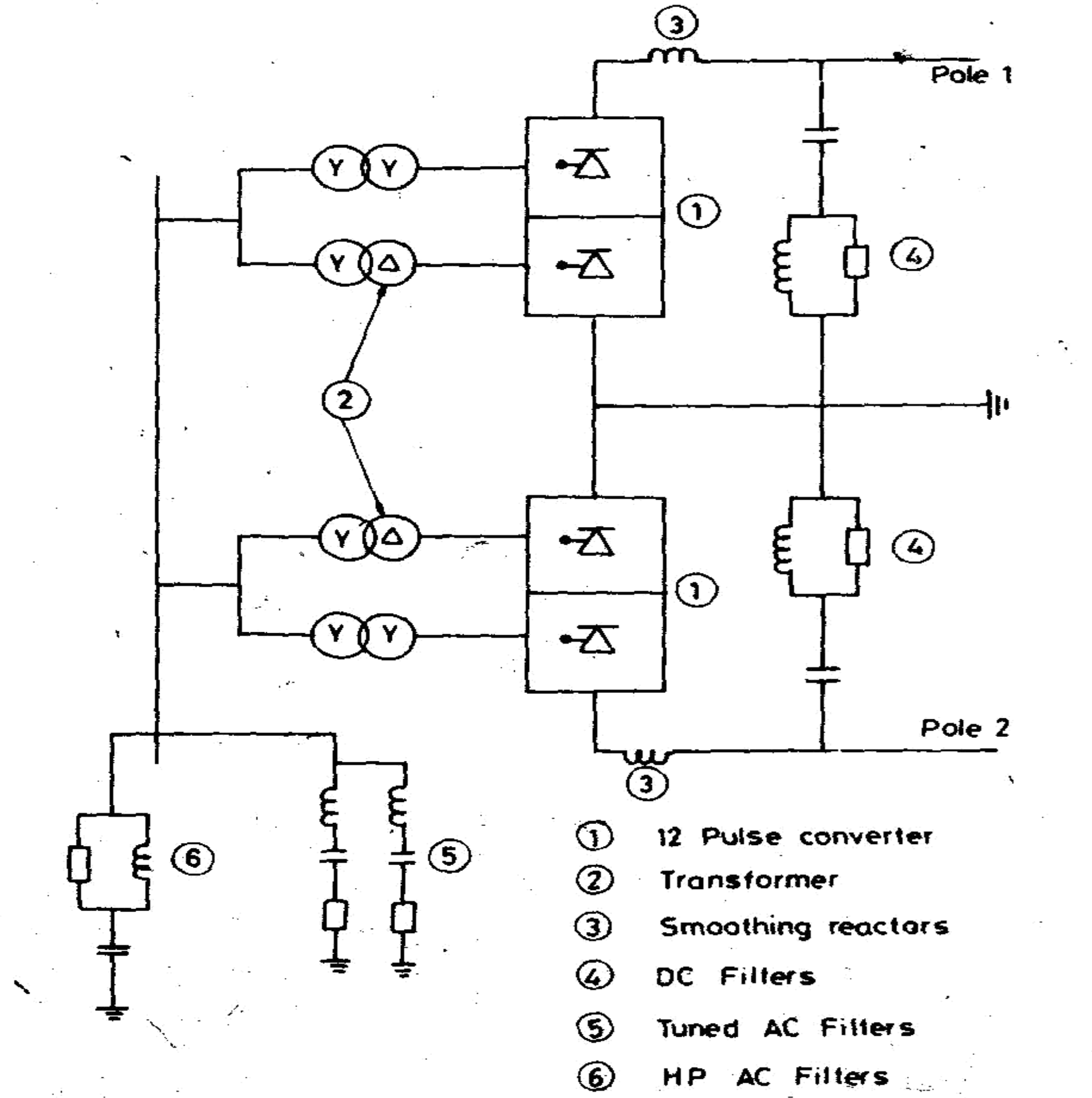


Fig. 1.5 Schematic diagram of a typical HVDC converter station.

Converter unit

•Each valve is used to switch in a segment of an AC voltage waveform.
•The converter is fed by converter transformers connected in star/star and star/delta arrangements.
•The valves are cooled by air, oil, water or freon.
•Liquid cooling using deionized water is more efficient and results in the reduction of station losses.

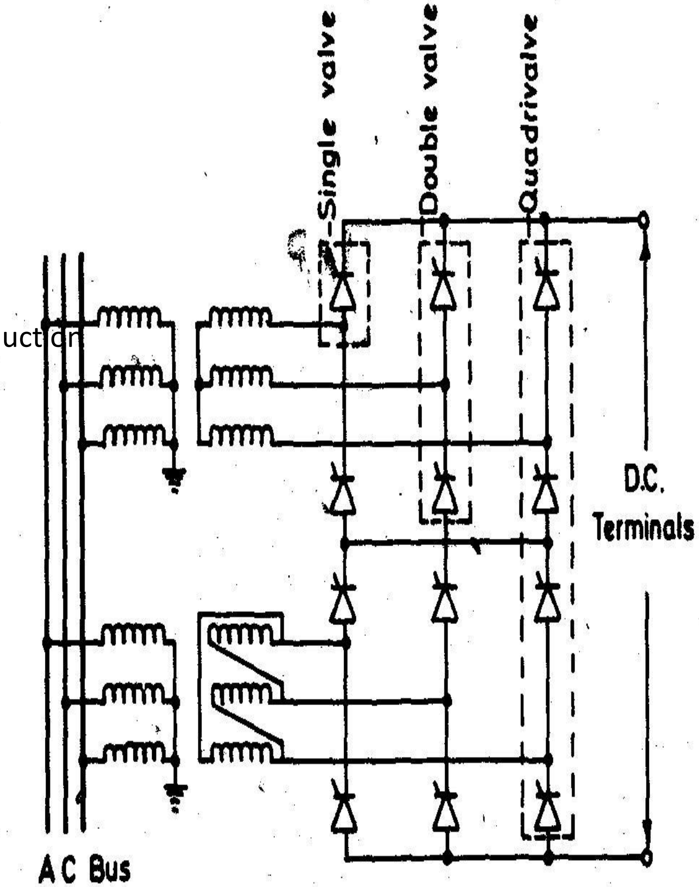


Fig. 1.6 A Twelve pulse converter unit

The ratings of a valve group are limited more by the permissible short circuit currents than steady state load requirements.
•The design of valves is based on the modular concept where each module contains a limited number of sedes connected thyristor levels.

• Valve firing signals are generated in the converter control at ground potential and are transmitted to each thyristor in the valve through a fiber optic light
guide system.
•The light signal received at the thyristor level is converted to an electrical signal using gate drive

amplifiers with pulse transformers.
•The valves are protected using snubber circuits, protectiye firing and gapless surge arresters.

Converter Transformer

- The converter transformer can have different configurations - (i) three phase, two winding,
  (ii) single phase,three winding,
  (iii) single phase, two winding.
- The valve side windings are connected in star and delta with neutral point ungrounded.

- On the AC side, the transformers are connected in parallel with neutral grounded .
- The leakage reactance of the transformer is chosen to limit the short circuit currents through any valve.
- The converter transformers are designed to withstand DC voltage stresses and increased eddy current losses due to harmonic currents.

•One problem that can arise is due to the DC magnetization of the core due to unsymmetric firing of valves
•In back to back links, which are designed for low DC voltage levels an extended delta configuration can result in identical transformers being used in twelve pulse converter units.

Filters

There are three types of filters used:

AC filters : These are passive circuits used to provide low impedance, shunt paths for AC harmonic currents.

Both tuned and damped filter arrangements are used. **DC filters :** These are similar to AC filters and are used for the filtering of DC harmonics.

High frequency (RFIPLC) filters: These are connected between the converter transformer and the station AC bus to suppress any high frequency currents.

Sometimes such filters are provided on high-voltage DC bus connected between the DC filter and DC line and also on the neutral side

Reactive power source

- Converter stations require reactive power supply that is dependent on the active power loading.
- Fortunately, part of this reactive power requirement

is provided by AC filters.

•In addition, shunt (switched) capacitors. synchronous condensors and static var systems are used depending on the speed of control desired.

Smoothing reactor

•A sufficiently large series reactor is used on DC side to smooth DC current and also for protection.

•The reactor is designed as a linear reactor and is connected on the line side, neutral side or at intermediate location.

DC switchgear

•This is usually a modified AC equipment used to interrupt small DC currents.

•DC breakers or metallic return transfer breakers (MRTB) are used, if required for interruption of rated load currents.

•In addition to the equipment described above, AC switchgear and associated equipment for protection and measurement are also part of the converter station.

EHV-AC Versus HVDC Transmission

- **For backbone network**.

  Voltage can be easily stepped-up, stepped-down. The network has natural tendency to maintain synchronism. Load-frequency control is easy and simple. Network can be tapped at intermediate points to feed underlying subtransmission network.

- **Bulk power long distance transmission lines**. HVDC proves economical above breakeven point. Number of lines are less. No need of intermediate substations for compensation.

•**Stability of transmission system**.

HVDC gives asynchronous tie and transient stability does not pose any limit. Line can be loaded upto thermal limit of the line or valves (whichever is lower).

•**Line loading**.

The permissible loading of an EHV-AC line is limited by transient stability limit and line reactance to almost one third of thermal rating of conductors. No such limit exists in case of HVDC lines.

•**Surge impedance loading**.

Long ERV-AC lines are loaded to less than 0.8 Pn.
No such condition is imposed on HVDC line.

•**Voltage along the line.**

Long EHV lines have varying voltage along the line due to absorption of reactive power. This voltage fluctuates with load. Such a problem does not arise in HVDC line. EHV-AC line remains loaded below its thermal limit due to the transient stability limit. Conductors are not utilized fully.

Number of lines.

EHVAC needs at least two three phase lines and generally more for higher power. HVDC needs only one bipole line for majority of application.

For AC line;

$$Pac = \frac{|V_1| \cdot |V_2|}{X} \sin \delta$$

Intermediate substations.

EHV-AC transmission needs intermediate substations at an interval of 300 km for compensation.

HVDC line does not need intermediate compensating substation.

Asynchronous tie.

System having different prevailing frequencies or different rated frequencies can be interconnected. HVDC link provides asynchronous tie. Frequency disturbance does not get tranferred large blackouts are avoided.

Better control.

Power flow through HVDC tie line can be controlled more rapidly and accurately than that of EHV-AC interconnector. HVDC-Power flow can be increased at a rate of 30 MW per minute. This is not possible with EHV-AC line.

Corona loss and radio interference.

For the same power transfer and same distance, the corona losses and radio interference of DC systems is less than that of AC systems, as the required d.c. insulation level is lower than corresponding a.c. insulation.

Power Transfer and Reactive Power.

The main difference between EHV-AC and HVDC transmission systems is in control of Real Power flow and Reactive Power Flow.

The AC line can be loaded upto transient stability limit which occurs at **δ**=30^0 and is given by

$$Pac\text{-}\max = \frac{1}{2} \cdot \frac{|V_1| \cdot |V_2|}{X}$$

AC line power cannot be changed easily, quickly and accurately as $|V_1|$ and $|V_2|$ should be kept around rated voltage levels and angle **δ** cannot be changed easily.

Secondly, the series reactance and shunt reactance of AC line result in reactive power flow, voltage regulation problems and additional transmission losses due to reactive component of current.

Power flow through HVDC link is given by

$$Pdc = \frac{(Ud_1 - Ud_2)}{R} \cdot Ud$$

By varying (U_{d1} — U_{d2}) by means of thyristor converter control and tap-changer control; the power flow P_{dc} can be changed quickly, accurately and easily.

Secondly, HVDC transmission does not have series reactance and shunt reactance; reactive power flow. Hence voltage regulation problems and stability problems transmission losses etc. due to the flow of reactive power flow are absent in HVDC transmission systems. Transmission losses are low.

Skin effect.

This is absent in d.c. current. Hence current density is uniformly distributed across the cross-section of the conductor.

Charging current.

Continuous line charging currents are absent in HVDC lines. Reactive Power (MVAr) does not flow continuously. Hence transmission losses are low.

Tower size.

The phase-to-phase clearance, phase to ground clearances and tower size is smaller for d.c. transmission as compared to equivalent AC transmission for same power and distance. Tower is simpler, easy to install and cheaper.

Number of conductors.

Bipolar HVDC transmission lines require two-pole conductors to carry DC power. Hence HVDC transmission becomes economical over AC transmission at long distance when the saving in overall conductors cost, losses, towers etc. compensates the additional cost of the terminal apparatus such as rectifiers and converters.

Earth return.

HVDC transmission can utilize earth return and therefore does not need a double circuit. EHV-AC always needs a double circuit.

Reactive power compensation.

HVDC line does not need intermediate reactive power compensation like EHV-AC line.

Flexibility of operation.

Bipolar line may be operated in a monopolar mode by earth as a return path when the other pole develops a permanent fault.

Staging facility.

DC valves may be connected in series and parallel to get desired DC voltage and current. Multiterminal schemes are now possible.

Short-circuit level.

In AC transmission, additional parallel lines result in higher fault level at receiving end due to reduced equivalent reactance. When an exiting AC system is interconnected with another AC system by AC transmission line, the fault level of both he system increases. However, when both are interconnected by DC transmission, the fault level of each system remain unchanged.

Rapid power transfer.

The control of convertor valves permit rapid changes in magnitude and direction of power flow. Limitation is imposed by power generation and AC system conditions.

Static Power Conversion Adopted in HVDC Transmission

- A Bipolar HVDC transmission system has an HVDC terminal substation at each end. Each terminal substation has AC/DC convertor. The convertors change AC to DC or DC to AC.

- The convertor terminal operating in rectifier mode changes AC power to DC power. Delay angle **α** is held at 15 to 18°.

- The convertor terminal operating in inverter mode changes DC power to AC power. Extinction angle **γ** is held at 15 to 18°.

- The complete HVDC Tansmission transfers electric power from one AC Network to another AC Network in the form of high voltage direct current.

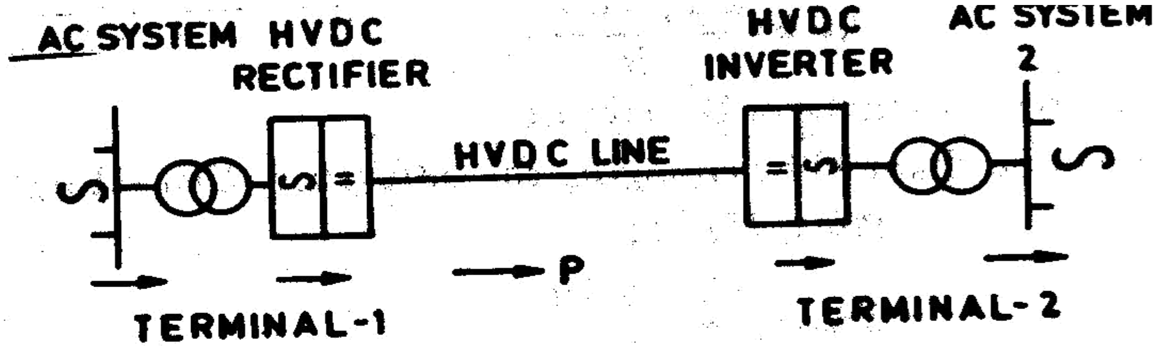


Fig. 2.2 Schematic diagram of an HVDC transmission system.

The convertor has two types of circuits:

- Main circuit through which high power flows. This comprises convertor transformers, thyristor valves, busbars, series reactor etc.
- Control and protection circuits for firing/blocking the valves in desired sequence, monitoring etc.

Six Pulse Converter Bridge (Graetz Bridge)

•A 6-pulse bridge has 6 valves arranged or 3 limbs for the vertical valve structure.

•AC supply is given from the three secondary leads of a converter transformer.

•The six valves are fired in a definite sequence (1, 2,...6).

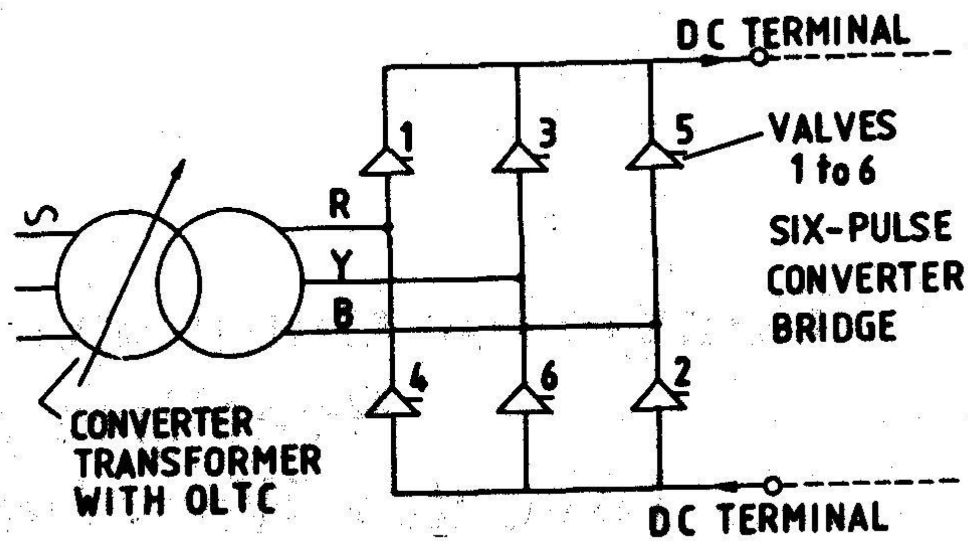


Fig. 4.1. Six-pulse converter bridge (Graetz Bridge)

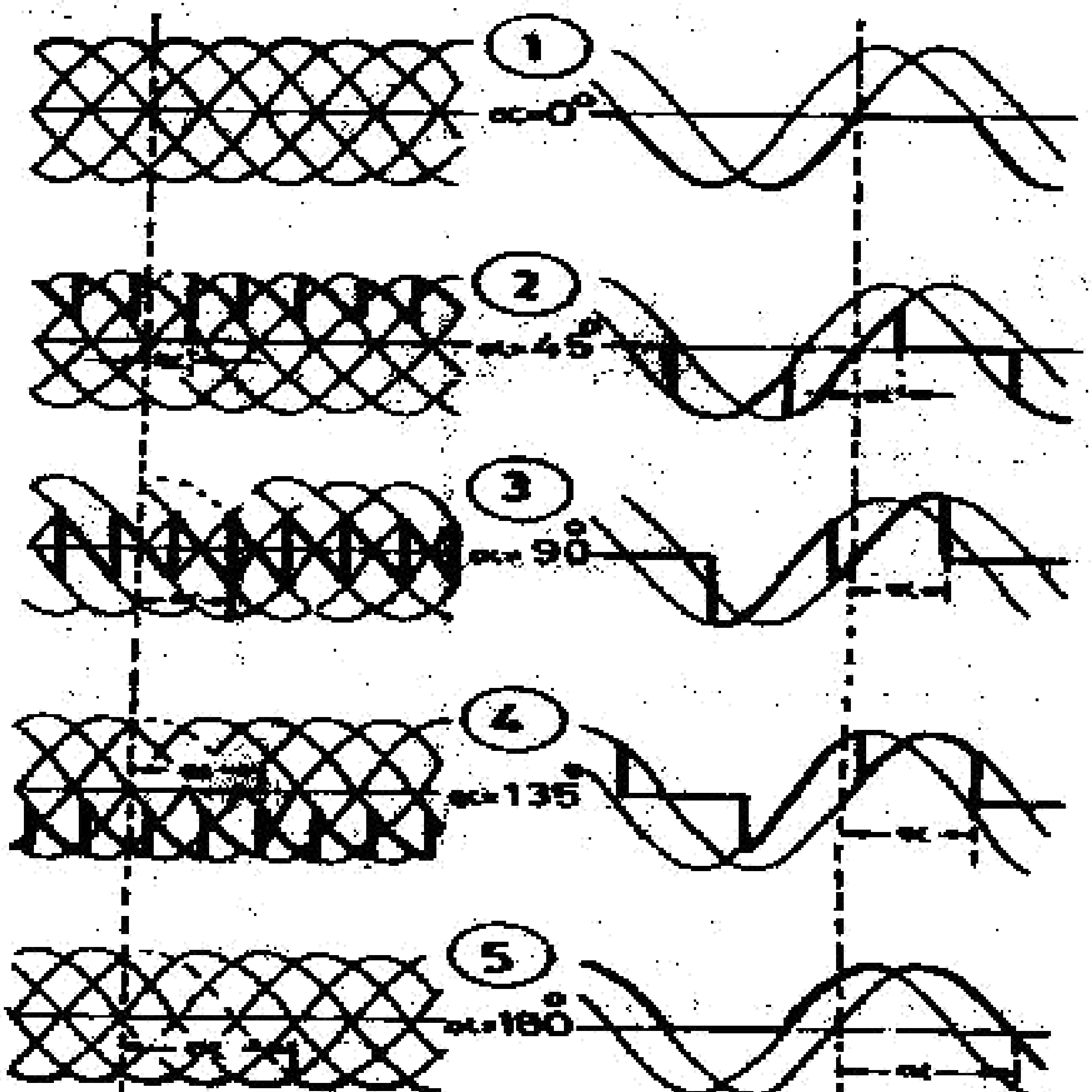
- At any instant, two valves are conducting in the bridge, one from the upper commutation group and the second from the lower commutation group.
- The firing of the next valve in a particular group results in the turning off of the valve that is already conducting.
- The assumption is that there is no overlap between the two valves in a group.
- Thus the valve 2 is fired 60^0 after the firing of valve 1 and valve 3 is fired 60^0 after the firing of second valve.
- Each valve conducts for 120^0 and the interval between consecutive firing pulse is 60^0 in steady state.
-

Assumptions:

- The d.c current is constant.
- The valves can be modelled as ideal switches with zero impedance when **'ON'** and with infinite impedance when **'OFF'**.
- The AC voltages at the converter bus are sinusoidal and remains constant.

DC voltage waveform

- The increase in the delay angle α causes corresponding delay in transfer from one valve arm to another, resulting in reduction of mean direct voltage. It is assumed that a large smoothing is connected on the DC side.
- With $\alpha = 0°$ the commutation takes place naturally and the convertor acts as a rectifier.
- With increase in α the average value of DC voltage is reduced.



(a) Bridge Voltages (b) Valve voltages

Fig. 4·11. Voltage waveforms for various values of α.

- When α becomes more than 60°, some negative spikes begin to appear in the DC voltage. i.e. the energy will flow from DC system to AC system through the convertor without change in the direction of current.
- For $\alpha = 90^0$. the area of positive portion of DC voltage spikes and negative portion of DC voltage spikes per cycle are equal. The mean value of DC voltage per cycle of AC wave is zero. The convertor is acting neither as rectifier nor as inverter. Energy transfer is zero.
- For α more than 90^0 ,the negative pulses have more area than positive pulses, Mean value of DC voltage is negative i.e. the energy flows from DC system to AC systems indicating inversion mode.
- For α = 180°, Full inversion is obtained.

Valve Voltage

- When the valve is conducting, this voltage is zero.
- When valve is not conducting, and the other valve arm of the same group is conducting, the voltage across the non-conducting valve arm corresponds to phase to phase voltage of transformer secondary terminals.

- **Definition of Delay Angle .** Delay angle α is the time expressed in electrical angle from the zero crossing(s) of the idealised sinusoidal commutating voltage and starting of forward current conduction(s).
- It can be conveniently understood as the angle between the Instant of natural commutaton (zero crossing) and instant of delayed commutation, (C).

- By delaying the triggering pulses, the duration of conduction a cycle is reduced, thereby the average value of DC voltage is reduced.

- By varying α from zero to 90° elec., the no load direct voltage changes from maximum(at $\alpha = 0$) to zero (at $\alpha = 90°$).

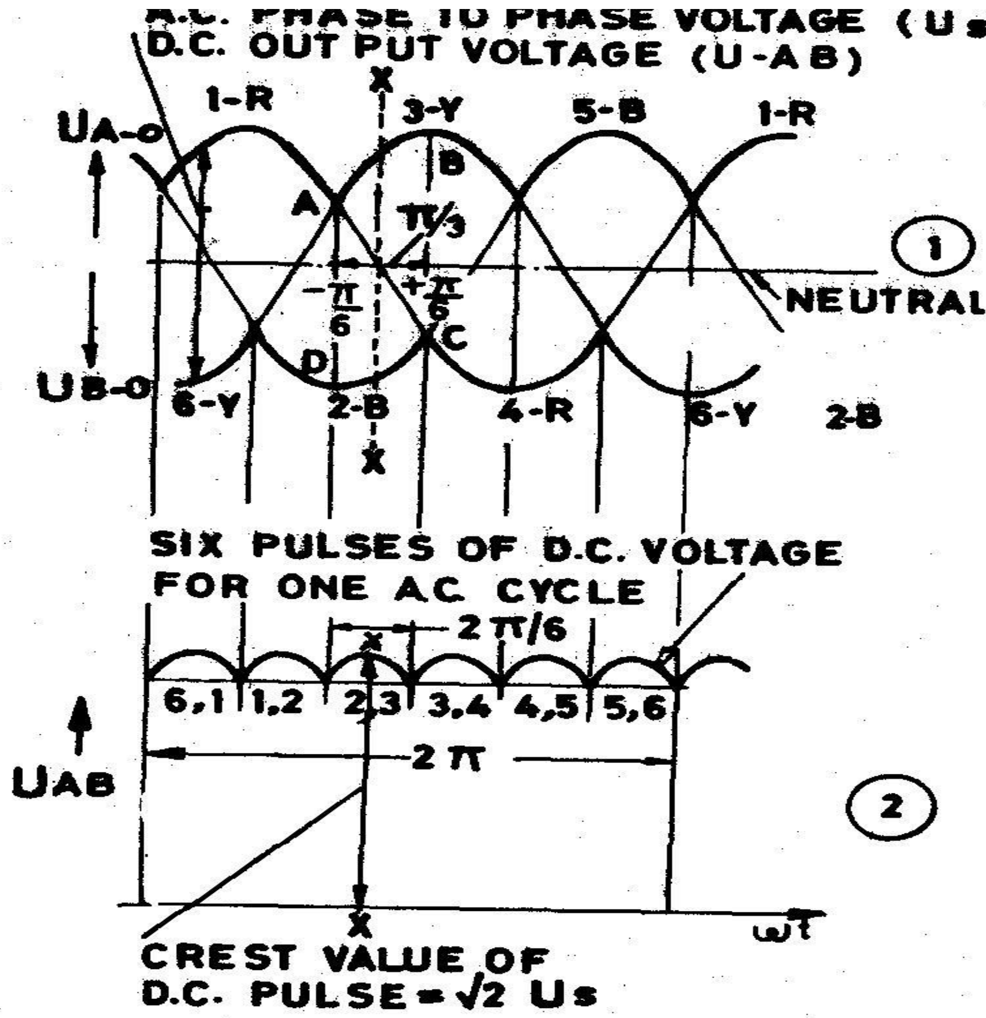
- The following are noted: -
  - $\alpha = 0^0$ Rectifier mode maximum DC voltage
  - $\alpha = 15°$ Rectifier mode reduced DC voltage
  - $\alpha = 90°$ Rectifier mode No power transfer, Zero DC voltage
  - $\alpha > 90°$ Inverter mode
  - $\alpha = 180^0$ Full inverter mode.

- The limits of delay angle α are 0 to 45^0
- In practice, for normal rectifier operating mode, the delay angle α is held between 50 to 15°.
- The choice of α has two opposite constraints.

    (1) The reactive power demand of convertor valves reduces with reduction in delay angle α. Hence smaller value of α is preferred with respect to reactive power requirements (AC shunt compensation)

    (2) But with smaller value of a the possibility of further increase in DC voltage on rectifier side is reduced.

No-load Voltage Equation for Rectifier with Zero Delay Angle



(1) Phase to phase, 3 ph, AC waveforms (2) Corresponding DC output voltage.
Fig. 5·3. No load voltage waveforms of a single six-pulse convertor.

•Secondary phase-to-phase voltage between terminals A and B of a six-pulse convertor bridge .

•It is a sinusoidal voltage with an equation

$$U_s = U_{sm} \cos \omega t$$

•RMS value of the wave u_S, is equal to U_S, which corresponds to phase-to-phase secondary voltage of a convertor transformer which feeds a six-pulse convertor. The crest value (peak value) of the voltage waveform U_{sm} occurs at XX and is given by

$$U_{sm} = \sqrt{2}\, U_s$$

where U_{sm} = peak value of voltage U_{AB} occurring at XX.

U_s = rms value of phase-to-phase secondary voltage

$\omega = 2\pi f$

f = frequency of AC wave.

•Integrating u $_s$ over segment ABCD between — **π**/6 and + **π**/6 as shown is Fig. and dividing by period **π**/3

$$Udo = \frac{1}{(\pi/3)} \int_{-\pi/6}^{+\pi/6} U_{sm} \cos \omega t \, . \, d\omega t$$

$$= \frac{U_{sm}}{(\pi/3)} [\sin \omega t]_{-\pi/6}^{+\pi/6}$$

$$= \frac{3}{\pi} U_{sm} \left[\sin\left(\frac{\pi}{6}\right) - \sin\left(-\frac{\pi}{6}\right) \right]$$

$$Udo = \frac{3}{\pi} U_{sm}$$

where Udo = Direct voltage between terminals of a six-pulse convertor, average value, no-load

U_{sm} = Crest value of secondary phase to phase voltage.

Substituting,

$$U_{sm} = \sqrt{2} \, . \, U_s \text{ in Eqn. } (5 \cdot 2),$$

$$\boxed{Udo = \frac{3}{\pi} \, . \, \sqrt{2} \, . \, U_s}$$

where U_s = secondary, rms, phase to phase voltage

- This fundamental, important equation co-relates DC voltage with phase-to-phase secondary AC voltage for a six-pulse-bridge.
- For a six-pulse bridge

$$Udo = \frac{3}{\pi} \cdot \sqrt{2} \cdot U_s$$

$$\boxed{Udo = 1{\cdot}35\ U_s}$$

where U_{do} = No-load direct voltage with zero phase control, for a six pulse bridge

U_s = Phase to phase rms voltage for secondary.

Rectifier Voltage Equations with No-Load and Delay Angle α

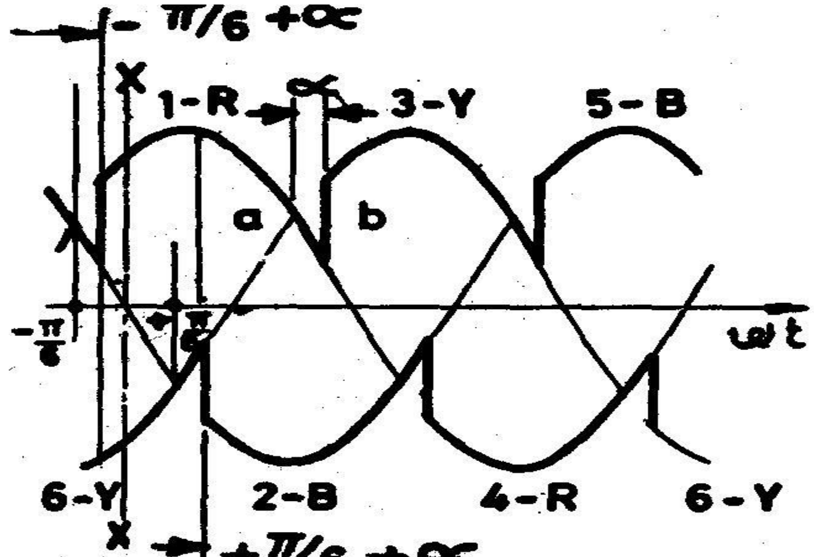


Fig. 5·4. Analysis of no-load voltage with delay angle α present (neglecting reactance drop and over-lap angle).

- The average value of DC voltage of a six-pulse convertor unit can be determined by finding average value of one segment between $(-\pi/6+\alpha)$ and $(+\pi/6+\alpha)$ with respect to peak phase to phase voltage at XX.

- Each segment covers **π**/3 duration. Hence

$$Ud = \frac{1}{\frac{\pi}{3}} \int_{-\pi/6+\alpha}^{+\pi/6+\alpha} U_{sm} \cdot \cos \omega t \cdot d\omega t$$

Where U_{sm} = Crest value of phase to phase AC secondary voltage

$=\sqrt{2}\, U_s$

U_s = Secondary phase to phase rms voltage

U_d = Direct voltage between terminals of one six-pulse unit operating at no load with delay angle α

$$Ud = \frac{3}{\pi} U_{sm} \left(2 \sin \frac{\pi}{6} \cdot \cos \alpha \right)$$

$$= \frac{3}{\pi} \cdot U_{sm} \cdot \cos \alpha$$

$$= \frac{3}{\pi} \cdot \sqrt{2}\, U_s \cos \alpha$$

$$\boxed{Ud = \left(\frac{3}{\pi} \cdot \sqrt{2} \right) U_s \cdot \cos \alpha}$$

Comparing with delay angle α we get

$$Ud = 1{\cdot}35\, U_s \cos \alpha$$

$$\boxed{Ud = Udo \cos \alpha}$$

- The Direct voltage with delay angle α is proportional to $\cos\alpha$
- By increasing delay angle α, the average DC voltage reduces.
- Maximum DC voltage occurs at $\alpha = 0$ and is equal to U_{do}

Analysis of Graetz circuit with overlap

- Due to the leakage inductance of the converter transformers and the impedance in the supply network, the current in a valve cannot change suddenly.
- Thus commutation from one valve to the next cannot be instantaneous.
- For example, when valve 3 is fired, the current transfer from valve 1 to valve 3 takes a finite period during which both valves are conducting.
- This is called overlap and its duration is measured by the overlap (commutation) angle **'μ'**.

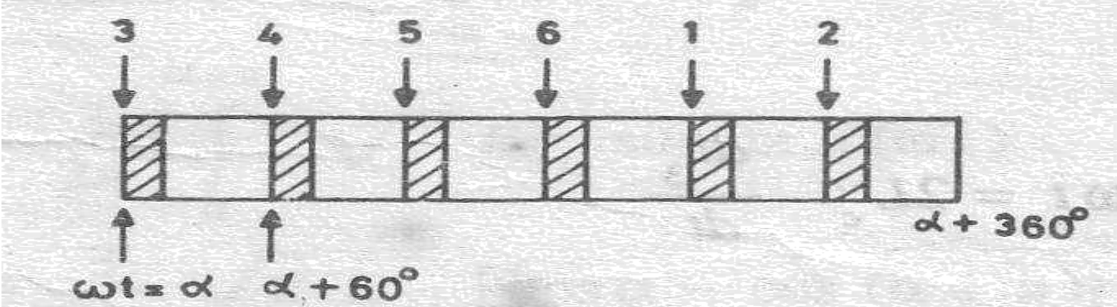


Fig. 3.7 Timing diagram

•Each interval of the period of supply can be divided into two subintervals

•In the first subinterval, three valves are conducting and in the second subinterval, two valves are conducting. This is based on the assumption that the overlap angle is less than 60°.

•As the overlap angle increases to 60°, there is no instant when only two valves are conducting.

- As the overlap angle increases beyond 60^0,there is a finite period during an interval, when four valves conduct and the rest of the interval during which three valves conduct.

Commutation

- The process of transfer of direct current from one path to another with both paths carrying currents simultaneously is called commutation.
- The commutation process takes place sequentially between two consecutive valve arms of group A connected to positive terminal.
- In forced commutation process, the commutating reactance of the load circuit of two valves undergoing commutaion causes the delay in the transfer from one path to another.

- During commutation process, the current i_s outgoing valve arm(1) reduces from full value I_d to zero in a small time interval.
- During the same interval of time, the current of incoming valve arm(3) rises from zero to full value(I_d).
- The time interval during which both the incoming and outgoing valves are conducting is measured in terms of electrical radians or degrees and is called angle of overlap.

Commutating Reactance

- The commutating reactance is defined as the reactance of the circuit consisting of commutating arms and the commutating voltage source during the process of active commutation.

• The commutating reactance reduces the steepness of the fall in current (i_1) in the outgoing valve arm.

• The commutating reactance also reduces the steepness of rise of current (i_3) in incoming valve arm.

• Without commutating reactance the current transfer from one path to another path would have been instantaneous.

•But the transformer secondary winding has inherent reactance which prevents the step change in current.

• The commutating reactance is predominantly active due to the reactance of transformer winding.

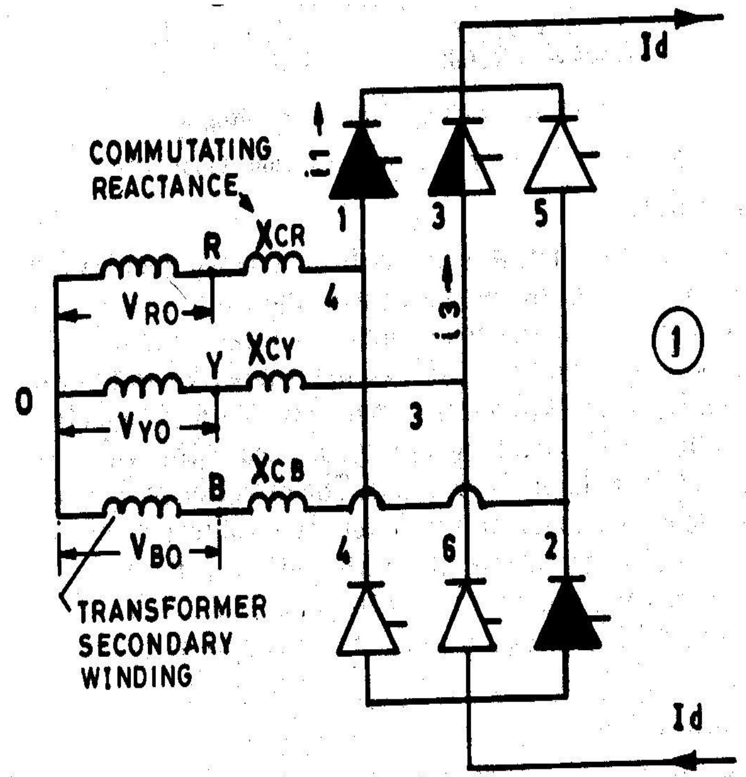


Fig. 4·13. Explaining commutation between valve arm 1 and 3.

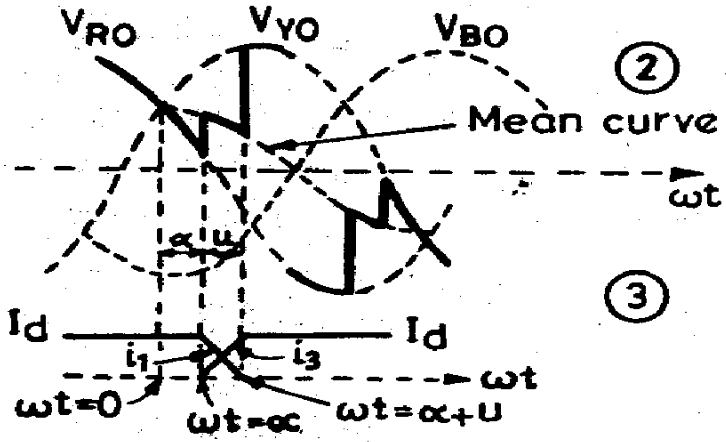


Fig. 4·14. Waveforms during commutation between valve arm 1 and 3 for rectifier mode.

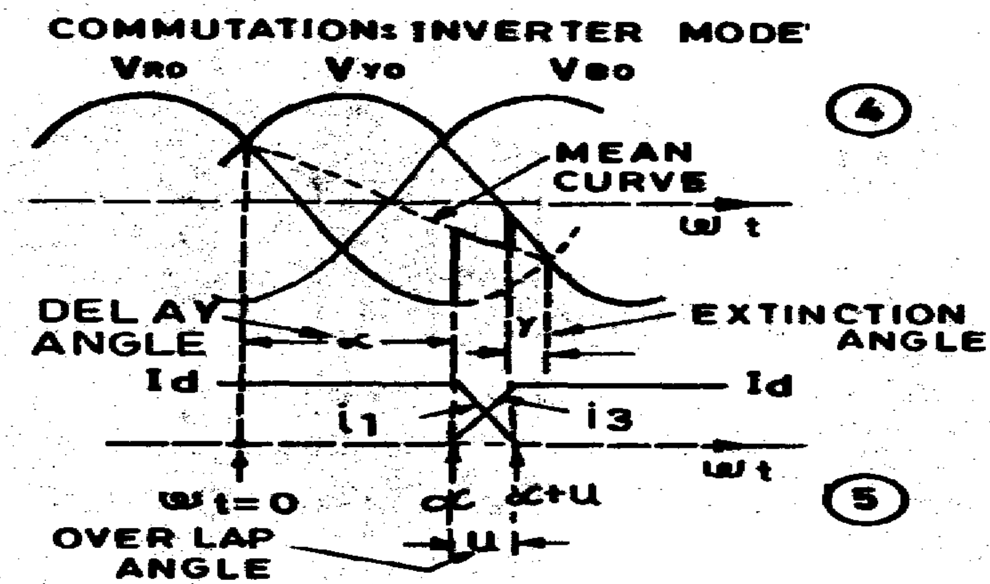


Fig.4·15. Waveforms during commutation between valve arms 1 and 3 for inverter mode.

• **The angle of overlap 'μ' appears due to voltage drop** in commutating reactance Xc.

• The path of i_S is through commutating reactances $2X_C$ offered by the secondary windings and the conducting path.

•The flow of i_S produces reactance voltage drop $i_S.X_C$ per phase.

•The waveform of mean voltage during commutation is shown in Fig.

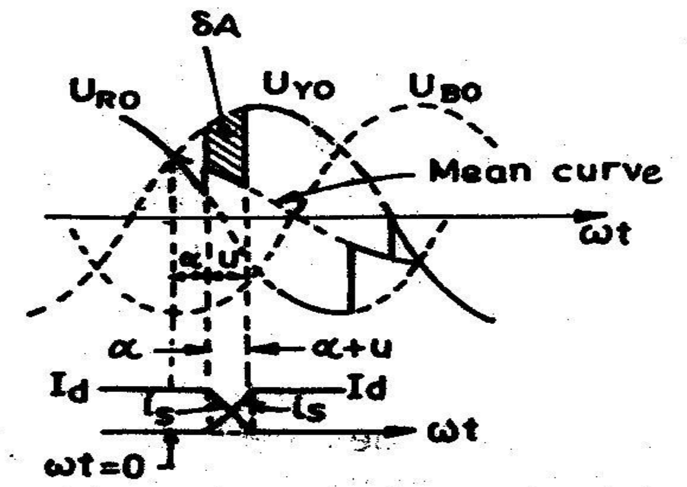


Fig. 5·6. Details of voltage waveform with delay angle α and overlap *u* for RECTIFIER MODE.

Voltage Equation.

Let v_S be the voltage between secondary phases which is responsible for commutating current i_S.

$$v_s = U_{sm} \sin \omega t$$

$$v_s = \sqrt{2}\, U_s \sin \omega t$$

Where U_{sm} = peak secondary ph. to ph. voltage

U_S = rms, ph. to. ph. secondary voltage

From basic circuit fundamentals, we know

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

In the local circuit of current i_S total inductance is $2L_C$ and current i_S.

$$2L_c \frac{di}{dt} = v_s = \sqrt{2}\, U_s \sin \omega t$$

$$di_s = \frac{\sqrt{2}\, U_s}{2L_c} . \sin \omega t . dt$$

Where L_c = Inductance of commutating circuit per phase.

Integrating both sides,

$$i_s = \frac{\sqrt{2}\,U_s}{2L_c} \cdot \frac{\cos.\omega t}{\omega} + C$$

Substituting initial condition, i.e. at wt = α ; i_S =0

$$C = \frac{U_s}{\sqrt{2}\,\omega L_c} \cdot \cos\alpha$$

Therefore,

$$i_s = \frac{U_s}{\sqrt{2}\,\omega L_c} \cdot (\cos\alpha - \cos\omega t)$$

Substituting final commutating condition, i.e. at wt = α +u; i_S=I_d

$$I_d = \frac{U_s}{\sqrt{2}\,\omega L_c} \cdot [\cos\alpha - \cos(\alpha + u)]$$

There is a small voltage drop due to area **δ**A between α and α + **μ** as shown in Fig.

$$\delta A = \frac{1}{2}\int_{\alpha}^{\alpha+u}\sqrt{2}\,U_s \sin\omega t\, d\omega t$$

$$= \frac{\sqrt{2}}{2}\left[U_s \cos\omega t\right]_{\alpha}^{\alpha+u}$$

$$= \frac{U_s}{\sqrt{2}}\left[\cos\alpha - \cos(\alpha + u)\right]$$

Average value of voltage drop during the period **π**/3 is

$$\delta V = \frac{\delta A}{\pi/3}$$

$$= \frac{3}{\pi}\cdot\frac{U_s}{\sqrt{2}}\left[\cos\alpha - \cos(\alpha + u)\right]$$

$$\frac{3U_s}{\sqrt{2}\,\pi} = \frac{Udo}{2}$$

$$\delta V = \frac{Udo}{2}\left[\cos\alpha - \cos(\alpha + u)\right]$$

$$Ud = Udo \cdot \cos\alpha - \delta V$$

$$= Udo\cos\alpha - \frac{Udo}{2}[\cos\alpha - \cos(\alpha + u)]$$

$$= \frac{Udo}{2}[\cos\alpha + \cos(\alpha + u)]$$

$$\frac{Ud}{Udo} = \frac{1}{2}[\cos\alpha + \cos(\alpha + u)]$$

where U_{do} = No load direct voltage

U_d = **Direct voltage on load with delay angle ' ' and overlap angle 'µ'.** α

Therefore,

$$Id = \frac{U_s}{\sqrt{2}X_c}[\cos\alpha - \cos(\alpha + u)]$$

where $X_c = 2\pi f L_c = wL_c$

$$\delta V = \frac{3}{\pi} \cdot \frac{U_s}{\sqrt{2}}[\cos\alpha - \cos(\alpha + u)]$$

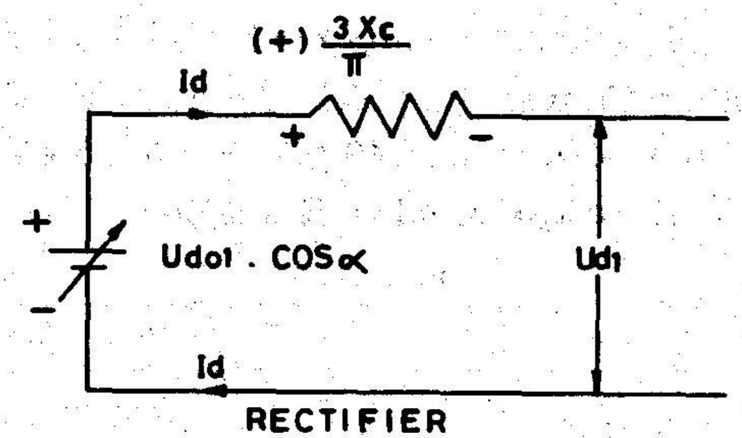
$$\delta V = \frac{3}{\pi} \cdot \omega L_c . Id$$

$$\delta V = \frac{3 X_c}{\pi} Id$$

$$Ud = Udo \cos \alpha - \delta V$$

$$\boxed{Ud = Udo \cos \alpha - \frac{3 X_c}{\pi} Id}$$

Equivalent Circuit of Rectifier



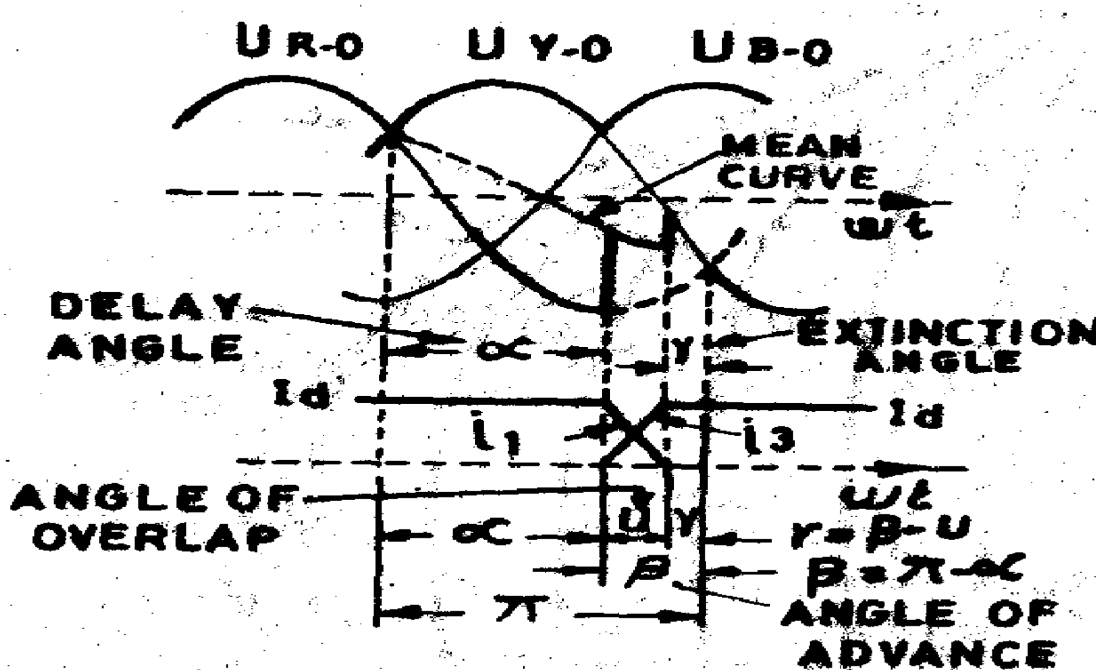
Extinction angle , Angle of advance

for $\alpha = 0$, $$Id = \frac{U_s}{\sqrt{2}\,X_c}\,[1 - \cos(\alpha + u)]$$

for α present, $$Id = \frac{U_s}{\sqrt{2}\,X_c}\,[\cos\alpha - \cos(\alpha + u)]$$

For same Id

$$1 - \cos(\alpha + u) = \cos\alpha - \cos(\alpha + u)$$



Definitions

1. Delay angle α. The time expressed in electrical angular measure from zero crossing of idealised sinusoidal commutating voltage to starting instant of forward current.

2.Angle of Advance . Time expressed in electrical angular measure from starting of current to zero crossing of idealised sinusoldal commutating voltage.

3.Relation between and .

$$\beta = \pi - \alpha$$

4.Angle of overlap u. Time during which two consecutive convertor arms carry current simultaneously.

5. **Extinction angle** (Margin angle). Time from end of current conduction to zero crossing of idealized commutating sinusoidal voltage.

6. **Relationship between , μ, .**

$$\gamma = \beta - u$$