INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)
Dundigal, Hyderabad -500 043

ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE DESCRIPTOR

Course Title	**HVDC TRANSMISSION**				
Course Code	BPSB03				
Programme	M.Tech				
Semester	I	EEE			
Course Type	Elective				
Regulation	IARE - R18				
Course Structure	**Theory**			**Practical**	
	Lectures	**Tutorials**	**Credits**	**Laboratory**	**Credits**
	3	-	3	-	-
Chief Coordinator	Dr. P. Sridhar, Professor, HOD, EEE				
Course Faculty	Dr. P. Sridhar, Professor, HOD, EEE				

I. COURSE OVERVIEW:

This subject deals with the importance of HVDC transmission, analysis of HVDC Converters, Harmonics and Filters, Reactive power control and Power factor improvements of the system. It also deals with basic modeling and analysis of HVDC system power flow regulation**.**

II. COURSE PRE-REQUISITES:

Level	Course Code	Semester	Prerequisites	Credits
UG	AEE010	V	Power electronics	4
UG	AEE012	VI	Power System Analysis	4
UG	AEE015	VII	High voltage engineering	4

III. MARKSDISTRIBUTION:

Subject	SEE Examination	CIAExamination	Total Marks
HVDC Transmission	70 Marks	30 Marks	100

IV. DELIVERY / INSTRUCTIONAL METHODOLOGIES:

✘	Chalk & Talk	✔	Quiz	✔	Assignments	✘	MOOCs
✔	LCD / PPT	✔	Seminars	✘	Mini Project	✘	Videos
✘	Open Ended Experiments						

V. EVALUATION METHODOLOGY:

Each theory course will be evaluated for a total of 100 marks, with 30 marks for Continuous Internal Assessment (CIA) and 70 marks for Semester End Examination (SEE). Out of 30 marks allotted for CIE during the semester, marks are awarded by taking average of two session examinations.

Semester End Examination (SEE): The SEE shall be conducted for 70 marks of 3 hours duration. The syllabus for the theory courses shall be divided into FIVE UNITs and each UNIT carries equal weight age in terms of marks distribution. The question paper pattern shall be as defined below. Two full questions with 'either' 'or' choice will be drawn from each UNIT. Each question carries 14 marks. There could be a maximum of three sub divisions in a question.

The emphasis on the questions is broadly based on the following criteria:

50 %	To test the objectiveness of the concept.
30 %	To test the analytical skill of the concept.
20 %	To test the application skill of the concept.

Continuous Internal Assessment (CIA):

For each theory course the CIA shall be conducted by the faculty/teacher handling the course as given in Table 4. CIA is conducted for a total of 30 marks, with 25 marks for Continuous Internal Examination (CIE) and 05 marks for Technical Seminar and Term Paper.

Table 1: Assessment pattern for CIA

Component	**Theory**		**Total Marks**
Type of Assessment	CIE Exam	Technical Seminar and Term Paper	
CIA Marks	25	05	30

Continuous Internal Examination (CIE):

Two CIE exams shall be conducted at the end of the 9th and 17th week of the semester respectively. The CIE exam is conducted for 25 marks of 2 hours duration, consisting of 5 one-mark compulsory questions in part-A and 4 questions in part-B. The student has to answer any 4 questions out of five questions, each carrying 5 marks. Marks are awarded by taking average of marks scored in two CIE exams.

Technical Seminar and Term Paper:

Two seminar presentations are conducted during I year I semester and II semester. For seminar, a student under the supervision of a concerned faculty member, shall identify a topic in each course and prepare the term paper with overview of topic. The evaluation of Technical seminar and term paper is for maximum of 5 marks. Marks are awarded by taking average of marks scored in two Seminar Evaluations.

VI. HOW PROGRAM OUTCOMES ARE ASSESSED:

Program Outcomes (POs)		Strength	Proficiency assessed by
PO 1	Identify, formulate and solve power system related problems using advancedlevel computing techniques.	3	Assignments/ Exams
PO 2	Explore ideas to carry out research / investigation independently to solve practical problems through continuing education.	2	Guest Lectures
PO 3	Demonstrate knowledge and execute projects on contemporary issues in multidisciplinary environment.	2	Design Exercises
PO 4	Ability to write and present a substantial technical report / document.	2	Presentation on real world problems
PO 5	Inculcate ethics, professionalism, multidisciplinary approach, entrepreneurial thinking and effective communication skills.	1	-----
PO 6	Function effectively as an individual or a leader in a team to propagate ideas and promote teamwork.	1	-----
PO 7	Develop confidence for self-study and to engage in lifelong learning.	1	-----

3 = High; 2 = Medium; 1 = Low

VII. HOW PROGRAM EDUCATIONAL OUTCOMES ARE ASSESSED:

Program educationalOutcomes (PEOs)		Strength	Proficiency assessed by
PEO 1	Impart engineering knowledge in specific and re-equip with latest technologies to analyze, synthesize the problems in power system and multidisciplinary sectors.	2	Assignments
PEO 2	Design, develop innovative products and services in the field of electrical power systems with the latest technology and toolset	2	Design Exercise
PEO 3	Inculcate research attitude and life-long learning for a successful career	2	Seminar
PEO 4	Attain intellectual leadership skills to cater the needs of power industry, academia, society and environment	1	-------

3 = High; 2 = Medium; 1 = Low

VIII. COURSE OBJECTIVES :

The course should enable the students to:	
I	Understand state of the art HVDC technology
II	Learn the methods to carry out modelling and analysis of HVDC system frontier- area power flow regulation

IX. COURSE OUTCOMES (COs):

COs	Course Outcome	CLOs	Course Learning Outcome
CO 1	Classify AC and DC transmission and understand control characteristics of HVDC system.	CLO 1	Illustrate the layout of HVDC converter stations.
		CLO 2	Understand the difference between HVDC and HVAC transmission
		CLO 3	Describe the converter control characteristics of HVDC systems.
		CLO 4	Analyze single phase and three phase converters and understand its properties
CO 2	Explain the working of HVDC converter in rectifier and inverter modes of operation.	CLO 5	Demonstrate the rectifier configurations of 12 pulse HVDC converter.
		CLO 6	Understand the working of inverter configuration of HVDC converter.
		CLO 7	Understand different modes of operation of converters.
		CLO 8	Analyze the output waveforms for rectifier and inverter circuits
CO 3	Understand different control schemes used in HVDC converters	CLO 9	Examine the control schemes for HVDC transmission systems.
		CLO 10	Analyze the characteristics of HVDC converter with respect to Constant current and Constant voltage
		CLO 11	Understand actual and desired characteristics of a converter
		CLO 12	Understand the concept of power reversal in HVDC converters
CO 4	Understand the nature of faults happening on both the AC and DC sides of the converters and formulate protection schemes for the same.	CLO 13	Illustrate the starting and stopping of converter bridge
		CLO 14	Analyze various aspects responsible for commutation failure
		CLO 15	Analyze the adverse effects of HVDC converter on equipment
		CLO 16	Understand different methods used in protection of HVDC converter
CO 5	Develop harmonic models and use the knowledge of circuit theory to develop filters and assess the requirement and type of protection for the filters.	CLO 17	Understand controllers for controlling the power flow through a dc link
		CLO 18	Analyze the Harmonics and use of filters to minimize the harmonics.
		CLO 19	Understand the importance of smoothening reactors in HVDC converters
		CLO 20	Analyze the harmonics and basis of protection for HVDC System.

X. COURSE LEARNING OUTCOMES (CLOs):

CLO Code	CLO's	At the end of the course, the student will have the ability to:	PO's Mapped	Strength of Mapping
BPSB03.01	CLO 1	Illustrate the layout of HVDC converter stations.	PO 1, PO 2, PO 3	2
BPSB03.02	CLO 2	Understand the difference between HVDC and HVAC transmission	PO 1, PO 2, PO 3, PO 4	2
BPSB03.03	CLO 3	Describe the converter control characteristics of HVDC systems.	PO 1, PO 2	2
BPSB03.04	CLO 4	Analyze single phase and three phase converters and understand its properties	PO 1, PO 2, PO 3	1
BPSB03.05	CLO 5	Demonstrate the rectifier configurations of 12 pulse HVDC converter.	PO 1, PO 2, PO 3	2
BPSB03.06	CLO 6	Understand the working of inverter configuration of HVDC converter.	PO 1, PO 2, PO 4	2
BPSB03.07	CLO 7	Understand different modes of operation of converters.	PO 1, PO 2, PO 4	3
BPSB03.08	CLO 8	Analyze the output waveforms for rectifier and inverter circuits	PO 1, PO 2, PO 3	1
BPSB03.09	CLO 9	Examine the control schemes for HVDC transmission systems.	PO 1, PO 2, PO 3	1
BPSB03.10	CLO 10	Analyze the characteristics of HVDC converter with respect to Constant current and Constant voltage	PO 1, PO 2	1
BPSB03.11	CLO 11	Understand actual and desired characteristics of a converter	PO 3, PO 4	2
BPSB03.12	CLO 12	Understand the concept of power reversal in HVDC converters	PO 1, PO 2	2
BPSB03.13	CLO 13	Illustrate the starting and stopping of converter bridge	PO 1, PO 2, PO 4	2
BPSB03.14	CLO 14	Analyze various aspects responsible for commutation failure	PO 3, PO 4	2
BPSB03.15	CLO 15	Analyze the adverse effects of HVDC converter on equipment	PO 2, PO 4	2
BPSB03.16	CLO 16	Understand different methods used in protection of HVDC converter	PO 2, PO 3	2
BPSB03.17	CLO 17	Understand controllers for controlling the power flow through a dc link	PO 2, PO 3	3
BPSB03.18	CLO 18	Analyze the Harmonics and use of filters to minimize the harmonics.	PO 2, PO 4	2
BPSB03.19	CLO 19	Understand the importance of smoothening reactors in HVDC converters	PO 1, PO 3	2
BPSB03.20	CLO 20	Analyze the harmonics and basis of protection for HVDC System.	PO 1, PO 2	2

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XI. MAPPING COURSE OUTCOMES LEADING TO THE ACHIEVEMENT OF PROGRAM OUTCOMES

Course Outcomes (COs)	Program Outcomes (POs)						
	PO 1	PO 2	PO 3	PO 4	PO5	PO6	PO7
CO 1	3	2	2	2			
CO 2	2	2	1	1			
CO 3	1	2	2	1			
CO 4	2		2	2			
CO 5			2	1			

XII. MAPPING COURSE LEARNING OUTCOMES LEADING TO THE ACHIEVEMENT OF PROGRAM OUTCOMES:

Course Learning Outcomes (CLOs)	Program Outcomes (POs)						
	PO1	PO2	PO3	PO4	PO5	PO6	PO7
CLO 1	2	2	2				
CLO 2	2	2	2	2			
CLO 3	2	2					
CLO 4	1	1	1				
CLO 5	2	2	2				
CLO 6		1	1	1			
CLO 7	1	1	1				
CLO 8	2	2		2			
CLO 9	1	1	1				
CLO 10	2	2					
CLO 11	2		2	2			
CLO 12	2		2	2			
CLO 13	2	2					
CLO 14	2	2		2			
CLO 15		2	2				
CLO 16		2	2				
CLO 17	2	2	2	2			
CLO 18			2				
CLO 19		2	2				
CLO 20	2	2					

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XIII. ASSESSMENT METHODOLOGIES–DIRECT

CIE Exams	PO 1,PO2, PO 3, PO 4	SEE Exams	PO1, PO2, PO 4	Assignments	PO 1	Seminars	PO 1, PSO 2
Laboratory Practices	-	Student Viva	-	Mini Project	-	Certification	-
Term Paper	-						

XIV. ASSESSMENT METHODOLOGIES-INDIRECT

✔	Early Semester Feedback	✔	End Semester OBE Feedback
✘	Assessment of Mini Projects by Experts		

XV. SYLLABUS

Unit-I	**GENERAL ASPECTS OF HVDC TRANSMISSION**
Evolution of HVDC transmission, comparision of HVDC and HVAC systems, types of DC link, components of HVDC system, value characteristics, properties of converter circuits, assumptions, single phase and three phase converters, pulse number, choice of best circuit for HVDC converters.	
Unit-II	**ANALYSIS OF BRIDGE CONVERTER**
Analysis of simple rectifier circuit, required features of rectification circuits for HVDC transmission, Analysis of HVDC converter, different modes of converter operation, output voltage waveform and DC voltage in rectification, output voltage waveforms and DC in inverter operation, thyristor/ valve voltages, equivalent electrical circuit	
Unit-III	**HVDC CONTROL TECHNIQUES**
Grid control, basic means of control, power reversal, limitations of manual control, constant current versus constant voltage, desired features of control, actual control characteristics. Constant minimum ignition angle control: Constant current control, constant extinction angle control, stability of control, tap changer control, power control and current limits, frequency control.	
Unit-IV	**CONVERTER FAULTS AND PROTECTION**
Converter mal-operations, commutation failure, starting and shutting down the converter bridge, converter protection.	
Unit-V	**REACTIVE POWER MANAGMENT**
Smoothing reactor and DC Lines, reactive power requirements, harmonic analysis, filter design, power flow analysis in AC, DC systems, modeling of DC links, solutions of AC, DC Power flow.	
Text Books:	
1. JArrillaga, "High Voltage Direct Transmission", Peter Peregrinus Ltd. London, 1st Edition, 1983. 2. K R Padiyar, "HVDC Power Transmission Systems", Wiley Eastern Ltd., 1st Edition, 1990.	
Reference Books:	
1. E. W. Kimbark, "Direct Current Transmission", Vol. I, Wiley Interscience, 1st Edition, 1971. 2. Erich Uhlmann, "Power Transmission by Direct Current", B.S. Publications, 1st Edition, 2004. 3. SN Singh, "Electric Power Generation, Transmission and Distribution, PHI, New Delhi, 2nd Edition, 2008. 4. V Kamaraju, "HVDC Transmission" Tata McGraw-Hill Education Pvt Ltd, New Delhi, 2nd Edition, 2011.	

XVI. COURSE PLAN:

The course plan is meant as a guideline. Probably there may be changes.

Lecture No	Topics to be covered	Course Learning Outcomes (CLOs)	Reference
1	Introduction of DC power transmission technology	CLO 1	T1:3.3 T2:1.2
2	Understand Economics of HVDC transmission	CLO 1	T1:3.4 T2:1.4
3	Comparison of AC and DC Transmission	CLO 2	T1:3.5 T2:1.5
4	Terminal equipment of HVDC	CLO 2	T1:3.7 T2:1.8
5	Application of DC transmission system	CLO 3	T1: 3.9 T2: 1.10
6	Reliability of HVDC systems, limitation of HVDC transmission	CLO 3	T1:5.5 T2:6.2
7	Modern trends in DC transmission	CLO 4	T1:5.6 T2:6.3
8	Single phase and three phase converters	CLO 4	T1:4.3 T2:5.2
9	Properties and characteristics of HVDC converter	CLO 5	T1: 4.4 T2:5.3
10	Choice of converter configuration	CLO 5	T1:4.5 T2:5.4
11	Planning for HVDC transmission, modern trends in DC transmission	CLO 6	T1:4.6 T2:5.5
12	Simplified analysis of Graetz circuit	CLO 6	T1: 4.5.2 T2: 5.6
13	Features of rectification circuit for HVDC transmission	CLO 7	T1:4.6 T2:5.5
14	Different modes of operation of converter	CLO 7	T1:4.6.2 T2:5.5.2
15	Characteristics of a twelve-pulse converter	CLO 8	T1:4.7 T2:5.6
16	Output voltage waveforms in rectification process	CLO 8	T1:4.7 T2:5.8
17	Output voltage waveforms in inverter operation	CLO 9	T1:4.7.2 T2:5.8.2
18	Introduction to grid control	CLO 9	T1:4.8 T2:5.9
19	Limitations in manual control and development of control schemes	CLO 10	T1:4.9 T2:5.7
20	Constant current vs constant voltage	CLO 10	T1:6.2 T2:5.6
21	Desired features of converter	CLO 11	T1:6.3 T2:5.7
22	Control schemes of HVDC converter	CLO 11	T1:6.4 T2:5.8
23	Principle of DC Link Control	CLO 12	T1:6.5 T2:5.3
24	Converter control characteristics	CLO 12	T1:6..6 T2:5.2
25	Firing angle control	CLO 13	T1:6.7 T2:5.3
26	Current and extinction angle control	CLO 13	T1:6.5 T2:7.5

Lecture No	Topics to be covered	Course Learning Outcomes (CLOs)	Reference
27	Effect of source inductance on the system	CLO 14	T1: 6.2, 6.3
28	Stability of control and tap changer control	CLO 14	T1: 6.2
29	Power control, current limits and Frequency control	CLO 15	T1:6.2 T2:7.2
30	Converter mal operations	CLO 15	T1:6.3 T2:7.3
31	Reasons for commutation failure and its effects on equipment	CLO 16	T1:6.4 T2:7.5
32	Starting and shutting down of converter bridge	CLO 16	T1: 6.2 T2: 5.6
33	Protection against over current and over voltage in converter station	CLO 16	T1:6.3 T2:5.7
34	Sources of reactive power	CLO 17	T1:6.4 T2:5.8
35	Ac Filters	CLO 17	T1:2.1 T2:9.1
36	Modeling of DC Links	CLO 17	T1:2.2 T2:9.2
37	DC Network-Dc Converter-Controller Equations	CLO 17	T1: 2.1 T2: 9.1
38	solution of Dc load flow	CLO 18	T1:2.6 R1:5.1
39	Solution of AC-DC power flow	CLO 18	T1:2.7 R1:5.2
40	Simultaneous method	CLO 18	T1:2.8 R1:5.5
41	Sequential method	CLO 19	T1:2.1 R1:5.6
42	Converter faults	CLO 19	T1:2.2 R1:5.4
43	Generation of harmonics.	CLO 19	T1:2.4 R1:5.5
44	Characteristics harmonics, calculation of AC harmonics	CLO 20	T1:2.4 R1:5.5
45	Non characteristics of Harmonics, adverse effects of harmonics	CLO 20	T1:2.4 R1:5.5

XVII. GAPS IN THE SYLLABUS-TO MEET INDUSTRY / PROFESSION REQUIREMENTS:

S. NO.	DESCRIPTION	PROPOSED ACTIONS	RELEVANCE WITH POs	RELEVANCE WITH PEOs
1	Methods for protection of HVDC converters.	Seminars/NPTEL	PO 1	PEO 1, PEO 2

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