Course Name: HVDC Transmission
Course Code: EE 801A
Credit: 3

Prerequisites:

Sl. No.	Subject	Description	Level of Study
01	Power System-I, II & III	Power Flow Studies, Power System Fault, Compensating Devices	5^{th}, 6^{th} and 7^{th}Sem
02	Control System-I & II	Block Diagram, Linear and Nonlinear control systems	5^{th}& 6^{th}Sem
03	Power Electronics	Power Electronics Devices, Converters, Inverters	6^{th}Sem

Course Objective:

- To introduce students with the concept of HVDC Transmission system.
- To familiarize the students with the HVDC converters and their control system.
- To expose the students to the harmonics and faults occur in the system and their prevention.

Course Outcomes:

At the end of the course, a student will be able to:

1. **Develop** the knowledge of HVDC transmission and HVDC converters and the applicability and advantage of HVDC transmission over conventional AC transmission.

2. **Formulate** and **solve** mathematical problems related to rectifier and inverter control methods and learn about different control schemes as well as starting and stopping of DC links

3. **Analyze** the different harmonics generated by the converters and their variation with the change in firing angles.

4. **Develop** harmonic models and use the knowledge of circuit theory to develop filters and assess the requirement and type of protection for the filters.

5. **Study** and **understand** the nature of faults happening on both the AC and DC sides of the converters and formulate protection schemes for the same.

6. **Review** the existing HVDC systems along with MTDC systems and their controls and recognize the need to follow the advancements in both the existing systems and HVDC systems and **determine** the most economic coexistence of both.

CO- PO mapping:

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
1	1	2	3	3	1	3	3	-	3	3	2	1
2	2	2	2	2	2	-	-	3	3	2	2	2
3	3	2	-	-	1	-	3	-	3	3	-	3
4	2	3	1	-	2	3	3	-	2	3	2	2
5	3	1	-	2	-	3	3	2	3	3	2	2
6	2	-	2	3	2	3	2	3	-	-	-	3

Correlation levels 1, 2 or 3 as defined above: 1: Slight (Low) 2: Moderate (Medium)3: Substantial (High) and "-" if there is no correlation.

Syllabus Indicating CO:

Module No.	Content	Relevant CO's
1	**Introduction:** Introduction of DC power transmission technology, comparison of AC and DCtransmission, limitation of HVDC transmission, reliability of HVDC systems, application ofDC transmission, description of DC transmission system, planning for HVDC transmission,moderntrends in DC transmission.	CO1,CO6
2	**Analysis of HDVC converters:** Choice of converter configuration, simplified analysis of Graetz circuit, converter bridgecharacteristics, Characteristics of a twelve pulse converter, detailed analysis of converters.	CO1, CO2
3	**Control of HVDC converter and systems:** Necessity of control of a DC link, rectifier control, compounding of rectifiers, power reversalof DC link, voltage dependent current order limit(VDCOL) characteristics of the converter,inverter extinction angle control, pulse phase control, starting and stopping of DC link,constant power control, control scheme of HVDC converters.	CO2
4	**Harmonics and filters:** Generation of harmonics by converters, characteristics of harmonics on DC side,characteristics of current harmonics, characteristic variation of harmonic currents withvariation of firing angle and overlap angle, effect of control mode on harmonics,noncharacteristic harmonic.Harmonic model and equivalent circuit, use of filter, filter configuration, design of band pass and high pass filter, protection of filters, DC filters, power line	CO2, CO3, CO4,CO5

	communication and RInoise, filters with voltage source converter HDVC schemes.	
5	**Fault and protection schemes in HVDC systems:** Nature and types of faults, faults on AC side of the converter stations, converter faults, faulton DC side of the systems, protection against over currents and over voltages, protection offilter units.	**CO2, CO4, CO5**
6	**Multiterminal HVDC systems:** Types of multiterminal (MTDC) systems, parallel operation aspect of MTDC. Control ofpower in MTDC. Multilevel DC systems.Power upgrading and conversion of AC lines into DC lines, Parallel AC/DC systems,FACTS and FACTS converters.	**CO5, CO6**

Lecture Plan:

Class No	Date	Topics	Remarks
1		**Introduction (Module 1):** Introduction of DC power transmission technology	
2		**Introduction (Module 1):** Comparison of AC and DC Transmission.	
3		**Introduction (Module 1):** Reliability of HVDC systems, limitation of HVDC transmission	
4		**Analysis of HDVC converters (Module 2):** Choice of converter configuration, simplified analysis of Graetz circuit	
5		**Analysis of HDVC converters (Module 2):** planning for HVDC transmission,modern trends in DC transmission	
6		**Analysis of HDVC converters (Module 2):** converter bridge characteristics	
7		**Analysis of HDVC converters (Module 2):** Characteristics of a twelve pulse converter	
8		**Analysis of HDVC converters (Module 2):** Detailed analysis of converters	
9		**Analysis of HDVC converters (Module 2):** Detailed analysis of converters	Problems to be solved
10		**Control of HVDC converter and systems (Module-3):** Necessity of control of a DC link, rectifier control, inverter extinction angle control	
11		**Control of HVDC converter and systems (Module-3):** Necessity of control of a DC link, rectifier control, inverter extinction angle control	
12		**Control of HVDC converter and systems (Module-3):** Compounding of rectifiers, power reversal of DC link	Problems to be solved
13		**Control of HVDC converter and systems (Module-3):** Voltage Dependent Current Order Limit(VDCOL) characteristics of the converter	
14		**Control of HVDC converter and systems (Module-3):** Pulse phase control	

Class No	Date	Topics	Remarks
15		**Control of HVDC converter and systems (Module-3):** Pulse phase control	
16		**Control of HVDC converter and systems (Module-3):** Starting and stopping of DC link	
17		**Control of HVDC converter and systems (Module-3):** Constant power control	
18		**Control of HVDC converter and systems (Module-3):** Control scheme of HVDC converters.	
19		**Harmonics and filters (Module-4):** Generation of harmonics by converters, characteristics of harmonics on DC side, characteristics of current harmonics	
20		**Harmonics and filters (Module-4):** Generation of harmonics by converters, characteristics of harmonics on DC side, characteristics of current harmonics	
21		**Harmonics and filters (Module-4):** Characteristic variation of harmonic currents withvariation of firing angle and overlap angle	
22		**Harmonics and filters (Module-4):** Effect of control mode on harmonics, Non-characteristic harmonic	
23		**Harmonics and filters (Module-4):** Harmonic model and equivalent circuit	
24		**Harmonics and filters (Module-4):** Use of filter, filter configuration	
25		**Harmonics and filters (Module-4):** design of bandpass and high pass filter	
26		**Harmonics and filters (Module-4):** protection of filters, DC filters	
27		**Harmonics and filters (Module-4):** power line communication and RInoise	
28		**Harmonics and filters (Module-4):** filters with voltage source converter HDVC schemes	Problems to be solved
29		**Fault and protection schemes in HVDC Systems (Module-5):** Nature and types of faults, faults on AC side of the converter stations	

Class No	Date	Topics	Remarks
30		**Fault and protection schemes in HVDC Systems (Module-5):** converter faults, Faulton DC side of the systems	
31		**Fault and protection schemes in HVDC Systems (Module-5):** Protection against over currents and over voltages	
32		**Fault and protection schemes in HVDC Systems (Module-5):** protection offilter units	
33		**Fault and protection schemes in HVDC systems (Module-6):** Types of multi-terminal (MTDC) systems, parallel operation aspect of MTDC.	
34		**Fault and protection schemes in HVDC systems (Module-6):** Control ofpower in MTDC.	
35		**Fault and protection schemes in HVDC systems (Module-6):** Multilevel DC systems	
36		**Fault and protection schemes in HVDC systems (Module-6):** Power upgrading and conversion of AC lines into DC lines	
37		**Fault and protection schemes in HVDC systems (Module-6):** Parallel AC/DC systems	
38		**Fault and protection schemes in HVDC systems (Module-6):** FACTS and FACTS converters	
39		**Fault and protection schemes in HVDC systems (Module-6):** FACTS and FACTS converters	
40		**Fault and protection schemes in HVDC systems (Module-6):** FACTS and FACTS converters	

Recommended Books:

1. HVDC Transmission, S. Kamakshaiah& V. Kamaraju, Tata McGraw hill education
2. HVDC Power transmission system, K.R.Padiyar, Wiley Eastern Limited
3. High Voltage Direct Current Transmission, J. Arrillaga, Peter Pregrinu
4. Power System Stability and Control by PrabhaKundur, McGraw hill
5. Power System Analysis: Operation and Control, AbhijitChakrabarti and SunitaHalder, PHI Learning Pvt. Ltd.