M. Tech

IN

HIGH VOLTAGE ENGINEERING

CURRICULUM AND SYLLABI

(Applicable from 2023 admission onwards)

Department of Electrical Engineering
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT
Kozhikode - 673601, KERALA, INDIA

The Program Educational Objectives (PEOs) of M. Tech in High Voltage Engineering

PEO1	Apply enhanced knowledge and skills in the area of high voltage engineering so as to excel in various sectors in modern power industry/utility and/ or teaching and/or higher education and / or research.
PEO2	Engage in design of novel products and strategic solutions to real life problems in the areas of high voltage engineering that are technically sound, economically feasible and socially acceptable.
PEO3	Exhibit professionalism, keep up ethics in profession and demonstrate communication skills, leadership qualities as well as willingness to work in groups.

Programme Outcomes (POs) of M. Tech in High Voltage Engineering

PO1	Ability to independently carry out research /investigation and development work to solve practical problems.
PO2	Ability to write and present a substantial technical report/document.
PO3	Ability to demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate bachelor program.
PO4	Ability to utilize the acquired knowledge to design and develop new techniques in order to tackle the problems pertaining to high voltage systems and also take up administrative challenges including the management of projects related to high voltage systems having multidisciplinary nature.
PO5	Willingness and ability to upkeep professional ethics and social values while carrying out the responsibilities as a High Voltage engineer/researcher in devising solutions to real life engineering problems in an independent manner.

CURRICULUM

Total credits for completing the M. Tech Programme in High Voltage Engineering is 75.

COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of M. Tech programme shall have the following Course Categories:

Sl. No.	Course Category	Minimum Credits
1.	Program Core (PC)	26
2.	Program Electives (PE)	12
3.	Institute Elective (IE)	2
4.	Projects	35

The effort to be put in by the student is indicated in the tables below as follows:
L: Lecture (One unit is of 50 minute duration)
T: Tutorial (One unit is of 50 minute duration)
P: Practical (One unit is of one hour duration)
O: Outside the class effort / self-study (One unit is of one hour duration)

PROGRAMME STRUCTURE

Semester-I

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	MA6003E	Mathematical Methods for Power Engineering	3	0	0	6	3	PC
2.	EE6501E	High Voltage Engineering	3	0	0	6	3	PC
3.	EE6502E	Power System Transients	3	0	0	6	3	PC
4.	EE6202E	Power Converters For Power System Applications	3	0	0	6	3	PC
5.		Programme Elective-1	3	0	0	6	3	PE
6.		Programme Elective-2	3	0	0	6	3	PE
7.		Institute Elective	2	0	0	4	2	IE
8.	EE6591E	High Voltage Lab	0	0	3	0	1	PC
	Total Credits		**20**	**0**	**0**	**43**	**21**	

Semester-II

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE6511E	Extra High Voltage Power Transmission	3	0	0	6	3	PC
2.	EE6512E	Computational Electromagnetics	3	0	0	6	3	PC
3.	EE6513E	Physics of Dielectrics	3	0	0	6	3	PC
4.	EE6514E	Condition monitoring of High Voltage Equipment	3	0	0	6	3	PC
5.		Programme Elective-3	3	0	0	6	3	PE
6.		Programme Elective-4	3	0	0	6	3	PE
7.	EE6592E	Seminar	0	0	0	3	1	PC
8.	EE6593E	Project Phase I	0	0	3	3	2	PC
	Total Credits		**18**	**0**	**3**	**42**	**21**	

Semester-III

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE7591E	Project Phase II*	0	0	6	3	3	PC
2.	EE7592E	Project Phase III	0	0	30	15	15	PC
	Total Credits		**0**	**0**	**36**	**18**	**18**	

** to be completed during Summer*

Semester-IV

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE7593E	Project Phase IV	0	0	30	15	15	PC
	Total Credits		**0**	**0**	**30**	**15**	**15**	

List of Electives**

Sl. No	Course Code	Course Title	L	T	P	O	Credits
1	EE6521E	Advanced Electrical Insulation Systems	3	0	0	6	3
2	EE6522E	HVDC Transmission	3	0	0	6	3
3	EE6523E	High Voltage Testing Techniques	3	0	0	6	3
4	EE6524E	High Voltage Power Transformers and Circuit Breakers	3	0	0	6	3
5	EE6525E	Electromagnetic Interference and Compatibility	3	0	0	6	3
6	EE6526E	Pulsed Power Engineering	3	0	0	6	3
7	EE6221E	Power Quality Issues and Remedial Measures	2	0	2	5	3

8	EE6222E	Wide Area Monitoring & Control of Power Systems	3	0	0	6	3
9	EE6223E	Power System Reliability	3	0	0	6	3
10	EE6224E	Distributed Processing of Power Systems	3	0	0	6	3
11	EE6225E	Smart Grid Technologies	3	0	0	6	3
12	EE6226E	Distributed Generation and Micro-Grids	3	0	0	6	3
13	EE6227E	Power System Automation	3	0	0	6	3
14	EE6228E	Data Analytics in Power Systems	3	0	0	6	3
15	EE6229E	Power Distribution Systems	3	0	0	6	3
16	EE6321E	Power Semiconductor Devices and Modelling	3	0	0	6	3
17	EE6322E	Static VAR Controllers and Harmonic Filtering	3	0	0	6	3
18	EE6323E	Digital Simulation of Power Electronic Systems	3	0	0	6	3
19	EE6324E	Advanced Control of Inverter-fed Induction Motor Drives	3	0	0	6	3
20	EE6325E	Linear and Digital Electronics	3	0	0	6	3
21	EE6326E	Power Electronic Drives for Special Machines	3	0	0	6	3
22	EE6327E	Computer Aided Design for Electromagnetic Systems	2	0	2	5	3
23	EE6328E	Electric Vehicle System Engineering	3	0	0	6	3
24	EE6329E	Advanced Microprocessor based systems	3	0	0	6	3
25	EE6427E	Sustainable Energy Systems & Design	3	0	0	6	3
26	EE6428E	Distribution Systems Management and Automation	3	0	0	6	3
27	EE6429E	SCADA Systems & Applications	3	0	0	6	3
28	EE6430E	Wireless & Sensor Networks	3	0	0	6	3
29	EE6431E	Network & Data Security	3	0	0	6	3
30	EE6432E	Advanced Algorithms & Data Structure Analysis	3	0	0	6	3

Institute Electives							
1.	ZZ6001E	Research Methodology	2	0	0	4	2
2.	MS6174E	Technical Communication and Writing	2	1	0	3	2
3.	IE6001E	Entrepreneurship Development	2	0	0	4	2

*** List of Electives offered in each semester will be announced by the Department. Any other PG level course approved by the senate offered in the Institute can also be credited as Programme Electives with the prior approval of the Programme Coordinator.*

MA6003E MATHEMATICAL METHODS FOR POWER ENGINEERING

Pre-requisites**: NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:

CO1: Solve systems of linear equations using the language of matrices.
CO2: Apply the concept of vectors spaces, eigenvalues and eigenvectors.
CO3: Solve unconstrained and constrained nonlinear programming problems.
CO4: Determine approximate solutions to transcendental equations and system of equations usingnumerical methods.
CO5: Evaluate definite integrals and solve ODEs using numerical methods.

Linear Algebra

System of linear equations: Range space and Null space of a matrix, Rank of a matrix, Existence and uniqueness of solution of the system of linear equations, Dimension of the Solution Space associated with the system of linear equations.
Vector Spaces: Definition of Vector space, Sub spaces, linearly independence and dependence, linear Span, Basis, Dimension. Eigenvalues and Eigenvectors, Properties of eigenvalues and eigenvectors, Similarity matrices, Complex matrices.

Optimization Methods

Unconstrained one-dimensional optimization techniques, Necessary and sufficient conditions, Unrestricted search methods, Fibonacci and Golden section method. Unconstrained n dimensional optimization techniques, Descent methods, Steepest descent, conjugate gradient. Constrained optimization Techniques, Necessary and sufficient conditions, Equality and inequality constraints, Kuhn-Tucker conditions, Gradient projection method.

Numerical Methods

Solution of algebraic and transcendental equations: fixed point iteration method, Newton Raphson method. Solution of linear system of equations, Gauss elimination method, Pivoting, Gauss Jordan method, Iterative methods: Gauss Jacobi, Gauss Seidel and relaxation method, Newton’s method for nonlinear system of equations. Numerical Integration: Trapezoidal and Simpson’s rule, Composite integration methods, Gauss quadrature methods. Numerical Solution of Ordinary Differential Equations: Euler's method, Euler's modified method, Taylor's method, Runge-Kutta method, Multistep methods, Milne's and Adams’ methods, Predictor-Corrector methods.

References:

1. G. Strang, *Introduction to Linear Algebra*, Wellesley MA: Cambridge Press, 2016.
2. D M Simmons, *Nonlinear Programming for Operations Research*, Prentice Hall, 1975.
3. G Mohan and Kusum Deep, *Optimization Techniques*, New age International Publishers,2009.
4. Jain M.K., Iyengar S.R.K., Jain R.K., *Numerical methods for Scientific and Engineering Computation*, 8th edition, New Age International (P) Ltd, 2022

EE6501E HIGH VOLTAGE ENGINEERING

Pre-requisites**: NIL**

Total Lecture Sessions: 39

L	T	P	O	C
3	0	0	6	3

Course outcomes:

CO1: Describe and analyze various generation and measurement techniques for high Voltages and Currents.
CO2: Understand the breakdown phenomenon in different insulating mediums.
CO3: Identify the over voltages in power systems and outline the principles of insulation coordination for various parts of power system.
CO4: Understand the construction and applications of high voltage cables.

Generation of High Voltages

Requirements of HV generation in laboratory, Generation of High voltages, AC voltages: Testing transformers-Series resonance circuits; DC voltages: symmetric and asymmetric voltage doubler circuits-electrostatic machines. Generation of Impulse voltages and currents: single stage and multistage circuits-wave shaping- modelling of impulse generator circuit-triggering and control of impulse generators. Generation of switching surge voltage and currents. Simulation of AC, DC and Impulse Voltage/Current generation circuits.

Measurement and Testing

Measurement of high voltages: Sphere gaps, factors affecting sphere gap measurements, correction factors. Measurement of high AC voltage: Capacitance voltage dividers, Chubb-Fortescue method, CVT, electrostatic voltmeters. Measurement of high DC voltage: Resistive voltage dividers, Generating voltmeter. Measurement of impulse voltage: Capacitance divider, Impedance matching. Measurement of transient currents: Resistive shunt, Magnetic coupling, Hall Effect current transducers, Integrating and differentiating type Rogowski coils. Digital techniques in HV measurements, DSO.

Insulation materials and Breakdown

Introduction to solid, liquid and gaseous insulators used in power equipment. Classifications of insulation based on temperature withstand limits, dielectric losses, ageing of insulation materials (paper–press board) and remaining life analysis. Applications of nanofilled materials for outdoor and indoor insulation. Introduction to solid, liquid and gaseous dielectrics. Breakdown in gas and gas mixtures-breakdown in uniform and non uniform fields- Paschen’s law-Townsends criterion-streamer mechanism-corona discharge-breakdown in electro negative gases. Breakdown in liquid dielectrics-suspended particle mechanism. Breakdown in solid dielectrics - intrinsic, streamer and thermal breakdown.

High voltage cables

Classification of High Voltage Underground cables, insulation materials for cables, general construction of a single core UG cable, 3 core,3 1/2 core and 4 core cables. Essential properties required for insulating material of Underground cables. Methods of laying Underground cables. Faults in Underground cable. Testing of cables

References:

1. Kuffel and Zaengl , *High Voltage Engineering Fundamentals*, 2nd ed., Newness, 2002
2. M. S. Naidu, V. Kamaraju, *High Voltage Engineering*, 3rd ed., McGraw-Hill,1995.
3. M. Khalifa, *High Voltage Engineering*: Theory and Practice, Dekker, 1990.
4. H. M. Ryan, *High Voltage Engineering and Testing*, IEE 2001.
5. Kuffel and Abdullah.M, *High Voltage Engineering*, Pergamon press,1978
6. Wadhwa C L, *High Voltage Engineering*, New Age International, New Delhi,1994
7. Relevant IS standards and IEC standards

EE6502E POWER SYSTEM TRANSIENTS

Pre-requisites**: NIL**

L	T	P	O	C
3	**0**	**0**	**6**	**3**

Total Lecture Sessions: 39

Course outcomes:
CO1: Analyse the source and characteristics of lightning, switching, and temporary overvoltages and solve them.
CO2: Analyse the effects of travelling wave propagation on transmission lines.
CO3: Design various protective devices and insulation level.
CO4: Model the power system components for digital computation and solve.

Analysis and modelling of electromagnetic transients in power system
Fundamental circuit analysis of electrical transients -The Laplace Transform method of solving- simple Switching transients –Damping circuits -Abnormal switching transients -Three-phase circuits and transients. Computation of power system transients -Principle of digital computation – Matrix method of solution- Modal analysis- Z transform- Modelling for computation of electromagnetic transients-wavelet technique for determining fault in transformer.

Temporary, Lightning and Switching and overvoltages
Temporary overvoltages: line dropping, load rejection, over voltages induced by fault, Ferranti effect, Ferromagnetic resonance. Switching overvoltages: Energizing transients - closing and re-closing of lines –Switching of cables and capacitor banks, Short line or kilometric fault, Switching HVDC lines.Lightning: Physical phenomena of lightning – Interaction between lightning and power system –Influence of tower footing resistance and earth Resistance- indirect lightning- protection by ground wires.

Travelling waves on transmission line
Circuits with distributed Parameters – Wave Equation –Reflection, Refraction, Behaviour of Travelling waves at the line terminations – Lattice Diagrams Attenuation and Distortion – Multi-conductor system and Velocity wave- Behaviour of transformer windings for surges- Protection of tapping winding of transformer under transmission line fault due to resonance.

Insulation coordination
Basics of Insulation Coordination • Definitions, principle of insulation coordination, Volt-time curves- Rated withstand voltage levels and clearances, relevant standard. Insulation Coordination as applied to Electrical Installation • Over-voltage protective devices, breakdown consequences, reduction of risks and levels of over-voltage, installation of surge arrestor.

References:
1. Allan Greenwood, *Electrical Transients in Power System*, Wiley & Sons Inc. New York, 2010.
2. Juan A. Matinez-velasco, *Power system Transients- Parameter determination*, CRC press, 2010
3. Philip C. Magnusson, Gerald C. Alexander, Vijai K Tripathi, Andreas Weisshaar, *Transmission lines and wave propagation*, CRC press, 2001.
4. Arieh L. Shenkman, *Transient analysis of Electric power circuits Handbook*, Springer, 2005.

EE6202E POWER CONVERTERS FOR POWER SYSTEM APPLICATIONS

Pre-requisites: **NIL**

Total Lecture Sessions: 39

L	T	P	O	C
3	0	0	6	3

Course Outcomes:

CO1: Understand various VSC Topologies used in various Power System applications of Power Electronic Converters
CO2: Appraise the operation and performance of Two-Level Single phase and Three phase VSCs under various modulation schemes.
CO3: Describe the operation of various multi pulse VSCs, three-level NPC VSCs and Cascaded H Bridge VSCs that are routinely employed in Power System Applications.
CO4: Develop the capability to model VSC based systems in *αβ- frame* and *dq-frame* for designing control systems for them.
CO5: Understand different operational and design aspects of controllers for controlling a grid-connected VSC System in *αβ-frame* and *dq-frame* for meeting different control objectives.

Introduction
Power Electronic Converters & Converter Systems : PE Switches – Switch Classification, Switch Characteristics, Classification of Converters – based on commutation process, based on terminal voltage & waveforms, Voltage-Sourced Converters (VSC) – Basic configurations.

Brief Survey of applications of VSCs in Power Systems : STATCOM, DSTATCOM, SSSC, DVR, PQC, UPFC, Active Filters, VSC-based HVDC, Renewable Energy Grid Interface etc., Self-sustained DC Bus versus Active DC Bus in Power System Applications of VSC, Two Basic Strategies for Control of AC Side and DC Side in VSC-Based Power System Applications – Synchronous Link Power Control Principles, Current Regulation in VSCs.

Advanced VSC Configurations : Multimodule VSC, Multipulse VSC, Multilevel VSC, Modular Multilevel VSC *(Ref.1 - Chapter 1)*

Two-Level VSC Modulation Schemes
Single Phase Two-Level VSC : Half-bridge and Full-bridge Single Phase VSC with square wave switching, Harmonic performance, Sinusoidal Pulse Width Modulation (SPWM) for Single Phase half-bridge and full-bridge VSC, Bipolar versus Unipolar SPWM, Harmonics and filtering, Leakage current issue in SPWM Single Phase Inverters fed from Solar Panels, The H5 Inverter for Photovoltaic application *(Ref.5 – Chapter 8, Ref.6 – Chapter 6, Ref.3 – Chapter 2)*

Three Phase Two-Level VSC : 180^0 and 120^0 square wave operation of basic 6-pulse three-phase Inverter - Analysis of waveforms for 180^0 mode with R-Load and RL-Load, Programmed Harmonic Elimination (PHE) for 2-Level three-phase VSC – Implementation of PHE, SPWM for 2-Level three-phase VSC – harmonics; choice of carrier frequency; DC Voltage utilisation; third harmonic injection ; filtering requirements, *(Ref.5 – Chapter 8, Ref.6 – Chapter 6, Ref.2 – Chapter 6, Ref.4 – Chapter 3)*

Space Vector Modulation (SVM) : Motivation for SVM for Three-phase Two-Level VSC, Switching States, Space Vectors, Dwell Time calculation, Modulation Index, Switching Sequence, Spectrum Analysis, Even Harmonic Elimination, Discontinuous SVM *(Ref.2 – Chapter 6)*

Introduction to Current Regulated Two-Level VSC: Application of Current-regulated VSCs in Power Systems – Grid side current regulation in a grid-connected single-phase two-level PWM inverter by hysteresis control – Hysteresis current control in grid-connected three-phase two-level PWM Inverter – Disadvantages of hysteresis current control *(Ref.5 – Chapter 8)*

Advanced VSC Configurations
Multipulse VSCs : Harmonics in 6-pulse VSC, 12-pulse VSC arrangement and magnetic involved, harmonic performance of 12-pulse VSC, 24-pulse VSC arrangement and magnetic involved, harmonic performance of 24-pulse VSC, 48-pulse VSC arrangement and magnetic involved, harmonic performance of 48-pulse VSC, Combining PHE and Multipulsing – motivation, implementation aspects. *(Ref.4 – Chapter 3)*

Diode Clamped Multilevel Inverters : Three Level Single Phase Half Bridge Neutral Point Clamped (NPC) VSC, PWM Scheme for Half Bridge NPC - Harmonic performance, Three Level NPC Three Phase VSC with impressed DC Voltages, NPC VSC with Capacitive DC Side Voltage Divider – Partial DC Side Voltage drift; DC Side Voltage Equalisation; DC Side Currents *(Ref.1 – Chapter 6, Ref.4- Chapter 3, Ref.2 – Chapter 8)*
Space Vector Modulation for NPC VSC *(**Self study** by using Ref.2 – Chapter 8 Sections 8.3 & 8.4)*

Cascaded H Bridge Inverters : CHB Inverter with equal DC voltages, CHB Inverter with unequal DC voltages, Carrier based PWM Schemes – Phase shifted Multicarrier Modulation; Level shifted Multicarrier Modulation; comparison, Staircase Modulation.*(Ref.2 – Chapter 7)*

Modelling & Control of Grid-Connected VSC

Half-bridge PWM VSC Modelling & Control : Switched Model, Averaged Model, Non-ideal Converter, Averaged Model for Non-ideal Converter, AC Side Control model of Half-bridge converter, Control of Half-bridge converter, Feedforward compensation and its impact, Sinusoidal Command Following *(Ref.1 – Chapters 2&3)*

Space Phasors & Two dimensional Frames : Space Phasor – definition; changing amplitude and phase of a three-phase signal; generating a controllable amplitude controllable frequency three-phase signal, *αβ*-frame – *αβ* representation of a space phasor; realization of signal generators and signal conditioners in *αβ* frame; power in *αβ*-frame; control in *αβ*-frame; representation of systems in *αβ*-frame, *dq*-frame – *dq* representation of a space phasor; realization of signal generators and signal conditioners in *dq* frame; power in *dq*-frame; control in *dq*-frame; representation of systems in *dq*-frame, Averaged Model of a two-level VSC, Model of a two-level VSC in *αβ*-frame, Model of a two-level VSC in *dq*-frame *(Ref.1 – Chapters 4&5)*

Control of Grid-Imposed Frequency VSC in αβ-frame : Structure of grid-imposed frequency VSC System, Real/Reactive Power Control – Current-mode versus Voltage-mode control; Model of Real/Reactive Power Controller *αβ*-frame ; Current-mode Control Real/Reactive Power in *αβ*-frame; Selection of DC Bus Voltage Level, Controlled DC Voltage Power Port – Model of Controlled DC Voltage Power Port in *αβ*-frame; DC Bus Voltage Control in *αβ*-frame. *(Ref.1 – Chapter 7)*

Control of Grid-Imposed Frequency VSC in dq-frame : Dynamic Model of Real/Reactive Power Controller *dq*-frame ; PLL and Compensator for PLL; Current-mode Control Real/Reactive Power in *dq*-frame; Selection of DC Bus Voltage Level; AC Side equivalent circuit, Controlled DC Voltage Power Port – Model of Controlled DC Voltage Power Port in *dq*-frame; DC Bus Voltage Control in *dq*-frame. *(Ref.1 – Chapter 8)*

References:

1. Amirnaser Yazdani & Reza Iravani, *Voltage-Sourced Converters in Power Systems,* IEEE Press, John Wiley & Sons, 2010
2. ,Bin Wu, *High Power Converters and AC Drives,* IEEE Press, John Wiley & Sons, 2006
3. Remus Teodorescu, Marco Liserre & Pedro Roderiguez, *Grid Converters for Photovoltaic and Wind Power Systems*, IEEE Press, John Wiley & Sons, 2011
4. ,Narain G. Hingorani & Laszlo Gyugyi, *Understanding FACTS*, IEEE Press, 2000.
5. Ned Mohan, William P. Robbins & Tom M. Undeland , *Power Electronics,* John Wiley & Sons.
6. Muhammad H. Rashid, *Power Electronics* , Third Edition, Pearson Education, 2004

EE6591E HIGH VOLTAGE LABORATORY

Pre-requisites**: NIL**

L	T	P	O	C
0	0	2	0	1

Total Practical Sessions: 26

Course Outcomes:

CO1: Use laboratory techniques, tools, and practices of high voltage engineering.

CO2: Design and implement high voltage insulation systems and electric field analysis.

CO3: Report concisely the results of the work in the laboratory accurately in appropriate detail.

CO4: Work in a team and communicate effectively to perform the design and implementation of control schemes for various processes.

List of Experiments:

1. AC, DC and impulse breakdown test of solid insulation
2. Oil breakdown test using oil test kit
3. Capacitance and tanʒ measurement of insulator.
4. Dielectric characteristics of solid insulating material using impedance analyser
5. Measurement of insulation resistance of cable
6. Mapping of electric field lines between two charges using MATLAB
7. Simulation of dc/impulse voltage generation circuits using PSPICE/PSCAD.
8. Travelling wave characteristics with different line terminations using PSCAD.
9. Plotting φ-q-n pattern for corona discharge using partial discharge detector
10. Preparation of epoxy nanocomposite plotting the electrical field distribution in an insulating material using COMSOL (with and without void).
11. Field distribution between plates of a parallel plate capacitor using ANSYS and COMSOL using Finite Element Method.

References:

1. Relevant IS and IEC standards.
2. Kuffel and Zaengl. 'High Voltage Engineering', Newnes, 2000.

EE6511E EHV POWER TRANSMISSION

Pre-requisites**: NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO1: Analyse the need of EHV and UHV systems.
CO2: Estimate the electric field from EHV lines.
CO3: Become familiar with the different types of substation earthing schemes
CO4: Understand the fundamentals of a GIS and GIL

Electrical power transmission at high voltages
Overview of Electrical power transmission at high voltages. Overhead transmission lines: Bundled conductors, Resistance, Inductance and capacitance calculations of EHV line and multiconductor configurations-sequence inductance and capacitance-line parameters for modes of propagation- Temperature rise of conductors and current carrying capacity.

Surface voltage gradient and its interference issues
Computation of surface voltage gradient on conductors, Corona: Power loss due to corona, Radio noise and Audible noise and their measurement as well as computation. Electric Field under transmission lines and its computation Effect of ES fields of humans, Animals and plants.

Substation grounding and Shielding
Functional Requirements of Earthing System, Equipment Earthing, Neutral Point Earthing, Substation Earthing System, Dimensioning of Earth Conductors, Step Potential and Touch Potential, Earth Mat, Resistance of Earthing System, Values of Soil Resistivity, Fencing, Procedure of Laying Earthing ,Shielding by wires and masts.

Gas Insulated Substation
Gas Insulated Substation: Evolution of GIS, Basics of GIS technology, Key design features, SF6 volume reduction, Reliability of GIS, Design tests, Gas tightness and monitoring, Global status of GIS. Gas Insulated Transmission Line: Why GIL, Historical development of GIL, Applications of GIL, Basic units of GIL, Basic insulation level and current carrying capacity of GIL, Gas mixture as insulation, Installation of GIL, Comparison of GIL with cables and overhead lines, sustainability aspect of various gases
used

References
1. Hermann Koch, *Gas Insulated Substations*, Wiley, 2014.
2. R.D. Begamudre, *EHV AC transmission engineering*, New age international, 2006.
3. Kimbark E.W., *HVDC transmission*, Wiley, 1965.
4. Arrilaga J, *High voltage Direct Current Transmission*, Peter Peregrinus, London, 2007

EE6512E COMPUTATIONAL ELECTROMAGNETICS

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO1: Understand and independently apply standard methods for electromagnetic wave propagation.
CO2: Develop new methods and software for finite difference and finite element differential equation models as well as charge simulation method for frequency domain models.
CO3: Design and estimate the effect of insulation systems on the electric field computation
CO4: Apply the techniques of numerical computation for the modelling of electrical apparatus for the impulse and power frequency voltages.

Basic Field Theory
Review of basic field theory – electric and magnetic fields – Maxwell's equations –Laplace, Poisson and Helmholtz equations – principle of energy conversion – force/torque calculation – Electro thermal formulation.

Numerical Field Computation
Limitations of the conventional design procedure need for the field analysis based design, problem definition and solution by analytical methods-direct integration method – separation of variables method –method of images, solution by numerical methods- Finite Difference Method- 1D and 2D planar and axial symmetry problem, Charge Simulation Method- 3D and 2D axial symmetry problem.

Finite Element Method
Finite element method (FEM) – Differential/ integral functions –Variational method –Energy minimization– Discretisation – Shape functions –Stiffness matrix –3D and 2D planar and axial symmetry problem.

Resistive and capacitive field computation
Resistive and capacitive field computation-Electromagnetic modelling of Insulators-Bushings, Transformers –Rotating machines for power frequency and impulse voltages.

References

1. S. Chakravorti, *'Electric Field Analysis'*, published by CRC Press (Taylor & Francis), USA, 2015, 1st Ed.
2. Karl E. Lonngren, Sava V. Savov, Randy J. Jost, *'Fundamentals of Electromagnetics with MATLAB'*, 2nd edition, SciTech Publishing, Inc., 2007.
3. JaanKiusalaas, *'Numerical Methods in Engineering with Python'*, Cambridge University Press, 2nd edition, 2010.
4. Chen, Cao and Mittra, *'Multiresolution Time Domain Scheme for Electromagnetic* Engineering', Wiley, 1st edition ,2005.
5. A Daniel G. Swanson, Wolfgang J.R. Hoefer, *'Microwave circuit modelling using electromagnetic field simulation*', Artech House, 2003.
6. Sergey N. Makarov, '*Antenna and EM Modelling with Matlab'*, Wiley, 2002.

EE6513E PHYSICS OF DIELECTRICS

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO 1: Analyze different dielectric polarization processes under static and alternating fields.
CO2: Identify the fundamental physical mechanism behind given relaxation/permittivity curves.
CO3: Identify the different mechanisms responsible for conduction in dielectrics.
CO4: Estimate the life of the insulation subjected to electrical and thermal stress by graphical and analytical method.
CO5: Identify partial discharge in dielectric materials by the electrical method of measurement.

Dielectrics and Polarization
Introduction to dielectrics and electrical insulation systems used in high voltage power apparatus: gaseous, vacuum, liquid, solid and composite insulation- Dielectric polarization under static fields-electronic, ionic and dipolar polarizations-behaviour of dielectrics in alternating fields, nonlinearity between D and E, complex dielectric constant, dissipation factor-Effect of temperature on dielectric constant- Electrostriction effect-Ferro and piezo electricity-Requirements of good insulating materials, mechanical strength, thermal properties, breakdown strength-Thermal classification of solid insulating materials-ageing of insulators.

Dielectric Conduction
Space Charge in dielectrics, Conduction Process in solid dielectrics, Ionic Conduction, electronic conduction, charge injection mechanisms in solid dielectrics, Treeing and Tracking, Conduction in dielectric liquids
.
Dielectric Formalism
Dielectric Formalism- Equivalent circuits-intrinsic dielectric strength-mechanisms of electrical and thermal breakdown in solids-Phenomenological theory of ageing, mechanisms of ageing under electrical, thermal and combined stresses- Accelerated ageing tests-Statistical models for Insulation failure, ageing data analysis- Effect of moisture on cellulose aging.

Basics of Partial Discharges
Ageing and failure due to Partial Discharge-Basics of Partial Discharge: Partial Discharge – how and where, Generation of PD pulses, Stress mechanisms activated by PD- Electrical method of PD detection and the relevant standard, Quantities related to PD measurement, External interference and noise elimination.

References:

1. K.C Kao, *Dielectric Phenomena in solids*, Elsevier, 2004.
2. T. S.Ramu and Chakradhar Reddy, *'Reliability and Life estimation of Power Equipment*, New Age International 2009.
3. Bottcher C.J.F., *Theory of Electric Polarisation*, Elsevier Publication, 1962.
4. Kuffel and Zaengl, *High Voltage Engineering*, Newnes,2000.
5. Relevant IS standards and IEC standards

EE6514E CONDITION MONITORING OF POWER EQUIPMENT

Pre-requisites**: NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO 1. Perform different electrical and non-electrical condition monitoring techniques used in transformers
CO 2. Identify the nature and type of faults from the diagnostic test data
CO 3. Understand the various reasons and processes of insulation degradation in transformers, cables and GIS.
CO 4. Design experimental set-up for Partial Discharge measurement.

Condition monitoring of transformer using chemical and non-electrical methods
Traditional Condition Assessment Techniques for Oil-Paper Composite Insulation: Dissolved Gas Analysis (DGA), Furan Analysis, Degree of Polymerization (DP). Moisture in Oil-Paper Composite Insulation: Moisture Distribution, moisture Dynamics, effects of moisture, moisture detection – Crackle Test, Karl Fischer Titration (KFT), equilibrium curves, comparison of equilibrium curves- ABB and Serena's Equations- moisture content in paper-moisture management-oil reclamation.

Condition Monitoring of Transformer using Electrical methods
Dielectric Response Measurement: Polarization Mechanisms in Dielectrics-Dielectric Response in Time-Domain-Polarization and Depolarization Current (PDC) Measurement-test set up and typical results-Recovery Voltage Measurement (RVM) fundamentals ,RVM Spectrum, typical RVM results-Dielectric Response in Frequency-Domain, Frequency Domain Spectroscopy (FDS), FDS equipment and analysis-Assessing the condition of transformers using FDS, PDC and RVM methods, Frequency Response Analysis.

Partial Discharge Measurements and Condition Monitoring of cables
Introduction to partial discharge measurements, electrical method, apparent charge-HFCT and Rogowsky coil-acoustic method- UHF method-Partial Discharges in HVDC. Condition monitoring of cables: Detection and localization of defects in cables by Partial discharge analysis-impedance spectroscopy-Electrical Treeing-Water Treeing-acoustic and UHF sensors and time domain reflectometry (TDR)

Condition Monitoring of Rotating Machines and GIS
Condition monitoring of rotating machines, stator faults and monitoring,rotor faults and monitoring-Condition monitoring of GIS: Analysis of SF6 samples from GIS, Gas density monitoring- online condition monitoring of GIS gas tightness and SF6 leakages, Partial discharge monitoring- Online insight in the condition of the dielectric strength of the GIS installation

References:

1. S.Chakravorti, D.Dey,B.Chatterjee, *Recent Trends in the Condition Monitoring of Transformers,* Springer, 2013.
2. Q. Su, R.E.James, *Condition Assessment of High Voltage Insulation in Power System Equipment*, IET 2008.
3. T.S. Ramu, *Partial Discharge Based Condition Monitoring of High Voltage Equipment*, New age International Publishers,2010.

EE6592E SEMINAR

Pre-requisites**: NIL**

L	T	P	O	C
0	0	2	1	1

Course Outcomes:

CO1: Summarize the objective of a research paper related to the field of high voltage engineering and critically review the effectiveness of the work.

CO2: Identify promising new directions of various cutting-edge technologies.

CO3: Prepare a detailed report describing the reviewed topic.

CO4: Communicate effectively through oral presentations.

Individual students will be asked to choose a topic in any field of high voltage engineering, preferably from outside the M.Tech syllabus and give seminar on the topic for about thirty minutes. The student has to present a critical review of the research paper and its relevant references in the seminar. A committee specialized on different fields of power electronics will assess the presentation of the seminars and award the marks to the students.

EE6593E PROJECT–PHASE I

Pre-requisites**: NIL**

L	T	P	O	C
0	0	3	3	2

Course Outcomes:

CO1: Identify and review research papers for understanding emerging technologies in the field of high voltage engineering.

CO2: Identify a research problem in the areas of control and/or instrumentation systems and its feasible solutions by summarizing the reviewed papers.

CO3: Demonstrate the identified problem and its feasible solutions through basic simulations or experiments.

CO4: Document the identified problem and its feasible solutions through a detailed report and demonstrate through an oral presentation.

Each student has to choose a topic in the field of high voltage engineering, outside the M. Tech syllabus and identify relevant literature. Students have to identify a research problem in the field and study the feasible solutions available in the literature. Basic experiments and/or simulations may be used for this. Students have to submit a detailed report of the work and give an oral presentation before a panel of examiners.

EE7591E PROJECT –Phase II

L	T	P	O	C
0	0	6	3	3

Pre-requisites: **NIL**

Course Outcomes:

CO1: Review literature on any topic in the fields of high voltage engineering and formulate a research problem.

CO2: Apply relevant techniques and tools to arrive at feasible solutions for the problem formulated

CO3: Evaluate the solutions developed through simulations and/or experiments.

CO4: Document the problem formulation and its feasible solutions through a detailed report and demonstrate through an oral presentation.

Each student has to identify and formulate a research problem in the fields of high voltage engineering, develop solutions for it and validate the solutions through experiments and/or simulations. This project shall be a continuation of Project Phase I. Students have to submit a detailed report of the work and give an oral presentation before a panel of examiners.

EE7592E PROJECT –Phase III

Pre-requisites: **NIL**

L	T	P	O	C
0	0	30	15	15

Course Outcomes:

CO1: Identify a research topic in the area of high voltage engineering, conduct literature survey, formulate the problem, and state the objectives.

CO2: Design and implement control techniques and/or instrumentation systems for the selected process/problem.

CO3: Apply new tools and techniques for development of cost effective and environment friendly designs in the areas of control and/or instrumentation systems.

CO4: Document the work through a technical project report, and publishing in reputed conferences/journals and oral presentations before a panel of examinations.

Project Phase III may or may not be the continuation of Project Phase I and/or Project Phase II. Faculty members propose projects/broad area of work and student will be asked to meet the faculty member who is offering the project of interest for guidance. Student can also select the topic after discussions with guide. Students are encouraged to take up interdisciplinary project too. Students can carry out their projects in R&D organizations/ industries which have facility in the proposed area with an officer from there as the external guide and a faculty from the department as internal guide. Students are required to undertake detailed technical work in the chosen area using one or more of the following: (i) Analytical models (ii) Computer simulations (iii) Hardware implementation. The complete project report is not expected at the end this semester. However, a 30-40 page typed report based on the work done will have to be submitted by the students to the assessing committee.

EE7593E PROJECT –Phase IV

L	T	P	O	C
0	0	30	15	15

Pre-requisites: **NIL**

Course Outcomes:

CO1: Develop comprehensive solutions to the issues identified in previous semester work and meet the requirements as stated in the objectives.

CO2: Demonstrate and validate the developed solutions through simulations and/or experiments.

CO3: Analyze the results critically, interpret the results and justify the achievement of the stated objectives.

CO4: Summarize the results and effectively communicate the research contribution and publish in reputed Journals /Conferences.

EE7593E Project Phase IV may be continuation of EE7592E Project Phase III. Students should complete the work planned in the third semester, attaining all the objectives, and should prepare the project report of the complete work done in the two semesters. They are expected to communicate their research contributions in reputed conferences and/or journals.

EE6521E ADVANCED ELECTRICAL INSULATION SYSTEMS

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO 1. Identify the insulating material based on the requirements of the electrical system.
CO 2. Design HVAC insulation system for transformers, cables and other high voltage equipment,
CO 3. Design HVDC insulation systems
CO 4. Analyze the various problems associated with space charge accumulation in HVDC insulation.

Insulating materials for high voltage systems
Solid insulating materials-glass, mica, porcelain and ceramics-thermoplastics, cross-linking, thermosetting polymers-epoxy resins-silicon-hydrophobic insulators-composite insulators-Paper and pressboards-Oil impregnation-insulating liquids- mineral oil, vegetable oils, synthetic insulating liquids, gaseous insulation-air, Sulphur Hexafluoride-Nano dielectric materials as insulation.

Typical Insulation systems for AC
Cables and Accessories-Paper insulated cables, Plastic-insulated cables, Cable joints and accessories-bushings-potential grading of bushings, capacitive grading- transformer insulation, oil-filled and dry-type transformers, design of oil-pressboard insulation-Circuit breakers, SF6 and vacuum circuit-breakers,-insulation of rotating machines, design of GIL

Typical Insulation systems for DC
Dielectric stresses at DC-HVDC Capacitors-HVDC transformers- AC and DC steady state stresses, HVDC Bushing-HVDC Cables, Paper insulated HVDC Cables, plastic insulated cables, design of HVDC cable insulation, HVDC cable accessories

Space Charges in HVDC insulation
Accumulation of space charge- space charge trapping,-insulation degradation and space charge, space charge measurement-PEA method, PWP method, surface potential decay.

References:

1. Kuchler, *High Voltage Engineering-Fundamentals,Technology and Application*, Springer,2017.
2. R. Aurora, W. Mosch, *High Voltage and Electrical Insulation Engineering*, Wiley, 2011
3. Du, *Polymer Insulation Applied for HVDC Transmission*, Springer 2020.

Department of Electrical Engineering, National Institute of Technology Calicut

EE6522E HVDC TRANSMISSION

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Analyze the relative merits and demerits of HVAC and HVDC Transmission Systems
CO2: Analyze various types and applications of HVDC Transmission Links and BTB Links
CO3: Develop capability to calculate various operating quantities of a LCC Based HVDC Link under various operating conditions and under various commutation modes.
CO4: Understand various HVDC Link Control Strategies for LCC Based HVDC Links
CO5: Understand the operation, converter control and link control of a two-level PWM VSC based HVDC Link
CO6: Develop a knowledge of the basic operation of MMC Converters and Voltage Balancing Strategies

Introduction

Description of HVDC Transmission Systems – Types of DC Links – Monopolar Link – Bipolar Link – Homopolar Link – Ground return versus Metallic return – HVDC Transmission Link versus HVDC BTB (Back To Back) Link – Types of Converters : Line Commutated Converter – Voltage Source Converters – Description of various VSC topologies used in practice – Description of various components in a LCC based HVDC Link – Description of various components in a VSC based HVDC Link – DC Cables and OH Lines – DC Breakers – Ground Electrodes for Monopolar operation.

Comparison of AC and DC Transmission – Limitations of AC System – Advantages of HVDC Transmission – Disadvantages of HVDC Transmission – Applications of HVDC Links and HVDC BTB Stations with examples of existing installations for various applications.

Historical Developments and Current State of HVDC Systems – Rene Thury System – History of Mercury Arc Valve based systems – Sweeden Gottland HVDC Link – Current state of HVDC Systems in the World – Evolution of HVDC Systems in India – Technical details of all existing HVDC Links and BTBs in India.

Line Commutated Converters for HVDC Applications

LCC without commutation overlap: Three Phase Half Wave Uncontrolled and Controlled Converters without Commutation Overlap - Three Phase Six Pulse Uncontrolled and Controlled Converters without Overlap - 12-Pulse Converter and Output & Input Harmonics -

6-Pulse LCC with commutation overlap: Mode-1, Mode-2 and Mode-3 Commutation Overlap and Voltage Notching in Six-Pulse Converter in Rectifier Operation, Rectifier Capability Curve.

6-Pulse LCC in Inversion mode: Commutation Overlap in Inverter Operation of a Six-Pulse Converter, Inverter Capability Curve, Commutation Failure in Inverter

Capacitor Commutated Converter: Operation and Commutation Margin Improvement in CCC

Reactive Power requirement of LCC HVDC Links and ways of meeting this requirement:

Harmonics & Filtering: Generation of Characteristic and Non-Characteristic Harmonics in the AC Side – Passive Filters for AC Side Filtering – Single tuned Filter , Double tuned filter, Damped filter – DC Side harmonics and filtering.

Control of LCC Based HVDC Link

Link Control: Steady-state equivalent circuits of a LCC HVDC Link – Steady-state relations for Rectifier mode and Inverter mode in terms of firing angle, firing advance angle and extinction angle – Current Margin Control principles – Link DC Voltage Control – Constant Extinction Angle Control – Power Reversal in the Link –

Phase Control Unit: Individual Phase Control (IPC) versus Equidistant Pulse Contro (EPC) – Avoiding generation of Non-characteristic harmonics – Line synchronisation – Transvector type PLL for Line Synchronisation – Supplementary control signals for α-modulation to reduce non-characteristic harmonics.

VSC Based HVDC Links and their Control

VSC HVDC Link: Voltage Source Converters – Advantages of VSC HVDC System – Disadvantages of VSC HVDC System – Comparison with LCC Based HVDC System – Overhead and Subsea/Underground VSC HVDC Transmission – DC Cable types with VSC HVDC – Monopolar and Bipolar VSC HVDC Topologies – VSC Converter Topologies : Two-Level PWM Converter , Modular Multilevel Converters (MMC) – VSC HVDC System Components

Two-Level SPWM VSC HVDC Converter Control: Two-Level SPWM VSC Operation – Converter Control objectives : DC Side Voltage Control, DC Side Power Control, AC Side PCC Voltage Control, AC Side Reactive Power Control – Link Control in *dq* domain – Model of AC Side in *dq* domain – Model of DC Side in *dq* domain – Decoupling feedback in *dq* domain - Control block diagrams in *dq* domain for P_{dc} control, V_{dc} Control and PCC Voltage Control

Two-Level SPWM VSC HVDC Link Control: Control strategies for two-terminal VSC HVDC Links : Master-Slave Control Scheme – Voltage Margin Control Scheme – Handling of abnormal conditions in Voltage Margin Control – Voltage Margin Control Scheme using Dynamic Saturation Limits

Introduction to Modular Multilevel Converter Based VSC: Half-Bridge MMC Converter Operation – Capacitor Voltage Balancing Problem – Capacitor Voltage Balancing by Sequence Rotation – Capacitor Voltage Balancing by Min/Max Criterion – Nearest Level Modulation (NLM) for Sinusoidal Output in MMC – Techniques to implement NLM – Voltage Balancing by Capacitor Voltage Sorting.

Introduction to MTDC Systems

MTDC Systems – Potential Applications of MTDC Systems – Types of MTDC Systems – The ±800kV 6000MW NER-Agra MTDC Project in India – A Voltage Margin Control Strategy for NER-Agra MTDC System – Proportional Power Sharing in Inverters in a MTDC System – Two-Stage Voltage Margin Control at Inverters – Implementation of Two-Stage Voltage Margin Control – Priority Power Sharing and its implementation – VSC Based MTDC Systems for Integration of Off-shore Wind farms with On-shore Grids – Power despatch schemes for such a system: Proportional sharing, Priority sharing, Fixed sharing – Voltage Margin Control strategies for implementing various power sharing schemes in an example wind farm integration MTDC.

References:

1. Dragan Jovcic and Khaled Ahmed, *'High Voltage Direct Current Transmission – Converters, Systems and DC Grids'* , John Wiley & Sons, 2015 *(Recommended as primary reference book)*
2. Edward Wilson Kimbark, *'Direct Current Transmission Volume I',* John Wiley & Sons, 1971
3. Vijay K. Sood et.al., *'HVDC Transmission – Power Conversion Applications in Power Systems'* , IEEE Press, John Wiley & Sons, 2009
4. K R Padiyar, *'HVDC Power Transmission Systems',* New Age International Publishers,3rd Edition, 2015
5. Ismunandar, C., Meer, van der, A. A., Gibescu, M., Hendriks, R. L., & Kling, W. L. (2010). Control of multi-terminal VSC-HVDC for wind power integration using the Voltage-Margin method. In *Proceedings of the 9th International Workshop on Large-Scale Integration of Wind Power Into Power Systems As Well As On Transmission Networks For Offshore Wind Power Plants, 18-19 October 2010, Quebec, Canada* (pp. 1-8). Hydro Quebec. *(for Module 5)*

EE6523E HIGH VOLTAGE TESTING TECHNIQUES

Pre-requisites**: NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO 1: Analyze the performanceof transformers by various type tests and routine tests .
CO 2: Analyze test results from the viewpoint of insulation integrity and risk of failure
CO 3: Designing test procedure during field tests of HV equipment.
CO 4: Design Grounding systems for HV installations

Introduction to High Voltage testing
Objectives of high voltage testing - classification of testing methods- self restoration and non-self restoration systems-indoor and outdoor insulations-routine tests and type tests-review of breakdown theory in dielectrics-Probability distribution functions in breakdown-'Multiple level method-Up and Down' method for determining the 50% disruptive discharge voltage - multi stress ageing - life data analysis.

Testing with High DC Voltages
Advantages and Disadvantages of DC testing -IR testing (Transformers, cables and other HV equipment)-PI testing-DC high potential tests-Testing of capacitors-Interpretation of test data.

Testing with High AC Voltages
Testing of insulators-Dry flashover test-correction for ambient temperature and humidity- Wet flashover test-Artificial pollution tests-Power Factor and Dissipation Factor tests-Power factor tests of transformer, bushings, cables and circuit breakers -interpretation of PF test data-Dielectric breakdown test of oil-PD tests-Specific AC tests for Cables-AC High potential test, VLF tests-Testing of switchgear and circuit breakers-AC tests on surge arrestors

Testing with Impulse Voltage/Current
Impulse Flashover tests-Testing of power transformers – testing methodology - recording of oscillograms - interpretation of test results-Impulse current testing of surge arrestors

Grounding and High Voltage safety practices
Electrical Power Apparatus Grounding & Ground resistance measurements-Selection of grounding method-selection of grounding system, ground resistance values, ground resistance measurements-Electrical switching practices and precautions

References:

1. Paul Gill ,*Electrical Power Equipment Maintenance and Testing* , Marcel Dekker Inc, New York, 1982
2. H. M. Ryan and Petr Pregrinusm, *High Voltage Engineering & Testing* ,IET Publications, 3rd Edition, 2013.
3. Mazen Abdul Salam, *High Voltage engineering: Theory and Practice,* Taylor and Francis, 2nd Edition, 2018

EE6524E HIGH VOLTAGE POWER TRANSFORMERS AND CIRCUIT BREAKERS

Pre-requisites**: Nil**

L	T	P	O	C
3	**0**	**0**	**6**	**3**

Total Lecture Sessions: 39

Course Outcomes:

CO1: Create knowledge about the build-up, modelling, and protection system of power transformers.
CO2: Describe power transformer features as loss phenomena, stray fields, impedance characteristics, insulation design etc.
CO3: Design the condition of the transformer by performing various tests.
CO4: Define knowledge about the different types of circuit breakers for protecting power system equipment.
CO5: Understand the testing of circuit breakers

Introduction to Power transformers

HV power transformers, principle and equivalent circuit, Magnetic characteristics-Excitation characteristics, over excitation performance, Inrush current. Impedance characteristics, Reactance calculation, Losses in transformers-eddy current loss, hysteresis loss and stray loss in power transformers.

Electrical circuit analysis of Transformers

Short circuit forces, failure mode due to radial and axial forces, Short circuit test, Effect of inrush current. Sweep frequency response of power transformer. Surge phenomenon-initial voltage distribution-ground capacitance calculations-capacitance of winding, inductance calculation- standing and traveling wave theory, Method for analysis of impulse distribution.

Testing of Transformers

Impulse testing, diagnostics and condition monitoring of transformers, Conventional tests, Dissolved Gas Analysis, Partial Discharge Diagnostics, Degree of Polymerization and Furan Analysis, Time domain and frequency domain dielectric response method. Impulse testing of power transformer for winding of low inductance

HV switching devices

Introduction to HV switching devices, electric arcs, short circuit currents, TRV, CB types, air, oil and SF 6 CB, short circuit testing.

References:

1. S.V. Kulkarni, S.A. Khaparde, *"Transformer Engineering: Design, Technology, and Diagnostics",* Second Edition, CRC Press Taylor and Francis Group, 2012.
2. Sivaji Chakravorti, DebangshuDey, Biswendu Chatterjee, *"Recent trends in the condition monitoring of transformers, Theory, Implementation and Analysis",* Springer Verlag London 2013.
3. Bernard Hochart, Power Transformer Handbook, Butterworth, 1987.
4. The J & P Transformer Book, 12th edition, M J Heathcote, Newnes, 1998.
5. Transformers, Bharat Heavy Electricals Limited, Tata McGraw Hill, 2001.
6. Blume, L.F., and BoyaJian, *Transformer Engineering*, John Wiley and Sons, 1951.
7. Garzon, R.D., *HV Circuit Breakers – Design and Applications*, Marcel and Dekker NY, 1996.
8. Flurscheim, C.H., *Power Circuit Breaker: Theory and Design*, Peter Peregrinus Ltd., 1975.
9. Ryan, H.M., and Jones G.R., *SF6 Circuit Breaker*, Peter Peregrinus Ltd., 1989.

E6525E ELECTROMAGNETIC INTERFERENCE AND COMPATIBILITY

Pre-requisites**: NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO1: Define EMI Environment, Coupling principles, Different sources of EMI and Mitigation Techniques.
CO2: Distinguish Measurement Techniques for Conducted Interference and the effect of power supply components on Conducted Emissions.
CO3: Describe the Grounding, Cabling, Shielding, Bonding mechanisms for EMC.
CO4: Describe various EMI filters and the EMI/EMC Standards.

EMI concept
Basic concepts Definition of EMI and EMC with examples, Classification of EMI/EMC - CE, RE, CS, RS, Units of Parameters.

EMI measurements
EMI measurements, basic principles of RE, CE, RS and CS measurements, EMI measuring instruments- Antennas, LISN, Feed through capacitor, current probe, EMC analyzer and detection technique open area site, shielded anechoic chamber, TEM cell. EMI control methods and fixes Shielding, Grounding, Bonding, Filtering, EMI gasket, Isolation transformer, opto isolator.

EMC standard and regulations
EMC standard and regulations National and Intentional standardizing organizations- FCC, CISPR, ANSI,
OD, IEC, CENEEC, FCC CE and RE standards, CISPR, CE and RE Standards, IEC/EN, CS standards, Frequency assignment - spectrum conversation.

EMI issues in high voltage engineering
EMI issues in high voltage engineering, Sources of EMI, EMI coupling modes - CM and DM, ESD Phenomena and effects, Transient phenomena and suppression, High frequency EMI sources, High Power EMI sources, EMC of High Voltage Equipments.

References:
1. Keiser, *‘Principles of Electromagnetic’ ,* Artech House , 3rd Edition ,1994
2. Donwhite Consultant Incorporate, *‘Handbook of EMI / EMC’ ,*Vol I ,1985
3. Clayton R. Paul, *‘Introduction to Electromagnetic compatibility’*, John Wiley & Sons,1992

EE6526E PULSED POWER ENGINEERING

Pre-requisites**: NIL**

L	T	P	O	C
3	**0**	**0**	**6**	**3**

Total Lecture Sessions: 39

Course outcomes:
CO1: Analyse various circuits for generating pulsed power signals
CO2: Design suitable insulation systems for pulsed power sources
CO3: Design pulsed power circuits for various application

Introduction to pulsed power systems
Introduction to pulsed power systems (examples and applications), Energy storage (capacitive, inductive, kinetic, chemical), Voltage multiplier circuits (Marx generators, Blumlein generators, and spiral generators, etc.), Transmission lines and pulse forming networks, Pulse transformers, Pulse modulators Magnetic pulse compression, FCG, Explosively driven FCGs, Homopolar generators. Power conditioning systems.

Insulation requirements for pulsed power systems
Insulation requirements for pulsed power systems - gaseous, liquid, solid and magnetic insulation and their behaviour under pulsed voltages. Measurement techniques of pulsed power parameters, safety of circuits, Pulsed power materials, High speed diagnostics (voltage, current, plasma, magnetic field, etc.)

High power switches
High power switches: spark gaps, low pressure switches, liquid and solid state switches, solid stage switches, magnetic switches, opening switches, Electromagnetic field analysis of pulsed power circuits

Applications
High Power Microwaves, mass drivers, pollution control, food processing, particle accelerators, lasers, manufacturing, Nuclear electromagnetic fields, High voltage hazards and accidents.

References :

1. Hansjoachim Bluhm ,*Pulsed Power Systems*, Springer, 2006.
2. Pai and Zhang, *Introduction to High Power Pulse Technology,* World Scientific Publishing, 1995.
3. Martin et al., *J. C. Martin on Pulsed Power,* Plenum Press, 1996.
4. G.A. Mesyats, *Pulsed Power*, Kluwer Academics/Plenum 2005.

ZZ6001E RESEARCH METHODOLOGY

Pre-requisites**: NIL**

L	T	P	O	C
2	0	0	4	2

Total Lecture sessions: 26

Course Outcomes:

CO1: Explain the basic concepts and types of research

CO2: Develop research design and techniques of data analysis

CO3: Develop critical thinking skills and enhanced writing skills

CO4: Apply qualitative and quantitative methods for data analysis and presentation

CO5: Implement healthy research practice, research ethics, and responsible scientific conduct

Exploring Research Inquisitiveness

Philosophy of Scientific Research, Role of Research Guide, Planning the Research Project, Research Process, Research Problem Identification and Formulation, Variables, Framework development, Research Design, Types of Research, Sampling, Measurement, Validity and Reliability, Survey, Designing Experiments, Research Proposal, Research Communication, Research Publication, Structuring a research paper, structuring thesis/ dissertation,

Research Plan and Path

Developing a Research Plan: Reviewing the literature- Referencing – Information sources – Information retrieval – Role of libraries in information retrieval – Tools for identifying literatures – Reading and understanding a research article – Critical thinking and logical reasoning; Framing the research hypotheses, Converting research Question into a Model; Data collection- Types of data-Dataset creation- Primary and Secondary data- Scales of measurement-Sources and collection of data- Processing and analysis of data-Understanding Data-statistical analysis, displaying of data-Data visualization-Data interpretation; Research design- Qualitative and Quantitative Research- Designing of experiments- Validation of experiments- Inferential statistics and result interpretation

Scientific Conduct and Ethical Practice

Plagiarism– Ethics of Research- Scientific Misconduct- Forms of Scientific Misconduct. Plagiarism, Unscientific practices in thesis work-Conduct in the workplace and interaction with peers – Intellectual property: IPR and patent registration, copyrights; Current trends – Usage and ethics of AI tools in scientific research.

References:

1. Leedy, P D, *Practical Research: Planning and Design,* USA: Pearson, Twelfth ed., 2018.
2. Krishnaswamy, K. N., Sivakumar, A. I., and Mathirajan, M., *Management Research Methodology*, Pearson Education, 2006.
3. Tony Greenfield and Sue Greener., *Research Methods for Postgraduates*, USA: John Wiley & Sons Ltd., Third ed., 2016.
4. John W. Creswell and J. David Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, USA: Sage Publications, Sixth ed., 2022.

MS6174E TECHNICAL COMMUNICATION AND WRITING

Pre-requisites: **NIL**

L	T	P	O	C
2	1	0	3	2

Total Lecture Sessions: 26

Course Outcomes:

CO1: Apply effective communication strategies for different professional and industry needs.

CO2: Collaborate on various writing projects for academic and technical purposes.

CO3: Combine attributes of critical thinking for improving technical documentation.

CO4: Adapt technical writing styles to different platforms.

Technical Communication

Process(es) and Types of Speaking and Writing for Professional Purposes - Technical Writing: Introduction, Definition, Scope and Characteristics - Audience Analysis - Conciseness and Coherences - Critical Thinking - Accuracy and Reliability - Ethical Consideration in Writing - Presentation Skills - Professional Grooming - Poster Presentations

Grammar, Punctuation and Stylistics

Constituent Structure of Sentences - Functional Roles of Elements in a Sentence - Thematic Structures and Interpretations - Clarity - Verb Tense and Mood - Active and Passive Structures - Reporting Verbs and Reported Tense - Formatting of Technical Documents - Incorporating Visuals Elements - Proofreading

Technical Documentation

Types of Technical Documents: Reports, Proposals, Cover Letters - Manuals and Instructions - Online Documentation - Product Documentation - Collaborative Writing: Tools and Software - Version Control Document Management - Self Editing, Peer Review and Feedback Processes

References:

1. Foley, M., & Hall, D., *Longman advanced learner's grammar, a self-study reference & practice book with answers*. Pearson Education Limited, 2018.
2. Gerson, S. J., & Gerson, S. M., *Technical writing: Process and product*, Pearson, 2009.
3. Kirkwood, H. M. A., & M., M. C. M. I., *Hallidays introduction to functional grammar* (4th ed.), Hodder Education, 2013.
4. Markel, M., *Technical Communication* (10th ed.). Palgrave Macmillan, 2012.
5. Tuhovsky, I., *Communication skills training: A practical guide to improving your social intelligence, presentation, Persuasion and public speaking skills,* Rupa Publications India, 2019.
6. Williams, R., *The Non-designer's Design Boo*k. Peachpit Press, 2014.

IE6001E ENTREPRENEURSHIP DEVELOPMENT

L	T	P	O	C
2	0	0	4	2

Pre-requisites: **NIL**

Total Lecture Sessions: 26

Course Outcomes:

CO1: Describe the various strategies and techniques used in business planning and scaling ventures.

CO2: Apply critical thinking and analytical skills to assess the feasibility and viability of business ideas.

CO3: Evaluate and select appropriate business models, financial strategies, marketing approaches, and operational plans for startup ventures.

CO4: Assess the performance and effectiveness of entrepreneurial strategies and actions through the use of relevant metrics and indicators.

Entrepreneurial Mindset and Opportunity Identification

Introduction to Entrepreneurship Development - Evolution of entrepreneurship, Entrepreneurial mindset, Economic development, Opportunity Recognition and Evaluation - Market gaps - Market potential, Feasibility analysis - Innovation and Creativity in Entrepreneurship - Innovation and entrepreneurship, Creativity techniques, Intellectual property management.

Business Planning and Execution

Business Model Development and Validation - Effective business models, Value proposition testing, Lean startup methodologies - Financial Management and Funding Strategies - Marketing and Sales Strategies - Market analysis, Marketing strategies, Sales techniques - Operations and Resource Management - Operational planning and management, Supply chain and logistics, Stream wise Case studies.

Growth and Scaling Strategies

Growth Strategies and Expansion - Sustainable growth strategies, Market expansion, Franchising and partnerships - Managing Entrepreneurial Risks and Challenges - Risk identification and mitigation, Crisis management, Ethical considerations - Leadership and Team Development - Stream wise Case studies.

References:

1. Kaplan, J. M., Warren, A. C., & Murthy V., *Patterns of entrepreneurship management.* John Wiley & Sons, 2022.
2. Kuratko, D. F., *Entrepreneurship: Theory, Process, and Practic*e. Cengage learning.
3. Barringer, B. R., *Entrepreneurship: Successfully launching new ventures*, Pearson Education India, 2015.
4. Rajiv Shah, Zhijie Gao, Harini Mittal, I*nnovation, Entrepreneurship, and the Economy in the US, China, and India,* Academic Press, 2014.
5. Sundar,K., *Entrepreneurship Developmen*t, 2nd Ed., Vijaya Nichkol Imprints, Chennai, 2022.
6. E. Gordon,Dr. K. Natarajan., *Entrepreneurship Development*, 6th Ed, Himalya Publishers, Delhi, 2017.
7. Debasish Biswas, Chanchal Dey, *Entrepreneurship Development in India*, Taylor & Francis, 2021.