GUJARATTECHNOLOGICALUNIVERSITY

Program Name: Bachelor of Engineering
Level: UG
Branch: Electrical Engineering
Subject Code: BE05009071

Subject Name: High Voltage Engineering

w.e.f. Academic Year:	2024-25
Semester:	5
Category of the Course:	Professional Elective Course - 2

Prerequisite:	Not Applicable
Rationale:	Electrical power transmission is continuously trending towards higher voltages to meet growing energy demands. Under such a scenario, a conceptual understanding of dielectric behavior, insulation coordination, and standardized testing of HV apparatus is a must for every electrical engineer. Furthermore, as the global power sector shifts towards sustainable practices, this subject equips students with knowledge of HV generation, measurement, non-destructive testing, and the latest eco-friendly insulating materials (such as alternatives and natural esters) in compliance with IS/IEEE/IEC standards

Course Outcome:

After Completion of the Course, Student will able to:

No	Course Outcomes
01	Analyze electrostatic fields and field stress control in diverse insulating materials. (Analyzing)
02	Explain the breakdown mechanisms in solid, liquid, and gaseous dielectrics under high voltage stress. (Understanding)
03	Apply appropriate techniques and circuit principles for the generation and measurement of high voltages. (Applying)
04	Evaluate overvoltage phenomena, insulation coordination strategies, and the performance of high voltage apparatus using standard testing procedures. (Evaluating)
05	Compare traditional insulating media with modern, eco-friendly alternatives for high voltage applications. (Understanding)

Teaching and Examination Scheme:

Teaching-Learning Scheme (in Hours per Semester)					Total Credits = TH/30	Assessment Pattern and Marks					Total Marks
						Theory		Tutorial/Practical			
L	T	P	PBL	TH		ESE (E)	PA (M)	PA(I)	PBL (I)	ESE(V)	
45	0	30	15	90	3	70	30	20	30	50	200

Where L = Lecture, T= Tutorial, P= Practical, TW/SL = Term-Work / Self-Learning, TH = Total Hours, ESE = End-Semester Examination, PA = Progressive Assessment

Course Content:

Unit No.	Content	No. of Hours	%of Weightage
1.	Electrostatic fields and field stress control: Electrical field distribution and breakdown strength of insulating materials - fields in homogeneous, isotropic materials - fields in multi-dielectric, isotropic materials. IS 13947	04	9
2.	Electrical breakdown in gases: Gases as insulating media - ionization and decay processes, Townsend first ionization coefficient, photo ionization, ionization by interaction of metastable with atoms, thermal ionization, deionization by recombination, deionization by attachment–negative ion formation, examples - cathode processes – secondary effects, photoelectric emission, electron emission by positive ion and excited atom impact, thermionic emission, field emission, Townsend second ionization coefficient, secondary electron emission by photon impact, examples - transition from non-self-sustained discharges to breakdown, the Townsend mechanism, examples - the streamer or 'kanal' mechanism of spark, examples - the sparking voltage– Paschen's law, penning effect. IS 2071	05	11
3.	Breakdown in liquid and solid dielectrics: Liquid as insulators, breakdown in liquids - electronic breakdown, suspended solid particle mechanism, cavity breakdown, examples - static electrification in power transformers, transformer oil filtration, transformer oil test, alternative liquid insulations like vegetable oils, esters and silicon oils - breakdown in solids, intrinsic breakdown, streamer breakdown, electromechanical breakdown, edge breakdown and treeing, thermal breakdown, erosion breakdown, tracking - breakdown of solid dielectrics in practice, partial discharges in solid insulation. IS 6792, IS 335, IS 1866, IS 12463	07	16
4.	Generation of high voltages: Generation of high direct voltages, half and full wave rectifier circuits, voltage multiplier circuits, Van de Graff generators, electrostatic generators, examples - generation of alternating voltages, testing transformers, cascaded transformers, resonant transformers, examples - impulse voltages, Standard lightning and switching surge and associated	07	16

	parameters and their corrections, design and construction of impulse voltage generator circuits, Marx circuit, operation, examples - impulse current generator. IS 2071 (Part 1 & 2), IS 6209, IEC 60060-1		
5.	Measurement of high voltages: High direct voltage measurement, peak voltage measurements by spark gaps, sphere gaps, reference measuring systems, uniform field gaps, rod gaps, factors affecting sphere gap measurements, examples - electrostatic voltmeters - generating voltmeters and field sensors - the measurement of peak voltages, the Chubb–Fortescue method, high- voltage capacitors for measuring circuits - voltage dividing systems and impulse voltage measurements. Numericals, IS 2071 (Part 2 & 3), IS 1567, IS 3716	06	13
6.	Over voltages, and insulation coordination: The lightning mechanism, energy in lightning, nature of danger - examples - insulation coordination, insulation level, statistical approach to insulation coordination, correlation between insulation and protection levels. IS 3716, IS 2165 (Part 1 & 2), IS 12729	06	13
7.	Non-destructive & High Voltage test techniques: Insulation: Measurement of d.c. resistivity - dielectric loss and capacitance measurements, the Schering bridge, current comparator bridges, Tan Delta measurement, Partial-discharge (PD) measurements - the basic PD test circuit, High Voltage Testing: Testing of insulators, bushings, cables, circuit breakers, and transformers according to relevant IS/IEEE standards, IS 2071 (Parts 1–4), IS 5561, IS 2099, IS 2026, IS 13947, IS 731	05	11
8.	Modern High Voltage Insulations Introduction; Gaseous Insulators: SF6 Alternatives and Eco-Friendly Gases - Fluoronitriles (e.g., C4F7N or g3 gas), Fluoroketones (e.g., C5F10O or AirPlus), Hydrofluorocarbons (HFCs, e.g., HFC-227ea and HFC-125), CO2/O2 Mixtures and Dry Air; Liquid Insulators: Biodegradable and Natural Esters - Natural Esters, Synthetic Esters; Solid Insulators: Silicone Rubber and Nano-Dielectrics. IS 12463, IS 335, BIS CED 47 (Electrotechnical)	05	11
	Total	**45**	**100**

Note:

1. 10%-20% weightage should be given to the Examples and Short/Multiple choice questions.
2. The institutes which do not have proper High Voltage Laboratory are advised to visit nearby High Voltage laboratory

Suggested Specification Table with Marks (Theory):

Distribution of Theory Marks					
R Level	**U Level**	**A Level**	**N Level**	**E Level**	**C Level**
20	20	20	20	20	0

Where, R: Remember; U: Understanding; A: Application, N: Analyze and E: Evaluate C: Create (as per Revised Bloom's Taxonomy)

Note: This specification table shall be treated as a general guideline for students and teachers. The actual distribution of marks in the question paper may vary slightly from above table.

References / Suggested Learning Resources:

Books:

1. Kuffel, E., Zaengl W.S., Kuffel J., "High Voltage Engineering: Fundamentals" Butterworth-Heinmann (A division of Reed Educational & Profession Publishing Limited), 2nd Edition, 2000.
2. Naidu M. S. and Kamaraju V., "High Voltage Engineering", fourth Edition, Tata McGraw- Hill Publishing Company Limited, New Delhi,2009.
3. Rakosh Das Begamudre, "High Voltage Engineering, Problems and Solutions", New Age International Publishers, New Delhi,2010.
4. Dieter Kind, Kurt Feser, "High Voltage Test Techniques", Reed educational and professional publishing ltd. (Indian edition), NewDelhi-2001
5. M. Khalifa, "High Voltage Engineering-Theory and Practice", Marcel Dekker, Inc. New York and Basel,1990.
6. Hugh M. Ryan, "High Voltage Engineering and Testing", 2nd edition, The Institution of Electrical Engineers, London, United Kingdom,2001.
7. Wadhwa C.L., "High Voltage Engineering", third edition, New Age publishers, New Delhi,2010.
8. Haddad, D. Warne, "Advances in High Voltage Engineering", IET Power and Energy, Series 40, 2007.
9. Sivaji Chakravorti, Debangshu Dey, Biswendu Chatterjee, "Recent Trends in the Condition Monitoring of Transformers", Springer, 2013.
10. Alston L L, High Voltage Technology, Oxford University Press, 2008.

Suggested Course Practical List:

1. Testing of conventional transformer oil breakdown voltage according to IS:6792.
2. Determine the breakdown voltage and dielectric strength for different types of solid insulating materials.
3. Comparative evaluation of breakdown voltage between conventional mineral oil and eco-friendly natural/synthetic ester oil.
4. Trace the equipotential lines and electric field through an electrolytic tank.

5. Simulate electrostatic field distribution between different electrode geometries using FEMM software.
6. Generation and visualization of corona discharge in a corona cage.
7. Generation of High A.C./D.C. voltages and measurement using standard sphere gap assembly.
8. Simulation of High D.C. voltage generation circuits (Combined: Voltage Doubler and 3-stage Cockcroft-Walton multiplier).
9. Impulse voltage generation and waveform analysis through Marx generator (Hardware/Simulation).
10. Measurement of capacitance and dielectric loss factor (Tan Delta) using Schering Bridge.
11. Perform Partial Discharge (PD) measurement and calibration for high voltage insulation.
12. A report on a visit to a High Voltage Laboratory / Testing Centre.

Design based Problems (DP)/Open Ended Problem:

1. Design of impulse generator with various combination of wave shaping resistor and capacitor
2. Design of CW type voltage multiplier with various stages
3. Design of tesla coil
4. Design of Generating voltmeter

These problems may be done on paper by hand and/or using some simulation software.

Major Equipment:

1. Multi stage Impulse voltage generator
2. Multi stage Impulse current generator
3. High voltage AC and DC generating source (Min 100kV)
4. Partial Discharge Measurement setup
5. Corona setup
6. Electrostatic generator
7. Cascade transformer
8. Resonant Transformer
9. Two to three sets of sphere gap assembly of various diameters
10. Faraday cage
11. Oil test kit
12. Solid insulation test kit
13. Schering bridge
14. DC resistivity measurement test kit
15. Surface resistance measurement test kit
16. Paschen's law test kit

List of Open-Source Software/learning website:

Open-source software:

1. Finite Element Method Magnetics FEMM
2. LTSpice for circuit simulation,
3. KiCAD for CAD application

Web-based tools for design:http://www.fairchildsemi.com/support/design-tools/power-supply-webdesigner/

1. http://www.ti.com/lsds/ti/analog/webench/overview.page

Circuit Lab:

1. https://www.circuitlab.com/editor/

Open-source Math Tools:

1. http://maxima.sourceforge.net/
2. http://www.sagemath.org/
3. http://www.scilab.org/
4. http://www.gnu.org/software/octave/

Online Experiment Portal

1. http://vlab-ee1.iitkgp.ernet.in

Learning website

1. http://www.electrical-engineering-portal.com/
2. http://nptel.iitm.ac.in/courses.php

Standards

1. "IEEE Standard Techniques for High-Voltage Testing", 6th edition, IEEE Std.4-1978.
2. "High-voltage test techniques, Part 1: General definitions and test requirements", IEC60060-1,1989.
3. "High Voltage Test Techniques, Part 2: Measuring Systems", IEC Publication 60060-2,1994.
4. "High Voltage Test Techniques, Part 3: Measuring Devices", IEC Publication 60060-3,1976.
5. "High Voltage Test Techniques, Part 4: Application Guide for Measuring Devices", 1st ed., IEC Publication 60060-4,1977.
6. Indian Standard specifications for High Voltage test techniques", Bureau of Indian Standard, IS 2071, New Delhi,1991.
7. "IEEE Standard for High Voltage Switchgear (Above 1000 V) Test Techniques - Partial Discharge Measurements" - IEEE Std. C37.301 - 2009.
8. "IEEE guide for the application and interpretation of Frequency Response Analysis for Oil-Immersed Transformers" - IEEE Std. C57.149 - 2012.
9. "Mechanical Condition Assessment of Transformer Windings Using Frequency

Response Analysis (FRA)" - CIGRE report by working group A2.26, April 2008.
10. "Power Transformers - Part 18: Measurement of frequency response" - IEC60076-18, 2012.
11. "Mineral oil-filled electrical equipment in service - Guidance on the interpretation of dissolved and free gases analysis" -IEC 60599 - 2015.
12. "IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers" - C57.104-2019.

SDG Relevance to – High Voltage Engineering

SDG	Title	Contribution of High Voltage Engineering Course
SDG 7	Affordable and Clean Energy	Through efficient insulation systems, reliable high-voltage transmission, and eco-friendly insulating materials
SDG 9	Industry, Innovation and Infrastructure	By enabling advanced high-voltage testing, diagnostics, and improving infrastructure reliability
SDG 11	Sustainable Cities and Communities	Via improved protection against overvoltages and ensuring resilient urban power systems
SDG 12	Responsible Consumption and Production	Through condition monitoring and extending equipment life using non-destructive testing techniques
SDG 13	Climate Action	By promoting alternatives to SF_6 gas and environmentally friendly insulation systems

- **Activities Suggested for Self-Learning:**

Sl. No.	Activity	**Suggested Hours**	**Evaluation Criteria**
1	Industry/Research Laboratory Visit (e.g., High Voltage Testing Lab, Transformer Manufacturing Plant, or Gas Insulated Substation)	Visit = 5h, Report = 5h, Total = 10h	Report with observations of testing setups (e.g., Marx generator, sphere gaps), safety protocols, and actual testing data.
2	Technical Video-based Learning (NPTEL, IEEE, CIGRE – topics like lightning phenomena, streamer mechanism, or PD measurement)	Video = 5h, Report = 5h, Total = 10h	Summary/presentation of learning outcomes and conceptual understanding.
3	Numerical Assignments (Townsend's criterion, Marx generator stage calculations, Chubb-Fortescue method, insulation coordination)	5 × 2h = 10h	Accuracy, methodology, and clarity of solved assignments.

4	**Micro Project:** Simulation/Coding Tasks in FEMM/MATLAB/Scilab (e.g., simulate electrostatic field stress between diverse electrode geometries, Marx generator circuit, or Cockcroft-Walton multiplier)	5 h	Simulation results, field trace plots, code documentation, and correctness.
5	Online Certification Course (minimum 10h) on High Voltage Engineering, Dielectric Materials, or Substation Design (Coursera, edX, NPTEL)	10h	Based on course completion certificate and performance in the course quiz.
6	Complex Problem Solving (e.g., analyzing insulation coordination margins for a 400kV substation, evaluating factors affecting Paschen's Law)	2 × 5h = 10h	Depth of analysis, logical reasoning, and correctness of the solution.
7	Industrial Safety Video Learning (Strict High Voltage lab safety, Faraday cages, proper grounding techniques, EMI shielding)	Video = 5h, Report = 5h, Total = 10h	Safety-focused quiz or detailed report on HV hazard mitigation.
8	Poster/Chart/PPT on topics like 'SF6 Alternatives and Eco-Friendly Gases', 'Lightning Surge Mechanisms', or 'Types of Solid Dielectric Breakdown'	6h	Quality of visuals, technical accuracy, depth of content, and presentation skills.
9	**Mini Project:** Working/Non-working Model (e.g., Tesla Coil, miniature Cockcroft-Walton multiplier, Corona cage model)	Working = 10h	Functionality/demonstration, adherence to safety, and innovation.
10	Industrial Exposure (2–3 days) – Study condition monitoring of transformers (oil breakdown testing) or surge arrester (MOA) maintenance	Visit = 5h, Problem-solving = 5h, Total = 10h	Evaluation of practical observations and proposed solutions for insulation life extension.
11	Group Discussion on emerging trends (e.g., Nano-dielectrics vs. traditional polymers, biodegradable esters vs. mineral oil)	1h each	Depth of knowledge, use of technical terminology, and contribution to the debate.
12	Technical Article/Blog Writing on modern HV topics (e.g., "The Future of G3 Gas in Switchgear" or "Understanding Partial Discharge")	Research = 6h, Writing = 4h, Total = 10h	Originality, clarity, technical depth, and proper use of IEEE/IEC standard references.
13	Annotated Video Explanation of a complex machine/HV concept (e.g., explaining the generation of impulse voltages using a Marx circuit)	10h	Accuracy of the explanation, clarity of voice/graphics, and presentation style.
14	Tech Blog/YouTube Channel Curation – Collect and review top resources on non-	10h	Summary report evaluating the quality and accuracy of the curated content.

	destructive testing (Schering bridge, PD test circuits)		
15	Patent Search & Innovation Gap Analysis (e.g., searching patents for new eco-friendly insulating esters or compact high-voltage DC generators)	10h	Number of patents reviewed, correct identification of technology trends, and novelty of gaps found.
16	Maintenance/Troubleshooting Logbook – Record & resolve lab equipment issues (e.g., calibrating sphere gaps, maintaining oil test kit electrodes)	10h	Completeness, safety adherence, and quality of troubleshooting documentation.

Note:

- All the suggested activities should be related to the subject.
- The number of hours is suggestive. Faculty can sub-divide the number of hours based on the activity. However, total number of hours is fixed.
- Rubrics for the evaluation can be prepared by the faculty.
- All records pertaining to the evaluation and assessment of self-learning activities must be properly maintained and preserved at the institute level. These records should be made available to the university upon request.
- Institutes are encouraged to utilize digital platforms, such as Microsoft Teams, for effective record-keeping and to ensure transparency in the evaluation and assessment of self-learning activities.
- In alignment with Outcome-Based Education (OBE) and NBA accreditation requirements, the subject High Voltage Engineering incorporates;
    - Mini Project – 10 Marks
    - Micro Project and – 5 Marks
- These activities are incorporated as integral Project-Based Learning (PBL) components. These activities are designed to foster experiential learning, encourage innovation, and strengthen problem-solving skills by engaging students in practical applications of High voltage insulation, generation, measurement and Testing. The inclusion of PBL ensures that learners develop higher-order cognitive abilities mapped to Bloom's taxonomy, while simultaneously enhancing teamwork, communication, and research competencies essential for professional engineering practice.

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