

**Department of Electrical and Computer Engineering
University of Waterloo**

**ECE 669 – Dielectric Materials
(Winter 2022)**

Course Outline

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Objectives:

- Understanding of the basics of insulating materials and their applications.
- Understanding of the physics of insulating materials, such as, the conduction and breakdown mechanisms in an effort to understand the ageing of system components like, transformers.
- Studying about electrical insulation systems of power components; transformers, circuit breakers, electric machines (generators and motors), line insulators and underground cables.
- Evaluating the material performance by using various techniques under high voltage and high field conditions.

A detailed course outline is given in the Table below (see pages 2 and 3).

Course Evaluation:

- Assignments¹ — 30%
- Final Exam² — 40%
- Project³ — 30%

1. Questions including numerical examples will be assigned at the end of each major topic. In addition, you will be asked to read and evaluate a few selected research papers.
2. It is an “open” book exam. You can have access to the *Reference Materials* that may be helpful for the final exam; in electronic or in printed format or in both formats.
3. During 6th or 7th week of the term, we will discuss the topics for project work.

References:

1. High Voltage Engineering – Fundamentals, 2nd Edition, E. Kuffel, W. S. Zaengl, and Kuffel, J. Oxford ; Boston; Newnes, 2000.
2. High Voltage Engineering – Theory and Practice, M. Khalifa, Marcel Decker Inc., New York, 1990.
3. Insulators for High Voltages, J. S. T. Looms, IEE Monograph, 1988.
4. ***Selected papers from the field of Dielectric Materials and Electrical Insulation. These papers will be posted on LEARN.***

Course Content

Gaseous Dielectrics	Description	No. of Lectures
Breakdown in uniform electric fields under static fields	Pre-breakdown phenomena, sources of charge carriers, V-I characteristics, Collisional ionization, Townsend's mechanism, first ionization coefficient α , avalanche formation. Ionization by other means; photoionization, and thermal ionization.	4
	Secondary processes; ionization due to electrode processes, positive ion impact, thermionic and field emissions, secondary ionization coefficient γ . Experimental determination of α and γ .	
Breakdown in uniform electric fields under static field, continued	Applicability of Townsend's mechanism, Paschen's law, Penning effects and limitation of Townsend's theory.	
	Streamer Mechanisms: Streamer theories; Streamer growth, cathode directed and anode directed streamers to explain practical breakdown conditions.	
Breakdown in Non-uniform fields and Corona Discharges	Influence of practical factors. Corona discharges: Some useful application of corona discharges, types of corona discharges, corona under static field, positive and negative corona. Corona suppressions, application of corona rings for HV and EHV lines and substation equipment.	
	Impulse or surge breakdown, statistical and formative time lags, breakdown probability, impulse time-volt characteristics.	
Breakdown in Electronegative Gases and HV Circuit Breakers	Electronegativity, sulphur-hexafluoride or SF ₆ gas, its properties Breakdown in SF ₆ , leader inception and propagation, phases of leader breakdown, stem mechanisms, precursor mechanisms. Applications: Air Blast and SF ₆ breakers' operations, Use of SF ₆ as arc quenching medium, and recovery voltages (transients).	
Liquid Dielectrics	Description (Transformer insulation system is covered extensively)	
Breakdown Mechanisms	Role of liquids in power apparatus; Properties of insulating liquids, Classification based on applications, based on materials, mineral oils, synthetic liquids.	2
	Ideal and practical liquids, practical insulating liquids vs laboratory experimental liquids, impurities, breakdown theories, electronic theory, cavitation or bubble theory, effects of particulate matters, and suspended particle theory.	
Conduction Mechanisms	V-I characteristics, low, medium and high field conduction regions, sources of charge carriers, presence of particles and other impurities. Effects of flow and temperature on conduction and breakdown.	
Flow Electrification	Introduction to power transformers – cooling system, self cooling, forced air cooling, and forced oil cooling. Electrification due to forced flow, its effect on breakdown, and transformer failures, Flow electrification models.	
	Mechanism of charge generation, separation, and accumulation. Role of cellulose and polarity effects. Electrostatic charging tendency (ECT), quantification of ECT of insulating liquids, measurement devices, and factors that influence ECT.	

Solid Dielectrics	Description	No. of Lectures
Breakdown and Failure mechanisms	Classification of solid insulating materials based on applications, based on materials used. General information on dielectric strength and conduction of different materials.	3
	Intrinsic breakdown, electromechanical breakdown, streamer breakdown, Thermal equilibrium and breakdown, progressive breakdown, treeing and tracking, chemical degradation.	
Conduction Mechanisms and Electrical Polarization	Dielectric materials, electrical properties, an ideal dielectric, a real dielectric, resistive properties, capacitive properties, dipole moments, energy diagrams, electronic mechanisms, tunneling and hopping, polarization	
	Complex permittivity, variation of permittivity, dielectric loss and loss angle – tangent delta, dispersion, relaxation and resonance. High field conduction, measurement techniques for dielectric properties measurements.	
Internal and Surface Discharges	Internal and Surface Discharges, detection methods, chemical, acoustic, optical and electrical. Three capacitance model, discharge in cavities,	
	Electric field enhancement, some practical examples, cable terminations, stator coils, and bushings. Treeing: electrical trees, and water trees.	
Practical Systems	Description	
Transmission line and station Insulators	Introduction to line and station insulators, ceramic and polymeric insulators, advantages and disadvantages of each type. Stresses on insulation, mechanical, electrical and environmental (chemical).	3
	Polymeric insulation, degradation and diagnostics: Hydrophobicity, insulators performance under polluted conditions, leakage current, dry-band arcing.	
	Performance evaluation; salt-fog chamber experiments, early ageing, onset of dry-band arcing, partial discharge patterns as a diagnostics, harmonics in leakage current, third harmonics as a index.	
	Tracking and Erosion: Composite materials, inorganic fillers, standard test methods to assess composites and coatings, alternative laser techniques, nanocomposites; filler dispersion.	
Machine and Cable Insulation Systems	Medium and high voltage machines; Type-A insulation, and Type-B insulation. Effect of non-sinusoidal waveforms on machine insulation.	
	Repetitive transients, space charge formation, effects on ground wall and enamel insulation, pulse ageing.	
	Introduction, method of suppressing discharges, standard capacitive and resistive stress grading systems, Cable terminations, and stator coils. Problems associated with PWM voltage waveforms and new alternative stress grading methods.	