# Department of Electrical and Computer Engineering
# University of Waterloo

## ECE 6608PD – Dielectrics and Electrical Insulation
### (Spring 2024)
## Course Outline

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### Objectives:

- Understanding the application of various dielectric materials as electrical insulation systems for power system components.
- 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, line insulators, transformers, machines and underground cables.
- Understanding the impacts of renewable energy resources and transport electrification on the grid.
- Evaluating the material performance by using various testing techniques under high voltage and high field conditions.
- Studying about electrical insulation systems of power components like transformers, electric machines (generators and motors), and outdoor insulators.

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

### Course Evaluation:

- Assignments[1] — 30%
- Final Exam[2] — 40%
- Project[3] — 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 6$^{th}$ or 7$^{th}$ week of the term, we will discuss the topics for project work.

### References:

1. Lecture Notes.
2. High Voltage Engineering – Fundamentals, 2$^{nd}$ Edition, E. Kuffel, W. S. Zaengl, and Kuffel, J. Oxford ; Boston; Newnes, 2000.
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, elastic and inelastic collisions, current growth, V-I characteristics, cross-section, mean free path. | **4** |
| | Collisional ionization, Townsend's mechanism, first ionization coefficient $\alpha$, avalanche formation. Ionization by other means; photoionization, and thermal ionization. | |
| | Secondary processes; ionization due to electrode processes, positive ion impact, thermionic and field emissions, secondary ionization coefficient $\gamma$. Experimental determination of $\alpha$ and $\gamma$. | |
| **Breakdown in uniform electric fields under static field, continued** | Deionization Processes: Recombination and attachment coefficients, $\beta$ and $\eta$. Breakdown in Non-uniform fields. | |
| | Applicability of Townsend's mechanism, Paschen's law, Penning effects and limitation of Townsend's theory. | |
| | Streamer Mechanisms: Streamer theories; Meek & Loeb's theory, Raether's theory. Streamer growth, cathode directed and anode directed streamers. | |
| **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 corona, streamer growth, onset, burst and breakdown streamers. Negative corona, streamer growth. | |
| | Transition to spark under static field, spark breakdown, corona discharges in AC, Trichel pulses, polarity effect, positive point or negative point. | |
| | Impulse breakdown, statistical and formative time lags, breakdown probability, impulse time-volt characteristics. Corona ring design and performance. | |
| **Breakdown in Electronegative Gases** | Electronegativity, Sulphur-hexafluoride or $SF_6$ gas, its properties.<br>Breakdown in $SF_6$, leader inception and propagation, phases of leader breakdown, stem and precursor mechanisms. $SF_6$ application in HV circuit breakers. | |
| **Liquid Dielectrics** | **Description**<br>(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 their influence, space charge formation and charge injection, electrohydrodynamics (EHD) motion, instability, liquid motion and convection assisted conduction current. Effect of flow and temperature on conduction and breakdown, applicable to power transformers. | |
| **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. | |