Department of Electrical and Computer Engineering
University of Waterloo
ECE 6609PD – Winter Term 2020

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Calendar Description:

This course is geared towards an audience having varying levels of knowledge about high voltage engineering. It will provide an extensive review of high voltage engineering from fundamentals to advanced levels. The course concentrates on the practical methods that are used by power engineers to assess the high voltage performance and condition of power system apparatus, components and designs used in the transmission and distribution of electrical power. It will be of direct interest to researchers and engineers looking forward to working with renewable energy sources. Alternatively, as the range of HV applications is no longer confined to the power industry, wide ranges of other industries use high voltage and often encounter problems needing solutions that are very diverse. These applications include electrostatic precipitators, medical imaging and treatment technologies, scientific instrumentation, electrospraying, pulse power for metal forming and water treatment, and electric vehicles, ships, and soon airplanes.

In the above context, the technological world today presents many challenges to engineers and scientists in keeping current and taking advantage of the latest developments. So the goal of the course is to introduce state-of-the-art technologies and to discuss future research and development needs of high voltage applications.

The course begins with a general overview of testing requirements, the various methods of generating and measuring high voltages and high currents in the laboratory and in the field, and in accordance with international test standards. Since electrical insulation forms the foundation for all high voltage applications, the course focuses on the techniques to evaluate insulation materials and insulator designs that are exposed to various environmental stresses. New polymeric materials for electrical insulation in outdoor applications that are exposed to various environment conditions are reviewed with a focus on the effects of pollution on electrical insulation materials and on insulation designs.

Renewable energy sources extensively use voltage source converters that generate fast transient voltages and these transients are a new type of stress on electrical insulation that are not always considered in insulation design. In addition, voltage converters are now extensively in use for powering electric automobiles, ships and soon air planes, to precise speed control medium high voltage motors for various industrial processes. The effects of these transient voltage on insulation design require special attention and the course focuses on the modifications to insulation designs that are required for satisfactory life.

The course ends with a discussion of modern trends in insulation materials and designs, condition assessment methodologies, state-of-the-art applications, and future demands.

Lectures:

- Twelve in the course, each 3 hours in duration
- First lecture week of [redacted]

Examination:

- Assignments per lecture (25 % of the final grade)
- Mid-term design project (25 % of the final grade)
- Final exam, proctored, closed book, 2-1/2 hours in length, (50 % of the final grade)

Objectives:

- Learn the methods of generating high voltage for testing and research
- Learn high voltage measurement techniques, errors, and testing safety
- Get familiar with testing methodology and international standards

- Learn field test methods for insulators, bushings, cables, gas insulated substations
- Learn how to improve the insulation strength in contaminated environments
- Understand the material limitations to electrical insulation
- Become familiar with the effects of voltage converter transients on electrical insulation
- Become knowledgeable about modern trends and future direction of high voltage engineering

References:

1. High Voltage Engineering – Fundamentals, 2nd Edition, E. Kuffel, W. S. Zaengl, and Kuffel, Newnes, 2000
2. High Voltage Engineering, 4th Edition, M. S. Naidi and V. Kamaraju, McGraw Hill company, 2009
3. IEEE Std. 4, Standard Techniques for High Voltage Testing
4. Selected archival papers and standards
5. Lecture notes

Prerequisite:

A basic knowledge of circuit analysis, low voltage measurement techniques, and some familiarity with electrical power system components are considered necessary in order to benefit from the course.

Content:

Lecture	Topic	Description
1	**Generation of High Voltages for Testing**	• Types and operation of various test sets including: single ended, cascade, and resonant AC, DC, lightning impulse and switching surge generators • Requirements of high voltage test equipment for various types of tests including: cables, gas insulated bus, power equipment and contamination testing • Grounding, limits of approach, safety considerations
2	**Measurement of High Voltages**	• Sphere gaps, potential dividers for ac, dc, impulse and switching surges • Measurement of very fast rise time pulses • Accuracy and sources of error in measurements • Digital recording
3	**Testing Methods for Self-Restoring and Non-Restoring Insulation**	• Up-and-down method for impulse and switching surge • Atmospheric correction factors • Wet and dry flashover at power frequency • Concept of Withstand • Withstand test methods for cables, SF_6 and equipment
4	**Testing in the Field**	• Cable commissioning tests • Rotating machine DC hi-pot and ramp test methods • Resonant testing of power cables and SF_6 equipment • Power factor and dissipation factor of bushings • Insulators
5	**Materials used for Electrical Insulation**	• Solids - porcelain, glass, polymeric, composite, Kraft paper, transformer board and other solids • Fluids – mineral, silicone and ester oils • Gasses – air, SF_6 and other gases

6	**Measurement and Interpretation of Corona & Partial Discharges**	• Introduction • Measurement circuits • Interpretation of discharge patterns • Diagnosis of origin of discharge
7	**Control of Electric Fields**	• Shaping conductors • Stress grading systems • Effects of transients from voltage converters
8	**Understanding Outdoor Insulators and making them work**	• Porcelain, toughened glass and polymer insulators • Design concepts, materials and manufacturing • Pollution flashover mechanism • Test methods • Performance enhancements
9	**Cables**	• Cable and cable accessories • Failure mechanisms • Cable life issues • Cable testing issues
10	**Insulation Co-ordination**	• Surge arresters • BIL and SS • Insulation co-ordination between lines and stations • Distribution and transmission systems
11	**Voltage Converters in Power Systems**	• Rotating machine insulation • Cable terminations • Transformer insulation problems • Life testing
12	**Modern Trends in Power System Applications**	• Polymer insulation • Wildlife concerns and problem mitigation • SF_6 insulation concerns • High temperature conductors • Mineral oil replacement • Synthesized power waveform problems