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DL: Abstracts of Talks and Tutorials

Talks

Talk 1: Transformer Engineering for Future Power System

Abstract: Power systems are undergoing significant changes these days and some of the major characteristics of future power systems would be deployment of both AC and DC technologies at transmission and distribution levels, significant penetration of renewable and distributed energy sources, widespread application of efficient and green technologies, and effective use of smart and artificial intelligence based solutions. Accordingly, transformers need to be specified, designed, operated, and monitored to enable their cost-effective operation, control and asset-management. Increasing numbers of transformers are being manufactured these days with environment-friendly ester oils. Power electronic converters will be used in applications involving solid-state transformers, static tap changers, and phase-shifting transformers. Low loss magnetic materials will make transformers efficient particularly at the distribution level. Miniaturized sensors are expected to enhance transformer diagnostics capabilities. Three-dimensional field computations will become essential for design and optimization of transformers. The talk will highlight futuristic nanotechnology based applications in transformers at the end.

Talk 2: Applications and Design of Magnetic Devices for High-Frequency Power Electronics Circuits

Abstract: Magnetic components like inductors and transformers are essential parts of power electronic circuits. They are used for galvanic isolation, voltage transformation, filters, etc. The size and overall dimensions of the circuit depend on how efficiently these components are designed and manufactured. Main requirements in designing these components are low losses and high power density with compact dimensions. Selection of core geometry and its magnetic material with desirable saturation magnetic flux density is the most important design step. Hysteresis, eddy and anomalous components make the total magnetic loss. Skin and proximity losses in windings can become critical at high frequencies. To overcome these challenges, relevant electromagnetic concepts including theory of eddy currents need to be properly understood. This talk focuses on such fundamental aspects in addition to design of magnetic circuits and coils for high frequency applications. Finally, steps in design of a high frequency inductor are elaborated.

Talk 3: Transformer System Interactions and Modeling

Abstract: Transformers are important components of power systems which often become vulnerable to transient overvoltages. Steeply increasing voltage transients associated with gas-insulated substations can be detrimental to bushing and windings. Transformers are also affected by many steady-state operating conditions like unbalanced operations, harmonics and ferroresonances. In addition, several unexpected phenomena or failures involving transformers are reported in literature due to their interactions with connected power network. For analyzing these interactions and suitably designing transformers, accurate modeling of magnetic circuits and windings is essential. Frequency-dependent properties of their materials need to be taken into account if required. Depending upon the frequency region of interest, models can be conveniently simplified to reduce computational efforts. In this talk, a few case studies on modeling of transformers for analyzing their different system interactions are presented.

Talk 4: Frequency Response Analysis of Transformers: Basics and Diagnostics

Abstract: Transformer windings may get deformed or displaced due to short-circuits, transport-induced stresses, and aging. Frequency Response Analysis (FRA) is a popular technique for deformation diagnostics of transformers. After explaining the causes and failure mechanisms leading to deformation/ displacement, basics of FRA including description of nature of response in various frequency regions are covered in the talk. Reasons for complex nature of the frequency response are enumerated using simple circuit theory. Parametric analysis is done to explain influence of various geometrical and material parameters on the frequency response. This talk will help practicing engineers and researchers in clearly understanding the art and science of deformation diagnostics. A few case studies will also be presented at the end.

Talk 5: Basics of Finite Element Method

Abstract: Finite Element Method (FEM) is a numerical technique to solve partial differential equations. Design, optimization, and analysis of electrical machines and equipment can be done by solving partial differential equations (PDEs) derived from Maxwell's equations. Solving these equations analytically for practical geometries is not straightforward. FEM has emerged as the most preferred tool by researchers and industry professionals for solving complex problems which may involve nonlinearity, anisotropy, heterogeneity, three-dimensional structures, and coupled fields. Many commercial FEM software programs are available; however, users tend to use them without properly understanding background concepts. The purpose of this talk is to give an exposure of governing principles of the method so that commercial programs can be used effectively with confidence. A step-by-step procedure of FEM is described for a simple example. A few case studies will also be presented highlighting capabilities of FEM in solving real-life problems.

Talk 6: Electromagnetics Made Easy

Abstract: Electromagnetics is one of the foundational subjects of electrical and electronics engineering disciplines. However, complex mathematical concepts tend to make the subject difficult-to-understand for students and difficult-to-teach for teachers. Practicing engineers also face difficulties when they encounter electromagnetic theory while working on a product or system. It is generally difficult for beginners to visualize fields in space. This talk elaborates a few topics, which are generally not well understood, using alternative descriptions and circuit components like capacitors and inductors, without going deep into mathematics. Participants will be able to consolidate their understanding of Maxwell's equations during the talk. A few concepts will also be explained using a web-portal, Virtual Electromagnetics Laboratory, developed in Electrical Engineering Department, IIT Bombay.

Tutorials

Tutorial 1: Transformers Design Principles and Advanced FEM Analysis
Duration: 6 hrs

Abstract: This tutorial starts with a typical design procedure of a power transformer (3-phase, 31.5 MVA, 132/33 kV), which covers broad electrical aspects involved in its design. In addition to describing important principles and operational aspects, step-by-step design procedure is elaborated starting with magnetic circuit followed by windings and insulation. After evaluating the leakage reactance by an approximate analytical formula, the losses in core, LV and HV windings and the parameters of the equivalent circuit of the transformer are determined. Subsequently, conflicting requirements for various engineering aspects (electromagnetic, thermal, mechanical) of design are enumerated. Limits on design variables imposed by temperature rise considerations, manufacturing processes, and transport restrictions are highlighted. Some of the performance figures like eddy and stray losses in windings and structural parts cannot be accurately determined by analytical formulae, necessitating use of Finite Element Method (FEM) for the purpose. Similarly, for determining response to transient overvoltages involving very high frequencies, detailed modeling of windings is essential. The equivalent circuit parameters for accurate transient analysis can be calculated using FEM. Basics of FEM formulations useful for design and analysis of transformers will be covered. Many complex phenomena in transformers involve interactions between electromagnetic fields and connected circuits and/or other physical fields (thermal, mechanical, fluid, and acoustic). A few case studies will be presented at the end which use coupled field computations in solving challenging problems encountered while designing and analyzing transformers.

Schedule:

Session	Duration	Title of the session
1	0.0 hr to 2.0 hr	Design of a 31.5 MVA, 132/33 kV transformer
2	2.0 hr to 2.5 hr	Design considerations for magnetic circuit
3	2.5 hr to 3.0 hr	Eddy and stray losses
4	3.0 hr to 3.5 hr	Short circuit strength of windings
5	4.0 hr to 4.5 hr	Surge performance
6	4.5 hr to 5.0 hr	Insulation design
7	5.0 hr to 6.0 hr	Coupled field computations

Tutorial 2: Revisiting Electromagnetic Concepts Relevant to Power Equipment and Systems
Duration: 3 hrs

Abstract: Electromagnetics is one of the fundamental subjects of electrical and electronics engineering. However, undergraduate students and practicing engineers face difficulty in understanding the subject because of associated complex mathematical theory. If corresponding physics and applications are not explained properly or adequately, the subject does not enthuse students as well as working professionals. Understanding its many concepts and principles starting with Maxwell's equations is essential while designing power equipment and analyzing complex phenomena involving power networks. This tutorial is split into two parts. The first part elaborates Maxwell's equations, Lorentz force and continuity equation. Basics of vector calculus, static and time-varying fields, and electromagnetic radiation are covered. Their relevance to Power Engineering will be emphasized. Virtual Electromagnetics Laboratory has been developed at Electrical Engineering Department, IIT Bombay, using JAVA based applets and FEM to explain subtle concepts effectively. A few examples from this web portal will be used to make the first session interactive and to give hands-on experience to participants. The second part covers biological effects of electromagnetic fields, theory of eddy currents, skin and proximity effects, electromagnetic shielding, frequency-dependent material parameters, and design of magnetic devices for high frequency power electronic applications.

Schedule:

Session	Duration	Title of the session
1	0 to 1.5 hr	Principles of Electromagnetics
2	1.5 hr to 3.0 hr	Electromagnetic Theory and Concepts Relevant to Power Equipment and Systems

Tutorial 3: Hysteresis Phenomena in Transformers and Rotating Machines: Physics and Modeling
Duration: 3 hrs

Abstract: Magnetization process in magnetic materials affects the performance of electrical machines and transformers. The energy spent during the process of magnetization can be termed as hysteresis loss. For proper optimization of design, an accurate hysteresis model is essential. The magnetization process of a material can be represented in terms of its hysteresis loop and the loop area gives the total material losses which include three components: static hysteresis loss, eddy current loss, and anomalous loss. The last two components together make frequency-dependent dynamic losses. Understanding physics behind the process and applying proper hysteresis

formalism in numerical analysis is important for accurate modeling of magnetic circuits in transformers and electrical machines.

This tutorial starts with classification of magnetic materials based on their characteristics. Magnetization phenomenon, involving reversible and irreversible magnetization processes, is explained in terms of domain theory. Influence of time-varying fields, direction of magnetization, and thermal and mechanical stresses on the core loss components is elaborated. In the second part of the tutorial, two popular hysteresis models, the Preisach and Jiles-Atherton (JA) models, used in numerical analysis are discussed in detail, along with their comparison, advantages, and disadvantages. The implementation of the JA model in a coupled circuit-FEM formulation for a three-phase transformer will be demonstrated. Along with these models, there are some curve fitting approaches based on mathematical functions like polynomials, tan hyperbolic function, exponentials, etc. In the second session, mathematical formulations based on these methods will be elaborated.

Schedule:

Session	Duration	Title of the session
1	0 to 1.5 hr	Classification of magnetic materials and factors influencing magnetic performance of transformers and rotating machines
2	1.5 hr to 3.0 hr	Preisach and JA based hysteresis formalisms and implementation of the JA model in numerical analysis