ELECTRICAL EQUIPMENT AND MACHINES: FINITE ELEMENT ANALYSIS

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PRE-REQUISITES : Basics of Electromagnetic Fields and Electrical Machines

INTENDED AUDIENCE : Electrical and Electronics Engineering Students, Electrical Industry Professionals

INDUSTRIES APPLICABLE TO : Companies manufacturing electrical and electronic products consisting of magnetic and insulating components

COURSE OUTLINE :

The course consists of theory and applications of Finite Element Method (FEM). This numerical technique, applied for solving partial differential equations, is popularly used by researchers and practicing engineers for design, development and optimization of electrical equipment and machines. A course of FEM is being included in many universities in India at UG and PG level. This module will be helpful for students and working professionals to understand and apply FEM effectively for analysis of devices. Freeware based FEM simulations and coding procedures will be a part of this course. Students can develop their own codes for practical two- dimensional problems using freeware software.There are two existing NPTEL courses on computational electromagnetics covering various numerical techniques especially for high-frequency electromagnetics. This course is exclusively for FE Analysis of low-frequency machines and equipment. Four unique features of this proposed course are:

1. Explanation of EM concepts relevant for low frequency electromagnetic computations

2. Use of field distributions and interactive Java based examples hosted in a virtual lab (https://www.ee.iitb.ac.in/course/~vel/)

3. Application of the Finite Element theory for different low frequency electromagnetic problems related to electrical machines and equipment

4. Solving the developed Finite Element formulations using freeware platforms like Scilab and Gmsh

Prof. S. V. Kulkarni has conducted many Continuing Education Programs for industry and academia on electromagnetic fields and numerical techniques (https://www.ee.iitb.ac.in/~fclab/Invited_talks_and_Training_Programs/CEP%20Courses%20Conducted.pdf) .For more details of his educational outreach and other credentials, please visit: "https://www.ee.iitb.ac.in/wiki/faculty/svk"

ABOUT INSTRUCTOR :

Prof. S. V. Kulkarni is Professor in the Department of Electrical Engineering, Indian Institute of Technology Bombay. He was INAE (Indian National Academy of Engineering) Chair Professor in the Department for two years (April 2018 - March 2020). He is a Fellow of IEEE and INAE. He was Editor of IEEE Transactions on Power Delivery and IEEE Power Engineering Letters (2012-2019). He worked at Crompton Greaves Limited (1990-2001) and specialized in the design and development of transformers up to 400 kV class. He was a recipient of the Young Engineer Award conferred by INAE in 2000 for his contributions to Electromagnetic Field Computations and High Voltage Insulation Design in transformers. He was also honoured with the Career Award for Young Teachers from All India Council for Technical Education in 2001. He received Best Paper Awards in international conferences on transformers held in 2002 and 2006.

He has authored a book Transformer Engineering: Design, Technology, and Diagnostics, Second Edition, published by CRC Press in September 2012 and he received IIT Bombay Research Dissemination Award 2016 for the book. He has also written a chapter Challenges and Strategies in Transformer Design in the book Transformers: Analysis, Design, and Measurement published by CRC Press in June 2012. He has adapted an undergraduate text book on electromagnetics for Asia, Principles of Electromagnetics, Oxford University Press, published in October 2015.

His extensive interactions with transformer and power industries are reflected in his numerous consultancy projects for them. He has organized several training programs on transformers and computational electromagnetics for engineers from industries and academia in India. He has also set up the Field Computation Laboratory and the Insulation Diagnostics Laboratory in the Electrical Engineering Department at IIT Bombay.

He has more than 190 publications to his credit in reputed journals and conferences, and has two US patents. His current areas of research include Analysis and Diagnostics of Power Transformers, Advanced Electromagnetic and Coupled Field Computations, and Distributed Generation and Smart Grids.

COURSE PLAN:

Week 1: Lecture 1: Course Outline and Introduction
Lecture 2: Analytical and Numerical Methods
Lecture 3: Revisiting EM Concepts: Vector Algebra & Coordinate Systems
Lecture 4: Revisiting EM Concepts: Vector Calculus and Electrostatics
Lecture 5: Revisiting EM Concepts: Current Densities and Electric Fields in Materials

Week 2: Lecture 6: Revisiting EM Concepts: Electrostatic Boundary Conditions and Shielding
Lecture 7: Revisiting EM Concepts: Magnetostatics
Lecture 8: Revisiting EM Concepts: Magnetic Forces and Materials
Lecture 9: Revisiting EM Concepts: Time Varying Fields
Lecture 10: Revisiting EM Concepts: Theory of Eddy Currents

Week 3: Lecture 11: FEM: Variational Approach
Lecture 12: Finding Functional for PDEs
Lecture 13: Whole Domain Approximation
Lecture 14: 1D FEM: Problem Definition and Shape Function
Lecture 15: 1D FEM: Procedure

Week 4: Lecture 16: 1D FEM: Scilab Code
Lecture 17: 2D FEM: Problem Definition and Shape Functions
Lecture 18: 2D FEM: Procedure
Lecture 19: 2D FEM Scilab Code: Manual Meshing
Lecture 20: 2D FEM Code: Gmsh and Scilab

Week 5: Lecture 21: Computation of B and H Field and Method of Weighted Residuals
Lecture 22: Galerkin Method
Lecture 23: Calculation of Leakage Inductance of a Transformer
Lecture 24: Calculation of Inductance of an Induction Motor and a Gapped-Core Shunt Reactor
Lecture 25: Insulation Design Using FE Analysis

Week 6: Lecture 26: Quadratic Finite Elements
Lecture 27: Time Harmonic FE Analysis
Lecture 28: Calculation of Eddy Current Losses
Lecture 29: Eddy Losses in Transformer Windings
Lecture 30: Torque Speed Characteristics of an Induction Motor and FE Analysis of Axisymmetric Problem

Week 7: Lecture 31: Permanent Magnets: Theory
Lecture 32: Permanent Magnets: FEM Implementation
Lecture 33: Periodic and Antiperiodic Boundary Conditions in Rotating Machines
Lecture 34: FE Analysis of Rotating Machines
Lecture 35: Voltage Fed Coupled Circuit Field Analysis

Week 8: Lecture 36: Current Fed Coupled Circuit Field Analysis
Lecture 37: Transient FE Analysis
Lecture 38: Nonlinear FE Analysis
Lecture 39: Computation of Forces using Maxwell Stress Tensor
Lecture 40: Computation of Forces using Virtual Work Method