# Numerical Methods for Eddy Currents Modeling of Planar Transformers

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**Having many advantages compared to classic wire wound technology; planar magnetic components are largely used. Modeling tools are required to help designers for less time consuming conception. Nevertheless, number of adapted modeling solutions is limited by the complexity of such geometries. The determination of appropriate description (2D or 3D) for eddy currents modeling and by this way AC copper losses evaluation are investigated in this paper. The validity of the approach is successfully presented on an industrial application from the current evaluation until thermal simulations.**

*Index Terms*—Eddy currents, finite element method, planar tranformers, 2D and 3D electromagnetic modeling, thermal simulation.

## I. Presentation

THE electronics industry represented 1140 billion Euros in 2008 which is comparable to the Car industry (1800 billion in 2008) [1]. Market of wounded components represented 35 billion Euros in 2008 showing the importance of this activity domain. Today, new societal needs for energy, security or health provide long-term growth perspectives. In consequence, intensive research and development efforts must be carried on. Non insulated Switched Mode Power Supplies (SMPS) versions are very limited. Transformers provide the advantages for safety reasons of input to output insulation. Moreover, multiple outputs can be obtained. The turn ratio can also be selected to optimize the duty cycle and minimize the peak currents. But their power losses, additional weight and size are some important disadvantages. The voltage spikes due to the leakage inductance need to be considered too. The MOSFET advent in the power electronic structures implies an increase of frequency so the size of transformers can be reduced. But with the conventional wire wound technology, this is no more possible. That is why planar technology is preferred. It allows overcoming this limit. The windings of the planar components are made of Printed circuit boards (PCBs) or copper foil lead frames conferring a low profile, small volume and a high power density (Fig. 1). The windings are pre-cooled so the repeatability and predictability are improved. The leakage inductance is reduced [2]. But at high frequency operation, due to skin and proximity effects, the non-uniform current distribution leads to an increase of winding ac resistance. Moreover, considering parallel layers, induced voltages and unfortunately circulation currents are produced by difference of flux flowing through parallel layers [3].

These frequency effects must be accurately taken into account for eddy current modeling [9]. By this way AC copper losses computation is possible and consequently, thermal management. A full modeling procedure is presented in this paper. But since industrial applications are complex, an accurate 3D complete modeling is not possible. So, in the next part, the possible assumptions to limit size of problem and simulation time

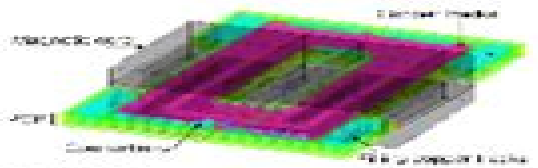

Fig. 1. Planar transformer.

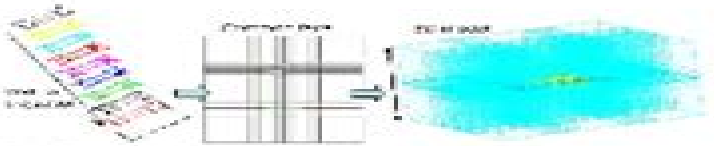

Fig. 2. 3D model construction.

are investigated. A 2D approach is defined and validated from a 3D one. Then, a full procedure is presented for AC copper losses computation taking into account SMPS waveforms. Finally, the validity of the approach from AC copper losses to thermal management is presented on an industrial full-bridge application.

## II. Models

### A. 3D Approach

Geometry complexity can be taken into account by numerical methods instead of analytical approaches [3]. Magnetic core, PCB corners and filling copper tracks which are used to reduce the quantity of injected resin suppose that 3D approaches are required (Fig. 1). Geometry is built by a vertical projection of the layers on a common face. The resulting geometry is extruded (Fig. 2). 3D adaptive meshing is performed in order to accurately take into account frequency effects (Fig. 3). Unfortunately such models require too high time consuming and memory size. For example, the device presented in Fig. 1 (initial geometry) and modeled in Fig. 4 has required more than 3Go of RAM (allowable memory of usual computers) for meshing and solving steps. So, simplifying assumptions are necessary. The study is focused on a Finite Elements analysis of 2D/3D behavior linked to frequency effects.

Manuscript received May 28, 2010; accepted October 26, 2010. Date of current version April 22, 2011. Corresponding author: G. Meunier (e-mail: Gerard.Meunier@g2elab.grenoble-inp.fr).

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# Numerical Modelling Of Eddy Currents

Rachid Touzani,Jacques Rappaz

**Numerical Modelling Of Eddy Currents:**

*Numerical Modelling of Eddy Currents* Andrzej Krawczyk,J. A. Tegopoulos,1993 Great progress has been made in developing and using numerical methods for solving electromagnetic field problems at low frequency recently Many of these problems refer to eddy currents which appear in various electromagnetic devices Originally such problems were tackled by analytical solutions which are limited to simple geometries and linear materials In practice though all electromagnetic devices have complex boundaries include non linear materials and may be treated exclusively by numerical methods This book gives systematically the matehmatical simulation of existing methods and discusses the siscretization of relevant equations The methods described are finite difference finite sums finite element boundary element and some variants Physical connotations of methods and problems are also given **Numerical Modelling of Eddy Currents** A. Krawczyk,J. Tegopoulos,1993 **Numerical Modelling** Peep Miidla,2012-03-23 This book demonstrates applications and case studies performed by experts for professionals and students in the field of technology engineering materials decision making management and other industries in which mathematical modelling plays a role Each chapter discusses an example and these are ranging from well known standards to novelty applications Models are developed and analysed in details authors carefully consider the procedure for constructing a mathematical replacement of phenomenon under consideration For most of the cases this leads to the partial differential equations for the solution of which numerical methods are necessary to use The term Model is mainly understood as an ensemble of equations which describe the variables and interrelations of a physical system or process Developments in computer technology and related software have provided numerous tools of increasing power for specialists in mathematical modelling One finds a variety of these used to obtain the numerical results of the book **Mathematical Models for Eddy Currents and Magnetostatics** Rachid Touzani,Jacques Rappaz,2013-10-01 This monograph addresses fundamental aspects of mathematical modeling and numerical solution methods of electromagnetic problems involving low frequencies i e magnetostatic and eddy current problems which are rarely presented in the applied mathematics literature In the first part the authors introduce the mathematical models in a realistic context in view of their use for industrial applications Several geometric configurations of electric conductors leading to different mathematical models are carefully derived and analyzed and numerical methods for the solution of the obtained problems are given Related issues such as convergence of the approximations and error estimates are discussed The second part of the monograph presents various coupled problems that involve eddy current or magnetostatic problems in particular magneto hydrodynamic problems and magnetic shaping problems concerning the melt flow of electrically conducting metals induction heating processes inductively coupled plasmas and ferromagnetic screening modeling The presentation of each model comes with numerical illustration from industrial applications **Numerical Modelling and Design of Electrical Machines and Devices** Kay Hameyer,Ronnie Belmans,1999-05-21 This text provides an overview of

numerical field computational methods and in particular of the finite element method FEM in magnetics Detailed attention is paid to the practical use of the FEM in designing electromagnetic devices such as motors transformers and actuators Based on the authors extensive experience of teaching numerical techniques to students and design engineers the book is ideal for use as a text at undergraduate and graduate level or as a primer for practising engineers who wish to learn the fundamentals and immediately apply these to actual design problems Contents Introduction Computer Aided Design in Magnetics Electromagnetic Fields Potentials and Formulations Field Computation and Numerical Techniques Coupled Field Problems Numerical Optimisation Linear System Equation Solvers Modelling of Electrostatic and Magnetic Devices Examples of Computed Models Mathematical Models and Numerical Simulation in Electromagnetism Alfredo Bermúdez de Castro,Dolores Gomez,Pilar Salgado,2014-07-22 The book represents a basic support for a master course in electromagnetism oriented to numerical simulation The main goal of the book is that the reader knows the boundary value problems of partial differential equations that should be solved in order to perform computer simulation of electromagnetic processes Moreover it includes a part devoted to electric circuit theory based on ordinary differential equations The book is mainly oriented to electric engineering applications going from the general to the specific namely from the full Maxwell s equations to the particular cases of electrostatics direct current magnetostatics and eddy currents models Apart from standard exercises related to analytical calculus the book includes some others oriented to real life applications solved with MaxFEM free simulation software , *Harmonic Balance Finite Element Method* Junwei Lu,Xiaojun Zhao,Sotoshi Yamada,2016-08-01 The first book applying HBFEM to practical electronic nonlinear field and circuit problems Examines and solves wide aspects of practical electrical and electronic nonlinear field and circuit problems presented by HBFEM Combines the latest research work with essential background knowledge providing an all encompassing reference for researchers power engineers and students of applied electromagnetics analysis There are very few books dealing with the solution of nonlinear electric power related problems The contents are based on the authors many years research and industry experience they approach the subject in a well designed and logical way It is expected that HBFEM will become a more useful and practical technique over the next 5 years due to the HVDC power system renewable energy system and Smart Grid HF magnetic used in DC DC converter and Multi pulse transformer for HVDC power supply HBFEM can provide effective and economic solutions to R D product development Includes Matlab exercises **Fusion Technology 1982** Gyoujin Cho,2013-10-02 Fusion Technology 1982 Volume 1 contains the proceedings of the 12th Symposium on Fusion Technology held at the J lich Nuclear Research Center in Germany on September 13 17 1982 The symposium provided a forum for assessing the state of the art in nuclear fusion as a source of energy The discussions are organized around the following themes first wall and vacuum systems power supplies divertor technology tritium handling remote handling blanket technology and shielding and safety Comprised of 99 chapters this volume first deals with nuclear fusion and spallation

sources for breeding fissile fuel followed by a discussion on the effects of pulsed loads on supply networks The reader is then introduced to key issues for remote inspection and repair of a Tokamak large scale commercial facility for production of elemental tritium and in situ coating of titanium carbide Subsequent chapters explore the use of turbomolecular pumps for plasma fusion experiments alternative for protecting ion sources of neutral injectors against damage from high voltage sparking the effect of capacitive stored energy on neutral beam accelerator performance and cooling of the divertor collector plates in the international Tokamak reactor This monograph will be of interest to practitioners and research workers engaged in fusion technology Electrical Machine Fundamentals with Numerical Simulation using MATLAB / SIMULINK Atif Iqbal,Shaikh Moinoddin,Bhimireddy Prathap Reddy,2021-04-12 A comprehensive text combining all important concepts and topics of Electrical Machines and featuring exhaustive simulation models based on MATLAB Simulink Electrical Machine Fundamentals with Numerical Simulation using MATLAB Simulink provides readers with a basic understanding of all key concepts related to electrical machines including working principles equivalent circuit and analysis It elaborates the fundamentals and offers numerical problems for students to work through Uniquely this text includes simulation models of every type of machine described in the book enabling students to design and analyse machines on their own Unlike other books on the subject this book meets all the needs of students in electrical machine courses It balances analytical treatment physical explanation and hands on examples and models with a range of difficulty levels The authors present complex ideas in simple easy to understand language allowing students in all engineering disciplines to build a solid foundation in the principles of electrical machines This book Includes clear elaboration of fundamental concepts in the area of electrical machines using simple language for optimal and enhanced learning Provides wide coverage of topics aligning with the electrical machines syllabi of most international universities Contains extensive numerical problems and offers MATLAB Simulink simulation models for the covered machine types Describes MATLAB Simulink modelling procedure and introduces the modelling environment to novices Covers magnetic circuits transformers rotating machines DC machines electric vehicle motors multiphase machine concept winding design and details finite element analysis and more Electrical Machine Fundamentals with Numerical Simulation using MATLAB Simulink is a well balanced textbook perfect for undergraduate students in all engineering majors Additionally its comprehensive treatment of electrical machines makes it suitable as a reference for researchers in the field **Review of Progress in Quantitative Nondestructive Evaluation** Donald O. Thompson,Dale E. Chimenti,2012-12-06 These Proceedings consisting of Parts A and B contain the edited versions of most of the papers presented at the annual Review of Progress in Quantitative Nondestructive Evaluation held at the Snowbird Ski and Summer Resort in Snowbird Utah on July 19 24 The Review was organized by the Center for NDE at Iowa State University in cooperation with the Ames Laboratory of the USDOE the American Society of Nondestructive Testing the National Aeronautics and Space Administration NASA the National Institute of Standards and Technology the Federal

Aviation Administration and the National Science Foundation IndustrylUniversity Cooperative Research Centers This year s Review of Progress in QNDE was attended by approximately 410 participants from the US and many foreign countries who presented a total of approximately 370 papers As usual the meeting was divided into 36 sessions with four sessions running concurrently The Review covered all phases of NDE research and development from fundamental investigations to engineering applications and inspection systems and methods of inspection science from acoustics to x rays The Review continues to benefit from increased participation from foreign laboratories This year the Review also welcomed members from the newly formed World Federation of NDE Centers and appreciate their participating in the program

**Electromagnetic Nondestructive Evaluation (XVIII)** Z. Chen,S. Xie,Y. Li,2015-06-10 Electromagnetic Nondestructive Evaluation ENDE is an invaluable tool for assessing the condition of a test object without permanently altering or harming it in any way It has become an indispensable technique for troubleshooting and research in diverse fields such as engineering medicine and art This book presents one plenary lecture and 41 selected papers from the 19th International Workshop on Electromagnetic Nondestructive Evaluation held in Xi an China in June 2014 The workshop focused on research into the theory and application of ENDE methods and provided a forum for the exchange of ideas and discussion of recent developments The papers are arranged in five sections material characterization analytical and numerical modeling inverse problems and signal processing new developments and innovative industrial applications and advanced sensors in ENDE

**Fusion Energy Update** ,1986 *Frontiers Of Accelerator Technology - Proceedings Of The Joint Us-cern-japan International School* Melvin Month,Shin-ichi Kurokawa,Stuart Turner,1996-10-25 This volume contains the proceedings of the Topical course on Frontiers of Accelerator Technology jointly organized by the CERN Accelerator School the KEK Accelerator School and the US Particle Accelerator School It was held at Maui Hawaii November 3 9 1994 The purpose was to disseminate knowledge on the latest ideas and developments in the technology of particle accelerators by bringing together world known experts and younger scientists in the field It was intended for individuals with professional interest in accelerator physics and technology for graduate students for post docs and for those working in accelerator based sciences The motivation to conceive and build accelerators comes from a most fundamental need of man to understand and control the world around us With beams and their associated accelerators scientists and engineers can gain understanding of the nature of matter and modify matter not possible by other means Areas already influenced by the developments in accelerator technology are high energy and nuclear physics atomic and molecular physics condensed matter physics and the biological sciences There is also a growing number of applications in medicine and industry The program was as follows lectures in superconductivity magnets RF feedback instrumentation high power sources beam stability and novel accelerator techniques seminars on accelerator applications the role of government and industry and perspectives on future technology round table the high energy accelerator frontier four short courses each including 8 hours of lectures problems and tutorials on

superconducting magnets superconducting rf instrumentation and linacs This book aims to summarize all the currently available knowledge on the technology driving the development of particle beams for science medicine and industry It is the most up to date and unique collection of information on this technology presently available **Electromagnetic Nondestructive Evaluation (IV)** Satish S. Udpa,2000 A description of the state of the art in electromagnetic nondestructive evaluation NDE techniques Topics covered range from magnetostatic to eddy current and microwave NDE methods Advances in materials characterization forward simulation models sensor design and inverse methodologies are discussed The book also includes contributions on benchmark problems and solutions **Proceedings of the 1st International Conference on Numerical Modelling in Engineering** Magd Abdel Wahab,2018-08-25 This book contains manuscripts of topics related to numerical modeling in Civil Engineering Volume 1 as part of the proceedings of the 1st International Conference on Numerical Modeling in Engineering NME 2018 which was held in the city of Ghent Belgium The overall objective of the conference is to bring together international scientists and engineers in academia and industry in fields related to advanced numerical techniques such as FEM BEM IGA etc and their applications to a wide range of engineering disciplines This volume covers industrial engineering applications of numerical simulations to Civil Engineering including Bridges and dams Cyclic loading Fluid dynamics Structural mechanics Geotechnical engineering Thermal analysis Reinforced concrete structures Steel structures Composite structures Non-linear Electromagnetic Systems Paolo Di Barba,A. Savini,2000 This text is a collection of contributions covering a wide range of topics of interdisciplinary character from materials to systems from microdevices to large equipment with special emphasis on emerging subjects and particular attention to advanced computational methods in order to model both devices and systems The book provides the solution to challenging problems of research on non linear electromagnetic systems and is expected to help researchers working in this broad area

Electromagnetic Nondestructive Evaluation (XI) Antonello Tamburrino,2008 The 12th International Workshop on Electromagnetic Nondestructive Evaluation ENDE 07 was held from the 19th to the 21st of June 2007 at the Wolfson Centre for Magnetics at Cardiff University Cardiff United Kingdom This publication contains the proceedings of the workshop

**Electromagnetic Nondestructive Evaluation (IX)** Lalita Udpa,Nicola Bowler,2005 Electromagnetic Nondestructive Evaluation has grown considerably in recent years largely due to advances in sensor technology computational modeling and data analysis techniques This publication discusses developments in numerical simulation of physical phenomena associated with electromagnetic NDE methods new electromagnetic sensors signal and image processing techniques and inverse solutions to NDE problems Electromagnetic Nondestructive Evaluation IX emphasizes basic science and early engineering developments in the field as well as practical application of emerging technologies to problems of direct relevance to industry The book contains thirty six technical papers covering topics on modeling forward and inverse problems new inspection methods materials characterization signal processing and applications **Emerging Technologies in NDT** D. van

Hemelrijck,A. Anastassopoulos,T. Philippidis,2022-01-26 This volume contains the papers presented at the 2nd International Conference entitled Emerging Technologies in NDT which was held in Athens Greece May 24 26 1999 This work covers frequently used non destructive testing methods and introduces innovative ideas in the field The title also focuses on visual and optical inspection acoustic emission and ultrasonics as well as a range of other closely related topics More than 50 papers were presented at the conferecne by invited and distinguished researchers from all over the world This volume forms a valuable record of important contributions to the relevant literature It contains not only the most up to date technology developments but provides also information regarding emerging NDT techniques technologies and their potential applications in the field The book covers frequently used NDT methods and introduces new and innovative ideas Focussing on visual and optical inspection acoustic emission ultrasonics nonlinear ultrasonics infrared methods X ray radiography special techniques material characterisation NDT of civil engineering structures inspection of pipes and reliability and validation this volume will be a great boon to engineers researchers quality control managers as well as teachers and graduate students in the field

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