
Guest editorial: Electromagnetic modelling exploiting fields and circuits

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1. Introduction

It is a great pleasure to introduce this special issue of COMPEL (*The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*) with selected and extended papers presented originally at the 27th Symposium on Electromagnetic Phenomena in Nonlinear Circuits (EPNC 2022) held from June 28 to July 1, 2022. Due to the pandemic, the symposium that was held in Hamburg, Germany, allowed online participation. The 27th EPNC Symposium was organized by the Chair of Electrical Machines and Drive Systems at the Helmut Schmidt University/University of the federal Armed Forces, Faculty of Electrical Engineering, Germany, and by the Poznan University of Technology, Faculty of Electrical Engineering, Poland. Professor Dr.-Ing. Christian Kreischer was the Chairman of the Organizing Committee.

The first EPNC Symposium took place in Poznań, Poland, in November 1972. The first 11 conferences were local meetings, although speakers from other countries also participated. The last 16 conferences were international events with proceedings published in English. Initially, selected papers from the EPNC conferences were submitted to regular issues of COMPEL. After EPNC 2004, for the first time, selected and extended papers from the EPNC were published as a special issue of COMPEL. The current issue of COMPEL is the 10th consecutive special issue. The aim of the EPNC conferences was to present the latest achievements in the analysis and synthesis of nonlinear electric and magnetic circuits as well as in nonlinear optics and nonlinear electromagnetic problems in medical science, and additionally to provide a forum for discussion and dissemination of the recent results on applications of nonlinear phenomena in electrical engineering. The EPNC conferences are intended to be an opportunity to exchange ideas and experiences between specialists and young PhD students in electromagnetic field modelling, electric drives, electronics, electrical machines and electric and magnetic materials. The topics of the symposiums included ferromagnetics and magnetic circuits, semiconductors and nonlinear electric circuits, nonlinear optics and wave propagation, as well as nonlinear electromagnetic problems in the field of medical science.

During the EPNC 2022, 30 papers were presented by participants from seven countries. Two-page versions of all papers were published in the conference proceedings prepared in an electronic version. A limited number of extended papers, selected in a peer review process, were chosen by the EPNC 2022 Editorial Board and COMPEL Guest Editors for publication in this special issue of COMPEL. The papers and the discussion at the symposium confirmed the recent trends in electromagnetism and electrical engineering.

The broad range of presented papers covers different aspects of analytical and numerical modelling, machine design, parameter identification, nonlinear effects and measurements. The finite element method (FEM) was used in most of the contributions.

Many publications focused on new types or the improvement of electrical machines, which indicates the high importance of this research field. The analysed types of electrical



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machines are induction machines (IMs), synchronous reluctance motors (SynRMs), permanent magnet synchronous machines (PMSMs), permanent magnet brushless direct current (PMBLDC) motors, doubly-fed induction generators (DFIGs) and an augmented multi-phase rail launcher.

The optimization method of differential evolution proved to be particularly effective and successfully applied in many research studies. Furthermore, several papers analysed the influence of different materials and material combinations as well as investigated their applications in high-temperature superconductors.

Some publications concentrated on improved calculation methods and model limits. Furthermore, electro-thermal fields in power cables, transformer models, fibre-based scaffolds, a machine with pole changing winding and an industrial billet furnace were investigated. In the following, the contributions of the COMPEL Special Issue are briefly discussed.

2. Topics discussed in papers of EPNC 2022 symposium

The purpose of the paper “Analysis of losses in the High-Speed PMBLDC Motor with Open Slot Stator core made of Amorphous Soft Magnetic Material” is to compare the losses in the core of a brushless DC motor with two different stator cores: one made of an iron–silicon material and the other made of an amorphous soft magnetic material called METGLAS. To achieve this aim, the authors built two prototypes of the motor with a power output of about 2 kW and a maximum speed of around 8,000 rpm. These prototypes had open slot stator cores, magnetically deposited rotors and a stator-to-rotor pole ratio of 9:12. The prototypes were tested on a laboratory test bench, and the results were compared to those obtained through analytical and numerical modelling using the FEM. The experimental tests showed that the prototype with a METGLAS stator had lower losses than the one with an iron–silicon stator, with a difference of around 40% at a rotational speed of 4,000 rpm. However, the tests also identified a problem with the material parameters used in the simulations.

The next paper titled “Parameter Identification of a Nonlinear D-Q Dynamic Model of an IPMSM by Using a FEM Model” presents a method to identify the constant parameters of a dynamic model of a small, highly saturated interior permanent magnet synchronous machine (IPMSM) for use in maximum torque per ampere (MTPA) control. The model is derived using a FEM simulation and considers the nonlinear effects of factors such as slotting, permanent magnets, cross coupling, cross saturation and a nonlinear iron core. The constant parameters are determined based on a fitting procedure using the nonlinear MTPA curve, and the resulting control performance is evaluated using a complete FEM-based nonlinear d-q model. The results show that the proposed method of extracting the constant parameters is effective for the MTPA operation of highly nonlinear IPMSMs, even when the parameters are limited to constant values. The performance of the control system is evaluated for various loads and different sets of constant parameters, and the results are compared and analyzed.

In the paper “Comparing Two Topology Transformer Hysteresis Models derived from DC Hysteresis Measurements”, the authors investigate the use of a DC hysteresis measurement taken at the terminals of a power transformer to parameterize two different hysteresis models in transformer topology models. The authors used a DC hysteresis measurement and an optimization process to parameterize the hysteresis models, and then the calculated current waveforms of the no-load transformer have been compared with the measured no-load current waveforms to validate the model. The transformer topology models used in the study are:

- The inductance-reluctance models; and
- The capacitance-permeance models.

The inductance-reluctance model represents the magnetic circuit of the transformer and its stray flux paths as inductances in an electric equivalent circuit, allowing the magnetic and surrounding electrical circuit to be modelled in the electrical domain. The capacitance-permeance model, on the other hand, uses a gyrator-capacitor approach and represents the transformer core with lumped circuit elements including hysteresis, saturation and eddy current effects. The results of the study showed that both models were able to reproduce the measured no-load current waveform with acceptable accuracy and that the parameters of the inductance-reluctance model could be recalculated for use in the capacitance-permeance mode.

The paper “Consideration of Saturation in a Multiple Coupled Circuit Model for Induction Motors with Parameter Identification” presents optimization algorithms to identify the parameters of a multiple coupled circuit model for squirrel cage induction motors. The aim is to use the model for condition-based maintenance in industry. The model regards the winding function method and saturation effects. The authors compare three optimization algorithms:

- (1) Genetic algorithm;
- (2) Differential evolution algorithm; and
- (3) Particle swarm optimization

by defining a search space for the required parameters and using the weighted mean squared error between measured data of stator currents, speed and simulation results as a fitness function. The results show that all three algorithms can successfully determine the parameters, although the differential evolution algorithm is the best. The identified parameters allow for the reproduction of the motor’s dynamic behaviour and can be applied in future monitoring and diagnosis.

Another paper entitled “Study of Convergence of Newton Method by FE Simulation with Vector Hysteresis Stop Model” presents a study of the convergence behaviour of the Newton method when used to solve non-linear magnetic field problems that incorporate vector hysteresis effects. The vector hysteresis stop model is a particularly suitable choice for modelling the hysteresis behaviour of soft magnetic materials in the magnetic vector potential formulation, which is commonly used in finite element analysis. However, the Newton method can be sensitive to the starting point and requires certain smoothness and monotonicity properties in the non-linear function, making it difficult to incorporate the vector hysteresis stop model. Additionally, the differential reluctivity tensor in the material model can be discontinuous due to the properties of the stop operators. To stabilize the Newton iteration, the authors apply two different line search methods: one that computes an error-oriented search direction and another based on the Powell-Wolfe method. The effectiveness of these methods in ensuring a stable convergence and improving the accuracy of the analysis are discussed.

The paper “Efficient High-Resolution Electric Field Simulations inside the Human Body in the Vicinity of Wireless Power Transfer Systems with Varying Models” discusses the use of numerical methods, specifically the Scaled-Frequency Finite Difference Time-Domain and Co-Simulation Scalar Potential Finite Difference schemes, for analyzing the potential harm of magneto-quasistatic fields emitted by inductive charging systems on the human body. The simulation of human exposure to these fields can be computationally expensive,

particularly when considering highly detailed models of vehicles and charging systems and the inclusion of human body models. The paper presents a tool and workflow for efficiently determining body-internal magnetic flux densities, electric field strengths and induced voltages in cardiac pacemakers using these methods, with the goal of reducing simulation time and computational cost while minimizing human workload. The efficiency of the methods is demonstrated through the presentation and comparison of four scenarios. The developed tool is able to calculate and compare exposure values in a relatively short time using a combination of CPUs and GPUs. Overall, the use of the Co-Simulation Scalar Potential Finite Difference scheme in combination with the Scaled-Frequency Finite Difference Time-Domain method allows for the efficient determination of human exposure to magneto-quasistatic fields emitted by inductive charging systems, reducing the required simulation time and computational cost and minimizing the human workload.

The aim of the paper “Influence of the Geometric Parameters of a Vertical Rotational Single Sheet Tester on Sample Field Homogeneity” was to investigate the influence of various parameters on the field homogeneity in the test sample of a vertical Rotational Single Sheet Tester (RSST). A 3D finite element model of a vertical RSST was developed and used to perform a sensitivity study on various geometrical parameters. The study found that the accuracy of the results obtained from a vertical RSST depends on the dimensions of the device and the sensors used for the measurements as well as the presence of holes required for the placement of the coils. It was noticed that the width of the yokes affects the field homogeneity in the middle of the test sample. It was also found that using a non-intrusive measurement method, such as the needle-based method, does not require consideration of sensor size but rather the size of the grains of the electrical steel being characterized. However, using a more common coil measurement method that requires holes to be drilled inside the sample can result in decreased accuracy due to local saturations. These local saturations can be reduced by using large sensors. Overall, this study aims to contribute to the optimization and standardization of vertical RSSTs.

In the study titled “Power Density Improvement of Axial Flux Permanent Magnet Synchronous Motor by Using Different Magnetic Materials”, the authors investigated the use of different magnetic materials in the design of a yokeless dual-rotor axial flux permanent magnet synchronous machine (PMSM) for electric traction applications with high operating speeds. The aim was to improve the power density and efficiency of the motor by optimizing the dimensions of the stator teeth and rotor yoke using magnetic materials with high permeability, high saturation flux density and low specific losses. The authors performed numerical simulations using finite element analysis and compared the performance of different structures made of non-oriented grain electrical steel (NOES), grain-oriented electrical steel (GOES) and iron–cobalt electrical steel. The results showed that using GOES and another iron–cobalt electrical steel in the stator teeth and/or rotor yoke can simultaneously improve both power density and efficiency compared to a conventional NOES structure. The authors plan to further optimize the design using thermal and mechanical simulations and to build a prototype for experimental testing.

The paper “Design Advantages and Analysis of a Novel Five-Phase Doubly-Fed Induction Generator” presents research into a new type of doubly-fed induction generator (DFIG) with a five-phase rotor, which aims to extend the range of possible modes of operation for an IM generation system. DFIGs are commonly used in wind energy conversion systems due to their advantages. However, they have the disadvantage of

requiring a power converter-controlled rotor energy supply. The five-phase DFIG is intended to improve fault tolerance and decrease the possibility of system downtime. The prototype DFIG used in the study was a six-pole, three-phase stator with a five-phase rotor and slip rings. The design and performance of the prototype were verified through simulations and measurements under various operating conditions. The five-phase DFIG was able to function as a regular three-phase machine in an electric power generation system, and even with a standard motor stator, it was able to supply both active and reactive power to the load.

The paper titled “Design and dimensioning of a test bench for investigating the relationship between critical temperature and axial mechanical stress of GdBaCuO tape conductors” analyzes the effects of applying axial mechanical tensions to two Gadolinium Barium Copper Oxide (GdBaCuO) tape conductors. A specially developed test bench has been used. Previous research has shown that there is a relationship between strain, compression and the critical current in these materials. The goal of this study is to better understand the relationship between the critical temperature and the applied tension, as well as to develop an analytical model to describe this relationship. The researchers also examine whether the effects of the tension are reversible or irreversible. The study is conducted by applying different levels of force to the tape conductors and measuring the resulting shift in the transition temperature. The results show that the transition temperature decreases as the applied force increases and that the temperature window (defined as the range of temperature over which the material exhibits superconducting behaviour) shifts towards lower temperatures with increasing force. The researchers also found that the temperature window is relatively constant, with a value of approximately 0.95 K across all measurements. The results provide important insights into the behaviour of GdBaCuO tape conductors under mechanical tension and can be used to more accurately model and characterize these materials.

The paper “Improved Methods for Stator End Winding Leakage Inductance Calculation” presents improved methods for calculating the stator end winding leakage inductance of an IM. The methods are based on 3D finite element analysis and consider the presence of the rotor in the simulated machine model. The authors show that considering end winding leakage inductance in the dynamic IM model can improve the model’s accuracy. The paper presents two methods for calculating end winding leakage inductance and compares them. The results show that the rotor has an influence on the value of end winding leakage inductance. The proposed methods are general and can be applied to other radial flux electric machines.

3. Conclusions

Based on the various papers discussed, it is clear that the field of electrical engineering is constantly evolving and advancing. Researchers are constantly finding new ways to improve and optimize the performance of electrical systems, whether through the use of different materials, the development of new measurement techniques or the design of innovative machines. These papers demonstrate the wide range of methods and approaches being used in the field and highlight the importance of staying up-to-date with the latest research and developments. Overall, these papers provide a valuable contribution to the field and offer valuable insights into the current state of the art in electrical engineering.

We are convinced that this issue of COMPEL will provide new, stimulating information to the readers.

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