electronics

MDPI

Editorial

Robust Design Optimization of Electrical Machines and Devices

Tamás Orosz [1,*], David Pánek [2], Anton Rassõlkin [3] and Miklós Kuczmann [1]

[1] Department of Automation, Széchenyi István University, Egyetem ter 1., 9026 Győr, Hungary; kuczmann@sze.hu
[2] Deparment of Theory of Electrical Engineering, University of West Bohemia, Univerzitni 26, 306 14 Plzen, Czech Republic; panek50@kte.zcu.cz
[3] Department of Electrical Power Engineering and Mechatronics, Tallinn University of Technology, Ehitajate Tee 5, 19086 Tallinn, Estonia; anton.rassolkin@taltech.ee
* Correspondence: orosz.tamas@sze.hu

This article introduces a Special Issue (SI) that contains fourteen chosen articles from robust design optimization of electrical machines and devices. Optimization is essential for the research and design of electromechanical devices, especially electrical machines. Finding the optimal solutions may lead to cheaper, more economical products, faster and more efficient production, or more sustainable solutions. However, optimizing such a complex system as an electrical machine is a computationally expensive optimization problem, where many physical domains should be considered together. However, a good, practical design needs to consider the electrical device's design parameters; it should be insensitive to parameter changes or manufacturing tolerances. This Special Issue focused on papers showing how modern artificial intelligence (AI) tools can be used for robust design optimization of electric machines and electrical devices, how these tools can be benchmarked, or the correctness of the result validated.

The articles which are published in this special issue present the latest results of current research fields. Hopefully, the presented models and various application fields will provide useful information for researchers and professionals interested in these techniques themselves or who have other problems from different fields.

Testing and benchmarking the numerical tools for electromagnetic analysis is an important task. The Compumag Society provides openly accessible, challenging benchmark problems (TEAM problems) for testing novel numerical solvers. In [1], the authors deal with a solution of a robust design of a solenoid, and the test problem aims to search for the optimal shape of a coil, which ensures a uniform field distribution in the control region, while the sensitivity and the mass/DC loss of the coil are also considered in the context of robust design. The paper points out that if we are looking for designs with acceptable tolerances, not only symmetrical designs can be favoured. The paper points out the fact that the cheapest solutions are symmetrical setups. They perform worse than the cheapest asymmetric ones in these uniformity and sensitivity criteria. Therefore, some asymmetric solutions that were previously neglected from the solution space can be competitive and interesting for practical design.

A variety of electromechanical systems requires special techniques for optimization; each optimization is unique and focused on specific parameters aimed at performance improvement. In [2], a fast and accurate optimization tool is presented for optimal exploitation of permanent magnet synchronous machine with hairpin winding intended for transport applications. The focus of the optimization is maximizing power density and efficiency. As a benchmark case study, a surface-mounted permanent magnet synchronous motor designed for a student racing competition vehicle was considered. Several optimization steps are presented in the paper, and as a result, the main indexes, such as efficiency, volume power density, and power losses, were improved by 0.15%, 10.55%, and 3.4%, respectively.

Citation: Orosz, T.; Pánek, D.; Rassõlkin, A.; Kuczmann, M. Robust Design Optimization of Electrical Machines and Devices. *Electronics* **2022**, *11*, 1427. https://doi.org/10.3390/electronics11091427

Received: 20 April 2022
Accepted: 25 April 2022
Published: 29 April 2022

Another study on permanent magnet synchronous machines [3] is focused on 8-pole 9-slot and 8-pole 12-slot machines and considers rotor eccentricity. Authors have performed a magnetic field analysis using an analytical method and the torque characteristics for benchmark machines. The optimization is based on perturbation and electromagnetic theories. In both cases, two models (slotted and simplified without slots) were analyzed using the FEM. The research work confirms that the slotted model can obtain similar results, even if the magnetic flux density is predicted without slots and the back-EMF is derived using it. The results obtained using the analytical method are compared with the FEM and experimental results.

The next paper in SI [4] aims to investigate the reconfigurations of rotor flux barriers for a five-phase permanent magnet assisted synchronous reluctance machines. That type of electrical machine is relatively new on the market. However, they are gaining popularity in industrial applications due to their electromagnetic characteristics (robustness, torque/power density, performance, etc.). In this research work, a Lumped Parameter Model conducted to a 2D FEM was applied to the proposed permanent magnet assisted synchronous reluctance motor models under the steady-state condition. Based on the FEM results, the maximum torque, minimum cogging torque, and minimum torque ripples were achieved. As a result, the optimal model of the electrical machine operates at high-performance values with desirable values of line-to-line back-EMF and air-gap flux density.

Wind generators are integrated with electrical machines that require a reliable operation. However, the increasing use of non-linear loads introduces undesired disturbances that may compromise the integrity of the electrical machines inside the wind generator. Ref. [5] proposed a five-step methodology for power quality disturbance detection in grids with the injection of wind farm energy. The proposed method is validated using a set of synthetic signals and is then tested using two different sets of real signals from an IEEE workgroup and from a wind park located in Spain.

In [6], the dielectric properties of a $Bi_3-xNdxTi_{1.5}W_{0.5}O_9$ material is investigated. Many recent studies showed that replacements of atoms in A and also in B-positions of an AP's crystal lattice led to a change in the structure, the dielectric properties and significantly influenced the polarization processes in this compounds.The dependences of the relative permittivity ϵ/ϵ_0 and the tangent of loss $tan\delta$ at different frequencies on temperature were examined in this paper, together with the piezoelectric properties of the material.

Nanotechnology provides an effective way to upgrade the thermophysical characteristics of dielectric oils and creates optimal transformer design. The properties of insulation materials have a significant effect on the optimal transformer design. Ester-based nanofluids (NF) are introduced as an energy-efficient alternative to conventional mineral oils, prepared by dispersing nanoparticles in the base oil. Ref. [7] presents the effect of graphene oxide and TiO_2 nanoparticles on the thermophysical properties of pure natural ester and synthetic ester oils with temperature varied from ambient temperature up to 80 °C. A range of concentrations of graphene oxide (GO) and TiO_2 nanoparticles were used in the study to upgrade the thermophysical properties of ester-based oils. The experimental results show that nanoparticles have a positive effect on the thermal conductivity and viscosity of oils which reduces with an increase in temperature

Low voltage cables are widely used in nuclear power plants and photovoltaic generators. In the case of nuclear power plants the low voltage cables link the system components with the controlling and monitoring instrumentation and control equipment and supplying power to the devices. During the service period these cables are exposed to a wide range of stresses: high-temperature, radiation, mechanical stresses, etc. Since the proper function of the low voltage cables is essential for these power plants' continuous and reliable operation. In [8], the authors examine the effect of mechanical stresses during the aging procedure of these cables, it shows that the Shore D hardness was also higher on the thermo-mechanically aged samples. These findings show the combined aging has a higher impact on the insulation properties. Hence, involving the mechanical stress in

the aging procedure of cable qualification enables the design of more robust cables in a harsh environment.

New materials and manufacturing technologies have influence also on design optimization process of electromechanical devices. In [9], the authors present an optimization of a additively manufactured permanent magnet coupling. Two approches are introduced - time-consuming Genetic Algorithm method and faster Taguchi method. The research work analyze the abilities of compared methods within the optimization of studied coupling with minimization of volume and maximization of transmitted torque as objectives. Taking into account that resulting optimal geometry (the clutch volume is reduced by 17%) and characteristics (magnetic torque density is enhanced by more than 20%) achieved by compared methods are nearly identical, the Taguchi method is found to be more time-efficient and effective within the considered optimization problem. The permanent magnet coupling was manufactured and simulation results were validated using an experimental setup.

Model predictive current control has recently become a powerful advanced control technology in industrial drives. In [10], the authors proposed a computationally efficient calcualtion of the current prediction control for synchronous reluctance motors. The porposed methodology can reduce the computational cost by a merging the predictive current control model with a simple hysteresis current control. Therefore, only four voltage vectors should used to predict the current and evaluate the cost function. The proposed methodology can reduce the computation cost of a classical predictve current model by about 20%.

Linear motors are a special type of electrical machine that requires special attention due to nonlinearities caused by side effects. The authors of the paper [11] propose a modified dynamic equivalent circuit model for a linear induction motor. A proposed model considering both longitudinal (speed-dependent) end effect based on conventional Duncan's approach and transverse edge effect investigated by using additional correction factors. In addition, the field-analysis method is used to include the typical linear motors iron saturation effect, the skin effect, and the air-gap leakage effect. Model simulation results show a good agreement between field analysis and FEM estimation of the electrical parameters. Moreover, to validate the proposed paper method, 3-D FEM was employed. Thrust-velocity characteristic of studied linear induction machines shows that the proposed method provides more precision as compared to Duncan's model.

An investigation of linear induction motors in SI continues with work by Zhang et al. in [12]. An improved equivalent circuit model of double-sided linear induction motors that takes into account the linear motor skin effect and the nonzero leakage reluctance of the secondary, longitudinal, and transverse end effects into consideration is proposed. The proposed equivalent circuit is presented described in detail and highlights the modification in comparison with the traditional equivalent circuit with longitudinal and transverse end effects. 3D FEM is used to verify the proposed equivalent circuit model under varying air gap width and frequency. The results show that the equivalent circuit model that takes into account only the longitudinal end effect considered, and the model considered with both longitudinal and transverse end effect have more than 11% errors with the FEM simulation results in the slip range, while the errors between the value of proposed equivalent circuit and simulation are less than 5%.

There is a great potential in small satellite technology for testing new sensors, processes, and technologies for space applications. The design of their receiving antennas for their ground stations needs a careful design to establish stable communication. Paper [13] shows an interesting solution to the antenna design problem with the antenna array technology. This novel approach can have many advantages over parabolic antennas. From a mechanical point of view, it does not require the design and maintenance of the drive system, which sets the azimuth and the elevation angles. Such systems have a simpler feeding network that cannot be disconnected during the connection time. These tools are insensitive to the moisture and weather conditions during the mission. Moreover, with a pattern reconfigurability algorithm, they can support multi-task missions. This work is

motivated by the design of an antenna array for a future rotatorless base station for the VZLUSAT group of Czech nano-satellites.

The advancement of a device like an insulated core transformer involves the optimization of several parameters. Special attention must be paid to parameters that affect the uniformity of disk output voltage. In the paper, Ref. [14], the accuracy of the FEM model was verified by comparing test data of the insulated core transformer prototype with the simulation results. Particle Swarm Optimization algorithm was implemented for the design parameters (including the number of secondary winding turns and the compensation capacitance) optimization of dummy primary winding. The optimization results presented in the research work show that the maximum non-uniformity of the disk output voltage is reduced from 11.1% to 4.4% from no-load to a full load for a 200 kV/20 mA for an insulated core transformer prototype. The proposed method improves the performance of the insulated core transformer high voltage power supply and cuts down the design time.

Funding: The research work by Anton Rassõlkin has been supported by the Estonian Research Council under grant PSG453 "Digital twin for propulsion drive of autonomous electric vehicle".

Acknowledgments: For this valuable collection of research works focuses on optimization of electrical machines and devices, the Guest Editors are thankful for all authors who submitted their manuscripts for this SI and congratulate them on publishing their research works with MDPI Electronics. This SI edition would not be possible without the the Academic Editors and all reviewers, our gratitude for their important work. Last but not least, we would like to thank the MDPI team for their support of this SI.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gadó, K.; Orosz, T. Robust and Multi-Objective Pareto Design of a Solenoid. *Electronics* **2021**, *10*, 2139. [CrossRef]
2. Soltani, M.; Nuzzo, S.; Barater, D.; Franceschini, G. A Multi-Objective Design Optimization for a Permanent Magnet Synchronous Machine with Hairpin Winding Intended for Transport Applications. *Electronics* **2021**, *10*, 3162. [CrossRef]
3. Lee, H.K.; Bang, T.K.; Lee, J.I.; Woo, J.H.; Shin, H.S.; Yoon, I.J.; Choi, J.Y. Analytical Study and Comparison of Electromagnetic Characteristics of 8-Pole 9-Slot and 8-Pole 12-Slot Permanent Magnet Synchronous Machines Considering Rotor Eccentricity. *Electronics* **2021**, *10*, 2036. [CrossRef]
4. Ghorbani, H.; Moradian, M.; Benbouzid, M. On the Optimal Selection of Flux Barrier Reconfiguration for a Five-Phase Permanent Magnet Assisted Synchronous Reluctance Machine for Low-Torque Ripple Application. *Electronics* **2022**, *11*, 41. [CrossRef]
5. Elvira-Ortiz, D.A.; Saucedo-Dorantes, J.J.; Osornio-Rios, R.A.; Morinigo-Sotelo, D.; Antonino-Daviu, J.A. Power Quality Monitoring Strategy Based on an Optimized Multi-Domain Feature Selection for the Detection and Classification of Disturbances in Wind Generators. *Electronics* **2022**, *11*, 287. [CrossRef]
6. Zubkov, S.V.; Parinov, I.A.; Kuprina, Y.A. The Structural and Dielectric Properties of $Bi_{3-x}Nd_xTi_{1.5}W_{0.5}O_9$ (x = 0.25, 0.5, 0.75, 1.0). *Electronics* **2022**, *11*, 277. [CrossRef]
7. Khan, S.A.; Tariq, M.; Khan, A.A.; Alamri, B.; Mihet-Popa, L. Assessment of Thermophysical Performance of Ester-Based Nanofluids for Enhanced Insulation Cooling in Transformers. *Electronics* **2022**, *11*, 376. [CrossRef]
8. Afia, R.S.A.; Mustafa, E.; Tamus, Z.A. Comparison of Mechanical and Low-Frequency Dielectric Properties of Thermally and Thermo-Mechanically Aged Low Voltage CSPE/XLPE Nuclear Power Plant Cables. *Electronics* **2021**, *10*, 2728. [CrossRef]
9. Andriushchenko, E.; Kallaste, A.; Belahcen, A.; Vaimann, T.; Rassõlkin, A.; Heidari, H.; Tiismus, H. Optimization of a 3D-Printed Permanent Magnet Coupling Using Genetic Algorithm and Taguchi Method. *Electronics* **2021**, *10*, 494. [CrossRef]
10. Benjamim, W.; Jlassi, I.; Cardoso, A.J.M. A Computationally Efficient Model Predictive Current Control of Synchronous Reluctance Motors Based on Hysteresis Comparators. *Electronics* **2022**, *11*, 379. [CrossRef]
11. Heidari, H.; Rassõlkin, A.; Razzaghi, A.; Vaimann, T.; Kallaste, A.; Andriushchenko, E.; Belahcen, A.; Lukichev, D.V. A Modified Dynamic Model of Single-Sided Linear Induction Motors Considering Longitudinal and Transversal Effects. *Electronics* **2021**, *10*, 933. [CrossRef]
12. Zhang, Q.; Liu, H.; Song, T.; Zhang, Z. A Novel, Improved Equivalent Circuit Model for Double-Sided Linear Induction Motor. *Electronics* **2021**, *10*, 1644. [CrossRef]
13. Pánek, D.; Orosz, T.; Karban, P.; Gnawa, D.C.D.; Neghab, H.K. Performance Comparison of Quantized Control Synthesis Methods of Antenna Arrays. *Electronics* **2022**, *11*, 994. [CrossRef]
14. Jiang, C.; Yang, J.; Fan, M. Application of Particle Swarm Optimization in the Design of an ICT High-Voltage Power Supply with Dummy Primary Winding. *Electronics* **2021**, *10*, 1866. [CrossRef]