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Guest Editorial: High Sustainable Electric Drives for Transportation Electrification

I. Introduction

GIVEN that nearly 23% of global CO2 emissions is blamed on the transport sector, its electrification becomes crucial for reaching the 2050 Net Zero Emissions scenario. The key enabler to this purpose is a sustainable design and development of electric powertrain systems, aiming at cutting the overall greenhouse gases emissions during each of the different life-cycle stages of the design, including procurement, manufacturing, use, and recycle or reuse.

This introduces new challenges in the design of batteries, power converters, and electric motors, which must now prioritize environmental sustainability without compromising key performance metrics such as power density, efficiency, cost, and reliability.

II. Aim of This Special Issue

To improve the sustainability of electric mobility, it is essential to evaluate the entire life cycle of batteries and electric drive components, while exploring alternative solutions aimed at reducing the number of components and the utilization of materials with high environmental load.

These solutions may include replacing copper with aluminum in the motor windings [1], [2], eliminating rare-earth magnets in favor of ferrite [3], [4] or wound-field topologies [5], [6], and reduction of hardware electronic components in the drive [7]. Consequently, focus is placed on selecting alternative, sustainable materials and understanding their impact on drive performance [8], [9]. Attention is also directed toward the adoption of innovative topologies for both electric machines and power electronics, along with the development of efficient end-of-life management solutions to support a closed-loop circular economy [10].

This special section aims to explore these solutions and provide a comprehensive contribution to the latest research advancements in the field of sustainable electric drives for transportation electrification.

Specifically, this special issue addresses topics such as alternative materials and design solutions for machine and power electronics components, along with implications of circular economy practices.

III. Overview of Articles

Following an extensive peer-review process conducted with the support of renowned international specialists in power electronics and machine design, the editorial team has chosen six exceptional articles for inclusion in this Special Issue of the IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN INDUSTRIAL ELECTRONICS. The wide scope of challenges covered in this issue falls into three main categories: 1) sustainable winding materials and strategies for reducing rare-earth magnets in sustainable electric machines, 2) reduction of power electronics components in sustainable electric drive systems, and 3) sustainable circular economy in electric mobility. The following sections provide brief summaries of each article's content and contributions to help guide readers through this Special Issue.

A. Sustainable Winding Materials and Strategies for Reducing Rare-Earth Magnets in Sustainable Electric Machines

In [A1], the authors explore the adoption of aluminum to replace copper in the hairpin windings of an automotive traction interior permanent magnet (IPM) machine, as despite the higher resistivity, aluminum is to be preferred in terms of environmental impact. The study provides a full experimental comparison of copper vs aluminum hairpin for the whole efficiency map, conducting the experiments on two identical prototypes, but with different conductor material. Based on the difference losses map and the corresponding difference efficiency map, it was observed that the increase in DC losses caused by aluminum's higher resistivity has a negligible effect on the overall efficiency of the WLTP driving cycle. This is because in most of the points of the driving cycle, the iron losses represent the largest share of total losses. In this context, the winding material choice is less influential. The study confirms that aluminum windings represent a viable substitute for copper in utility vehicle applications.

In [A2], a novel asymmetrical IPM machine design is introduced for reducing the magnets utilisation while increasing the torque density. This is achieved through a flux barrier which moves the magnetic and reluctance axes from their conventional positions, thus aligning the reluctance peak torque and the magnet peak torque at the same angle. In this way, the aimed electromagnetic torque is achieved with 30% less magnet volume. This makes the studied topology suitable for transportation applications with compact size.

In [A3], the authors present a wound-field flux-switching machine which aims at high efficiency in low torque – high speed conditions, while eliminating the rare earth magnets or brushes and slip rings from the rotor design, as all excitations' sources are located on the stator. The study compared different winding configurations and stator-rotor pole combinations through a multi-segment magnetic flux path analysis. The outcome demonstrates that adopting through a circumferential field and armature winding configuration avoids longer magnetic paths. This results in a 57% volumetric torque density

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increase with respect to configurations with longer magnetic flux paths. The increase of torque density and efficiency at highway driving conditions makes this solution attractive for traction in automotive application.

In [A4], a Pulse and Glide (PnG) control strategy is implemented to enhance the sustainability of a drive system that utilizes a wound field machine. Pulse and Glide (PnG) is a discontinuous torque control in which, during cruising conditions, the vehicle alternates between periods of acceleration at peak efficiency operating points and coasting phases. This approach delivers the required average torque while improving overall system efficiency. Driver comfort is maintained by limiting speed variations through jerk control, whose implementation is based on a vehicle model that estimates the forces acting on the vehicle. This approach enabled an energy consumption reduction by slightly decreasing losses in both the motor and the wound-field power converter, thus laying the foundation for more sustainable drives. A further sustainability footprint is given by the replacement of the rare-earth permanent magnets (PM) with a wound field rotor topology. This also allows for rotor de-excitation under zero-torque conditions, eliminating core losses. Furthermore, in field-weakening (FW) conditions, rotor de-excitation prevents uncontrolled braking.

B. Reduction of Power Electronics Components in Sustainable Electric Drive Systems

In [A5], the authors propose a software based low-cost hardware solution for resolvers used in PMSM, as alternative to the integrated circuit (IC) based resolver to digital conversion (RDC) systems. The proposed RDC method aims at lowering cost of the system while improving its dynamic tracking and error suppression capabilities. Specifically, the angle accuracy from RDC is improved by adopting an adaptive filter for removing the DC offset errors, and through a double second order generalized integrator frequency-locked loop (DSOGI-FLL), which solves imbalance amplitude errors while achieving good frequency tracking. Finally, the angle signals are reconstructed by a third-order rational fraction polynomial approximation (TRFPA). Replacing the integrated circuit (IC) with a software-based, low-cost hardware solution for the RDC achieves a 70% cost reduction, establishing it as a more convenient and therefore more sustainable alternative.

Multiphase drives are increasingly used due to their increased power density and reliability, which make these solutions preferable from a sustainable point of view. In this regard, the authors in [A6] present a three-phase, five-level stacked dual output (FLSDO) converter, intended for supplying a single six phase or two three-phase loads, independently and simultaneously. The proposed typology can produce all output states attainable by conventional MLIs, while aiming at higher reliability, reduced size and fewer switches. Specifically, the topology involves hybrid multilevel converter with dual flying capacitors (FCs) stacked with selector switches, thus extending the operating boundary region compared to the previously proposed dual-output converters. This study provides a convenient solution for sustainable electric vehicles utilizing multiple three-phase motor drives or multiphase machines.

C. Sustainable Circular Economy in Electric Mobility

In [A7], tha authors address the need of closing the loop on the circular economy of the electric drives and batteries within the transportation electrification sector, thus aiming at a more sustainable mobility. The study comprehensively reviews state-of-the-art and future technologies for managing the components end-of-life, such as multi-purpose use, reuse, and recycle strategies. For extending the life of electric vehicle batteries, multipurpose and reuse strategies emerge as the most promising approaches, while the use of advanced disassembly and sorting techniques for printed circuit boards is preferable for an efficient recycling and reutilisation of power electronics components. For electric machines, the paper highlights the importance of environmentally conscious design, which involves eliminating rare earth materials, using soft magnetic composites, segmented structures, and more sustainable options like aluminum windings instead of copper.

IV. Summary and Conclusion

Different facets of sustainable electric mobility have been explored in this special issue. While significant progress has been made, many challenges remain in advancing the sustainable electric drives design to support the net zero emissions scenario. Although this special issue covers only a fraction of the ongoing research in this field, the editorial team hopes this guest editorial provides several perspectives for inspiring further advancements in the field of sustainable electric drives design. Finally, the editorial team extends its best wishes for an engaging and informative experience with the articles featured in this Special Issue.

Acknowledgment

The editorial team would like to thank all contributing authors and reviewers for their invaluable contributions and constructive comments on this Guest Editorial. They would also like to thank the Editorial Board of the IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN INDUSTRIAL ELECTRONICS for their exceptional assistance and patience, as well as for accepting this Special Issue. Special thanks go to the Editor-in-Chief, Prof. Chandan Chakraborty, for his outstanding support throughout all phases leading to the publication.

Appendix
Related Articles

[A1] G. Cutuli, S. Nuzzo, D. Barater, T. Zou, S. Nategh and T. Bertoncello, ”Replacing Copper With Aluminum in Hairpin Windings Motors Intended for Utility Cars,” in *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*, doi: 10.1109/JESTIE.2025.3546030

[A2] D. Barman, S. B. Santra, D. Chatterjee, R. Palisetty and P. Pillay, ”Cogging Torque Computation in an Asymmetrical Interior Permanent Magnet Machine for Electric Vehicles,” in *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*, doi: 10.1109/JESTIE.2024.3494594

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[A3] M. Fereydoonian, D. Bobba and W. Lee, ”Multi-Segment Magnetic Flux Path Analysis of Wound-Field Flux-Switching Machines with Different Winding and Stator-Rotor Combinations,” in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, doi: 10.1109/JESTIE.2024.3474516

[A4] P. Korta, V. K. Kurramsetty, L. V. Iyer and N. C. Kar, ”Discontinuous Control Strategy for Loss Reduction in Wound-Field Synchronous Machine based Electric Vehicle Powertrain System,” in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, doi: 10.1109/JESTIE.2025.3558373

[A5] S. Wang, Y. Bao and G. Buticchi, ”A DSOGI-FLL Based Resolver-to-Digital Conversion Method With Error Calibration Capability Used In PMSM,” in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, doi: 10.1109/JESTIE.2024.3514817

[A6] D. Dwivedi, A. Hussein and K. A. Chinmaya, ”Design of a Novel Five-Level Stacked Dual-Output Converter for EV Application,” in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, doi: 10.1109/JESTIE.2025.3547789

[A7] M. Fereydoonian, K. Lee, C. Kiriella, J. Moon and W. Lee, ”Closing the Loop on Circular Economy in Transportation Electrification: Reuse, Repurposing, and Recycling of Batteries, Power Electronics, and Electric Machines,” in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, doi: 10.1109/JESTIE.2025.3530914

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[1] G. Cutuli, S. Nuzzo, T. Zou, G. Franceschini, C. Gerada, and D. Barater, “Multi-objective optimizations of copper and aluminum hairpin windings: a comparison,” in *2023 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2023, pp. 3796–3801.

[2] J. D. Widmer, R. Martin, and B. C. Mecrow, “Precompressed and stranded aluminum motor windings for traction motors,” *IEEE Transactions on Industry Applications*, vol. 52, no. 3, pp. 2215–2223, 2016.

[3] T. Jahns, “Getting rare-earth magnets out of ev traction machines: A review of the many approaches being pursued to minimize or eliminate rare-earth magnets from future ev drivetrains,” *IEEE Electrification Magazine*, vol. 5, no. 1, pp. 6–18, 2017.

[4] H. Tahanian, M. Aliahmadi, and J. Faiz, “Ferrite permanent magnets in electrical machines: Opportunities and challenges of a non-rare-earth alternative,” *IEEE Transactions on Magnetics*, vol. 56, no. 3, pp. 1–20, 2020.

[5] G. Petrelli, S. Nuzzo, T. Zou, G. Cutuli, D. Barater, and C. Gerada, “On comparing aluminum and copper in wound field synchronous motors for traction applications,” in *2024 International Conference on Electrical Machines (ICEM)*, 2024, pp. 1–7.

[6] F. Graffeo, O. Stiscia, S. Vaschetto, A. Cavagnino, and A. Tenconi, “Doubly excitated synchronous machines for traction applications,” in *2021 IEEE 30th International Symposium on Industrial Electronics (ISIE)*, 2021, pp. 1–8.

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[8] M. Raimondo, G. Cutuli, S. Nuzzo, and D. Barater, “Assessing thermal and efficiency aspects of aluminum hairpin motors in passenger cars,” in *2024 International Conference on Electrical Machines (ICEM)*, 2024, pp. 1–7.

[9] L. Cinti, P. G. Carlet, L. Ortombina, and N. Bianchi, “Impact of rotor excitation current during flux-weakening control of hybrid-excited permanent magnet synchronous motor,” *IEEE Transactions on Industry Applications*, vol. 61, no. 1, pp. 313–321, 2025.

[10] E. Kasagga and A. EL-Refaie, “Recyclable electrical machine designs: Current approaches and perspectives,” in *2024 International Conference on Electrical Machines (ICEM)*, 2024, pp. 1–7.

Davide Barater (Senior Member, IEEE) received the Ph.D. degree in Information Technology in 2014 from the University of Parma Italy. He is currently Associate Professor at the University of Modena and Reggio Emilia, Italy. His research area is focused on power electronics and electrical machines for e-mobility and motor drives. He is the Coordinator of the European Project AUTO-MEA that aims to develop novel solutions for windings structures based on hairpin technology for improved power density, efficiency and increased frequency operation. He is Vice-Chair of the IEEE Industrial electronics society Electrical Machines Technical Committee and Associate Editor of IEEE Transactions on Industry Applications.

Shafigh Nategh (Senior Member, IEEE) received the Ph.D. degree in electric power engineering from KTH Royal Institute of Technology, Stockholm, Sweden. He was a Visiting Scholar with the University of Illinois at Urbana-Champaign, Urbana, IL, USA, from 2012 to 2013. From 2013 to 2015, he was a Lead Designer of PM machines for marine segment with the Rolls-Royce Group, Trondheim, Norway. He continued his career as a Designer of traction motors for railway applications with Bombardier Transportation, Västerås, Sweden, from 2015 to 2018. He was an R&D Senior Engineer with E-mobility Department, ABB AB, Västerås, Sweden, in 2018–2020, and Principal Engineer with Volvo Cars, Göteborg, Sweden, in 2020-2022. During this period, he held a position as Adjunct Associate Professor at Chalmers University of Technology. He was a Senior Principal Engineer and also Manager of Electric Drive Unit CAE and Electromagnetic Design with Polestar, Göteborg, Sweden. He is currently an Electric Motor Expert at Huawei Research Center. Dr. Nategh is a Chair of IEEE IES Electrical Machines Technical Committee, Associate Editor of IEEE Transaction on Industrial Electronics, and technical Chair/Co-chair of several electrical machine conferences.

Tianjie Zou (Member, IEEE) received Ph.D. degree in electrical engineering from the Huazhong University of Science and Technology, Wuhan, China, in 2018, respectively. In 2018, he joined the Power Electronics, Machines and Control (PEMC) Group, University of Nottingham, UK, as a Research Fellow. He transited to academic role in 2023, and he is currently an Assistant Professor with the Department of Electrical and Electronic Engineering, University of Nottingham. His main research interests include design, analysis, and intelligent control of electric machines, with special attention paid on advanced winding-integration technology in high-speed, high-power PM and reluctance type machines for future electrified transportation. He was the recipient of 2023 Second Prize Best Paper Award from IEEE Transactions on Transportation Electrification.

Mauro Di Nardo (Member, IEEE) received the M.Sc. (Hons.) degree in electrical engineering from the Polytechnic University of Bari, Bari, Italy, in 2012, and the Ph.D. degree in electrical machine design from the University of Nottingham, Nottingham, U.K., in 2017. From 2017 to 2019, he was with the AROL spa leading the RD team focusing on electrical drives design for mechatronics applications. Between 2019 and 2023, he was with the Power Electronics and Machine Control Group of the University of Nottingham as Research Fellow. He is currently an Assistant Professor in electrical machine and drives with the Polytechnic University of Bari, Italy. Dr. Di Nardo serves as an Associate Editor for the IEEE OPEN JOURNAL OF INDUSTRY APPLICATIONS AND IEEE TRANSACTIONS ON ENERGY CONVERSION.