

Tutorial on

Thermal Management of Electrical Machines - Fundamentals and Advancements

Tutorial Presenter

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Biography of the Presenter



Rafal Wrobel received the M.Sc.Eng., Ph.D., and Habilitation degrees in electrical engineering in 1998, 2000, and 2013, respectively. He is currently a Principal Research Associate at Newcastle University, UK. With over three decades of engineering and research experience, his work focuses on the multidisciplinary design, modelling, and experimental validation of high-performance electrical machines. He has contributed to the development of physically grounded thermal modelling methodologies, anisotropic material characterisation techniques, and advanced cooling architectures enabling higher power-density and improved reliability in demanding applications. His research integrates first-principles physics, computational optimisation, and targeted experimentation, with emphasis on thermal–electromagnetic coupling and model-informed design. He has led and contributed to nationally and internationally collaborative research programmes in electric propulsion and energy conversion systems. Dr Wrobel is a Senior Member of IEEE and an active contributor to the international electrical machines community through research dissemination, technical committees, and collaboration with industry and academic partners.

Abstract

Thermal management increasingly defines the achievable torque density, efficiency, and reliability of modern electrical machines. As electromagnetic loading rises and machines become more compact, thermal constraints transition from secondary considerations to primary performance limiters. Yet thermal design methodologies often remain inconsistent, insufficiently validated, or poorly transferable across applications.

This tutorial provides a rigorous and experimentally grounded framework for thermal modelling and advanced cooling design in electrical machines. The first part revisits heat transfer fundamentals—conduction, convection, radiation—in the specific context of laminated magnetic cores, impregnated windings, and composite insulation systems. Emphasis is placed on anisotropic thermal behaviour, contact resistance, equivalent material representation, and formulation of physically consistent reduced-order models suitable for design optimisation. Practical strategies for thermal parameter identification and model calibration through targeted experimentation are discussed.

The second part presents research-informed case studies addressing accelerated thermal model formulation, measurement of anisotropic winding properties, standardised methodologies for deriving transferable thermal parameters, and material compatibility within electrical insulation systems. Advanced cooling concepts are critically examined, including direct air cooling, liquid-cooled hollow conductors, winding-integrated channels, and rotor cooling, with discussion of practical integration constraints and theoretical thermal envelope limits.

The tutorial aims to equip attendees with a structured, physics-based approach to reliable thermal design, enabling informed evaluation of advanced cooling architectures and supporting the development of higher power-density, application-ready electrical machines.

Further information

The tutorial is structured as a research-oriented lecture combining foundational principles with application-driven case studies. The first part (~60 minutes) establishes the methodological framework for reliable thermal design of electrical machines, addressing key modelling assumptions, parameter identification challenges, and experimental validation strategies.

The second part builds upon these foundations through focused case studies drawn from research and industrial practice. These examples illustrate common pitfalls in thermal modelling, treatment of anisotropic and interface effects, and integration constraints associated with advanced cooling architectures.

Throughout the session, short discussion points will be incorporated to encourage engagement and critical reflection. The tutorial concludes with a dedicated extended discussion and Q&A session (~30 minutes), providing participants with the opportunity to explore specific technical challenges relevant to their own research or applications. The overall objective is to provide a structured and practically transferable framework for thermal analysis and cooling design, bridging first principles, modelling methodology, and experimental validation.

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