Tutorial on

High-Speed PMSM Design and Drive: Sizing and Feasibility, Multiphysics Optimisation, and Minimum Loss Control

Tutorial Presenters

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Biographies of the Presenters

Rukmi Dutta (S'03-M'08-SM'16) is with the Energy Systems Research Group in the School of Electrical Engineering and Telecommunications, UNSW Sydney. She received the PhD degree in Electrical Engineering from UNSW Sydney, Australia, in 2007 and a Bachelor of Engineering degree also in Electrical Engineering from Assam Engineering College of Guwahati University, India, in 1996. Before joining UNSW, she worked as an Electrical Engineer at CMG Pty Ltd, as a Research Associate at the Institute of Industrial Science (IIS) of Tokyo University, Japan and as an Assistant Manager at Reliance Industry Ltd, India. Her research interests span electric machines and drive systems, electric and hybrid electric vehicles, renewable energy, wireless power transfer, electromagnetics, and power electronics.

Clay (Guoyu) Chu (S'18-M'21) is a Lecturer in Energy Systems with the School of Electrical Engineering and Telecommunications, UNSW Sydney. He received his B.E. degree in electrical engineering and automation from the Shandong University of Science and Technology, China, in 2014, and the M.E. degree in electrical engineering from the UNSW Sydney, Australia, in 2016. After completing his hardware engineering internship at Ventia, he returned to UNSW in 2017 to pursue his PhD in electrical engineering and received it with the Dean's Award in 2021. Dr Chu is passionate about contributing to decarbonization through innovating more advanced electric drive and energy conversion technologies. He has recently been awarded the

Australian Research Council's Early Career Industry Fellowship and the Malcolm Chaikin Prize for Research Excellence in Engineering in 2023 for his research on more sustainable high-speed motor design and drive systems.

Faz Rahman (Life Fellow) is currently an Emeritus Professor in the School of Electrical Engineering and Telecommunications at the University of New South Wales (UNSW), Sydney, Australia, having retired from UNSW in January 2021. His teaching and research are in Electric Machines, Electric Drive Systems, Power Electronics and Energy Systems. His research contributions are in the areas of design and control of high-performance electric drives, with particular focus on design and control of compact IPM synchronous machines with a wide field-weakening range, direct torque, model predictive and sensorless controls. He has played many active roles in the international engineering community through leading roles in professional societies and in the organisation of many flagship technical conferences. He is a frequently invited speaker and has delivered many tutorials, distinguished lectures and keynotes at international forums.

Abstract

Very-high-speed permanent-magnet synchronous machines (PMSMs) are increasingly being sought and used in electrified compressors, turbo-machinery, flywheel energy storage, and transportation systems. Designing these machines is inherently multidisciplinary: electromagnetic sizing is constrained by rotor mechanical stress, thermal limits, high-frequency losses, and inverter voltage/ current capabilities. Moreover, achieving high efficiency and accurate control over a wide speed range requires addressing parameter variation and inverter non-idealities, and often calls for current trajectory selection beyond standard MTPA and flux-weakening strategies.

This tutorial provides a practical, end-to-end methodology for designing and driving high-speed interior PMSMs (IPMSMs). We start with a compact fundamentals recap, then introduce analytical sizing and constraint trade-off mapping for electromagnetic, thermal, and mechanical limits. Participants will be guided through quick-check calculators that screen rotor stress, gearbox selection, voltage margin and dominant loss components, and we show how to embed these checks into a repeatable workflow linking analytical models with finite-element analysis and parametric optimisation.

We then focus on high-speed-specific loss modelling (core loss, AC copper loss, PM eddy loss) and on trajectory control options: MTPA, flux-weakening, loss-minimisation control and hybrid trajectories, with attention to inductance variation, parameter identification and inverter effects such as deadtime and current ripple. Throughout the tutorial, we will use a 100,000 rpm, 5 kW IPMSM with a peak power density of 7 kW/kg as a reference example that we have successfully designed, built, and experimentally

tested to demonstrate the complete workflow from early feasibility checks to validated performance and control implementation. A short case study also highlights system-level impacts using a mechanical speed-reducer model, illustrating the trade-offs between electrical drive requirements and mechanical design choices.

List of contents

- High-speed PMSM landscape and key constraints (speed, voltage, thermal, mechanical).
- Analytical sizing and constraint trade-offs (electromagnetic / thermal / mechanical).
- Rotor mechanical integrity at high speed: stress estimation, bridges/sleeves, safety factors.
- Practical workflow of the design optimisation of a 100,000 rpm, 6 kW IPMSM: quick-check calculators → parametric FEA → optimisation and validation.
- High-frequency loss modelling: core loss, AC copper loss, PM eddy loss; mitigation options.
- Inverter non-idealities at high speed: switching limits, deadtime/current ripple, measurement and calibration.
- Control and drive aspects: MTPA, flux-weakening, loss-minimisation and hybrid trajectories; parameter variation.
- Case study: system-level impacts using a mechanical speed-reducer model