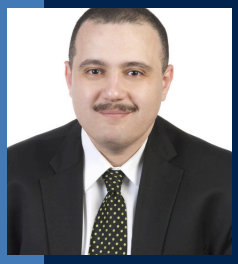
TUTORIAL 5

"High Power Density Motor Equipped with Additively Manufactured Windings Integrated with Advanced Cooling and Modular Integrated Power Electronics"

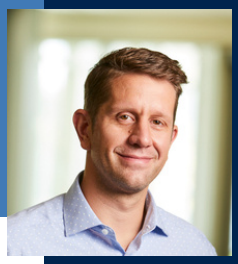
There has been a special focus on aerospace electrification over the past few years. Electric machines and their drive systems have been at the center of these research efforts. Considering the power density and efficiency requirements for aerospace electrification, conventional machine/drive systems might not be feasible for such an application. To that end, the concept of integration of the machine, drive system, and cooling system known as Integrated Modular Motor Drive (IMMD) has been introduced.

On the power electronics side, the possibility of achieving high power density and efficiency is increased by the emergence of the wide band gap devices (WBGDs). Their intrinsic benefits such as low on-state resistance and fast turn on/off speed contribute to lower conduction and switching losses which in turn lead to higher efficiency. However, designing a proper thermal management system, optimized component placement, and optimal PCB layout is challenging due to processing high power at small footprints. On the machine side, the focus is typically on increasing the machine electric and magnetic loading as well as the mechanical tip speed. This can be achieved via novel machine topologies, advanced materials, advanced manufacturing as well as integrated systems with shared advanced cooling.

In this tutorial, the step-by-step design of a motor and its integrated drive system is presented. The advanced cooling system design for both motor and drive system is described. Finally, the overall integrated system is demonstrated, and test results are presented.



SPEAKER
Ayman EL-Refaie
Marquette University



SPEAKER
Nathan Weise
Marquette University

SPEAKER
Ali Al-Qarni
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SPEAKER
Armin Ebrahimian
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SPEAKER
Salar Koushan
Marquette University

SPEAKER
Seyed Iman Hosseini Sabzevari
Marquette University

IEMDC 2025
International Electric Machines & Drives Conference
Houston, TX May 18 - 21, 2025

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BIOS

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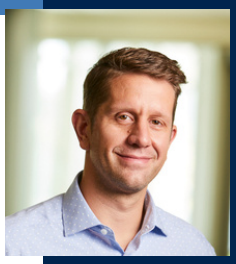

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Ayman EL-Refaie (Fellow, IEEE) received the B.S and M.S degrees in electrical power engineering from Cairo University, Giza, Egypt, in 1995 and 1998, respectively. He received the M.S. and Ph.D. degrees in electrical engineering from the University of Wisconsin-Madison, Madison, WI, USA, in 2002 and2005, respectively. Between 2005 and 2016, he has been a Principal Engineer and a Project Leader with the Electrical Machines and Drives Lab at General Electric Global Research Center. Since January 2017, he joined Marquette University as the Werner Endowed Chair for Energy Sustainability. He has over 160 journal and conference publications. He has 48 issued US patents. At GE, he worked on several projects that involved the development of advanced electrical machines for various applications including aerospace, traction, wind, and water desalination. His research interests include electrical machines and drives. Dr. EL-Refaie was the chair for the IEEEIAS Transportation Systems committee and an Associate Editor for the Electric Machines committee. He was a Technical Program Chair for the IEEE 2011 Energy Conversion Conference and Exposition (ECCE). He was the General Chair for ECCE 2014 and 2015 ECCE steering committee chair. He was the general chair of IEMDC 2019. He is the past chair of the IEEE IAS Industrial Power Conversion Systems Department and currently he is the IEEE Industry Applications Society Publications Department chair.

Nathan Weise (Senior, IEEE) is an associate professor at Marquette University in Milwaukee, Wisconsin. Dr. Weise has extensive academic and industrial experience pertaining to the design, building, and operation of high-power electronics. He was the lead PI of a DOE ARPA-E CIRCUITS program ($632,437) which is focused on high power density, high frequency, and high specific power converters utilizing wideband gap devices. The project developed a 1MW electric vehicle charger that charged an electric vehicle with 200-300 miles of range in two minutes. The project has ambitious goals of 1MHzeffective switching frequency, doubling of state of the art power density and doubling of state of the art specific power. Additionally, he is currently serving as the lead PI of an active DOE ARPA-EBREAKERS program ($500,000). This program focuses on realizing a novel DC circuit breaker for medium voltage systems. The project is developing an extremely fast less than 500 micro-second DC circuit breaker utilizing a novel actuator and current source with SiC and GaN devices. Furthermore, Dr. Weise and Marquette University competed in the Department of Energy Wave Energy prize as the team lead for the electrical engineering design and control system design. The team made it through multiple technology gates, became one of nine finalists, and finished in fifth place overall. Lastly, Dr. Weise was recently awarded, as a Co-PI, a project through the ARPA-EASCEND program which focuses its efforts on producing an all-electric propulsion system for commercial aviation applications.

Ali Alqarni (Student, IEEE) received the B.Sc. degree in electrical engineering from King Khalid University, Abha,Saudi Arabia, in 2015, and the M.S. degree in electrical engineering from the Marquette University, Milwaukee, WI, USA, in 2020. He is currently a research assistant and working towards his Ph.D.degree. His research interests include the analysis, design and optimization of magnetic gears, magnetically geared machines, advanced permanent-magnet machines, and ultra-fast actuators.

Armin Ebrahimian (Student, IEEE) received the B.S. degree in electrical engineering from the Ferdowsi University of Mashhad, Mashhad, Iran in 2014, and the M.Sc. degree in electrical engineering from Shahrood University of Technology, Shahrood, Iran in 2017. He began pursuing his Ph.D. at Marquette University, Milwaukee, WI in 2019. He has co-authored more than 18 conference papers and also has co-instructed tutorials and seminars in APEC, ECCE, and IEMDC. His current research interest includes design and digital control of high power density power electronic converters, Wide Band Gap Devices applications in power electronics, transportation electrification, and variable frequency drives.

Salar Koushan (Student, IEEE) received the B.Sc. degree in electrical engineering from the University of Tabriz, Tabriz, Iran, in 2014, and the M.Sc. degree from Middle East Technical University, Ankara, Türkiye, in 2020. Since 2021, he has been working toward the Ph.D. degree with Marquette University, Milwaukee, WI, USA. His research interests include the design and optimization of electrical machines, and electromagnetic analyses using FEA.

Seyed Iman Hosseini Sabzevari (Student, IEEE) received the B.S. and M.S. degrees in electrical engineering from the Ferdowsi University of Mashhad, Mashhad, Iran. He is currently pursuing a Ph.D. degree in electrical engineering with an emphasis on power electronics at Marquette University, Milwaukee, WI, USA. His research interests include control of power electronics converters, drive systems, electric vehicles, and the application of WBG devices in power converters.