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Tutorial Title

Electric Propulsion: Challenges and Opportunities

Instructor Team

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Abstract

For better fuel economy and carbon oxide reduction, future aircrafts calls for electric propulsion. Though there have been significant developments in electric machines and power electronics in the last few decades, electric propulsion presents significant challenges and opportunities. At the system level, the high power rating of the electric propulsion calls for higher distribution voltage. Currently, the distribution voltage for more electric aircrafts is limited to 540 V because of partial discharge related issues. In the future, where a single aisle commercial aircraft will require more than 10 Megawatt of propulsion power, the electric power distribution voltage is expected to reach as high as 4 kV, which presents a significant challenge in the system architecture and insulation designs. At the sub-system level, to realize high fuel economy, electric machines and power electronics drives are expected to have ultra-high power densities of 14 kW/kg and 25 kW/kg, respectively, which requires significant innovations in material, device, machine structure, power electronic packaging, control and thermal management. This tutorial will start with an introduction of different types of turbo and hybrid propulsion systems and state-of-the-arts of power electronics and electric machines for aircrafts. Then the tutorial will first focus on the partial discharge phenomena at low air pressure and how it will affect the designs of power electronics and electric machines. On the topic of integrated high power density motor drives, the tutorial will first introduce the state of the art high specific power electrical machines for various sectors of the aviation hybrid/electric space. Difference in requirements and challenges for each sector will be discussed. The pros and cons of different machine topologies including various stator structures, winding configurations and rotor configurations will be discussed highlighting key opportunities and challenges. Key factors in terms of achieving high specific power such as advanced thermal management and advanced materials will also be introduced. Then, the development status of SiC devices and megawatt level power converters will be discussed. A case study based on state-of-the-art commercially available SiC power modules will be presented as an example. The high power density partial discharge free design together with test waveforms will be presented. Thermal management of the integrated motor drive for electric propulsion will also be discussed in detail. Specific challenges in thermal designs for aerospace applications will be introduce first. Then multiple advanced thermal design approaches for integrated electric machines and power electronics will be discussed in detail. The last part of the tutorial will provide the final update on the development of the 2-kV 1-MVA integrated motor drive for electric propulsion. Final test results that were achieved at NASA's NEAT facility will be presented. Problems and lessons learned will be discussed too. Though the material presented in this tutorial is aerospace

application oriented, the knowledge presented on high power density electric propulsion systems can be extended to many applications where high power rating, high power density and high efficiency are expected.

Instructor Team Biographies

Dr. Jin Wang (IEEE Fellow) is a Full Professor at The Ohio State University. Dr. Wang has over 200 peer-reviewed journal and conference publications and 9 patents. His research interests include wide bandgap power devices and their applications, high-voltage and high-power converter/inverters, electrification of transportation and integration of renewable energy sources. Dr. Wang initiated and served as the General Chair for the 1st IEEE Workshop on Wide Bandgap Power Devices and Applications in 2013. Currently, Dr. Wang serves as the Chair for the Technical Committee on Aerospace Power at the IEEE Power Electronics Society and an Associate Editor for IEEE Transactions on Power Electronics and IEEE Journal of Emerging and Selected Topics in Power Electronics (J-ESTPE).

Dr. Thomas M. Jahns (IEEE Fellow, NAE Member) is a Grainger Professor of Power Electronics and Electric Machines at the University of Wisconsin – Madison. A member of the US National Academy of Engineering, Dr. Jahns is a recognized international authority on high-performance permanent magnet (PM) synchronous machines. Before joining UW in 1998, Dr. Jahns worked 15 years for GE Corporate R&D (now GE Global Research) where he was a leading researcher on motor drives and power electronics, including leadership of a “more-electric aircraft” initiative to develop high-power-density power converters and machines for several demanding aerospace applications including integrated starter/alternators.

Bulent Sarlioglu is a Jean van Bladel Professor with the University of Wisconsin-Madison and the Associate Director of the Wisconsin Electric Machines and Power Electronics Consortium. From 2000 to 2011, he was with Honeywell International Inc.'s Aerospace Division, Torrance, CA, USA, most recently as a Staff Systems Engineer. His expertise includes electrical machines, drives, and power electronics, with a particular emphasis on electrification of transportation and industrial applications. He is the inventor or co-inventor of 20 U.S. patents and many international patents. In addition, he has more than 200 technical papers that are published in conference proceedings and journals. Dr. Sarlioglu was the recipient of the Honeywell's Outstanding Engineer Award in 2011 for his outstanding contribution to aerospace, the NSF CAREER Award in 2016, and the 4th Grand Nagamori Award from Nagamori Foundation, Japan, in 2018. Dr. Sarlioglu is the recipient of the IEEE PES Cyril Veniott Award in 2021. Dr. Sarlioglu became a fellow for the National Academy of Inverters in 2021 and IEEE Fellow in 2022.

Dr. Patrick McCluskey (Ph.D., Materials Science and Engineering, Lehigh University, Bethlehem, PA) is a Professor of Mechanical Engineering at the University of Maryland, College Park and the Division Leader for Electronic Products and Systems. He has over 20 years of research experience in the areas of thermal management, reliability, and packaging of electronic systems for use in extreme temperature environments and power applications. Applications have included wind turbines, hybrid electric vehicles, and aerospace generators. Dr. McCluskey has published three books and well over 100 peer reviewed technical articles.

Dr. John Kizito is an Associate Professor in Mechanical Engineering at North Carolina A&T State

University in Greensboro with research portfolio in thermal management of electromechanical systems of the Air Force Research Lab (AFRL) in Dayton, Ohio. Dr Kizito has numerous awards including membership to Translation to Space Exploration Systems Panel of the Decadal Survey on Space (National Academics of Science, Engineering and Medicine), NASA faculty fellow and four NASA team achievement awards from NASA Glenn Center in Ohio. Also, Dr Kizito serves as the Campus Director for NASA/NC Space Grant.

Dr. Julia Zhang is an Associate Professor at The Ohio State University. Dr. Zhang has three years' automotive industry experience with Ford Motor Company and is currently leading multiple projects on megawatt level electric machines for electric propulsions. Her research interests include the design of high power density, high torque density AC electric machines for vehicle systems, robotic systems and renewable energy generation systems, modeling and control of AC electric machine drive systems.