Review of Reaching the Full Potential of Integrated Machine Drives (IMD)

Dr. Thomas M. Jahns led a comprehensive, technical presentation on Integrated Machine Drives at the IEEE Madison PES/IAS Joint Chapter virtual meeting on October 29, 2020. The event was co-sponsored by the Milwaukee PELS Chapter. Dr. Jahns is a Grainger Professor of Power Electronics and Electric Machines in the Department of Electrical and Computer Engineering. He is the Director of the Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC), a university/industry consortium with over 85 international sponsors.

Electric machines use 55% of the electrical energy followed by lighting at 21%. The purpose is to change the paradigm of conventional Adjustable-Speed Motor Drives (ASDs) to IMDs. The presentation will illustrate how we can meet application performance and raise efficiencies which in turn will lower CO2 emissions.

Early Landmarks

One of the earliest applications of integrated power electronics was in the 1960's with automotive alternator rectifiers. In 1983 the F/A-18 jet plane had a 40 kVA Variable-Speed Constant Frequency (400 Hz) with a 6-phase generator. The generator had 36 thyristors. From the 1990's to today we have had several manufacturers providing industrial-grade integrated motor/drives. The controllers were in a separate module mounted to the motors up to 10 kW. Automation of servo drives occurred in 2007 with the ability to daisy-chain the connection of the drives with a hybrid cable for performance and communication.

Progress in Hybrid- and Battery- Electric Dives

The Prius Synergy drive began in 2000 and the physical integration of the power split transaxle merged into the same assembly in 2004. The power electronics improvements were overcoming thermal and vibration extremes. In 2012 the Tesla Model S had a 325 kW IGBT inverter mounted in a rear-wheel transaxle assembly together with geartrain and induction machine. By 2014 the traction drive had a sintered planar interconnection without wire bounds and has shared water cooling. Efforts are now progressing for IMDs moving to multi-megawatt power ratings for use in hybrid-electric aircraft propulsion systems. It may not be too long before there are shorter regional, hybrid-electric flights. NASA has an experimental aircraft named X-57 Maxwell in progress.

IMD Vision and Challenges with Wide Bandgap Semiconductors and Current Source Inverters

One of the next steps is to have the control functions implemented wirelessly without the need for the more fragile control wiring. There are several key technical challenges: lower cost power electronics, higher power density for lower mass and volume, higher temperature environments (200° C), vibrations tolerance, and higher reliability. The frontier is pushing the maturity of the Wide Bandgap (WPG) power switches with beyond the present domain of Silicon with Silicon Carbide (SiC) and Gallium Nitride (GaN). High temperature power electronics will be able to penetrate further into the applications of lighting, solar PV, motor drives and automotive. For instance, changing a 200 kW Si-IGBT inverter to a SiC-MOSFET has 4 times the power density and the loop cooling eliminated. The inclination to replace the Si power switches with SiC or GaN in Voltage Source Inverters (VSI) creates complications. One should re-consider of using Current Source Inverters (CSIs) for future IMDs for better characteristics for: EMI, mass, efficiency, high-temperatures, and fault response. In conjunction with ARPA-E a next generation IMD is in progress. The Year 3 prototype, CSI IMD is rated at 3 kW, 230 v, 3ph and has 3 times the power density of a state of the art VSI. The Year 3 performance is meeting and/or exceeding performance expectations. The total current THD is less the 1.5%, efficiency at 98%, mass and volume density targets are being exceeded, and EMI is less than 95 dBµV over the full regulated range of 150 kHz to 3 MHz.

Future IMD Technology Directions

The power converter continues to penetrate hostile thermal and vibration environments. This is being done with improved converter integration technology. The new power electronics engineer needs a team to simultaneously consider the competing demands of efficiency, EMI, thermal management, cost, power density and reliability. This a great opportunity for teams of difference disciplines such as, electrical, mechanical, and materials to work on the integration challenges.

Conclusions

IMDs are the most promising paths to achieve the full potential of ASDs. WBG power semiconductors combined with CSI technology is the path for going forward. The fulfillment of the new IMD will take a multi-disciplinary approach. It is time for current-source inverters to be re-considered and rise again!

The September 2020 issue of IEEE Power Electronics magazine contains the article, “The Incredible Shrinking Motor Drive” by Thomas M. Jahns and Bulent Sarlioglu. For more information one can contact: T. M. Jahns at jahns@engr.wisc.edu.

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