Monitoring Power Module Degradation via Lifetime-Varying Parameters

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Abstract

This tutorial introduces and breaks down thermal response monitoring and degradation diagnosis techniques especially applicable to power electronic modules. Such monitoring technologies are essential in next-generation integrated power electronic systems that require reduced size, weight and cost while ensuring highly reliable operation over ever extending lifetimes. The introduced methodology ultimately enables realization of predictive maintenance strategies that utilize power converters fully until critical degradation thresholds are reached. They allow operating lifetimes of power conversion systems to be maximized or optimized according to engineering and availability constraints.

Degradation mechanisms in power electronic modules occur at material interfaces in large part due to mismatches in thermal expansion coefficients. Resulting thermal cycles periodically induce strain at these material interfaces which, in turn, leads to fatigue, i.e., crack growth and delamination. In many cases, the growth of cracks and delamination occurs within the primary heat dissipation path of a power device, thus altering thermal response. The presented scheme of detection, localization, and overall quantification of different degradation mechanisms is based on systematically monitoring lifetime-varying electrothermal response properties and parameters. This tutorial has the objective to present and clarify details of the many promising research approaches that have been recently proposed to realize in situ health monitoring and diagnosis.

After establishing motivation, this tutorial reviews electrothermal modeling approaches especially applicable to power modules and examines typical electrothermal response characteristics. Moving forward, it details thermal real-time monitoring systems that combine temperature data, extracted via sensors and temperature-sensitive electrical/optical parameters, with 3-D real-time models. It is demonstrated how the fusion of model and sensor data can detect abnormal thermal responses, which are linked to occurrences of degradation.

The tutorial provides an overview on thermal characterization technologies that measure thermal impedance in time and frequency domain. It is analyzed how thermal impedance reflects different degradation mechanisms and can serve as the focal point of a scheme to localize and quantify these mechanisms. Addressing the broad array of implementation options, the final part of the tutorial investigates real-time technologies that can extract life-time varying thermal parameters, in particular thermal impedance, during normal converter operation. It finally shows how extracted degradation sensitive data can be utilized for degradation diagnosis using artificial intelligence technologies.

Instructor Biography

Christoph H. van der Broeck received the B.Sc., M.Sc. and Ph.D. degree in electrical engineering from RWTH Aachen University, Germany, in 2010, 2013 and 2018. Between 2011 and 2013 he was with AixControl GmbH, Aachen. From 2011 to 2012 and 2017 to 2018 he joined the Wisconsin Electric Machine and Power Electronic Consortium (WEMPEC) at the University of Wisconsin-Madison, USA, as a Fulbright and DAAD scholar. After completing his Ph. D. degree, he became chief engineer and head of the Reliable Power Electronics Group at the Institute for Power Electronics and Electrical Drives at RWTH Aachen. In 2020 he joined FEV Europe GmbH in Aachen as Senior Technical Specialist for power electronics and electrical drives. He has authored more than 40 technical articles and received two IEEE Prize Paper Awards for his work. His research interests include multi-physics modeling, monitoring and control of power electronics and drive systems. At previous ECCE conferences he organized two tutorials on reliability-oriented modeling, monitoring and control as well as control design for power converters.

Timothy A. Polom earned a B.S. degree from Michigan State University in 2013, and M.S. and Ph.D. degrees from the University of Wisconsin-Madison in 2016 and 2019, all in mechanical engineering. During his graduate studies, Tim worked within the Wisconsin Electric Machines and Power Electronics Consortium and spent time as a visiting scholar at RWTH Aachen University's Institute for Power Electronics and Electrical Drives. During his undergraduate studies, he conducted research at IIT Madras and RWTH Aachen through study abroad programs. He has industrial experience from roles at General Motors, Detroit Diesel, Loc Performance Products, and Delta Electronics. While at University of Wisconsin-Madison, Tim had teaching assistant roles for control theory and electric machine drive control laboratory courses. Tim's current research interests involve dynamic modeling, control, power conversion, and thermal engineering. Since December 2019, he has been scientist in the division of power electronics at Silicon Austria Labs GmbH in Villach, Austria.