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ONLINE MONITORING OF IGBT DEGRADATION FOR ENHANCED RELIABILITY IN RAILWAY TRACTION SYSTEMS

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Summary: As highlighted in [1], the railway passenger market has demonstrated sustained growth, reaching 429 billion passenger-kilometres in 2023, in Europe. This consistent demand underscores the need to maintain strict timetables and control operational costs, despite challenges posed by harsh electrical operating environments.

The typical life cycle of railway vehicles averages 15-30 years between major maintenance cycles. However, with increasing railway usage, managing maintenance schedules and reducing in-line breakdowns have become significant challenges. These factors point to the growing importance of status monitoring and preventive maintenance practices. Furthermore, the modernization of older vehicles introduces additional stress on newer power semiconductors, such as IGBTs. These components are more susceptible to voltage spikes in older, more inductive circuits compared to GTO technology, which was more tolerant but has been phased out.

As discussed in [2], railway power semiconductors operate under demanding conditions, including high voltage, high current, and large temperature cycles, leading to various failure modes. While some failures occur suddenly, many involve progressive degradation that eventually leads to failure. This degradation can be monitored through two key metrics: threshold voltage and saturation voltage. Saturation voltage provides critical insights into junction temperature and other accessory data, making it a valuable indicator for quantifying the life cycle of an IGBT module.

This paper proposes using online VCE (collector-emitter voltage) saturation measurements to monitor the condition and degradation of IGBTs in traction and auxiliary modules of electric railway vehicles. By implementing this monitoring system, it aims to reduce in-line failures and synchronize maintenance schedules with the actual condition of one of the most failure-prone components in electrical traction systems.

The measurement system focuses on high-voltage, high-power IGBTs (e.g., 6500 V, 1000 A). By measuring saturation voltage with current and ambient temperature, the system calculates the apparent on-resistance of the IGBT. As degradation progresses, the apparent on-resistance increases, signaling potential issues such as bond wire connection loss or other thermally induced failures. Early detection of these problems can prevent converter failure and enhance system reliability.

The developed measurement device compensates for diode losses and thermal measurement fluctuations to detect even minimal variations in saturation voltage. Additionally, the device's power supply complies with railway-specific isolation voltage requirements, while data communication with an onboard recording module is achieved through a fiber optic modulated serial connection. Using pre-existing systems, this data is transmitted to an off-site server for plotting and analysis, enabling the identification of potential malfunctions.

The proposed solution was validated using NomadTech's power modules and data acquisition and transmission solutions as part of an investigation into new auxiliary power converters. This approach facilitated precise saturation voltage measurements and demonstrated the viability of the system in real-world applications

[1] Railway passenger transport statistics - quarterly and annual data - Statistics Explained
[2] A Comprehensive Review Toward the State-of-the-Art in Failure and Lifetime Predictions of Power Electronic Devices