ABSTRACT

Methods for Resolving the Limitations of Degradation Diagnosis

for SiC Power MOSFET

by

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Modern society is in quest of more electric power in various sectors. The rising power demand has driven the development trend of power electronic converters toward higher power density. Power electronic converters, however, are subject to continuous electrical and thermal strains that threatened their reliability. Any unexpected failure can incur unnecessary economic loss or even worse, safety hazards. Semiconductor power devices are the backbones in a power electronic converter, and yet, they are recognized as one of the most failure-prone components. Therefore, early detection of a power device's incipient abnormality due to either aging, electrical stress or defect is crucial.

Degradation diagnosis is a process of identifying an evolving damage before it develop into destructive failure. A variety of degradation diagnosis techniques have been proposed in earlier works. Among them, the time-domain on-state characteristics and thermal path integrity are the most frequently chosen properties as indications of device wear-out. As the measureable electrical variations associated degradation are typically subtle, the measurements are susceptible to system's noise and loading conditions. Besides, as power applications are pursuing higher switching frequency to gain power density, the measurement system are demanding for higher bandwidth and could reach its data rate

bottleneck. For reliable and accurate prediction of developing faults, these challenges must be addressed.

In this thesis, silicon carbide (SiC) MOSFET is chosen as the device for degradation diagnosis study, as it has shown great promise for high power density converter (HPDC) design owing to the excellent material property for high-frequency and high-temperature operation. The practical reliability issues responsible for power device degradation and challenges in degradation diagnosis are investigated. Special solutions are proposed to counter these challenges. Firstly, a voltage monitoring circuit with built-in isolation is proposed and experimentally verified up to 100 kHz. The embedded isolation eliminates EMI influence on the measured data, allows direct processing of the measured voltage information, and relaxes the data rate bottleneck of the data transmission interface of a measurement system. Secondly, a non-intrusive measurement method that measures the on-state impedance of a power device in frequency-domain for degradation diagnosis is proposed. The method overcomes the shortcomings of the conventional time-domain methods, which are easily affected by system’s noise and may have difficulties on detecting subtle electrical changes associated with reliability issues. Finally, a temperature sensor-less method is proposed to estimate power MOSFET’s junction temperature. It has experimentally demonstrated that by means of device saturation current ($I_{d,sat}$) measurement, junction temperature can be estimated either by $I_{d,sat}$, $\sqrt{I_{d,sat}}$, or the extracted threshold voltage.

AUTHOR'S PUBLICATIONS

[1] **H.-C. Yang**, K. Y. See, R. Simanjorang and K. R. Li, "Offline health diagnosis of power device based on non-intrusive inductively coupled approach," *IEEE J. Emerg. Sel. Topics Power Electron.*, accepted for publication. DOI:10.1109/JESTPE.2018.2811753.

[2] **H.-C. Yang**, R. Simanjorang and K. Y. See, "A method for junction temperature estimation utilizing turn-on saturation current for SiC MOSFET," *Proc. Int. Power Electron. Conf. (IPEC-Niigata 2018 -ECCE-Asia),* Niigata, Japan, May. 2018, pp. 2296–2300.

[3] **H.-C. Yang**, K. Y. See, K. J. Tseng and R. Simanjorang, "Real-time integratable isolated voltage monitoring unit of semiconductor power switch to improve power converter reliability," *Proc. IEEE Appl. Power Electron. Conf. and Expo. (APEC)*, Tampa, FL, USA, Mar. 2017, pp. 1614–1619.