

Bond Wire Lift-Off Detection in Power Modules Using Convolutional Neural Networks

マミー, ザットリー

<https://hdl.handle.net/2324/7396269>

出版情報 : Kyushu University, 2025, 博士 (工学), 課程博士
バージョン :
権利関係 :



氏 名 Name : MAMEE THATREE

論文名 Title : Bond Wire Lift-Off Detection in Power Modules Using Convolutional Neural Networks
(畳み込みニューラルネットワークを用いたパワーモジュールのワイヤ剥がれ検出)

区分 Category : 甲

論文内容の要旨 Thesis Summary

This research demonstrated a novel approach for detecting bond wire lift-off in power modules using Convolutional Neural Networks (CNNs) applied to gate voltage waveforms. The study confirmed that CNNs are capable of effectively learning from waveform features to classify lift-off levels with high accuracy. Comprehensive experimentation involving various digital gate control (DGC) strategies and operational conditions (e.g., emitter current, junction temperature, and bond wire lift-off level) was conducted. This research was carried out using three main experimental setups and two types of IGBT modules. The results are summarized below.

Chapter 1. Introduction

The introduction includes a literature review to provide a comprehensive overview of reliability-driven power electronic devices. It covers power cycling failure mechanisms in power devices and identifies key measurement indicators for real-time monitoring. Additionally, it is highlighted that a key challenge in current real-time monitoring technologies lies in the trade-off between detection accuracy and system complexity.

Chapter 2. Fundamentals and background knowledge

This chapter provides the fundamental background necessary to support the research presented in this thesis. It includes an overview of Double Pulse Testing (DPT), DGC, and AI-based approaches relevant to reliability analysis and real-time monitoring.

Chapter 3. Wire lift-off detection

High-accuracy detection of wire lift-off was demonstrated through a combination of CNNs and DGC, using only the gate voltage waveform as an indicator. The results reveal that the waveform is influenced by changes in parasitic inductance, which are caused by the induced voltage. Key sensitivity features identified include the gate voltage spike, spike amplitude, and spike timing shift. Furthermore, sensitivity is enhanced through the use of a digital gate driver employing a two-step vector control (2-sVC) mode. This mode not only improves detection sensitivity but also enhances switching performance by optimizing the trade-off between switching loss and surge voltage.

Chapter 4. Current and temperature detection

As an application of CNNs, highly accurate current and temperature detection was experimentally demonstrated. In contrast to previous experiments, which considered fixed operating parameters, this investigation incorporated junction temperature and emitter current as critical thermosensitive electrical parameters (TSEPs). The results demonstrated that the CNN model can effectively classify variations in junction temperature and emitter current. The inclusion of TSEPs revealed their substantial impact on waveform features, particularly the gate-emitter voltage response. The waveform sensitivity characteristics varied significantly with changes in temperature and current. These variations were successfully captured by the CNN, indicating the model's strong learning capability and adaptability to multi-dimensional parameter spaces. Moreover, the experiment confirmed that switching control strategies significantly affect classification performance. These findings underscore the potential of combining optimized DGC with AI-based learning to enable robust and scalable monitoring of power device degradation under diverse operating conditions.

Chapter 5. Detection of current, temperature, and number of wires

The proposed framework exhibited strong generalization to multiple parameter combinations of sensitivity. This is attributed not only to the influence of bond wire lift-off on the gate-emitter voltage waveform but also to the impact of emitter current and junction temperature, which were accordingly investigated. The results show that evaluation of the CNN model under four different control strategies using two types of IGBT modules achieved the highest testing accuracy, reaching over 99%. The effectiveness of detection is closely tied to the specific characteristics of each module. Therefore, careful selection of control strategies and parameter settings is essential to maximize detection sensitivity. The findings not only validate the feasibility of AI-based condition monitoring but also provide a foundation for future real-time diagnostic systems in power electronics reliability.

In summary, this study demonstrated that wire lift-off in IGBT modules during switching operation can be detected by applying machine learning using a CNN on gate voltage waveforms. It was also shown that detection accuracy can be improved through DGC, while simultaneously maintaining high switching performance. Additionally, it was verified that the module's operating conditions, such as junction temperature and emitter current, can also be detected simultaneously. These results indicate that the proposed method is effective for real-time monitoring.

Therefore, the monitoring method developed in this study is expected to make a significant contribution to reliability and system design technologies, which are essential for the future development of power electronics systems. It is therefore considered an industrially important research effort.