Liu *et al. Green Manuf Open* 2024;2:7
DOI: 10.20517/gmo.2024.032201

Green Manufacturing Open

Editorial

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Health monitoring: the key technology for sustainable utilization of insulated gate bipolar transistors

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How to cite this article: Liu H, Li X, Liu Z. Health monitoring: the key technology for sustainable utilization of insulated gate bipolar transistors. *Green Manuf Open* 2024;2:7. https://dx.doi.org/10.20517/gmo.2024.032201

Received: 22 Mar 2024 **Accepted:** 26 Mar 2024 **Published:** 28 Mar 2024

Academic Editor: Hong-Chao Zhang **Copy Editor:** Pei-Yun Wang **Production Editor:** Pei-Yun Wang

INTRODUCTION

Insulated Gate Bipolar Transistors (IGBTs), as core components in high-power applications, play a crucial role in modern energy conversion and power transmission systems[1,2]. However, facing long-duration high-load operations and complex working environments, these devices may encounter performance degradation and even failure, severely threatening the power system reliability[3]. To address this challenge, health monitoring of IGBTs has become a widely focused research area[4-6]. The core objective is to monitor the operational status of devices in real time and identify any potential failures or performance declines in advance, ensuring the continuous and stable operation of power systems[7]. Their health monitoring has shown great potential in preventative maintenance and device reuse. Accurately monitoring their health status not only extends their lifespan but also promotes more efficient reuse, thereby contributing to sustainable utilization in the power electronics industry[8].

FAILURE MODES OF IGBTS

The failure modes of IGBTs are closely related to the electrical, thermal, and mechanical stresses they endure[9]. On the one hand, voltage and current fluctuations can lead to transient failures. On the other hand, long-duration operation may cause cumulative damage and aging[10]. These failure modes are mainly divided into two categories: chip- and package-level failures. Chip-level failures usually occur instantaneously and are difficult to avoid through traditional condition monitoring methods. Package-level failures in IGBTs, such as bonding wire and solder layer failures, accumulate over time. Therefore, health monitoring of IGBTs mainly focuses on preventing package-level failures.

HEALTH MONITORING METHODS FOR IGBTS

Health monitoring of IGBTs is key to their sustainable utilization, mainly including junction temperature monitoring, electrical parameter monitoring, and life expectancy estimation[11]. Junction temperature-based monitoring approaches involve measuring the junction temperature of IGBT modules using physical contact, infrared thermal imaging, and temperature-sensitive parameter techniques to ensure the reliability of IGBTs and avoid overheating[12]. Electrical parameter monitoring entails measuring and analyzing the electrical characteristics of IGBTs to assess their health status. This monitoring provides real-time information about their health, crucial for averting failures and maintaining stable power system operation[13,14]. Life expectancy estimation of IGBTs employs data-driven methods and physical models to predict their remaining lifespan under normal operating conditions. This prediction is essential for planning maintenance, preventing unexpected failures, and prolonging equipment life[15,16].

SUSTAINABILITY AND ENVIRONMENTAL IMPACT OF IGBT HEALTH MONITORING

The health monitoring of IGBTs not only enhances the longevity and reliability of power systems but also plays a pivotal role in promoting environmental sustainability. Effective health monitoring and reliability prediction of IGBTs directly influence energy efficiency. By preventing failures and reducing downtime, energy loss during power conversion and transmission is minimized. This translates to reduced energy consumption overall, supporting efforts in energy conservation. Furthermore, sustainable utilization and extended lifespan of IGBTs, facilitated by accurate health monitoring, aid in reducing electronic waste. This aspect is critical in the context of environmental protection, as it mitigates the ecological impact associated with the disposal and recycling of electronic components. Moreover, optimizing the operation and maintenance of IGBTs can indirectly contribute to emissions reduction. By ensuring efficient functioning and reducing the need for frequent replacements, the carbon footprint associated with manufacturing and disposing of these components is significantly decreased. Therefore, the health monitoring of IGBTs is not just a technical necessity for power system reliability but also a strategic approach to achieving more sustainable energy practices and reducing environmental impact.

POTENTIAL OF DIFFERENT METHODS IN ACHIEVING SUSTAINABLE UTILIZATION OF IGBTS

Junction temperature monitoring can prevent overheating in a timely manner and enable efficient thermal management decisions. By analyzing temperature trends, preventive maintenance can be initiated, extending the life of IGBTs. Electrical parameter monitoring is crucial for identifying potential problems and preventive maintenance. It helps to respond to abnormal fluctuations promptly, preventing damage to IGBTs, and enables predictive maintenance, reducing the risk of failures and maintenance costs. Life expectancy prediction is vital for recycling and reusing IGBTs, estimating their remaining operational time, guiding efficient recycling decisions, and enhancing the resource recycling efficiency.

FUTURE TRENDS IN HEALTH MONITORING

In the field of IGBT health monitoring, future trends are expected to closely integrate intelligent technology with the concept of sustainable utilization. With the advancement of artificial intelligence and the Internet of Things, more intelligent monitoring methods are expected to emerge. These techniques can monitor the operating state of IGBTs in real time and accurately, using efficient data analysis to predict potential failures, effectively reducing maintenance costs and downtime. Additionally, the integration of preventive maintenance strategies will not only extend the lifespan of IGBTs but also improve the efficiency and reliability of device operation, reducing resource wastage. Moreover, these monitoring methods will focus more on reusing and recycling IGBTs. This intelligent technology lays the foundation for building a more reliable, efficient, and environmentally friendly power system.

DECLARATIONS

Authors' contributions

Conceptualization, methodology, software, validation, data curation, writing - original draft: Liu H
Formal analysis, investigation, writing-review and editing: Li X
Resources, writing - review and editing, project administration, visualization, supervision, funding acquisition: Liu Z

Availability of data and materials

The data supporting the findings of this study are not publicly available due to privacy concerns. However, the data are available from the corresponding author Zhifeng Liu, upon reasonable request and with permission from Anhui Province Key Laboratory of Low Carbon Recycling Technology and Equipment for Mechanical and Electrical Products.

Financial support and sponsorship

This work is financially supported by the Ministry of Science and Technology of the People's Republic of China (No. 2019YFC1908002).

Conflicts of interest

All authors declared that there are no conflicts of interest. Liu Z is an Editorial Board Member of the journal *Green Manufacturing Open*.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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