J. Electrical Systems 20-11s (2024): 1523-1527

[1]**Hirenkumar Brahmbhatt,**
[2]**Dr. Thangadurai N**

Analysis of a New Protection Technique for IGBT using Active Collector Current and Voltage Clamping Method

Abstract: This research presents a new method for protecting semiconductors to improve the availability and reliability of converter or inverter in power electronics systems. The concept involves a newly developed active voltage and current clamping circuit that effectively mitigates IGBT voltage overshoot during short circuit events. This technique controls the IGBT's collector-emitter voltage during turn-off by partially re-activating the IGBT when its collector-emitter voltage surpasses a predefined threshold. By doing so, the IGBT operates in a linear mode, which slows down the reduction rate of the collector current and minimizes overvoltage across the collector-emitter. Additionally, a high-precision Hall-effect sensor continuously monitors the collector current during short circuits, detecting overcurrent and generating a fault signal in less than 2μs. The integrated voltage and current monitoring system significantly lowers the risk of IGBT failures during abnormal conditions.

Key Words: *IGBT (Insulated Gate Bipolar Transistor), Reliability, VCE (collector-emitter voltage), TVS (Transient Voltage Suppressor)*

1. INTRODUCTION:

Insulated Gate Bipolar Transistors (IGBTs) are widely utilized in power electronics due to their numerous advantages, including high switching frequency, the ability to handle high voltages, low on-state voltage drop, and ease of driving in switching circuits. These characteristics make IGBTs essential components in high-power applications such as inverters, where efficient and reliable performance is crucial [1][2].

However, in practical applications, the rapid switching characteristics of IGBTs can present challenges. During the switching-off process, the collector current of the IGBT decreases at a fast rate. This rapid current reduction can induce excessive transient voltage spikes between the collector and emitter terminals due to the parasitic inductance in the circuit. If these voltage spikes exceed the rated collector-emitter voltage of the IGBT, they can lead to device breakdown. This breakdown poses a significant threat to the operational safety and reliability of inverter circuits, potentially resulting in system failures or damage to other components.

Therefore, managing these transient voltage spikes is critical in the design and operation of circuits employing IGBTs. Techniques such as adding snubber circuits, optimizing gate drive circuits, and minimizing parasitic inductance in the layout are commonly employed to mitigate these issues and ensure the safe operation of the inverter systems

In electric vehicles semiconductor switches are critical components within the power electronic system [3][4]. However, their lifespan is significantly shorter than that of the vehicle's overall drive system. As a result, these switches are considered "consumables," meaning they are subject to wear and must be replaced multiple times during the system's operational life, typically before the vehicle reaches 600,000 kilometres or 15 years of use.

This limited durability of semiconductor switches presents a key challenge for EV manufacturers and designers [5]. It highlights the need to optimize the power electronic system to enhance efficiency, reliability, and performance throughout the vehicle's lifecycle [6] [7]. To address this, manufacturers and engineers focus on improving power density, system efficiency, and reliability, ensuring the power electronic system remains robust and contributes to a sustainable and dependable EV driving experience [8].

---

[1]Research Scholar, Department of Electrical Engineering, Sankalchand Patel University, Visnagar, IN
[2]Additional director – Research, Vinayaka Mission's Research Foundation, Salem, Tamil Nadu, IN
1 hirelect@gmail.com , 2 mrgoldspu2021@gmail.com

2. IGBT FAILURE SCENARIOS:

In reliability engineering, the classic bathtub curve of semiconductor devices, illustrated in Fig. 1, provides a comprehensive representation of the failure behavior over the lifecycle of these devices. This curve is characterized by three distinct phases: the early failure stage, the random failure stage during the device's operational life, and the wear-out failure stage toward the end of its lifespan.

The **early failure stage** occurs shortly after the device is deployed and is often attributed to manufacturing defects or material imperfections. Failures in this phase typically decrease over time as defective components are identified and removed.

The **random failure stage**, also known as the useful life period, is marked by a relatively constant and low failure rate. During this phase, failures are typically caused by unforeseen external factors or random operational stresses.

Finally, the **wear-out failure stage** is characterized by an increasing failure rate due to aging and degradation of materials, leading to a loss of functionality. This phase represents the natural end of the device's operational lifecycle.

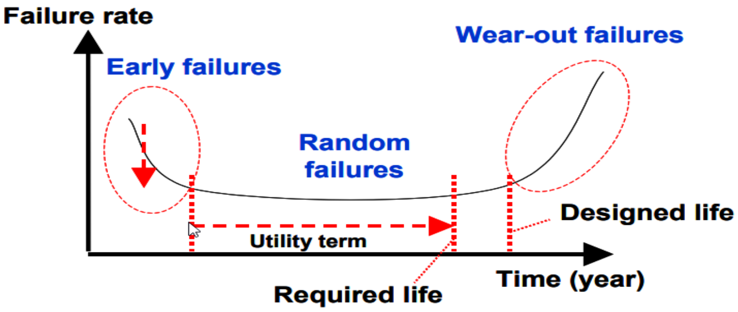


Fig. 1. Typical bathtub curve for IGBT switches

To monitor and manage these failure modes effectively, the IGBT (Insulated Gate Bipolar Transistor) gate driver incorporates protective functions. These protective mechanisms are capable of detecting deviations in random failure rates and identifying early signs of wear-out through parameters such as voltage, current, and temperature variations. By providing timely feedback, these protective features help enhance the reliability and longevity of semiconductor devices in various applications.

Table 1. Failure modes of IGBT modules

External Abnormalities	**Cause**	**Device failure mode**
Short Circuit (Arm Short circuit, output short cir- cuit, Ground short circuit)	Logic circuit malfunction, less dead band, Load short circuit or wrong wiring	Outside SCSOA
Overload	Over current protection error OR logic circuit malfunction	Overheating
Collector over voltage	Excessive input voltage, Failure of sensing circuit OR	C-E Over Voltage
Gate over voltage	Static electric charge OR Volt- age spikes due to long length wire	G-E Over Voltage
Mechanical Stress	Stress from external wiring	Disconnection from circuit

3. CONCEPT OF DYNAMIC VOLTAGE AND CURRENT CLAMPING:

Dynamic clamping is new technique to limit the collector-emitter voltage of an IGBT during the turn-off event. The IGBT is partially turned on as soon as its collector-emitter voltage exceeds a pre-defined threshold. The IGBT is then maintained in linear operation, thus reducing the fall rate of the collector current and therefore the collector-emitter over-voltage.

In the event of an IGBT short circuit, all IGBTs no longer have to be turned off in a dedicated sequence to avoid excessive IGBT collector-emitter voltages. Instead, the dynamic clamping function limits the maximum collector-emitter voltage of the IGBTs to a safe level, enabling the IGBTs to be simply turned off as soon as the fault condition is detected. When the IGBTs are driven with a pulse that is shorter than the response time in the event of a short circuit, the fault is not detected, and the conventional driver turns off too quickly. Hence there are more chances of IGBT destroyed by the resulting over-voltage.

Below Fig.2 shows the simulation model of the proposed dynamic active clamping technique. The simulation is done for 1200V IGBT, which is commonly used in the traction converters of EV application. Considering the availability of the TVS diodes, 400 V diodes are used to create a breakdown voltage of nearly 1200V considering the tolerances. Fig 3(a) shows the waveform of voltage at collector without dynamic clamping. Fig 3(b) shows the waveform with the dynamic clamping of voltage using the TVS diode chain.

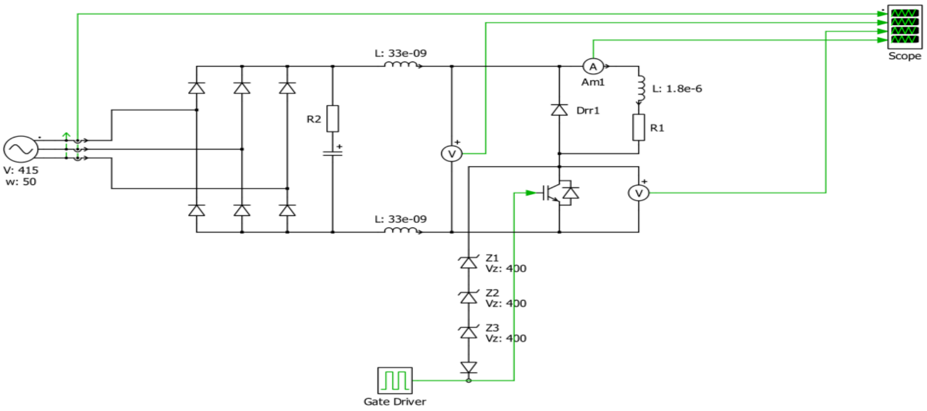
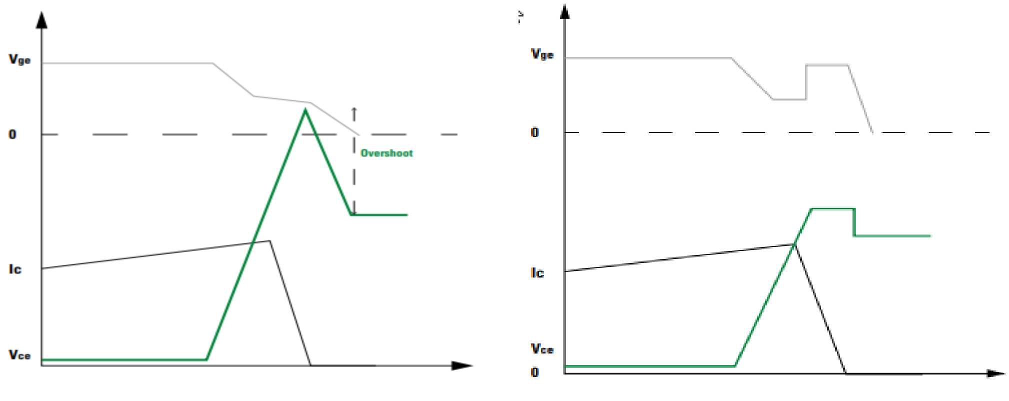


Fig. 2. Simulation model of dynamic voltage clamp using TVS diode chain



(a) (b)

Fig. 3. Vce waveform (a) without dynamic clamp (b) with dynamic clamp

For the purpose of clamping the voltage across IGBT in the situation of a short circuit, this technique makes use of the Transient Voltage Suppressor chain. The selection of TVS is performed to ensure that the total breakdown voltage of the TVS chain remains below the rated voltage of the IGBT. While the on-board current sensor ACS37002LMABTR from Allegro, which measures collector current with great accuracy, allows for collector current clamping. The device is a Hall-effect current sensor housed in an SOIC package. It is factory-trimmed to ensure high accuracy across the entire operating range, eliminating the requirement for any programming. A rapid overcurrent fault output facilitates short circuit detection for IGBT protection, featuring a fault threshold that is proportional to the current range and can be configured using an analog input. Compared to analog sensors, this one has error feedback within 2 µs, which is far faster.

4. SUMMARY

This paper provides a comprehensive analysis of dynamic collector current and voltage clamping in applications that are associated with power electronics. In order to safeguard the Insulated Gate Bipolar Transistor (IGBT) within the system, a gate driver is implemented that employs a dynamic turn-off transient control method. The proposed method is distinguished from the foremost advanced gate drivers presently on the market by its exceptional robustness, affordability, and simplicity of implementation.

The paper addresses a significant challenge related to the selection of a transient voltage suppressor. The component selection procedure is complicated by the fact that the maximal clamping voltage of the TVS is substantially greater than the breakdown voltage. The breakdown voltage is defined within a wide tolerance range, which complicates the precise identification of the optimal TVS component for the system.

This paper introduces a novel approach to dynamically clamping collector current and voltage by employing a specialized gate driver. In comparison to the current sophisticated gate drivers, this approach exhibits superior robustness, straightforward implementation, and significant cost-effectiveness. The inconsistency between the maximal clamping voltage and the defined breakdown voltage range, however, highlights the complexities associated with selecting appropriate TVS components. The results contribute to the advancement of EV power electronics systems and underscore the importance of meticulous component selection to ensure optimal performance and protect critical components, including the IGBT.

5. CONCLUSION

The paper introduces a novel method for dynamic collector voltage and current clamping that employs a specialized gate driver. In comparison to current sophisticated gate drivers, the method provides a high level of robustness, simplicity of implementation, and cost-effectiveness. Nevertheless, it also underscores the intricacy of selecting the appropriate TVS components as a result of the discrepancy between the maximal clamping voltage and the specified breakdown voltage range. These discoveries facilitate the development of EV power electronics systems and emphasize the necessity of meticulous component selection to guarantee the optimal performance and preservation of critical components, such as the IGBT.

REFERENCES:

[1] Dr. D. Graovac, Dr. A. Christmann, M. Münzer, “Power Semiconductors for Hybrid and Electric Vehicles”, 8th International Conference on Power Electronics - ECCE Asia, May 30-June 3, 2011, The Shilla Jeju, Korea.

[2] Naoki Sakurai, Koichi Yahata, “Gate Driver Integrated Circuit for High-Current and High- Speed Insulated-Gate Bipolar Transistors used in Hybrid Electric Vehicle and Electric Ve- hicle Inverters, 2017 IEEE.

[3] Katsumi Ishikawa, Koichi Suda*, Masataka Sasaki and Hideki Miyazaki, “A 600V Driver IC with New Short Protection in Hybrid Electric Vehicle IGBT Inverter System”, Proceed- ings of the 17 International Symposium on Power semiconductor Devices & IC's May 23- 26, 2005, Santa Barbara, CA.

[4] Yan Zhou, Lihua Chen, Shuitao Yang, Fan Xu and Alam Khorshed, “A Low-Cost Gate Driver with Dynamic Turn-off Transient Control for HEV/EV Traction Inverter Application, ©2017 IEEE

[5] Z. John Shen, Ichiro Omura, “Power Semiconductor Devices for Hybrid, Electric, and Fuel Cell Vehicles”, Proceedings of the IEEE | Vol. 95, No. 4, April 2007

[6] Anup Anurag, Sayan Acharya, Yos Prabowo, “Design Considerations and Development of an Innovative Gate Driver for Medium Voltage Power Devices with High dv/dt”, IEEE transactions on power electronics, 2018

[7] Joe Drobnik, Praveen Jain, “Electric and Hybrid Vehicle Power Electronics Efficiency, Testing and Reliability “, World Electric Vehicle Journal Vol. 6 - ISSN 2032-665, Barcelona, Spain, November 17-20, 2013.

[8] Shaokun Zhang, Tao Fan, Xuhui Wen, “Research on High Power Density IGBT Driver Circuit, 2018 21st International Conference on Electrical Machines and Systems (ICEMS) October 7-10, 2018, Jeju, Korea

[9] KangHo Jeong, KiJong Lee, JiWoong Jang,” The Optimized Gate Driver Design Techniques for IGBT Properties and Downsizing in Eco-Friendly Vehicle”, PCIM Europe 2016, 10 – 12 May 2016, Nuremberg, Germany