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Research Article

Analysis of Electromagnetic Disturbance Sources in IGBT and MOSFET Circuits in Common and Differential Modes

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Abstract *–*The development of semiconductors, stemming from advancements in physics, has led to the emergence of a new discipline in electrical engineering: power electronics. This field has introduced innovative methods, excluding rotating machines, to ensure more flexible, efficient, and economical control and management of electrical energy. Systems designed to handle electrical energy are known as static converters. They enable the adaptation, either reversible or not, of the energy form—whether AC or DC—between the grid and the load. However, the use of control components, such as IGBTs and MOSFETs, generates electromagnetic disturbances (EMD). These disturbances can occur in various forms, such as conducted modes (common mode CM or differential mode DM) or radiated modes. The aim of this work is to compare these two switching components and conduct an in-depth analysis using machine learning techniques to study electromagnetic interference in common mode.

Keywords –EMD Electromagnetic Disturbances, CM Common Mode, DM Differential Mode, AC Alternating Current, DC Direct Current.

I. INTRODUCTION

Electromagnetic Interference (EMI) has become a critical concern in contemporary electrical engineering due to the increasing adoption of advanced technologies such as Adjustable Speed Drives (ASDs) and electric motors across various industrial domains [1]–[8]. These systems are integral to modern automation, manufacturing, and energy infrastructure but are also significant sources of EMI. As these technologies evolve, addressing EMI challenges is crucial for ensuring the reliability and safety of electrical systems while adhering to ever-stricter electromagnetic compatibility (EMC) standards.

This paper investigates EMI generation and propagation in motor systems, specifically focusing on disturbances arising in both Common Mode (CM) and Differential Mode (DM). CM interference, characterized by currents and voltages that propagate through unintended paths such as grounding systems, poses a substantial risk to the electromagnetic environment. It disrupts system performance, reduces energy efficiency, and exacerbates electromagnetic pollution. Similarly, DM interference, associated with signal transmission between phases, can undermine the stability of sensitive components and degrade system operations. As global EMC standards demand enhanced mitigation measures, understanding these disturbance mechanisms is fundamental for compliance and for safeguarding the integrity of industrial and energy systems.

The effective management of EMI in systems employing Insulated-Gate Bipolar Transistors (IGBTs) and Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) is critical, given their widespread use in power electronics. These semiconductor devices operate at high switching frequencies, generating rapid voltage and current transitions that contribute to both CM and DM noise. The combined effects of these noise sources can propagate through connected cables and components, necessitating detailed models to analyze and mitigate their impact.

Recent studies underscore the importance of EMI control in enhancing energy efficiency and system performance. For example, Swami [25] highlights the role of precise design standards in optimizing low-power embedded systems while maintaining robust electromagnetic characteristics. Further, investigations such as [26] examine the influence of multilayer driver configurations in high-voltage environments, while [27,28] emphasize the significance of EMI control for the reliability of smart manufacturing systems. These findings emphasize the need for a holistic approach to managing EMI, focusing on both CM and DM disturbances in advanced power electronics.

By addressing the sources and propagation mechanisms of EMI in circuits employing IGBT and MOSFET technologies, this paper aims to provide insights into the development of effective mitigation strategies. These strategies are essential for achieving not only EMC compliance but also the long-term operational stability, energy efficiency, and reliability of modern industrial systems.

Technology plays a crucial role in modern society by facilitating communication, improving workplace efficiency, and providing access to information. However, ethical challenges related to data privacy and excessive dependence on technology must be proactively addressed. The use of semiconductors, particularly in power electronics, plays a critical role in controlling machines, robots, and in fields such as computing. These technologies have become indispensable in modern life due to their ability to optimize energy management and control. DC-DC static converters are widely employed for machine control in both industrial and domestic applications. These systems, especially choppers, utilize power switches such as thyristors, IGBTs, and MOSFETs to ensure proper operation. However, the operation of these systems is often accompanied by the occurrence of electromagnetic interferences (EMI), which can disrupt their performance and that of nearby equipment. These interferences manifest in various forms, conducted disturbances in common mode or differential mode, radiated disturbances, potentially affecting the electromagnetic environment. It is therefore essential to address these phenomena to ensure optimal system performance and compliance with electromagnetic standards [29,30].

II. CONDUCTED EMI MEASUREMENT

These emissions encompass undesired high-frequency currents that flow within the device, along with overvoltage’s that may arise at the load terminals when powered through an extended cable.

To ensure meaningful and repeatable measurements, it is essential to decouple the assembly under test from the power supply network by providing a known impedance through which disturbances can be forced to pass. This is the role of a device known as a Line Impedance Stabilizing Network (LISN), which is inserted between the power supply network and the assembly under test (Fig. 1).

The LISN acts as a filter inserted between the supply network and the input of the equipment under test. Its main functions are as follows:

1. Isolating the equipment under test from the power supply network to prevent external interference,
2. Setting a prescribed impedance at the measurement points to ensure consistent and standardized results,
3. Channeling conducted disturbances to the measurement receiver for analysis.

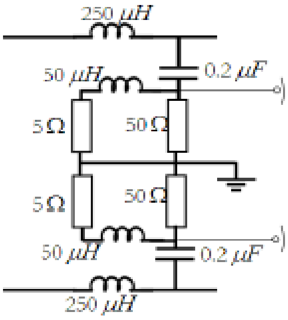

Fig. 1. LISN topology (defined according to the International Special Committee on Radio Interference standards).

Conducted disturbances typically involve high-frequency currents that circulate within the device. The term "high-frequency" generally refers to frequencies ranging from 150 kHz to 30 MHz, as this frequency band corresponds to the limits defined by prevailing EMC (Electromagnetic Compatibility) standards. These disturbances can be analyzed in two distinct modes Common Mode (CM) and Differential Mode (DM), as depicted in Fig. 2.

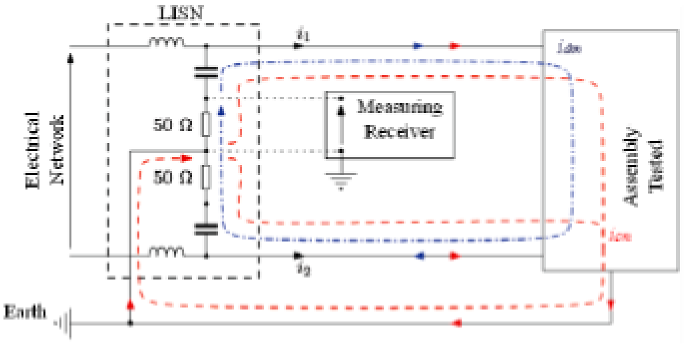

Fig. 2. High-frequency CM (Icm) and DM (Idm) currents

The Differential Mode (DM) current (I_{dm}) characterizes the portion of the current that forms a loop within the power conductors between the power source and the load. This is the primary current path; however, the high-frequency components within it are undesirable. The Common Mode (CM) current (I_{cm}) refers to the portion of the current that flows through the ground wire. This path typically does not participate in power transfer but can carry high-frequency components, especially through capacitive coupling. Regardless of the coupling mode, these high-frequency currents ultimately loop back through the internal impedances of the electrical network, making their measurement dependent on the specific configuration and layout of the network. All power transistors are sources of pollution due to parasitic elements stemming from the power supplies themselves [10-12].

Like most electrical equipment today, they must comply with EMC standards. While their predominant use in the industrial sector may sometimes allow them to bypass these constraints, their increasing application in the tertiary sector means that adherence to these standards is now necessary, or at least should be anticipated. Companies specializing in the design of power supplies and, more broadly, static converters are increasingly confronted with these requirements. Power transistor applications, now common across many service sectors, represent some of the most complex power systems in terms of design and modeling. Each regulatory body has a specific standard for conducting EMC tests, with measurements being carried out according to EN 55022 [19-22]. This standard imposes a precise measurement protocol, which ensures the reproducibility and reliability of measurements performed on the equipment under test. To further explain the process to illustrate the layout of the various system components and the configuration of the normative measurements, we present the synoptic diagram of the test bench in Fig. 3. The conducted emission test configuration adheres to EN 55022. All devices are positioned on a copper ground plane, ensuring proper grounding and minimizing interference. The equipment under test (EUT) is placed on a plane that is electrically isolated from the surrounding area, ensuring that any emissions are properly captured and measured according to the standards.

In the context of conducting a comparison regarding conducted EMI in CM and DM, involving a series chopper associated with a resistive load, two static converters were utilized for reference purposes: the IGBT reference FGH40N60 and the MOSFET reference IRFP4060, along with a BYT12 diode. An experimental setup was established to assess the conducted EMI, where a chopper fed a resistive load at a continuous 24 V voltage level. The primary measurement elements included the LISN connected before the chopper, as well as a spectrum analyzer to measure the conducted disturbances in both CM and DM across various load values.

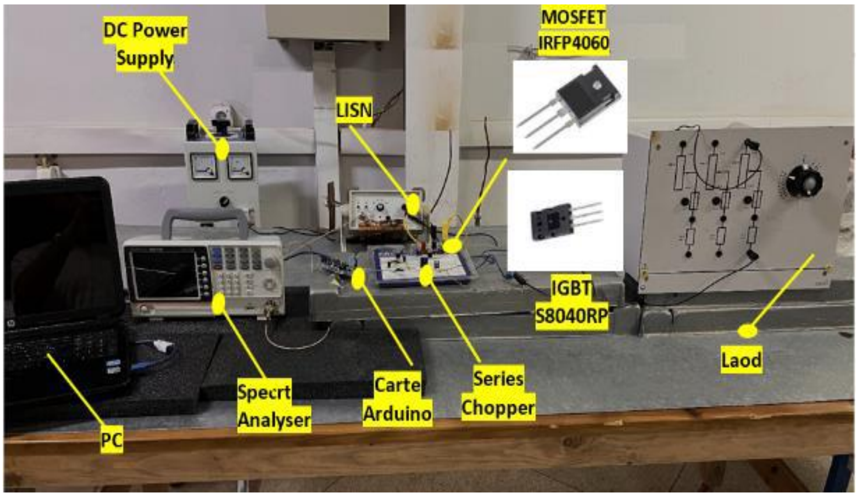

Fig. 3. EMC bench for measuring conducted EMI

In the second part of This Study, to conduct a thorough analysis of the electromagnetic disturbances (EMI), we will utilize machine learning on the results of the measurements. This approach will allow us to identify and better understand the complex behaviors of electromagnetic emissions in the tested system. The main goal is to find the most suitable mathematical model to describe these disturbances, considering the variability of experimental conditions and the characteristics of the devices. Machine learning will provide the opportunity to explore nonlinear relationships and process large volumes of experimental data to extract relevant information. By applying appropriate algorithms, we will be able to optimize the identification of disturbance sources and establish accurate predictions of their behavior under different scenarios. This will contribute to a better understanding of electromagnetic phenomena and the development of strategies to minimize the impact of these disturbances in real-world systems.

III. RESULTS

The most important features and trends in the results should be described but should not interpreted in detail. Fig. 4 show the frequency Spectrum of disturbances after using the MOSFET respectively in common-mode with different loads (50 Ohm, 100 Ohm and 200 Ohm).

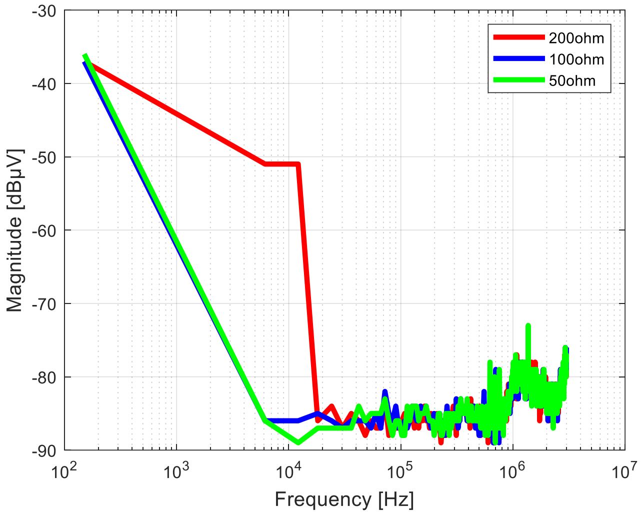

Fig. 4. MC EMI (MOSFET)

The observed common-mode interference patterns for the IGBT power switch for different loads are nearly the same (Fig. 5), except for a spike for both the 50 Ohm and 100 Ohm loads relative to the 200 Ohm load.

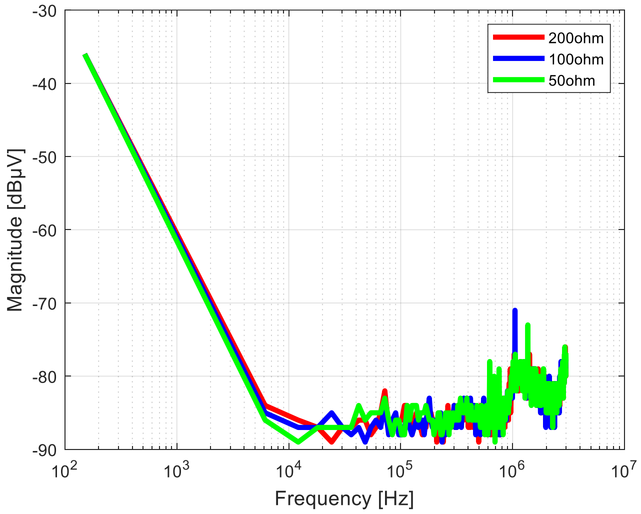

Fig. 5. MC EMI (IGBT)

In Fig.6, both power switches exhibit similar conducted interference for a 50 Ohm load. The only difference is that the IGBT takes longer to transition to the second region than the MOSFET, due to the slower turn-on speed of the IGBT.

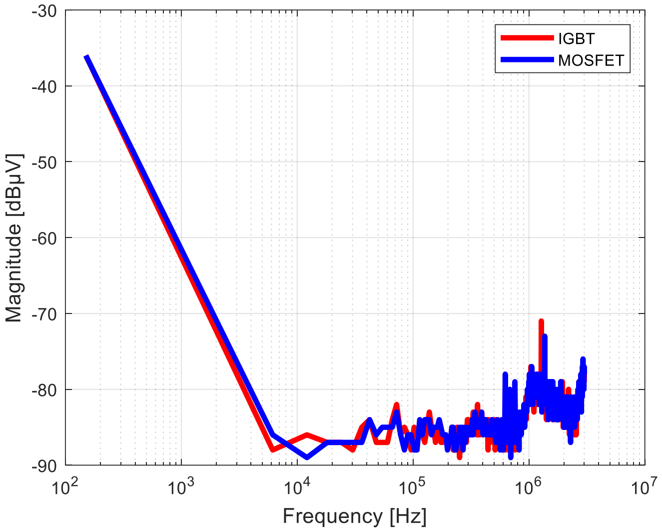

Fig. 6. MC MOSFET/ IGBT for a 50 Ohm load

When the load is increased to 200 Ohms, the conducted disturbances in common mode (Fig. 7) remain the same as those for a 50 Ohm load in both operational regions for both switches.

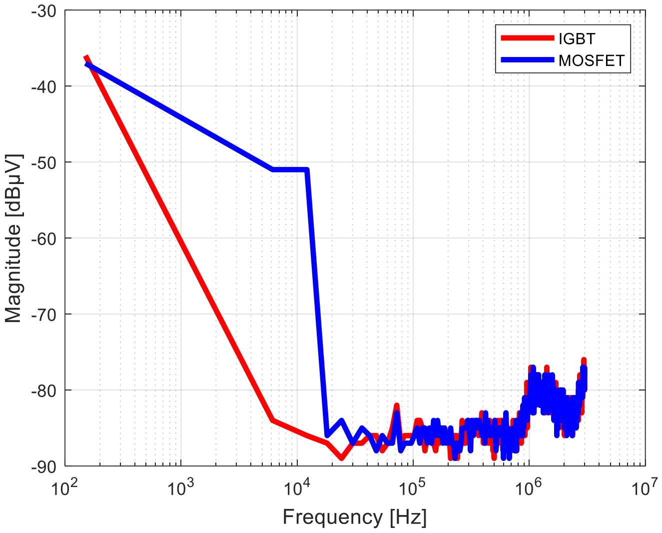

Fig. 7. MC MOSFET/ IGBT for a 200 Ohm load

The results demonstrate a strong agreement between the measured and predicted values, as evidenced by both the regression (Fig. 8) and correlation plots (Fig. 9). The regression plot highlights a satisfactory fit in the mid-frequency range, with the polynomial model accurately capturing the experimental data. However, significant deviations are observed at the extremes, particularly at very low and very high frequencies. These discrepancies can be attributed to nonlinear physical phenomena or parasitic effects in the MOSFET that are not accounted for in the model. The correlation plot further confirms the strong consistency between the measured and predicted values, with most data points closely aligned along the identity line. This indicates the model's ability to reliably represent the overall system behavior. Nonetheless, deviations for extreme values, such as those near -90 dB and -40 dB, emphasize the need to refine the model to better capture these edge cases. Together, these analyses validate the overall relevance of the model while highlighting opportunities for improvement to ensure greater accuracy across the entire frequency range.

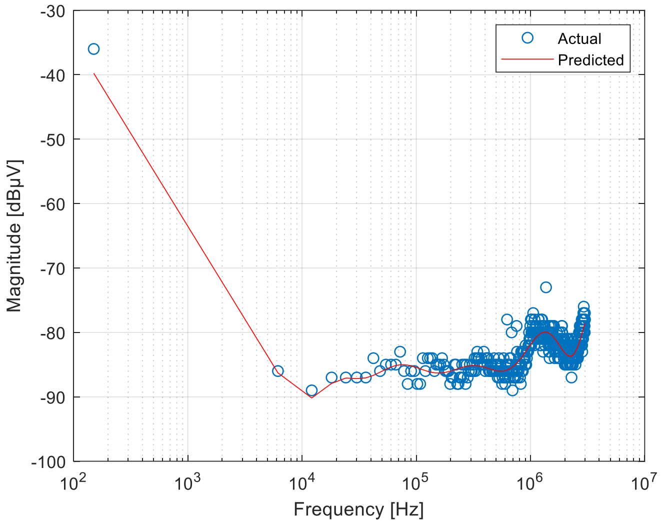

Fig. 8. CM of the MOSFET transistor for a 50Ω load: Polynomial regression.

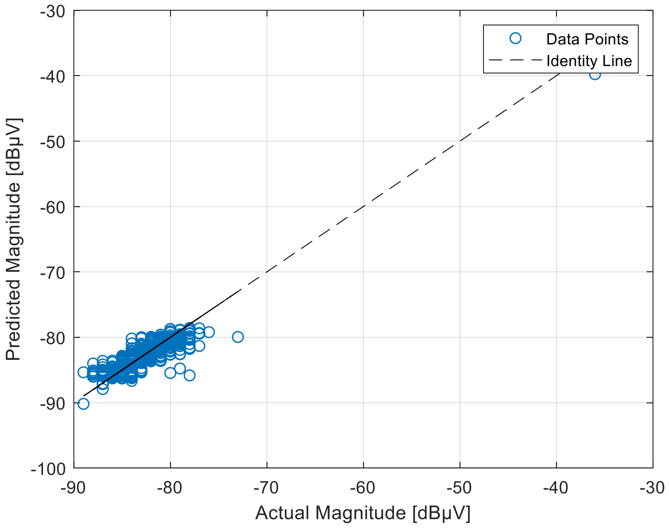

Fig. 9. Correlation of the polynomial regression method

The study on the IGBT under a 200 Ω load highlights both the strengths and limitations of the predictive polynomial model. While the model accurately predicts system behavior in the mid-frequency range (10^4–10^6 Hz), significant deviations occur at low frequencies (10^2–10^4 Hz) and certain high frequencies (10^7 Hz), likely due to unmodeled nonlinear phenomena or parasitic effects. The correlation plot shows strong alignment between predicted and experimental values, though outliers suggest challenges in extreme cases. To improve accuracy, future work could incorporate additional terms to address these discrepancies or explore advanced modeling techniques such as neural networks or hybrid approaches.

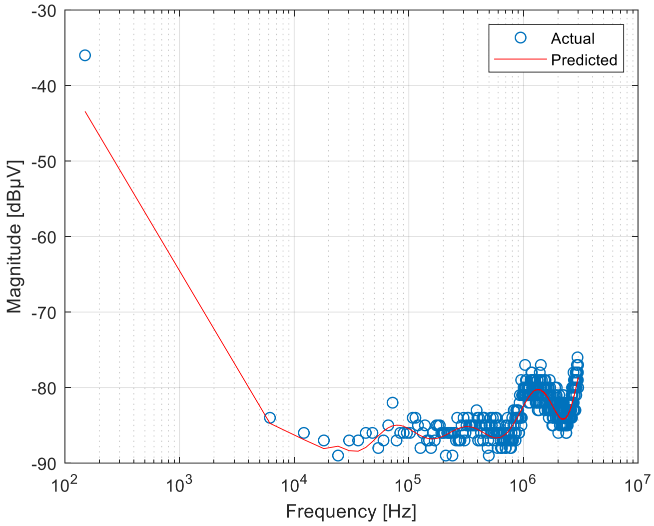

Fig. 10. CM of the IGBT transistor for a 200Ω load: Polynomial regression.

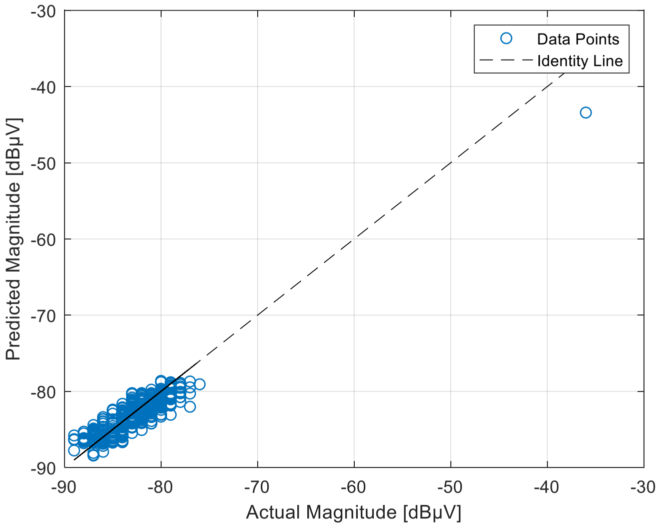

Fig. 11. Correlation of the polynomial regression method.

IV. CONCLUSION

This study investigated the performance characteristics of MOSFETs and IGBTs under varying load conditions and frequencies. The results demonstrate distinct behavior for each device type, emphasizing their respective operational strengths and limitations.

Key findings include:

1- Frequency Response: Both devices exhibit significant attenuation in common-mode signals as frequency increases, with notable variations across different load resistances (50 Ω, 100 Ω, and 200 Ω). The MOSFET shows relatively consistent performance across frequencies, while the IGBT displays more pronounced deviations under higher loads.

Predictive Modeling Accuracy: The regression analysis yielded accurate predictions of the devices' behavior, as evidenced by the close alignment between actual and predicted values. The correlation analysis further validates the model's effectiveness, particularly in capturing the trends for both MOSFET and IGBT data points.

2- Device Comparison: Comparing the two devices under identical conditions highlights the superior stability of MOSFETs at higher frequencies and varying loads. However, IGBTs offer comparable performance in lower frequency ranges, making them suitable for applications prioritizing energy efficiency over high-speed operation.

Overall, this work underscores the importance of load resistance and frequency in determining the optimal choice of semiconductor devices for specific applications. The developed regression model and analytical framework provide valuable tools for predicting performance and guiding design decisions in power electronics systems. Future work may explore the integration of thermal effects and switching dynamics for a more comprehensive assessment.

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