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Impact Analysis of Control Frequency Variations Using SI MOSFETs and SIC IGBTs in Boost Converter

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Abstract — This article aims to conduct a comparative study between different types of MOSFETs based on silicon (Si) and IGBTs based on silicon carbide (SiC). Specifically, three MOSFETs (IRF530, IRF630, IRF730) and one IGBT (APT25GF100BN) were analyzed. The study evaluates characteristics such as V_{DS} and V_{CE} voltages, current during transistor turn-on and turn-off, and examines the impact of varying the frequency of the control signal. Transient process data during activation and deactivation were simulated using LTspice software. The analysis focused on their application in a static boost converter to determine conducted emissions in common mode and differential mode. Results indicate that the choice of MOSFET and the switching frequency significantly influence electromagnetic interference (EMI) noise levels.

Keywords — MOSFET, IGBT, common mode, differential mode, switching frequency.

I. INTRODUCTION

Switching power supplies are widely adopted in modern electronic systems because of their ability to deliver high power in a small footprint, at a competitive cost and with optimal energy efficiency [1-4]. However, their operation at high frequencies and the large variations in current (di/dt) and voltage (dV/dt) associated with fast switching cycles pose considerable challenges for electromagnetic compatibility (EMC). These challenges require specific design measures to mitigate electromagnetic interference (EMI) and ensure the smooth operation of electronic systems in various environments [4-6].

The selection and integration of MOSFETs (metal-oxide-semiconductor field-effect transistors) and IGBTs (insulated-gate bipolar transistors) play a crucial role in EMC management. MOSFETs are valued for their ability to switch rapidly at high frequencies, making them ideal for applications requiring optimum switching efficiency. As majority-carrier devices, they are distinguished by their low on-resistance and fast switching capability, while generating potentially high EMI levels due to abrupt current and voltage transitions. In contrast, IGBTs combine the advantages of MOSFETs and bipolar transistors, offering low on-state voltage drop and the ability to handle high currents, making

them essential for high-power applications. Their use as minority carrier devices gives them increased robustness and better performance in environments requiring high voltages and currents, such as traction systems for electric vehicles and industrial speed variators. [7-10].

Switching converters, integrated in power electronics systems, are significant generators of electromagnetic interference. This EMI manifests itself mainly in the form of conducted disturbances, propagated through electrical conductors, and radiated disturbances, diffused as electromagnetic fields in the air [11-14]. The distinction between these two types of disturbances is crucial for the development of effective EMI mitigation strategies, aimed at ensuring optimal EMC of electronic systems. Careful design and the application of advanced EMI mitigation techniques are essential to maintain the performance and compliance of electronic systems with stringent electromagnetic compatibility standards.

The main contribution of this paper is to determine the impact of the transient parameters of current flowing in the MOSFET for the different types, and IGBT, as well as the voltage V_{DS} and V_{CE} , describing the switching at opening and closing, then the temporal behavior of MOSFET, IGBT as a function of the frequency variation, in the second part, and in the second part we are interested in applying the different types of MOSFET, IGBT on a Boost DC/DC converter, and analyze the electromagnetic disturbances conducted in two modes: common mode, differential mode.

II. TEMPORAL BEHAVIOR OF VOLTAGE AND CURRENT IN SI-BASED MOSFET

Figure 1 shows the electrical circuit used to measure the dynamic characteristics of the MOSFET for the different types IRF530, IRF630, IRF730, and IGBT type APT25GF100BN. In this simulation circuit, the inductance L_1 represents the overall parasitic inductances in the assembly that causes the oscillation when the electronic

switch is opened and closed. The switching frequency is equal to $F = 33.33 \text{ kHz}$ and a duty cycle is equal to 50%.

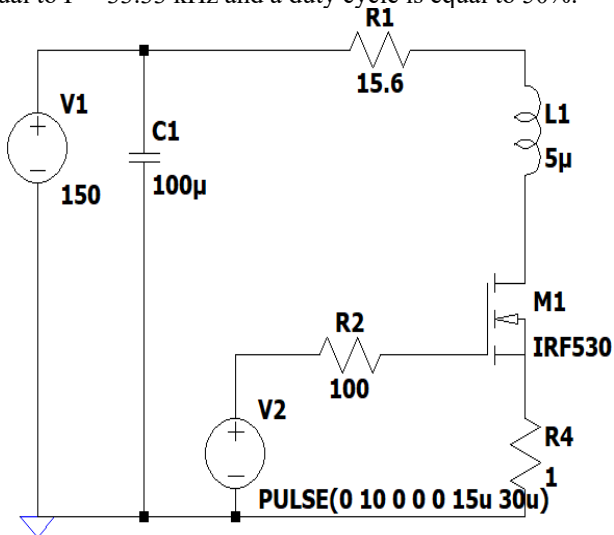


Fig. 1. Diagram of identification of the dynamic parameters of the electronic switches when opening and closing [8].

Figures 2 and 3 highlight the current and voltage characteristics during the turn-on transition for different types of silicon (Si) MOSFETs. An important observation concerns the IRF730 and IRF630 MOSFETs, which show significant current (dI/dt) and voltage (dV/dt) transients during their turn-on switching. These transients can potentially generate high levels of electromagnetic interference (EMI), mainly due to the rapidity with which the current and voltage change during switching. In particular, the turn-on switching induces an initial overcurrent often followed by an oscillatory phenomenon, amplified by the parasitic inductances present in the circuit. These oscillations can contribute to electromagnetic disturbance spikes. In contrast, for the IRF530, the data shows that the voltage rise time is slightly slower compared to the other MOSFET types examined. This suggests smoother switching with less initial surges and post-switching oscillations, which may reduce the levels of EMI generated.

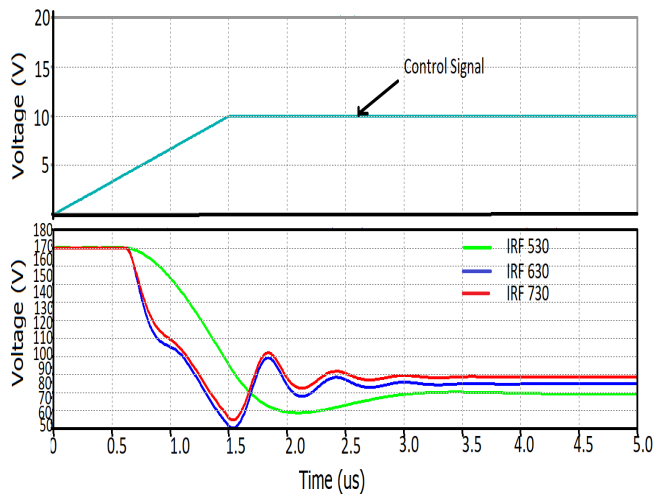


Fig. 2. Voltage at the terminal of the MOSFETs Type IRF with Si base in the case of turn On.

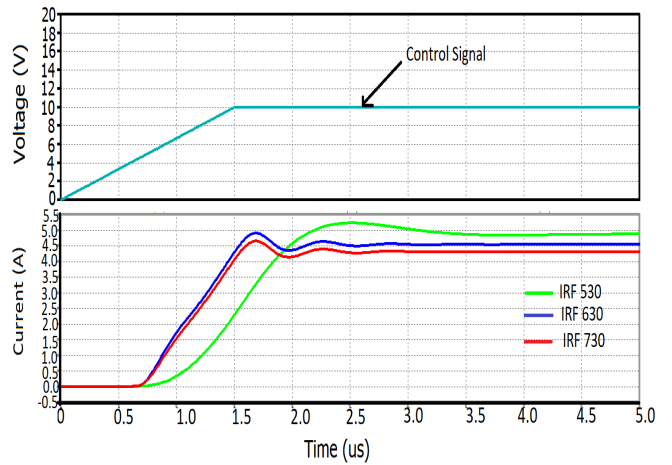


Fig. 3. Current flows in the IRF type MOSFETs in the turn case.

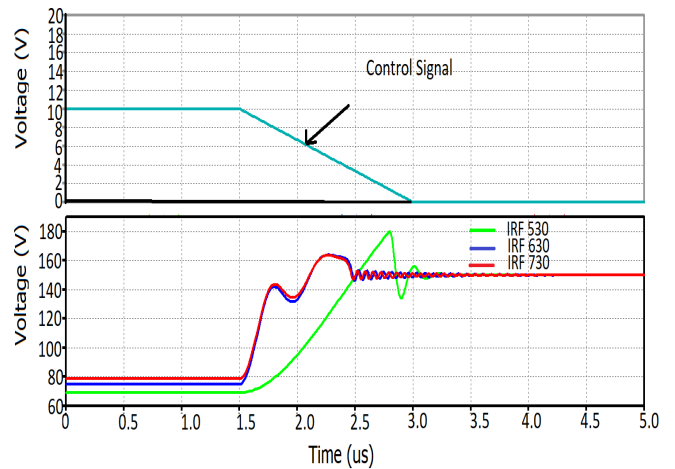


Fig. 4. Voltage at the terminal of the MOSFETs Type IRF with Si base in the case of turn Off.

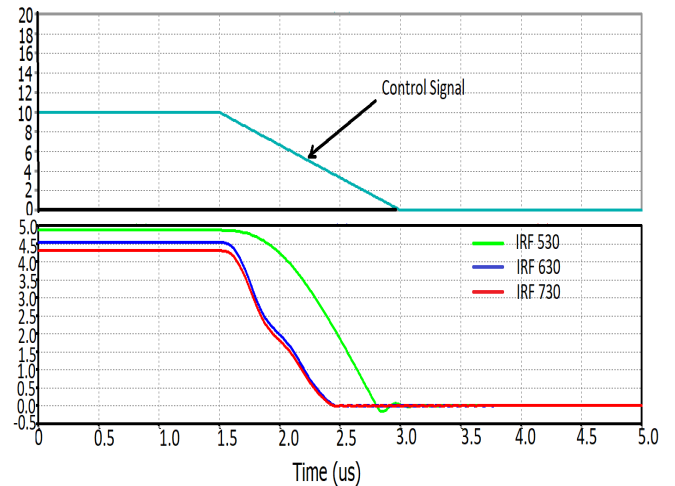


Fig. 5. Current flows in the IRF type MOSFETs in the turn of case.

Figures 4 and 5 illustrate the voltage and current characteristics during the transition from a conductive state to an off-state for different MOSFETs, specifically the IRF630, IRF730, and IRF530. A significant observation is that the IRF630 and IRF730 exhibit very fast voltage rise times, accompanied by marked oscillatory phenomena. This rapidity and oscillation can be attributed to the presence of parasitic inductances in the circuit. In contrast, for the IRF530, the data show that the voltage rise time is slower,

and there is a voltage overshoot up to $V_{DS}=180$ V. In addition, the fall current is also slower compared to the other MOSFETs examined. This observation suggests that the IRF530 has smoother switching dynamics and is less prone to oscillations due to reduced parasitic inductance or better management of energy stored in the circuit..

III. COMPARATIVE STUDY OF CURRENT AND VOLTAGE CHARACTERISTICS BETWEEN IGBT AND MOSFET

In this part, we compared between IGBT and MOSFET type IRF530 in the case of “Turn on” and “Turn off”; we used the same simulation scheme, just replace the MOSFET with the IGBT. Figures 6 and 7 present the simulation result of a comparative study of voltage V_{DS} , and IGBT for VCE, and the current in the case of “Turn On”, or we notice in the case of turn on, the very fast fall time in the IGBT compared to IRF530, with an oscillatory phenomenon in the voltage characteristic. Figure for the current, the very fast rise time in the IGBT than the MOSFET, but the overshoot in the MOSFET larger than the IGBT exceeds 5A.

Figures 8 and 9 show the voltage and current characteristics during the turn-off switching process for a MOSFET and an IGBT. An important observation is that the IGBT shows a very short voltage rise time during switching, often accompanied by an oscillatory phenomenon. However, despite these oscillations, the IGBT does not generate a significant overvoltage. On the other hand, for the MOSFET, a noticeable overvoltage is observed during turn-off, which can be attributed to the rapid switching and the presence of parasitic inductances in the circuit.

Regarding the current, the figure shows that the current fall time in the IGBT is very fast compared to the MOSFET. Moreover, the current in the IGBT does not show significant oscillations after switching, indicating a more controlled switching and a rapid current reduction. In contrast, in the MOSFET, the current fall time is slower and oscillations are visible after switching, which can be problematic in terms of power management and electromagnetic interference

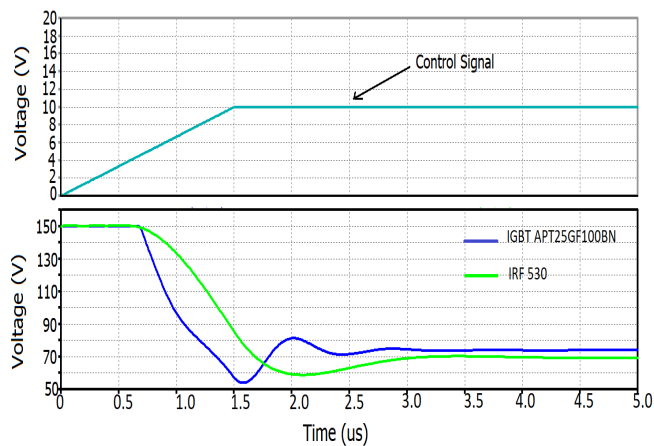


Fig. 6. Comparative study of the voltage at the terminals of the MOSFET and IGBT in the turn-on case.

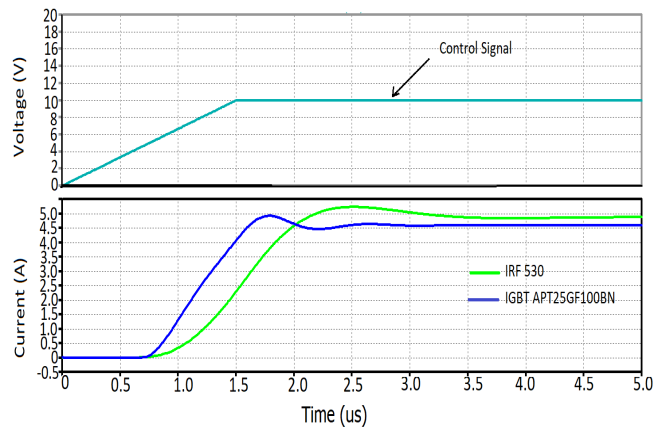


Fig. 7. Comparative study of the current flowing in the MOSFET and IGBT in the case of turn On control signal..

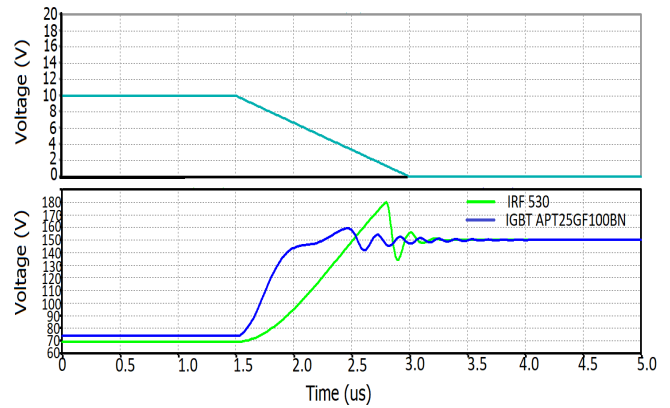


Fig. 8. Comparative study of the voltage across the MOSFET and IGBT terminals in the case of turn Off control signal.

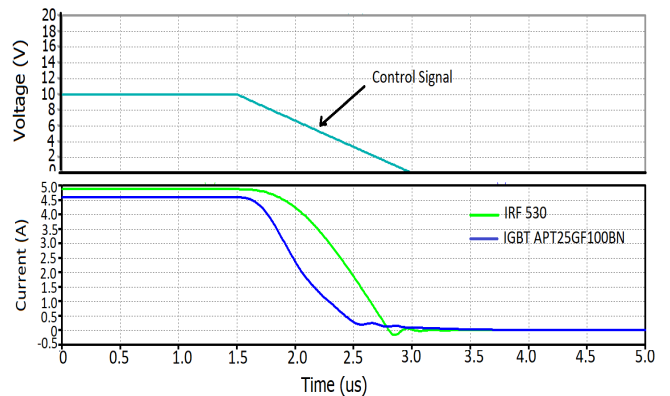


Fig. 9. Comparative study of the current flowing in the MOSFET and IGBT in the case of turn Off the control signal.

IV. VOLTAGE AND CURRENT CHARACTERISTICS IN MOSFET AND IGBT AS FUNCTION OF SWITCHING FREQUENCY

In the third part we studied the impact of variation of the control frequency on the voltage at the terminals of the MOSFET in both cases “Turn On”, “Turn Off”, we take three frequencies: $F = 33.3$ kHz, $F = 25$ kHz, $F = 16.6$ kHz, where we notice that with the increase in the switching frequency of the MOSFET, the time to descend reduces with the increase in frequency in the case of turn on, for the case of turn off, the rise time also reduces with the increase in frequency, with creation of an overvoltage which exceeds 170 V, as indicated

in Figure 10, this phenomenon can be explained by the rapid variation of voltage, with a rapid oscillatory phenomenon

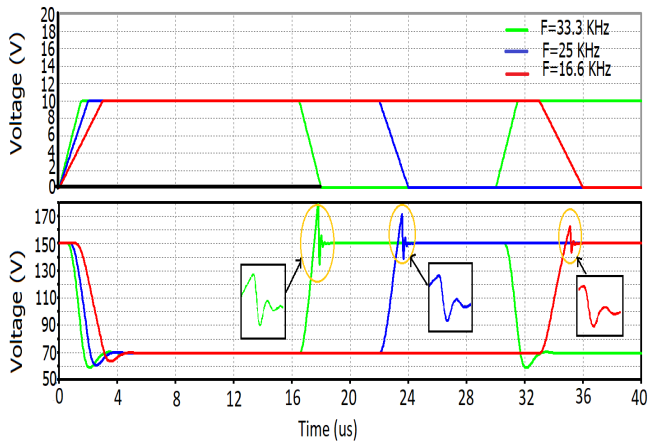


Fig. 10. Impact of varying the control frequency on the voltage across the MOSFET in both cases Turn on, and Turn Off

Figure 11 shows the current flowing in the MOSFET as a function of the variation of the control frequency, where we notice that in the case of turn on, the rise time reduces with the increase in the switching frequency, with an overcurrent due to the rapid variation of current as a function of time, for the case of turn off, the same thing, the time to decrease the current with the increase in frequency, with an overshoot and an oscillatory phenomenon

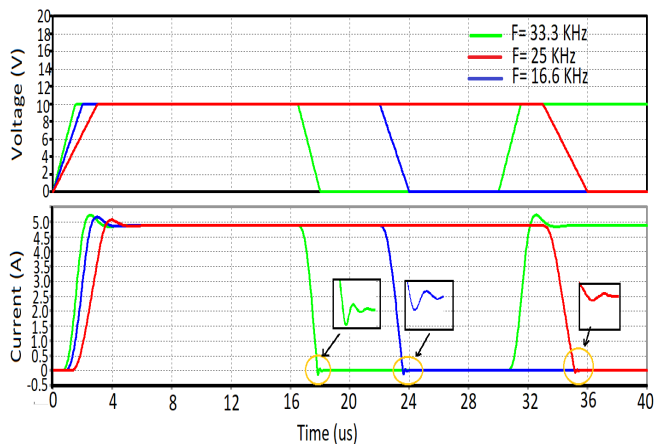


Fig. 11. Impact of varying the control frequency on the voltage across the MOSFET in both cases Turn on and Turn Off

V. VOLTAGE AND CURRENT CHARACTERISTICS IN MOSFET AND IGBT AS FUNCTION OF SWITCHING FREQUENCY

In the last part of this work, we studied the electromagnetic disturbances conducted in two modes as a function of variation of the electronic switch, IGBT, and MOSFET in a DC/DC Boost converter (figure 12), with a switching frequency equal to $F=50$ kHz, and the duty cycle of 50%.

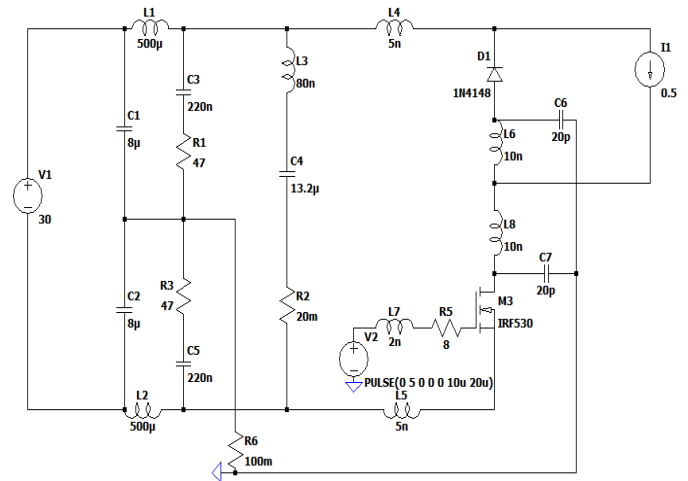


Fig. 12. Boost converter with LISN under Ispice software.

The two-mode conducted electromagnetic disturbances were determined as shown in Figure 13, where it was found that the common mode noise exceeds the differential mode noise in the frequency range 150 kHz and 30 MHz according to the EN55015 EMC standards.

In Figures 14 and 15, the common-mode and differential-mode disturbances are compared according to the type of MOSFET used, namely the IRF530 compared to two other MOSFETs. The observations show that the IRF530 exhibits less pronounced disturbance peaks than the other MOSFETs studied. This difference can be explained by the dynamic characteristics of the MOSFET during switching phases, such as turn-on and turn-off. The IRF530 MOSFET appears to have slower voltage (and current) rise and fall times compared to the other MOSFETs examined. In other words, it takes longer to reach its full conduction (turn-on) and to close completely (turn-off). Even the reduction of unwanted oscillations during switching phases also contributes to an overall reduction of the emitted electromagnetic noise.

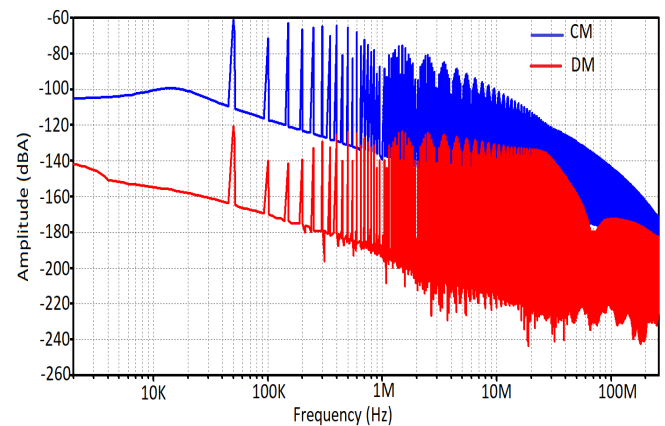


Fig. 13. Electromagnetic disturbances conducted in two modes generated by the Boost converter.

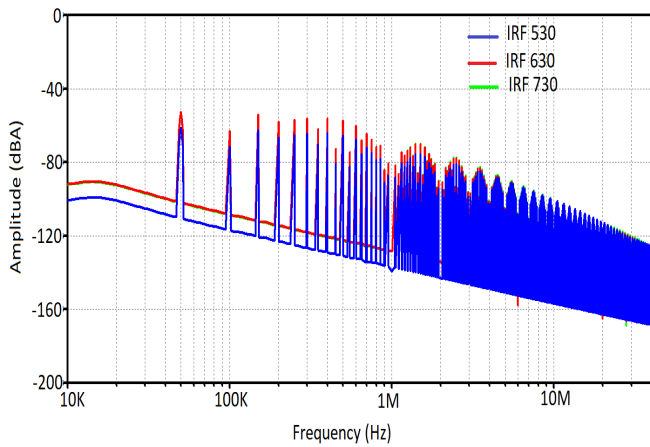


Fig. 14. Common mode as function of different IRF type MOSFETs.

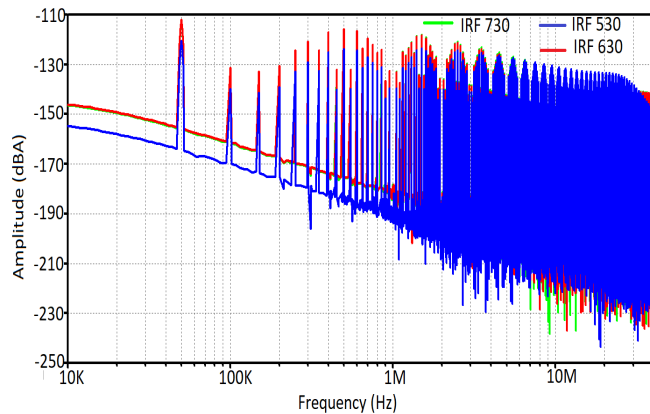


Fig. 15. Differential mode as function of different IRF type MOSFETs.

In this study, we investigated the effect of varying the switching frequency on the MOSFET-driven disturbances. Figure 16 shows the output voltage spectra of the DC/DC converters as a function of different switching frequencies. It is clearly observed that these spectra increase as the frequency applied to the MOSFET increases..

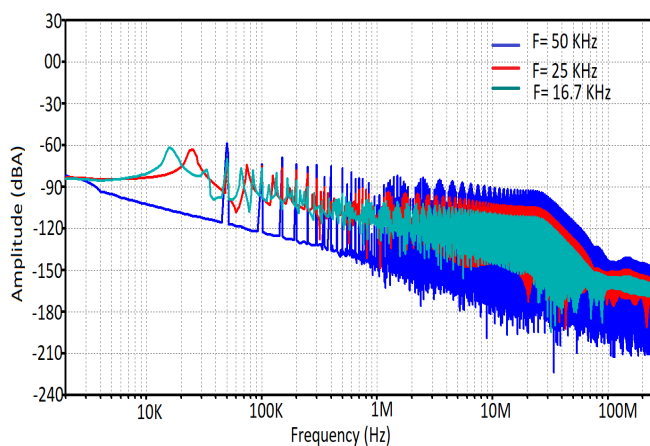


Fig. 16. Frequency variation of voltage at the converter output for different MOSFET switching frequencies

As the switching frequency of a MOSFET in an electronic circuit increases, this has a direct effect on the conducted common-mode and differential-mode disturbances, as illustrated in Figures 17 and 18. By increasing the switching

frequency, the time during which the signal is applied to the MOSFET decreases, often resulting in faster transitions between the conductive and off-states of the transistor. This rapid switching generates steeper voltage and current transients, as well as higher levels of switching noise. In common-mode, where disturbances propagate equally on all signal or power lines relative to ground, increasing the switching frequency broadens the bandwidth of the disturbances. This means that higher harmonics are generated, which can increase the level of electromagnetic radiation. In differential mode, where disturbances manifest themselves as potential differences between signal or power lines, increasing the switching frequency can also influence noise levels. Although differential mode disturbances are generally less sensitive to the forward switching frequency of the MOSFET.

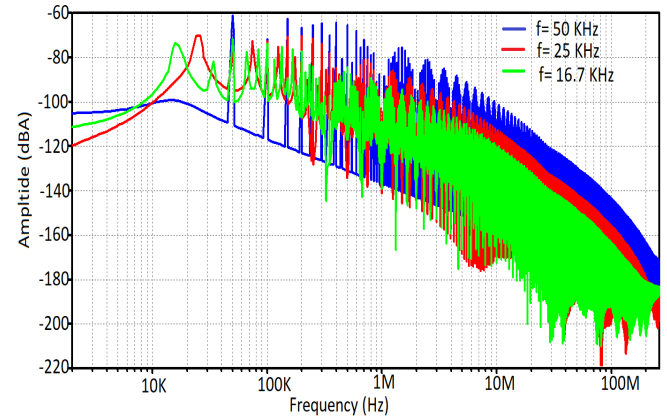


Fig. 17. Common mode disturbances as function of the variation of the switching frequency of the MOSFET

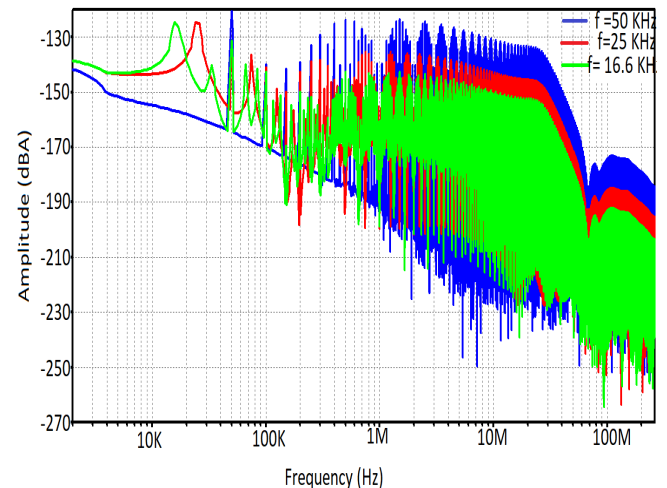


Fig. 18. Differential mode disturbances as a function of the variation of the switching frequency of the MOSFET.

VI. CONCLUSION

In this paper, we studied the impact of switching component selection and switching frequency on conducted electromagnetic interference. We started with a comparative study between silicon (Si) based MOSFETs and silicon carbide (SiC) based IGBTs by determining the dynamic characteristics of the studied components. The following type MOSFET: IRF530, IRF630, IRF730, and IGBT type APT25GF100BN. Then the impact of switching frequency

variation in the turn on and turn off cases. Then an application of these parameters in a boost converter. The results indicate that the component selection and switching frequency significantly influence EMI noise levels, both in common mode and differential mode. In particular, MOSFETs like the IRF530 show smoother switching and less prone to oscillations compared to the other types examined, which could contribute to reducing EMI.

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