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Research Article

Determination of Conducted EMI in SiC Based Dual Active Bridge Converter

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ABSTRACT

Power converters are required to work faster and with higher power density with the developing technology. Therefore, the converter is expected to work in more than one direction. Usage of Dual Active Bridge DC-DC Converter is an example. To increase the power density of the converters, it is necessary to increase the switching frequency. In conventional Si MOSFET based converters, power losses are very high and cause high electromagnetic interferences at high frequencies. These disadvantages lead developers to the use of wide-band gap semiconductor based converters such as SiC However, SiC MOSFETs will also emit electromagnetic interference (EMI) above a certain frequency. In this study, the EMI, emitted at certain frequencies by the Dual Active Bridge (DAB) DC-DC Converter, is simulated by the LTspice. It was observed that the Si-based inverter parts of the DAB converter generate 10 V EMI on the linear base, that means 140 dBμV EMI on the logarithmic base, at 20 kHz. The SiC-based converter does not emit any noise at the same frequency. However, when the frequency was increased to 250 kHz, it was determined that the SiC based converter emitted 2.3 V noise on the linear base, thus 123 dBμV noise on the logarithmic base. This study shows that not only Si MOSFET's but only SiC MOSFET's emit EMI over a certain frequency.

1. Introduction

Conversions from Alternating Current (AC) to Direct Current (DC), DC to AC, or DC to DC are the fundamentals of power electronics. Today, DC-DC converters have especially become mandatory for use in electric vehicles. Examples can be extended from laptops to the LED drivers. Bidirectional Dual Active Bridge (DAB) DC-DC converters are preferred especially in charging systems, micro grids and hybrid energy systems. These converters have high power density and high efficiency due to their lightness and small size. Regenerative braking systems in electric vehicles and multi-source hybrid DC systems in micro grid systems are examples that bidirectional converters are used in. With the developed semiconductor units, bidirectional converters can be used at higher switching frequencies, so it can be provided to have lighter and smaller dimensions, thus achieving higher power density.

In addition to this importance, EMI effects are meaningful according to the usage area of bidirectional converters (CISPR 25 directives). As a result of the review of literature, EMI filter design will be required to suppress this interference. No matter how efficient a device is, it has to be environmentally compatible. Therefore, it should work in accordance with the directives published in its field.

Power converters which are used in large areas such as space applications [1], electric vehicles' chargers [2] and micro grid converters [3] are required to have a more flexible way of working and also are desired to be lighter and smaller.

Those mentioned add to the importance of studies on bidirectional converter circuits. When the evolution of the transducers is analyzed, it is seen that the volume, weight and price of the transformer used to change the voltage level decrease as the switching frequency increases. In addition, it can be seen that the converter interference can be suppressed to a large extent in cases where the switching frequency is

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above 20 kHz [4].

1.1. Bidirectional DC-DC Converters

Bidirectional DC-DC converters (BDC) are the devices which are used for increasing or decreasing voltage with forward or reverse power flow. For example, in electric vehicles, a bidirectional converter should be used to both transmit the power from the battery to the motor and transmit the power from the motor to the battery for charging at the time of braking [5].

Bidirectional converters are divided into two as isolated bidirectional DC-DC converter (IBDC) and non-isolated bidirectional DC-DC converter (NIBDC) according to the presence of galvanic isolation between input and output. NIBDC is a converter that does not use a high frequency transformer to provide electrical isolation between source and load. For this reason, these converters are not used in high power applications due to security necessities. However, these converters are more efficient in low power applications. They are light and easy to control because of the absence of a transformer. Besides, IBDCs have galvanic isolation to protect the source at overload. Therefore, these converters are used in high power units such as hybrid vehicles, electric vehicles and micro grids. Dual half bridge and dual active bridge bidirectional converters are examples of the IBDCs [6]. In this study, a DAB-IBDC is examined because of its high efficiency and more detailed control.

1.2. Wide-Bandgap (WBG) Semiconductors

On electrical vehicles, converters are desired to work not only bidirectional but also more efficiently and with smaller size. However, it is not possible to make the converter both small and efficient with Si MOSFETs. Therefore, in these conditions, WBG semiconductors such as SiC and GaN, which are more efficient [7] and emit less EMI at high frequency [8] [9], are used.

Frequency-efficiency analysis of Si, SiC and GaN semiconductors are shown in Table 1. As seen in the table, the efficiency of SiC and GaN semiconductors also decreases at 200 kHz and above. Besides, it can be estimated that WGB semiconductors emit EMI at these frequencies.

In this study, SiC Based Dual Active Bridge DC-DC Converter is designed on LTspice simulation program. Also, at 200 kHz and above frequencies, emitted EMI is discussed.

Table 1. Material-Frequency Efficiency [10]

Element	Frequency (kHz)	Efficiency (%)
Si	40	98
SiC	100	99
	200	97,5
	250	97,3
GaN	100	99
	200	97,5

2. DAB-IBDC Simulation Design

DAB-IBDC circuit is modelled and simulated by LTspice environments. LTspice contains many units used in switching power supplies, it can run lots of models created by MOSFET manufacturers and makes them all available for free. Therefore, it has a wide user network [11]. In this study, LTspice was preferred for the use of SiC MOSFET models and for the display of real-time dynamic parameters.

2.1. Line Impedance Stabilization Network - Artificial Network (LISN – AN)

Conducted emission tests are operated for determination of EMI on the line. However, unwanted noises can occur between mains and device under test (DUT). LISN is used to prevent unwanted noises. LISN has 4 tasks in the test:

- It increases the impedance between input and ground while decreasing the impedance between input and output at operating frequency. Therefore, it allows power flow from main to DUT.
- It decreases the impedance between input and ground while increasing the impedance between input and output at high frequencies. Therefore, it prevents the noise that causes measurement errors.
- It provides stabilization of the load impedance.
- It allows measurement from both of lines.

In this way, common mode and differential mode interferences can be analysed [12] [13].

In order to simulate the EMC conducted emission on LTspice, it is necessary to add the appropriate LISN circuit to the input of the DAB-IBDC circuit. LISN, which complies with the CISPR22-CISPR25 directives and which is added to the input of the DAB-IBDC circuit, is shown in Fig. 1.

In this study LISN in Fig. 1 is used for all simulations.

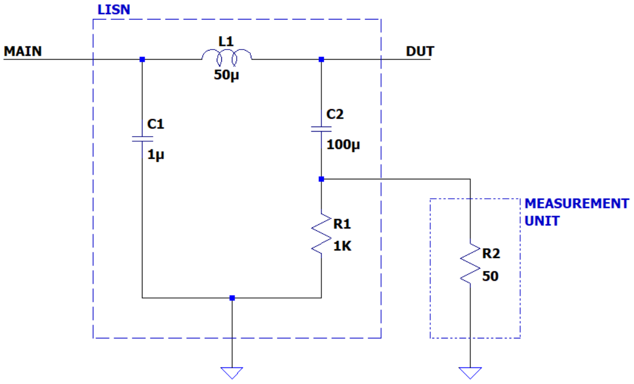

Figure 1. Circuit Structure of LISN for Single Phase

2.2. Si and SiC MOSFET Based DAB-IBDC Circuit Simulation on LTspice

Simulation circuits with Si and SiC MOSFETs at 20 kHz are shown in Figure 2 and Figure 3 respectively. In addition, the EMI emitted by the Si and SiC MOSFET based DAB-IBDC circuits at LISN measurement output port is shown in Figure 4 and Figure 5 respectively.

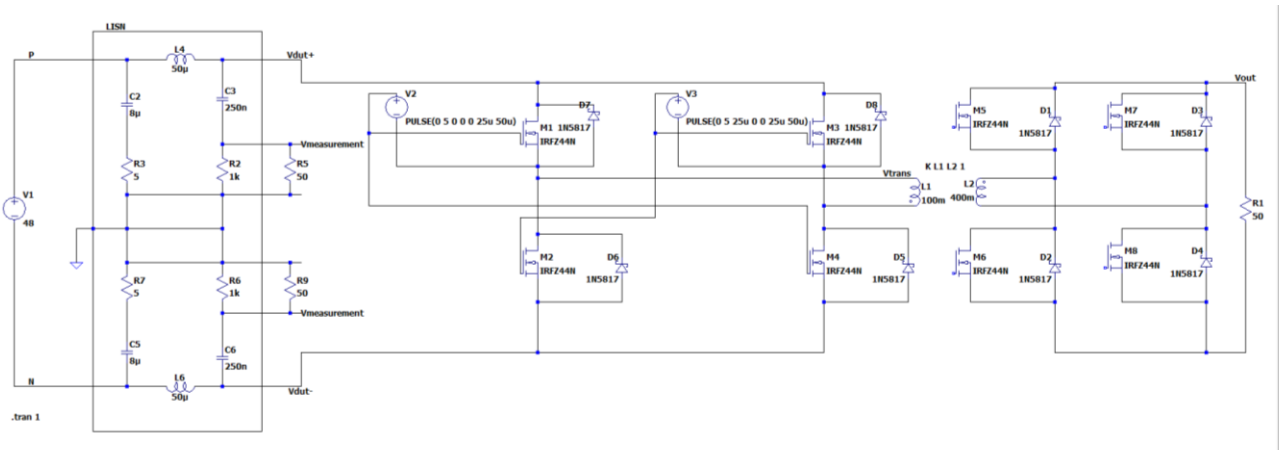

Figure 2. Si MOSFET-based DAB DC-DC Converter Circuit

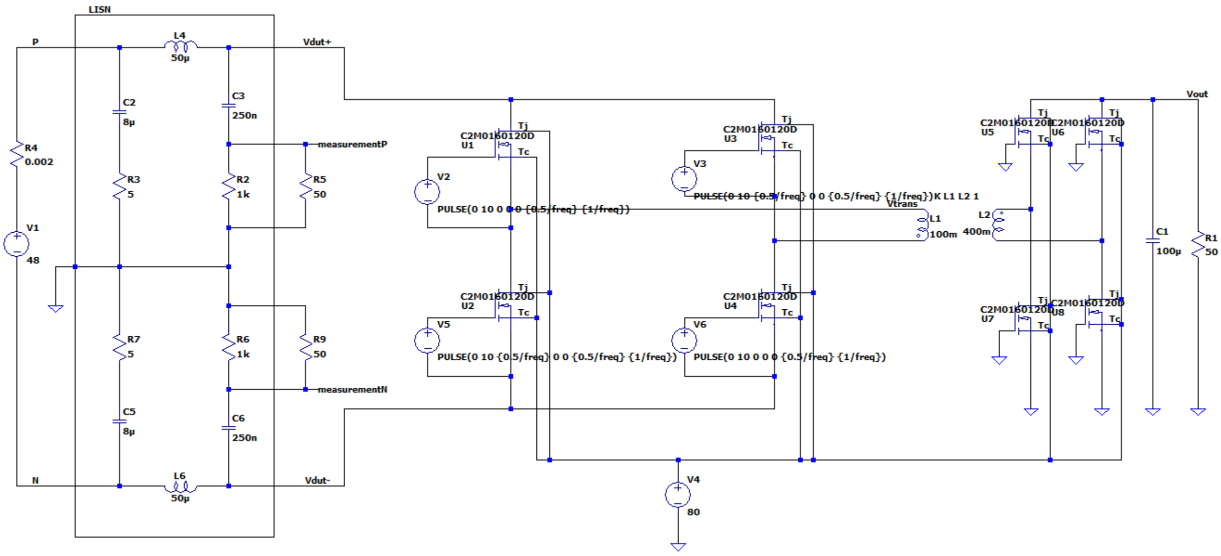

Figure 3. SiC MOSFET-based DAB DC-DC Converter Circuit

The Si MOSFET base DAB circuit operating at 20 kHz emits 10 V (140 dBµV on logarithmic base) conducted emission as shown in Fig. 4. It is known from related directives that the interference should not exceed 46 dBµV at the same frequency. Conversely, the SiC MOSFET base DAB circuit operating at 25 kHz emits almost no emission. However, when the switching frequency of the SiC MOSFET based DAB circuit is increased to 250 kHz, SiC MOSFET circuit also begins to emit EMI. Conducted emission of the circuit is 2,3V (123 dBµV on logarithmic base) as shown in Fig. 6.

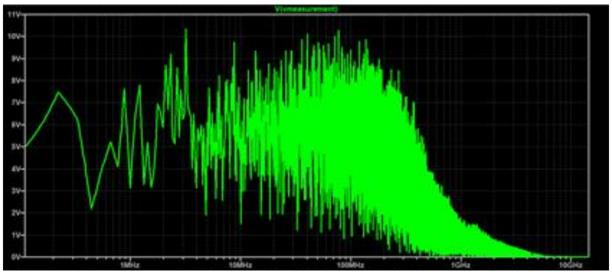

Figure 4. EMI of Si MOSFET-based DAB-IBDC at 20kHz on Linear Base

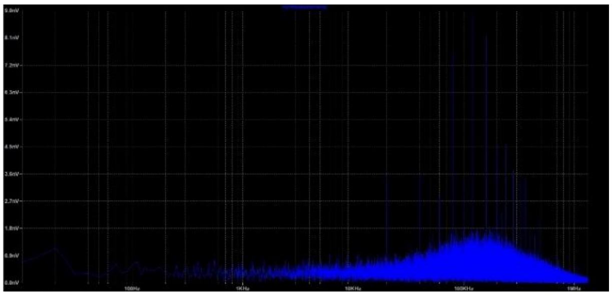

Figure 5. EMI of SiC MOSFET-based DAB-IBDC at 25kHz on Linear Base

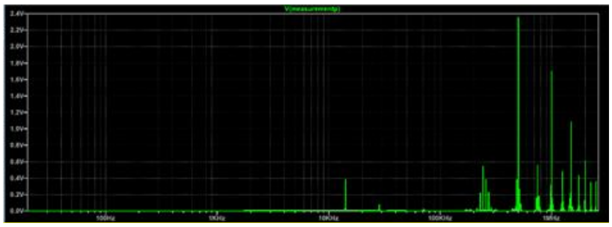

Figure 6. EMI of SiC MOSFET-based DAB-IBDC at 250 kHz on Linear Base

WBG semiconductor, such as SiC and GaN, based MOSFET's will be used on most of power conversion units in the future cause of their high power density and efficiency. Moreover, the power density will be increased by raising switching frequency. But this study shows that the switching frequency has a limit.

Both Si and WBG semiconductor MOSFET's have parasitic capacitances such Cgs, Cds and Cgd cause of their structure. Due to these capacitances and therefore dV/dt ratio, all of MOSFET's can work efficiently up to a certain switching frequency. Even if SiC MOSFET based DAB DC-DC converters work more efficient and emit less EMI than Si MOSFET's at same frequency, these converters emit EMI above the limits set by related standards. This situation is shown on this study. WBG MOSFET's emit EMI above a certain frequency. Thus EMI reduction methods should be applied for DAB DC-DC converters operating at corresponding frequencies.

3. Conclusions

Bidirectional power converters are fast and occupy less space. So they have great importance in both electrical vehicle regenerative power flow systems and micro grid battery systems. The development of bidirectional converters as DAB-IBDC will contribute to increase both power density and efficiency. With using WBG semiconductor technology in bidirectional systems DAB converters will be much more useful. Especially, the statement that SiC MOSFET's can work at higher temperatures and more efficiently than Si based MOSFET's, provide DAB converters operate at higher switching frequencies thus reach higher power densities. However, this study shows that SiC WBG MOSFET based DAB-IBDC circuits also emit EMI above a certain switching frequency.

In this study, when the switching frequency of DAB circuit was 25 kHz no conducted emission was observed. However, when the switching frequency was increased to 250 kHz, EMI occurred at the level of 123 dBµV. This study shows that EMI suppression methods should be applied in SiC MOSFET based DAB-IBDC's above 250 kHz. The study is ongoing. EMI suppression methods such as phase shift modulation and EMI filter circuit are studied. The suppression methods will be applied for detected EMI on simulation. Success of the methods will be analyzed and applied on board. Results will be published.

Author's Note

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