UDC 621.314 https://doi.org/10.20998/2074-272X.2023.4.05

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Experimental study of electromagnetic disturbances in common and differential modes in a circuit based on two DC/DC boost static converter in parallel

Introduction. *An electronic control and closing control at the switch (MOSFET) will allow a parallel connection of two DC/DC boost converters. The reason for paralleling converters is to increase the efficiency of the power conversion process. This means that the overall power loss on the main switches is half the power loss on the main switch of a converter. It has been proven that DC-DC converters operating in parallel have different dynamics than a single converter. In this paper, the study is based on a system of two boost converters operating in parallel under current mode control. Although two converters operating in parallel increase the efficiency of the system, if the control parameters are not chosen correctly, the system becomes unstable and starts to oscillate.* ***Purpose*** *of this work is to present the analysis of high frequency electromagnetic disturbances caused by the switching of power switches in DC/DC boost static converters mounted in parallel in the presence of cables. We will study the improvement of the electromagnetic compatibility performances which can be brought by the choice of a static converters for industrial use.* ***Methods****. For the study of the path of the currents in common mode and in differential mode, it was possible to evaluate experimentally the electromagnetic compatibility impact in common mode and in differential mode of two boost converters connected in parallel in an electric circuit in connection with the source through a printed circuit board of connection between the source and the load, while using the two basic methods, namely the prediction of the conducted electromagnetic interference, the temporal simulation and the frequency simulation.* ***Results****. All the obtained results are validated by experimental measurements carried out at the Djillali Liabes University Sidi-Bel-Abbes in Laboratory of Applications of Plasma, Electrostatics and Electromagnetic Compatibility (APELEC). The experimental results obtained in common mode and in differential mode at low, medium and high frequencies are compared between the parallel boost test with and without electromagnetic compatibility filter.* References 17, figures 10.

Key words: **DC/DC converter; electromagnetic compatibility; conducted emissions; printed circuit board connection; electromagnetic disturbances; common mode; differential mode; high frequency.**

Вступ*. Електронне керування та керування замиканням на перемикачі (MOSFET) дозволяють паралельно підключати два підвищувальні DC/DC перетворювачі. Причина паралельного підключення перетворювачів полягає у підвищенні ефективності процесу перетворення енергії. Це означає, що загальні втрати потужності на головних вимикачах становлять половину втрат потужності на головному вимикачі перетворювача. Було доведено, що DC-DC перетворювачі, що працюють паралельно, мають іншу динаміку, ніж одиночний перетворювач. У цій статті дослідження засноване на системі двох підвищувальних перетворювачів, що працюють паралельно при управлінні по струму. Хоча два перетворювачі, що працюють паралельно, підвищують ККД системи, але при неправильному виборі параметрів управління система стає нестійкою і починає вагатися.* ***Метою*** *даної роботи є представлення аналізу високочастотних електромагнітних перешкод, викликаних перемиканням силових ключів у підвищувальних статичних DC/DC перетворювачах, встановлених паралельно за наявності кабелів. Ми вивчимо покращення показників електромагнітної сумісності, яке може бути викликане вибором статичних перетворювачів для промислового використання.* ***Методи****. Для дослідження шляху струмів у синфазному та диференціальному режимах вдалося експериментально оцінити вплив електромагнітної сумісності у синфазному та диференціальному режимах двох підвищувальних перетворювачів, включених паралельно в електричний ланцюг при з'єднанні з джерелом через друковану плату з'єднання між джерелом та навантаженням, використовуючи два основних методи, а саме прогнозування кондуктивних електромагнітних перешкод, тимчасове моделювання та частотне моделювання.* ***Результати****. Усі отримані результати підтверджені експериментальними вимірюваннями, проведеними у Djillali Liabes University Sidi-Bel-Abbes у Laboratory of Applications of Plasma, Electrostatics and Electromagnetic Compatibility (APELEC). Експериментальні результати, отримані в синфазному та диференціальному режимах на низьких, середніх та високих частотах, порівнюються з паралельним форсованим тестом з фільтром електромагнітної сумісності та без нього.* Бібл. 17, рис. 10.

Ключові слова: **DC/DC перетворювач; електромагнітна сумісність; кондуктивні перешкоди; підключення друкованої плати; електромагнітні перешкоди; загальний режим; диференційний режим; висока частота.**

Introduction. Switching power supplies are widely used in modern electronic systems because they allow a high level of integration, low cost and high efficiency. In the automotive field, the integrated circuits embedded in vehicles for chassis or security applications offer all the power components and control circuits necessary for buck or boost energy conversion (power less than 10 W) [1-4].

Electromagnetic compatibility (EMC) is a scientific and technical discipline which finds its justification today in the problems of cohabitation between industrial systems and their environment. While these problems have always existed, they are now becoming increasingly important due to the concentration in the same environment of devices or systems with very different power and sensitivity levels [1, 5].

Electrical systems based on static converters are designed with an ever increasing level of complexity. Effects on EMC and signal integrity are observed. The presence of a printed circuit board (PCB) connection in a static converter based electrical system is more than necessary nowadays. The EMC design of PCBs plays an important role in the electrical interconnections of any electrical system.

On the other hand, it gives rise to many electromagnetic interferences (EMIs) conducted and radiated. The origin of the latter is related to variations in electrical quantities over short periods of time with high amplitudes and high frequencies [2, 3, 5].

The static DC/DC converter, which is realized with the help of controllable on/off power switches such as MOSFETS, consists of periodically establishing and then interrupting the source-load link by means of the power switch [6-8]. The present work is devoted to the study of low and high frequency conducted electromagnetic disturbances in common mode (CM) and differential mode (DM) generated by two step-up choppers in parallel in the presence of a connection PCB in the electrical study circuit. Thus to highlight the disturbances caused by these converters, we conducted experimental tests on a test bench consisting of a source + LISN (line impedance stabilization network) + cable + connection PCB + cables + + two converter «Boost» in parallel + cables + load.

Our study presents the comparison of the spectral envelopes of the currents at the LISN in CM and DM of the electrical circuit with and without filter for the case of two boosts in parallel.

Disruptive effect of a step-up chopper on a DC voltage source. With the advent of dispersed generation, more and more static converters are being connected to power grids. They inject the electrical power supplied by the generators, but unlike conventional electric systems, they also introduce low and high frequency disturbances. The objective of this experimental research work is to study the EMC impact of MOSFET-based step-up choppers on a DC voltage source in an electric circuit [9]. In order to highlight the principle of creation of low frequency disturbances by the chopper, we considered the basic model illustrated in Fig. 1. This model allows us to determine the LISN current in CM and DM with and without a filter in a mode where the two boosts are connected in parallel.

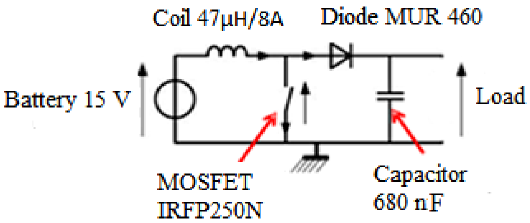

Fig. 1. Boost chopper circuit integrating the elements [7]

Principle of frequency modeling. The boost chopper circuit is shown in Fig. 1. The parasitic inductances and capacitances of the components and tracks are represented and taken into account in the simulation because they will modify the propagation of the HF harmonic currents. These currents are generated by switching the current and voltage. Figure 2 shows the waveform of the switched voltage across the MOSFET.

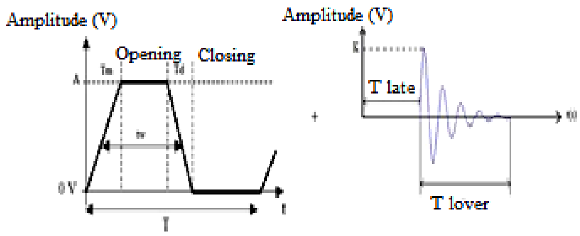

Fig. 2. Temporal model of the disturbance source [8]

This voltage is the sum of a trapezoidal voltage at the switching frequency and damped sinusoidal ripples produced by the parasitic components. The amplitude of this voltage is determined by the V_{DC} bus voltage. The rise and fall times depend on the intrinsic parameters of the power components and the gate resistance of the MOSFET [7, 10]. To realize a boost converter it is necessary to have four electronic components: a coil, a diode, a capacitor and a switch controllable with the ignition and the de-ignition typically a transistor (Fig. 1).

By replacing the diode and MOSFET with voltage sources reproducing trapezoidal and damped oscillatory shapes, we can simulate CM conducted electromagnetic disturbances (Fig. 2). In the literature, it is recommended to replace the switching cell with current sources in the case of DM disturbances [8, 11].

Analysis of high frequency EMC disturbances caused by switching. This work is based on the study of two boost converters in parallel in an electrical circuit connected to the source via a PCB which is loaded by a resistor. One of the two boosts used in the electrical circuit it's essentially composed of:

- MOSFET IRFP250N;
- Diode MUR460;
- Filter capacitor with its parasitic elements.

Disturbing effect of a boost chopper in an electric circuit. The electronic structures of energy conversion are well suited to illustrate the mechanisms of conducted emissions and provide the building blocks for modeling these phenomena. The EMC tends to show that it is necessary to limit the rapid variations of electrical (voltage and current) and electromagnetic fields quantities, whereas switching structures generate brutal variations, at least electrically, to manage the desired energy transfer with lower losses [10]. Indeed, the switching cell, easily identifiable in non-insulated structures, represents the association of two switches, controlled or not. It is the seat of strong voltage and current gradients [12-14].

Average model of the studied system. The model must be close enough to the original system so that the study through the derived model can be performed which is illustrated in Fig. 3. The two boost choppers are connected at the input to a LISN [10] (Fig. 4) via a two-wire shielded connection (cable 1), a connection PCB, cable 2 and cable 3 and at the output, cables 4 and 5 directly connected to the load (Fig. 4).

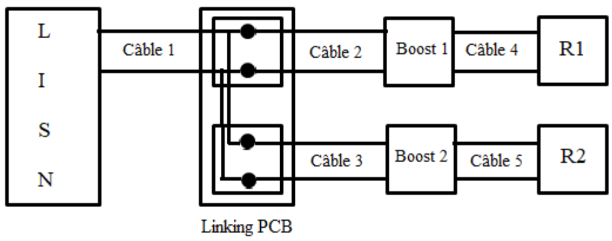

Fig. 3. Block diagram of studied model

For different types of cable lengths upstream and downstream from the PCB, which is intended for the connection of cables to supply two static boost converters in parallel loaded by two resistors there are several structures for an LISN. The one used in this work is shown in Fig. 4. It is compatible with international standards and is the structure available in the laboratory for the experimental tests carried out [15-17].

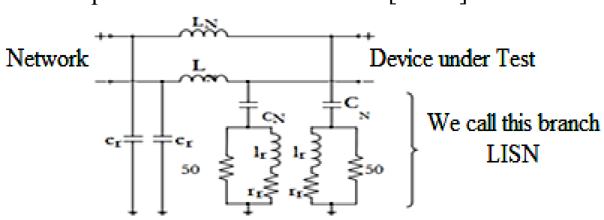

Fig. 4. Line impedance stabilizing network [10]

This paper presents the operation of two DC/DC boost converters in parallel and what problems this can cause without changing the cable lengths. Finally, the possible solutions will be presented, especially the one applied in this study, which worked well.

Experimental results for sum test measurement (both boosts connected in parallel). In this case, we supply both converters boost 1 and boost 2 at the same time, the electrical data of the study system are: $V_s = 16.4$ V; $I_s = 2.12$ A; V_{in} (boost) = 14 V; V_{out} (boost) = 42.1 V; $R_1 = R_2 = 70\ \Omega$ (Fig. 3).

For the test bench, the materials and tools used are:

- DC source (AL936N 60 V 6 A);
- LISN with $L_N = 250$ μH, $C_r = 1$ μF, $C_N = 220$ nF;
- $L_r = 50$ μH, $R_r = 5\ \Omega$;
- Two identical boost converters (14 V / 42 V);
- Two loads 54 Ω / 5 A;
- Electronic oscilloscope (Tektronix MSO 5204);
- Spectrum analyzer (ROHNDE / SCHWARZ 10 Hz – 3,6 GHz);
- A current probe (Tektronix P6021A);
- Two-wire cables.

Both converters have been sized to switch at a frequency of 100 kHz. For the measurement of the LISN currents, a spectrum analyzer and an electronic oscilloscope were used. It was also necessary to use an interconnection device to allow reproducibility of the measurements for the experimental study, the measurement of LISN current in both DM and CM with and without a filter according to the circuit Fig. 3.

Measurement without filter. Our study system follows the circuit (LISN + cable 1 + connecting PCB + cable 2 + boost 1 + cable 3 + load) in parallel with the circuit (cable 4 +boost 2+ cable 5 + load), without filter.

Differential mode. For the experimental study, the measurement of the LISN current in DM following the circuit (LISN + cable 1 + PCB connection + cable 2 + boost 1 + cable 3 + load R_1) in parallel with the circuit (cable 4 + boost 2 + cable 5 + load R_2) is shown in Fig. 5.

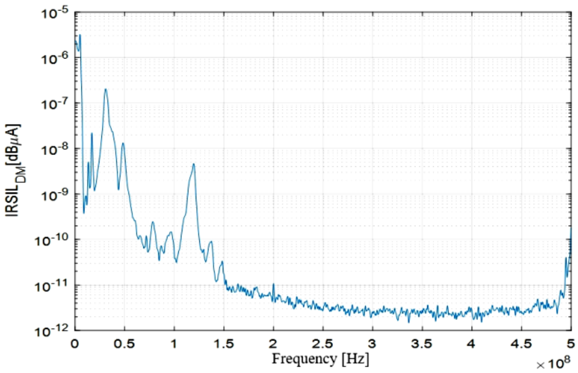

Fig. 5. Frequency response of the LISN current in DM without filter for a circuit with two boosts connected in parallel

In Fig. 5 we notice that the signal presents resonance peaks with amplitudes from 10^{-5} dBμA to 10^{-9} dBμA with frequencies from 1 MHz to 100 MHz due to the disturbances of the switching cell at the level of the two boosts in parallel and to the impact of the cable parasites. Not forgetting the impact of the input impedance of the two converters, as well as the blocked state capacitances of the semiconductors on the signal.

Common mode. We use the same electrical study circuit as in the DM (Fig. 6).

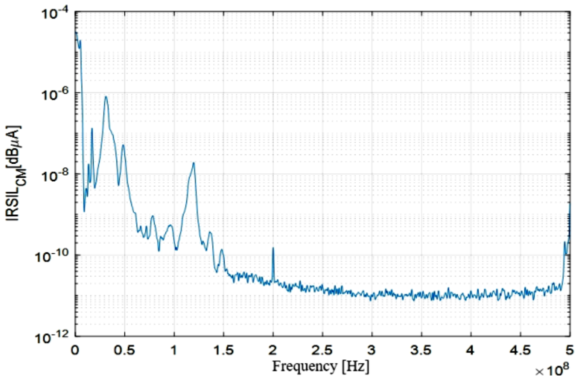

Fig. 6. Frequency response of the LISN current in CM without filter for a circuit of two boosts in parallel

In Fig. 6, the signal clearly shows resonance peaks with amplitudes of 10^{-4} dBμA to 10^{-8} dBμA from 1 MHz to 120 MHz due to the effects of the parasitic CM capacitances of the two boosts, and then from 150 MHz onwards, the signal shows slight EMI due to the inductive effect of the power cables.

Measurement with filter. Our study system follows the circuit (LISN + cable 1 + connecting PCB + cable 2 + boost 1 + cable 3 + load) in parallel with the circuit (cable 4 + boost 2 + cable 5 + load), with filter.

Differential mode. We use the same electrical study circuit as the one without filter (Fig. 7). Figure 7 shows the frequency response of the LISN current in DM with filter for a circuit with two boosts in parallel. The signal shows resonance peaks with amplitudes of 10^{-9} dBμA to 10^{-10} dBμA in the frequency range from 1 MHz to 40 MHz, which are due to switching disturbances at the boosts and cable inductances. At 40 MHz, it can be seen that there is a suppression of the electromagnetic interference due to the presence of the filter.

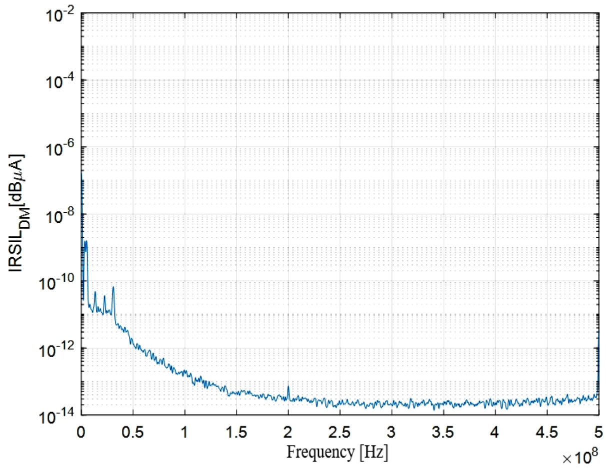

Fig. 7. Frequency response of the LISN current in DM with filter for a circuit of two boosts in parallel

Common mode. The measurement of the LISN current in CM with filter according to the circuit (LISN + cable 1 + connection PCB + cable 2 + boost 1 + cable 3 + load R_1) in parallel with the circuit (cable 4 + boost 2 + cable 5 + load R_2), is shown in Fig. 8. Figure 8 shows the frequency response of the LISN current in CM with filter for a circuit of two boosts in parallel whose signal shows resonance peaks of amplitude 10^{-7} dBμA to 10^{-10} dBμA from 1 MHz to 30 MHz due to the inductance of the cables and the parasitic capacitances in CM of the two boosts, then from 40 MHz and above, it can be seen that the signal shows slight EMI due to the presence of the filter.

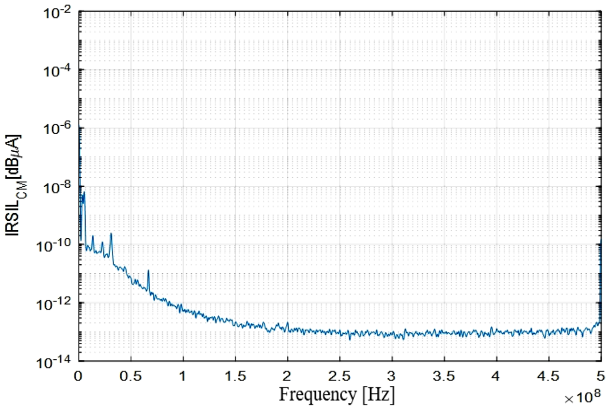

Fig. 8. Frequency response of the LISN current in CM with filter for a circuit of two boosts in parallel

Comparison test in CM with and without filter. Figure 9 shows clearly the CM comparison test for a two boost circuit in parallel between the two cases without and with filter. Figure 9 shows the frequency response of the LISN current in CM with and without filter, as function of the disturbances generated by the two boosts. It can be clearly seen that, over the whole frequency range, the disturbances of CM with filter (blue spectrum) are largely minimal and have low amplitudes of the order of 10^{-8} dBμA compared to that without filter (red spectrum) which are due on the one hand to the effect of the filter, the inductive effect of the power cables and on the other hand to the effect of the CM capacitances of the two boosts.

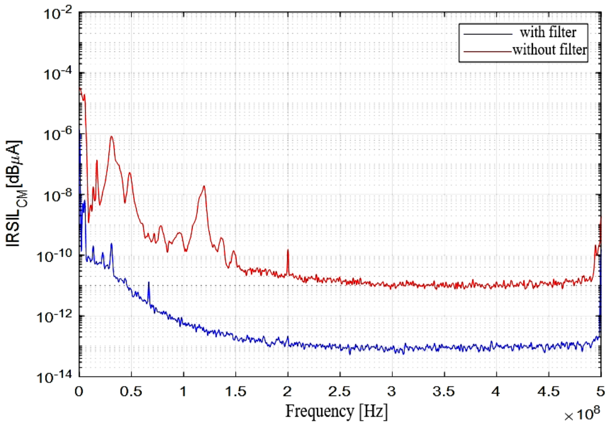

Fig. 9. Frequency response of the CM LISN current with and without filter for the two boost circuit in parallel

Comparison test in DM with and without filter. Figure 10 shows clearly the comparison test in DM between the two cases without and with filter.

We notice that there is no concordance between the two spectra. The spectrum (blue) has less amplitude because of the presence of the filter, but the signal (red) has resonance peaks on the frequency range from 1 MHz to 120 MHz. On the other hand, beyond 150 MHz the two signals present the same EMI appearance because of the inductance of the cables and the parasitic capacities in DM of the two boosts.

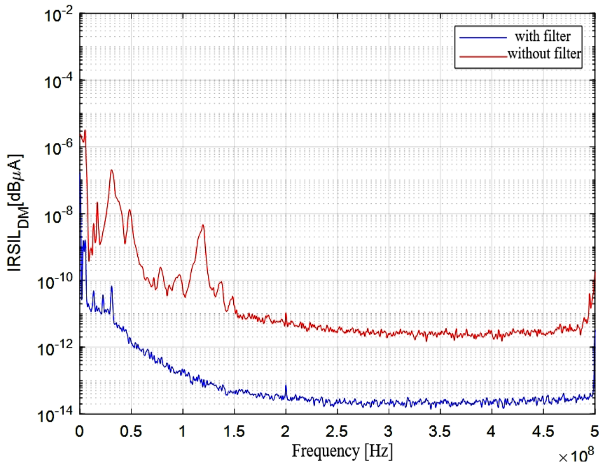

Fig. 10. Frequency response of the LISN current in DM with and without filter for a two boost circuit in parallel

Conclusions.

1. Experimental results showed that parallel connected boost converters start oscillating at 1 MHz up to 110 MHz, but are perfect beyond that. Nevertheless, the overall electromagnetic compatibility disturbance result for the «sum» test case of two boosts with and without a filter in differential and common mode is the main focus, and is illustrated by the line impedance stabilizing network current.
2. It can be seen that the differential or common mode capacitive effect generated by the two boosts is very important. Common mode impedances are usually low parasitic capacitances and therefore high at low frequencies, while differential mode impedances are high parasitic capacitances (negligible compared to the common mode).
3. It can be said that electromagnetic disturbances are transmitted to the outside of any electrical study system via various couplings. The objective of this paper was to present some experimental methods in differential and common mode, which complement other theoretical research previously conducted in order to identify and define the source of electromagnetic interferences that are generated by parallel boosts in a power system.
4. It can be clearly seen that electromagnetic interferences will be increasingly lower in filtered differential mode than in common mode. The experimental results of parallel converters have been presented as a proof of concept. The proposed method can be easily applied to support high power levels. The design of two static DC/DC boost converters in parallel in an electrical circuit is more than desirable in relation to electromagnetic interferences minimization.

Acknowledgement. This research was supported by «La Direction Générale de la Recherche Scientifique et du Développement Technologique (DGRSDT)».

Conflict of interest. The authors declare no conflict of interest.

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Received 09.09.2022
Accepted 13.11.2022
Published 01.07.2023

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How to cite this article:
Benazza B., Bendaoud A., Slimani H., Benaissa M., Flitti M., Zeghoudi A. Experimental study of electromagnetic disturbances in common and differential modes in a circuit based on two DC/DC boost static converter in parallel. *Electrical Engineering & Electromechanics*, 2023, no. 4, pp. 35-39. doi: https://doi.org/10.20998/2074-272X.2023.4.05