Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **62**, *3*, pp. 246–251, Bucarest, 2017

COMMON AND DIFFERENTIAL MODES OF CONDUCTED ELECTROMAGNETIC INTERFERENCE IN SWITCHING POWER CONVERTERS

MOHAMED MILOUDI, ABDELBER BENDAOUD, HOUCINE MILOUDI

Key words: Differential mode (DM), Common mode (CM), Electromagnetic interference (EMI) filter, Power factor correction (PFC), Switch-mode power supply (SMPS), Line impedance stabilization network (LISN).

In this study, we investigated conducted electromagnetic disturbances generated by a single-phase diode bridge rectifier with a boost converter, which is frequently encountered in power electronics. We propose a technique that can be used to improve the electromagnetic interference (EMI) performance. Our study deals solely with conducted EMI and its two types, the common-mode and differential-mode noise, in power converters. Our study focuses on the suppression of conducted EMI emission from a conventional boost converter. The experimental results were compared with the simulation results.

1. INTRODUCTION

As we know, power factor (PF) correction (PFC) technique is well applied to the ac/dc converters because it can provide almost sinusoidal input current. In this way, the ac/dc power converters can meet the IEC61000-3-2 limits [1]. Electromagnetic interference (EMI) in electronic and electrical products is a major phenomenon that must be taken into account in order to meet the electromagnetic compatibility (EMC) standards. Among these products, switched mode power supplies (SMPS) have considerable EMI due to high di/dt and dv/dt at switching instants [2]. The switch mode power supplies (SMPS) are main origin of the electromagnetic interferences (EMI) [3]. The use of increasing clock frequencies in combination with decreasing rise and fall times increases the emission of electromagnetic disturbances [4]. Electromagnetic interference (EMI) is a critical and rapidly increasing form of environmental pollution. Electromagnetic compatibility (EMC) is the ability of an apparatus to function in an environment without being susceptible to or causing noise, impulses, or transients. An electrical device or system is considered to be compatible with the environment when its operation is not affected by electrical and magnetic disturbances, and conversely, the environment is not disturbed by the device or system. Thus, EMC exists if everything works as intended. EMC has become a key criterion for designing switching power supplies. The required standards guarantee the ability of a system to operate in its environment satisfactorily without introducing intolerable electromagnetic disturbances to neighboring devices.

Since the main EMI sources in power electronics come from the converters switching and basically produce conducted emissions [5], on the basis of their modes of propagation, disturbances can be distinguished into two types: i) conducted disturbances, which propagate through electrical conduction and ii) radiated disturbances, which circulate through an electromagnetic field [6, 7]. A switch-mode power supply (SMPS) must adhere to the pipe standards similar to most modern-day electrical equipment. Although its use is predominant in the industry, it can be progressively used in the tertiary environment only if they satisfy the compatibility electromagnetic. Most companies specializing in designing the switching power supply have this requirement [8].

EMI in power electronic interference is defined as the inhibition or prevention of clear reception of broadcast signals or the distorted portion of a received signal [9], although a more appropriate term meeting this definition would be disturbance (unwanted noise). In the case of EMI, impurity signals are collected while a desired signal is traveling along a path.

Taking EMI into account in initial design stage can ensure designers to satisfy EMC at low cost before realization. In order to reduce design cycle and cost, EMI prediction should be well attended through an accurate modelling [10].

Several studies [9–12] on EMC pollution have presented various control techniques; however, we selected the filter technique because it is most represented in the industry and the easiest to master. Our results highlight that EMC filtering can mitigate conducted disturbances below the limits as required by the EMC specifications.

Concerning EMI emission, there are few papers [6, 9, 10, 13–15], on soft-switching converters. But employing various EMI reduction techniques in soft-switching converters and a proper comparison is lacking in this area [10]. The available EMI reduction techniques [10, 14–20] for switching power converter are mainly implemented in control and power sections [10].

Designing EMI filters for aerospace applications can be quite challenging as they need to be optimized for both weight and volume [21]. It is extremely difficult to analytically obtain a design of an EMC filter. Thus, we propose a practical approach to design such a filter and summarize the design procedure in this paper.

2. CONDUCTED EMI MEASUREMENT SETUP

An active power electronic switch is a noise source because of its parasitic elements. Parasitic inductances from a package lead cause high-frequency ringing on the switch voltage waveform. In addition, a cooler that is used to protect the device causes parasitic capacitance. This capacitance creates common-mode (CM) noise currents that flow into the ground plane. This noise can be attenuated by floating the heat sink voltage. However, there may be safety concerns and mechanical considerations. In addition, any abrupt change in current or voltage generates high-frequency harmonics.

To predict EMI, it is necessary to characterize the main parasitic elements in the circuit. Therefore, exact models for components such as inductor, capacitor, resistor, and switch

---

University Djillali Liabes of Sidi Bel Abbes, Faculty of Engineering, Department of Electrical Engineering, APELEC Laboratory, Sidi Bel Abbes, Algeria, E-mail: mohamed.miloudi@univ-sba.dz

should be considered. For semiconductor devices, the thermal resistance of the heat sinks was adjusted to be consistent with the experimental results.

Figure 1 depicts the measurement setup for conducted EMI noise in a single-phase power factor correction (PFC) converter. Two line impedance stabilization networks (LISNs) were inserted between each ac line and the PFC. An equivalent circuit for the LISN is presented in Fig. 2. LISNs were used to stabilize the impedance of the input line and ensure that the measuring results were only related to the equipment under test (EUT), with no influence from the impedance of the ac lines.

Three detectors were used to measure the EMI noise: peak, average, and quasi-peak [14, 22]. The peak detector selects the maximum amplitude of the noise signal for each frequency. The average detector selects an envelope-detected signal and passes it through a low-pass filter with a bandwidth much lower than the resolution bandwidth. The filter integrates (averages) higher frequency components such as noise. The quasi-peak detector allows a weighted form of peak detection. The measured value of the quasi-peak detector decreased when the repetition rate of the measured signal decreased.

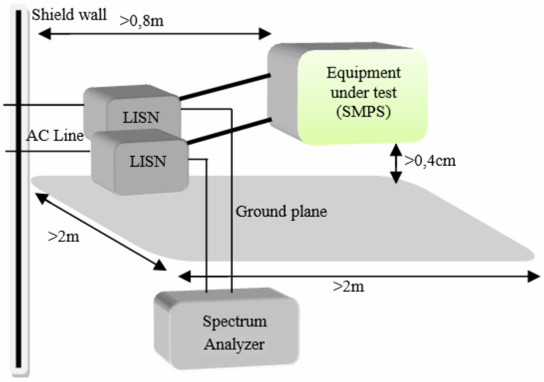

Fig. 1 – Measurement setup for conducted EMI noise.

An artificial network (LISN) is essential for the normative measurement of conducted disturbances. This artificial network isolates the equipment under test (EUT) from the noise generated by the power network (filter part). Furthermore, the measurements were independent of the supply network (role reproducibility of measurements) [7].

The equivalent circuit for the measurement setup using the PFC converter as the EUT in Fig. 1 is presented in Fig. 3. Each LISN was connected to a 50 Ω termination or a spectrum analyzer with an input impedance of 50 Ω. A voltage drop on either 50 Ω impedance is the total conducted noise voltage. The configuration of LISN as per standards is presented in Fig. 2.

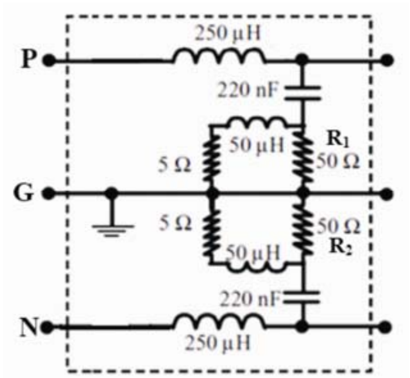

Fig. 2 – LISN topology (defined according to the International Special Committee on Radio Interference standards).

3. CONDUCTED EMI IN SMPS

Power electronic converters, connected to the electrical grid, inject conducted electromagnetic interferences (EMI), which propagate inside the network throw conductors and shielding structures [23]. Our study deals with the reduction of EMI in SMPS. It is imperative that SMPS adheres to the standard EN–55022 limits [9]. The disturbances can be reduced by inserting suppressor filters, which are expensive. Therefore, we investigated the pollution at the first stage (single-phase diode bridge rectifier) and developed a model for the second stage (boost) and full converter (PFC).

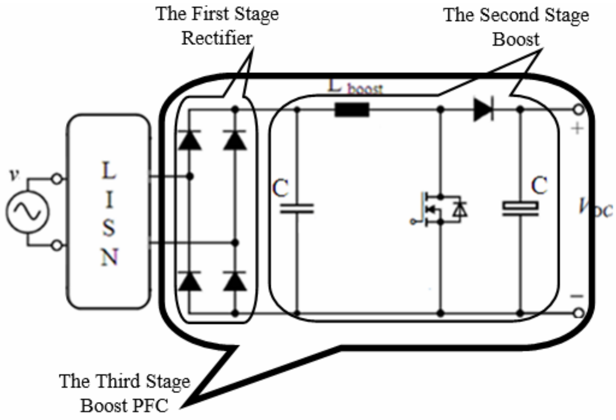

Fig. 3 – Boost PFC.

Conducted electromagnetic interference is the noise that is conducted to the power source of the converter. The EMI is conducted through common and differential modes [24]. In the first setup, the terminal connections, a single-phase diode bridge rectifier was used. Two diodes were placed with the cathode facing the positive node of a loop transmitter and the anode facing each of the terminal blocks. Similarly, two diodes were placed with the anode facing the return node of the loop transmitter and the cathode facing each of the terminal blocks.

This arrangement ensures that the loop connections are rectified regardless of which terminal is connected to the supply node and which one is connected to the return node. Figure 4 presents conducted EMI emission results.

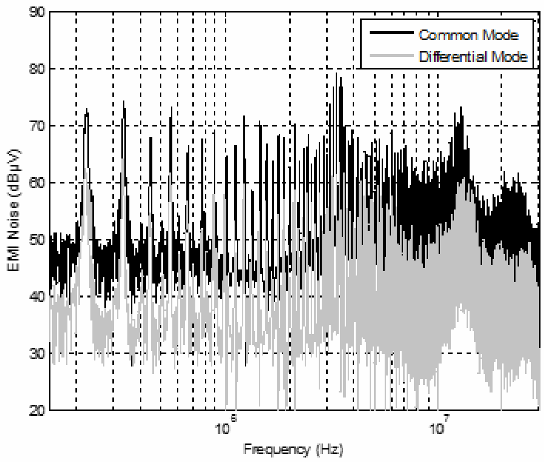

Fig. 4 – Conducted EMI noise spectrums in the bridge rectifier.

In the second stage, the boost converter follows a new trend of power generation. Switching time is a crucial factor in the mechanism of disturbance generation because it controls “d*v*/d*t*” and “d*i*/d*t*”. A decrease in switching speed reduced the conducted interference but generated additional switching losses.

Any findings or assumptions must be verified experimentally using simple and common equipment such as a converter. Therefore, we used a realistic circuit with a simple boost converter, which is commonly used in the automobile industry and generates EMI. The growing demand for highly compact systems increases the concern for EMI problems.

The current flows from the higher side to the lower side of the inductor when the converter is operating in the boost mode. If the minimum current decreases to zero, then the converter is on the border between continuous and discontinuous mode.

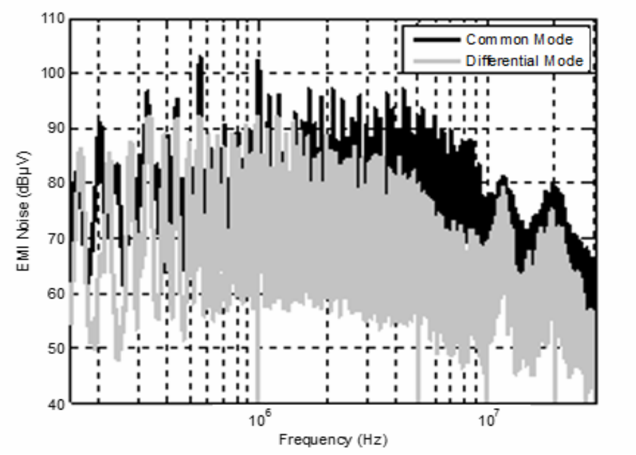

Fig. 5 – Conducted EMI noise spectrums in the boost converter.

A metal-oxide-semiconductor field-effect transistor (MOSFET) was selected on the basis of the current and voltage specifications [25, 26]. As this converter need not be designed to satisfy any cost or thermal conditions, the selected MOSFET was overrated to enable various testing conditions without replacement.

For any EMI prediction in the converter (PFC boost), the device parasitics and magnetic component parasitics contribute majorly to the EMI levels. The high-frequency boost PFC circuit includes some of the most crucial parasitics. A study of the common and differential paths helps to identify parasitics that contribute the highest EMI levels.

The undesired (unintentional) coupling of electromagnetic energy from one apparatus (emitter) to another (receptor) is termed EMI [15]. CM and DM are the two main modes of pollution. In the equipment, the DM pollution is mainly transmitted between the phase and neutral, and the CM pollution is mainly transmitted among the phase, neutral, and ground through the parasitic capacitances [11, 24].

4. CM NOISE IN PFC BOOST CONVERTER

CM is coupled through C_{DG}, the parasitic capacitance between the drain of the MOSFET and the metal enclosure of the power supply [16]. CM noise can flow through parasitic or tray capacitances at high frequencies that exist between system components and the ground. Parasitic/stray capacitances between two lines within a circuit can cause CM. CM noise flows through two supply lines in the same direction and returns through the ground wire with a magnitude of the sum of the two CM currents flowing in the two lines. These two CM currents flowing in the lines have the same magnitude and thus, return through the ground. The CM noise path is denoted by dashed lines in Fig. 6.

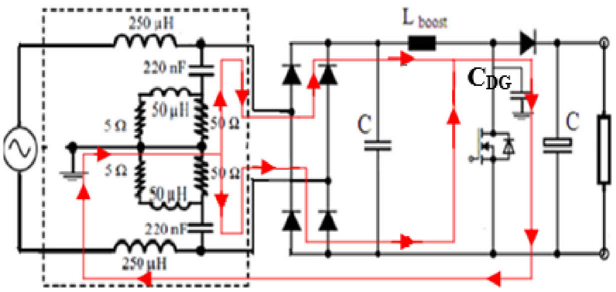

Fig. 6 – CM noise in a PFC boost converter.

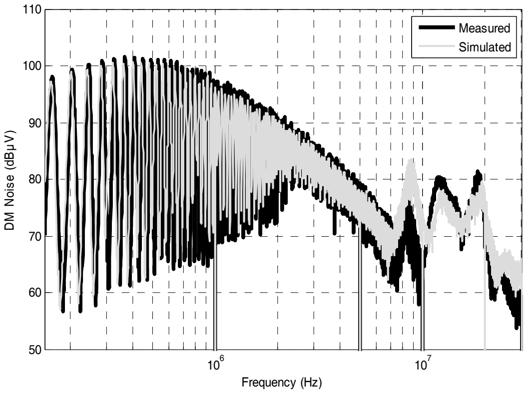

Fig. 7 – Experimental and simulated CM noise spectrums without filter.

The CM noise current, I_{CM}, is defined as the current between ac lines and the ground, denoted by a green solid curve in Fig. 6. C_{DG} is the parasitic capacitor from the heat sink of the switch to the ground, which is critical in the CM noise propagation path.

Figure 7 illustrates the comparison of the experimental and simulated CM noise spectrums [9] obtained using the spectrum analyzer. The errors increased with an increase in frequency; however, the model was, in general, fairly efficient.

The magnitude of CM noise on the two supply lines were similar, whereas the magnitude of CM noise returning through the ground wire was twice that of the noise on one of the supply lines.

5. DM NOISE IN PFC BOOST CONVERTER

The second mode of conducted noise is presented in Fig. 8. The stray capacitance, referred to as parasitic capacitance, C_P, is an unintentional capacitance to the ground from the circuit and its nodes and is in the order of a few pico farads. The magnitude of the current flowing to the ground at a given node and the size of the capacitance were determined by the d*v*/d*t* value at that point. The points where the effects were the highest are termed as points of interest. The capacitance to the ground was the highest in semiconductor devices at points where the semiconductor was connected to a heat sink that had a large surface area.

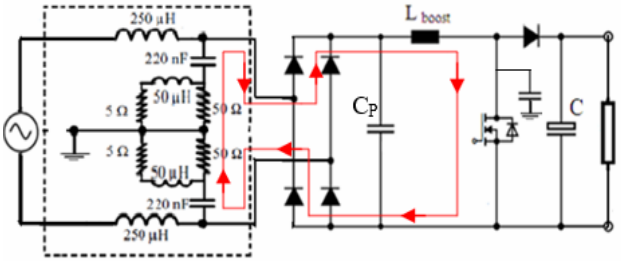

Fig. 8 – DM noise in a PFC boost converter.

The DM noise current, I_{DM}, is defined as the current between ac line (hot) and ac line (neutral).

Figure 9 presents the results when the heat sink was connected to the ground [17]. DM noise was almost unchanged, which proved the satisfactory performance of the prototype.

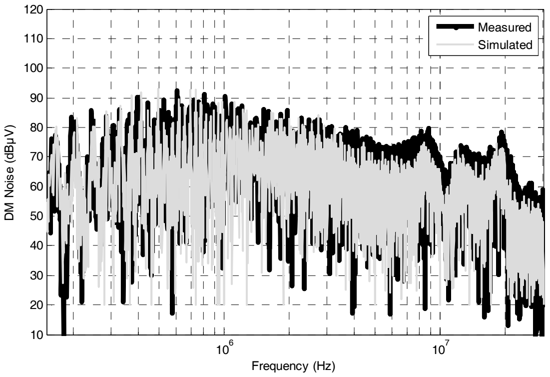

Fig. 9 – Experimental and simulated DM noise spectrums without filter.

6. EMI FILTER DESIGN

A typical mains filter consists of filtering components for conducted noise. The CM components are the CM choke and CM capacitors (caps). To filter DM currents, DM capacitors (caps) were used. Figure 10 shows a typical mains filter and its components. The CM choke was connected to the phase and neutral. DM caps were connected between phase and neutral, whereas CM caps were connected between the phase and earth as well as between the neutral and earth [24].

Conducted noise can enter the system through the ground, if the ground wire contains electrical signals because of induced currents from other equipment or remote grounds. Most electronic equipment possess a particular type of EMI filter at its input.

The filter is usually placed and sized to meet standard specifications, which necessitates the introduction of filters to minimize the high-frequency noise. Filtering not only prevents the product from emitting high-frequency noise into the environment but also makes the product less susceptible to any high-frequency noise already present in the environment. In many high-power applications, large filters are often required and may take up a high percentage of the total volume. In the current market scenario, the size and cost of a product often determines its marketability. If the size of the filtering elements is reduced, then the overall size and cost of the product decreases and the product becomes more marketable. To decrease the size of the filtering elements, EMI must be minimized/combated within the converter itself. Filters are usually incorporated post-design and require additional space. Therefore, it is crucial to make the necessary space provisions for EMI filters. Figure 10 illustrates the topology of an equivalent circuit for EMI filter.

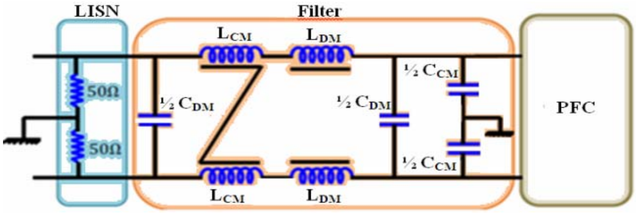

Fig. 10 – Topology of the EMC filter using PFC.

Nowadays miniaturization of conducted electromagnetic interference (EMI) filters is one of the key concerns in modern electronics industry. Since all modern electronic devices become smaller and smaller, conducted EMI filters must follow these trends. Reduction of passive EMI filter size can be achieved, mainly, by placing the filter components very close to each other [28, 29]. In many practical situations, an EMC designer would prefer to have a fast, although approximate, solution to the problem in order to speed up the design process. To this end, an approach was proposed [30].

The design procedure can be summarized as follows:

Step 1. Measure baseline EMI conducted noise and CM and DM noise.

Step 2. The required attenuation is the discrepancy between the baseline noise and the EMI specifications and a correction factor. The attenuation is generally "+ 3 dB" for CM and "+ 6 dB" for DM.

$$\left(V_{CM_{req}}\right)_{\text{dB}} = \left(V_{CM_{\max}}\right)_{\text{dB}} - \left(V_{\lim}\right)_{\text{dB}} + 3\text{ dB}, \quad (1)$$

$$\left(V_{DM_{req}}\right)_{\text{dB}} = \left(V_{DM_{\max}}\right)_{\text{dB}} - \left(V_{\lim}\right)_{dB} + 6\,\text{dB}, \quad (2)$$

where $V_{CM_{\max}}$ and $V_{DM_{\max}}$ are the noise voltages, and $V_{\lim}$ is the limit of conducted EMI.

Step 3. Determine filter corner frequencies as follows:

$$\left(V_{CM_{req}}\right)_{\text{dB}} = 40\log_{10}\left(f_{CM_{\max}} / f_{C_{CM}}\right), \quad (3)$$

$$\left(V_{DM_{req}}\right)_{\text{dB}} = 40\log_{10}\left(f_{DM_{\max}} / f_{C_{DM}}\right), \quad (4)$$

where $f_{C_{CM}}$ and $f_{C_{DM}}$ denote the cutoff frequencies of the filters for CM and DM noise, respectively. $f_{CM_{\max}}$ and $f_{DM_{\max}}$ are the frequencies at which the spectrum of conducted EMI showed maximum amplitude in CM and DM, respectively [11].

Step 4. Determine filter component values for: inductor (L_{CM}, L_{DM}) and capacitor (C_{CM}, C_{DM}). The filter component values can be calculated as follows:
First order CM filter:

$$f_{C_{CM}} = 1/(50\pi C_{CM}). \quad (5)$$

Second order CM filter:

$$f_{C_{CM}} = 1/(2\pi\sqrt{L_{CM}.C_{CM}})\,. \tag{6}$$

First order DM filter:

$$f_{C_{DM}} = 25/(\pi L_{DM}). \tag{7}$$

Second order DM filter:

$$f_{C_{DM}} = 1/(2\pi\sqrt{L_{DM}.C_{DM}}). \tag{8}$$

Step 5. This step was used to measure conducted EMI again with the filter. If the low-frequency specifications are not satisfied, the corner frequencies obtained in Step 3 should be lowered and those obtained in Step 4 should be repeated. If the high-frequency specifications are not satisfied, certain tuning measures must be taken. The design was completed after satisfying both low- and high-frequency specifications [17].

A typical mains filter comprises filtering components for both CM and DM noise and the actual CM and DM filter insertion losses are lower than the standard limit. The attenuation begins well below the 150 kHz cut-off frequency the transfer gain alluded to. This showed that the filter, considered to be used at a high frequency, could be optimized further to substantially decrease the EMI filter size [13].

The aim of the EMI optimization formulation is to improve the EMI response of the filter compared to the reference one. For this purpose, we considered a maximum upper limit equal the maximum spectrum value of the reference filter and we decided to make an overall minimization of the spectrum peaks according to these EMI limits. Therefore, as an objective we chose to minimize the EMI criterion and we considered the audio and the power losses criteria as constraints. Figure 11 presents the experimental result is on black and the simulation result is on grey.

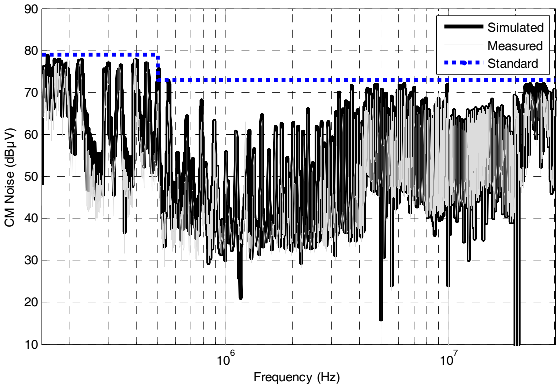

Fig. 11 – Experimental and simulated CM EMI spectrum with filter.

The frequency range of interest for emissions from most products is 150 kHz–30 MHz. The emissions were measured using the spectrum analyzer and compared with the limits for industrial applications (standard EN-55022). The spectrum analyzer sweeps the entire spectrum range and indicates emission levels.

The sweep range is 150 kHz–30 MHz, and the CM and DM indicate the limits for light industrial and domestic use. The two frequency curves for the EUT are at quasi-peak. The vertical scale is in dBµV. The limits are indicated and frequencies with acceptable emission levels are highlighted.

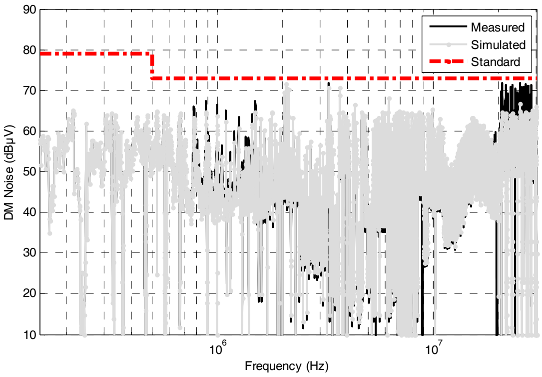

Fig. 12 – Experimental and simulated DM EMI spectrum with filter.

These results indicate that the spectrum after filtering experienced a sufficient decrease in the conducted disturbances, within the limits of EN-55022. The effectiveness of the filter used enabled us to adopt filtering technique as a favorable solution to reduce EMI disturbances in the frequency range of 150 kHz–30 MHz as required by the EMC standard (the experimental result is on black and the simulation result is on grey).

7. CONCLUSIONS

We discussed ground loops and their influence on CM noise. In addition, we discussed the criticality of CM noise and its effects on the environment. Common EMI reduction techniques and EMI reduction through filtering were described in detail. Furthermore, we discussed the problem that was investigated and previous research conducted to resolve this problem. In addition, an example of how CM EMI originates from SMPS was presented. The study of EMC can be conducted after acquiring basic knowledge of electronic circuits.

The results show a very good performance of the filter. The electromagnetic conducted emissions have reduced levels enabling the use of the filter in EN-55022 standard. The EMC demands related to converter as resulting from international standards are presented. To reduce the amplitude of the noise, CM chokes should be used. CM choke can effectively attenuate ground noise current, no matter it is in the form of CM or in the form of DM.

Received on November 27, 2016

REFERENCES

1. Xiaogao Xie, Chen Zhao, Qiang Lu, Shirong Liu, *A Novel Integrated Buck–Flyback Nonisolated PFC Converter with High Power Factor*, IEEE Transactions on Industrial Electronics, **60**, *12*, pp. 5603–5612, 2013.
2. Mohammad Rouhollah Yazdani, Hosein Farzanehfard, Jawad Faiz, *Conducted EMI Modeling and Reduction in a Flyback Switched Mode Power Supply*, Proc. Int. Conf. 2nd Power Electronics, Drive Systems and Technologies Conference, Tehran, Iran, February 2011.

3. Piotr Musznicki, Marcin Rucinski, Marek Turzynski, Stanisław Abramik, *Prediction of Ringing Frequencies in DC-DC Boost Converter*, Proc. of the 2016 International Symposium on Electromagnetic Compatibility – EMC Europe 2016, Wroclaw, Poland, September 5–9, 2016, pp. 672–675.
4. Andy Degraeve, Tim Claeys, Filip Vanhee, Keith Armstrong, *Development of an EMC Demonstration Unit*, Proc. of the 2016 International Symposium on Electromagnetic Compatibility – EMC Europe 2016, Wroclaw, Poland, September 5–9, 2016, pp. 422–427.
5. Jordi Espina, Josep Balcells, Antoni Arias, Carlos Ortega Nestor Berbel, *EMI Model of An AC/AC Power Converter*, IEICE Electronics Express, **8**, *1*, pp. 13–19, 2011.
6. M. Miloudi, A. Bendaoud, H. Miloudi, S. Nemmich, Etude et réduction des emissions conduite générées par une alimentation à decoupage, Proc. Int. Conf. CI'03, Tizi–Ouzou, Algérie, April 2013.
7. M. Miloudi, A. Bendaoud, H. Miloudi, *Characterization of Conducted Electromagnetic Interference (EMI) Generated by Switch Mode Power Supply (SMPS)*, Proc. Int. Conf. International Electrical Engineering Conference, Batna, Algeria, Novembre 2012.
8. Mario Olicar Crosato, *An Investigation of Charge Balancing in Planar Inductors from an Electro-Magnetic-Compatibility Perspective*, PhD Thesis, Rand Afrikaans University, February 2004.
9. S. Brehaut, *Modélisation et optimisation des performances CEM d'un convertisseur AC/DC d'une puissance de 600 W*, PhD Thesis, François-Rabelais University, 2005.
10. Mohammad Rouhollah Yazdani, Hosein Farzanehfard, *EMI Analysis and Evaluation of an Improved ZCT Flyback Converter*, IEEE Transactions on Power Electronics, **26**, *8*, (2011).
11. J. Kaewchai, W. Khanngern, S. Nitta, *A snubber for reducing reverse-recovery current related to EMI reduction in boost converter*, Proc. Int. Conf. International Symposium on Electromagnetic Compatibility, Bangkok, 2012.
12. Gang Yang, *Design of a High Efficiency High Power Density DC/DC Converter for Low Voltage Power Supply in Electric and Hybrid Vehicles*, PhD Thesis, Paris University, April 2014.
13. M. Miloudi, A. Bendaoud, H. Miloudi, *Characterization of differential-mode and common-mode EMI noise in a flyback switched-mode power supply (SMPS)*, Proc. Int. Conf. TELFOR Conference, Belgrade, Serbia, November 2012.
14. Tarateeraseth, S. Kye Yak, F.G. Canavero, R.W. Chang, *Systematic electromagnetic interference filter design based on information from in-circuit impedance measurements,* IEEE Transactions, Electromagnetic Compatibility, August 2010, pp. 588–598.
15. H. Miloudi, A. Bendaoud, M. Miloudi, H. Slimani, F. Tounsi: *Reduction of electromagnetic interference and optimization EMC filter in adjustable speed drives system,* Proc. Int. Conf. International Electrical Engineering Conference, Batna, Algeria, November 2014, pp. 257–261.
16. M. Andersen, *Fast prediction of differential mode noise input filter requirements for flyback and boost unity power factor converters,* Proc. Int. Conf. European Conference on Power Electronics, Applications, Norway, September 1997, pp. 2806–2809.
17. C.R. Paul and K.B. Hardin, *Diagnosis and reduction of conducted noise emissions*, IEEE Transactions, Electromagnetic Compatibility, November 2014, pp. 553–560.
18. M. Miloudi, A. Bendaoud, H. Miloudi, S. Nemmich, *Characterizing and reducing of conducted EMI noise in switched-mode power supply*, Proc. Int. Conf. CIMGLE Conference, Paris, France, November 2013.
19. Mohamed Miloudi, Abdelber Bendaoud, Houcine Miloudi, *Evaluation and Minimization of Conducted Emissions of Electromagnetic Interference Noise Generated by Power Factor Correction*, Proc. of the 2016 International Symposium on Electromagnetic Compatibility – EMC Europe 2016, Wroclaw, Poland, September 5–9, 2016, pp. 730–735.
20. Veera Venkata Subrahmanya Kumar Bhajana, Pavel Drabek, Martin Jara, *Performance Evaluation of LLC Resonant Full Bridge Dc-Dc Converter for Auxiliary Syst EMS In Traction,* Rev. Roum. Sci. Techn. – Électrotechn. et Énerg, **60**, *1*, pp. 79–88, (2017).
21. Hemant Bishnoi, Andrew Carson Baisden, Paolo Mattavelli, *Analysis of EMI Terminal Modeling of Switched Power Converters,* IEEE Transactions on Power Electronics, **27**, *9*, pp. 3924–3933 (2012).
22. H. Rebholz, S. Tenbohlen, *Prospects and limits of common- and differential-mode separation for the filter development process*, Proc. Int. Conf. EMC Europe, International Symposium on Electromagnetic Compatibility, Hamburg, Germany, September 2008, pp. 1–6.
23. M.A. Cheurfi Belhadj, A. Ales, A. Zaoui, Z. Chebbat, J.L. Schanen, J. Roudet, *Analytical Model of DC-DC Converters Based on Switching Impedances and EMI Sources*, Proc. of the 2016 International Symposium on Electromagnetic Compatibility – EMC EUROPE 2016, Wroclaw, Poland, September 5–9, 2016, pp. 750–755.
24. G.N. Wooding, A.S. De Beer, *The Effect of Leakage Inductance and Snubbing on Electromagnetic Interference Generated by a Flyback Converter*, IEEE Africon 2011 – The Falls Resort and Conference Centre, Livingstone, Zambia, September 13–15, 2011.
25. Yohann Luque, Eric Kerherve, Nathalie Deltimple, Didier Belot, *CMOS Power Amplifier des IGN Dedicated to Umts (3g) Applications in 65 nm Technology,* Rev. Roum. Sci. Techn. – Électrotechn. et Énerg, **55**, *1*, pp. 80–89 (2010).
26. Paul Ion, Bogdan Cristian Florea, *Pulse Amplifier Used in Ultrasonic Nondestructive Testing,* Rev. Roum. Sci. Techn. – Électrotechn. et Énerg, **62**, *1*, pp. 68–71 (2017).
27. C. Tantisukarom, W. Khan-ngern, S. Nitta, *Conducted emission charactiristic of active snubber boost converter,* IEEE Transactions, Electromagnetic Compatibility, November 2011, pp. 7803–7809.
28. A. Asmanis, G. Asmanis, D. Stepins, L. Ribickis, *Modeling of EMI Filters with Shields Placed Between the Filter Components*, Proc. of the 2016 International Symposium on Electromagnetic Compatibility – EMC Europe 2016, Wroclaw, Poland, September 5–9, 2016, pp. 776–779.
29. G. Asmanis, D. Stepins, L. Ribickis, A. Asmanis, *Modeling of Mutual Coupling between Inductors*, Proc. of IEEE Symposium on Electromagnetic Compatibility and Signal Integrity, USA, Santa Clara, March, 2015, pp. 294–299.
30. H. Azizi, F. Tahar Belkacem, D. Moussaoui, *Analytical and Numerical Study for Electromagnetic Shielding Effectiveness of a Metallic Enclosure with Apertures*, Proc. Int. Conf. 7th International Conference on Electrical Engineering, Batna, Algeria, October 2012, pp. 534–538.