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Modulation technique to reduce EMI in power multiconverters

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Abstract: A new technique to reduce EMI in modular power multiconverters is described. The technique is based on a combination of switching frequency modulation and a variable delay between commutation signals of the single converters. The proposed technique has been validated experimentally in a four converters parallel topology. A significant EMI reduction has been obtained with regard to conventional techniques.

Keywords: spread-spectrum clock generation (SSCG), switching frequency modulation (SFM), interleaving, conducted EMI, power converters.

Classification: Electromagnetic compatibility (EMC)

References

[1] Y. Poiré, M. Meyer, M. Ramdani, R. Perdriau, and M. Drissi, "Design approach for EMI filters in power supplies," *Electron. Lett.*, vol. 44, pp. 235–236, Jan. 2008.

[2] K. K. Tse, H. S.-H. Chung, S. Y. Hui, and H. C. So, "Analysis and spectral characteristics of a spread-spectrum technique for conducted EMI suppression," *IEEE Trans. Power Electron.*, vol. 15, pp. 399–410, March 2000.

[3] D. Gonzalez, J. Balcells, A. Santolaria, J.-C. Le Bunetel, J. Gago, D. Magnon, and S. Brehaut, "Conducted EMI Reduction in Power Converters by Means of Periodic Switching Frequency Modulation," *IEEE Trans. Power Electron.*, vol. 22, pp. 2271–2281, Nov. 2007.

[4] J. Balcells, A. Santolaria, A. Orlandi, D. Gonzalez, and J. Gago, "EMI reduction in switched power converters using frequency Modulation techniques," *IEEE Trans. Electromagn. Compat.*, vol. 47, pp. 569–576, Aug. 2005.

[5] K. B. Hardin, R. A. Oglesbee, and F. Fisher, "Investigation into the interference potential of spread-spectrum clock generation to broadband digital communications," *IEEE Trans. Electromagn. Compat.*, vol. 45, pp. 10–21, Feb. 2003.

[6] S. Ozeri, D. Shmilovitz, S. Singer, and L. Martinez-Salamero, "The mathematical foundation of distributed interleaved systems," *IEEE Trans. Circuits Syst.I*, vol. 54, pp. 610–619, March 2007.

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1 Introduction

Switched mode power supplies (SMPS) generate signals with high dv/dt and di/dt. This situation produces conducted electromagnetic interference (EMI) in the power and signal lines that can affect other circuits or devices, mainly through capacitive coupling. Usually, the SMPS are controlled by square switching signal with constant frequency and duty cycle (D) adjusted to the response of the control loop. Therefore, the main component of the EMI is the switching frequency and its harmonics. One of the conventional techniques in order to reduce EMI consists of using passive filters. In this sense, several works have been developed recently in order to minimize the size of these filters [1]. Another EMI reduction strategy in SMPS consists of applying the switching frequency modulation (SFM). This technique is based on the original spread-spectrum clock generation (SSCG) techniques [2, 3, 4], used in such as microprocessor systems [5]. Using the SFM, technique a tradeoff between the amplitude reduction of the EMI harmonics and the generation of a set of additional side-band harmonics with small amplitude appears.

On the other hand, in applications that require high level of power or redundancy, such as microprocessors power supplies, the modular power systems with parallel topology are used. In these systems, the interleaving technique, which consists of introducing a given shift delay between the switching patterns of the converters, is commonly used in order to reduce the voltage output ripple as well as to achieve harmonics cancellation effect [6].

In this paper, an optimized technique based on the combination of SFM and interleaving is applied to power supply systems with parallel topology. Theoretical study and experimental test show that a significant EMI reduction can be achieved by using the proposed method.

2 Theoretical analysis

In modular power supplies with parallel topology, the interleaving technique is used to equally share the total power to be delivered among the number of converters, N. In this case, all converters operate with the same frequency but with a shift delay equal to T_c/N in each converter with regard to the previous one, as illustrated in Fig. 1 (a), where T_c is the switching period. Fig. 1 (b) shows the equivalent source of noise generated in the power lines, $s(t)$, which corresponds to the addition of the N switching pattern ($c_1(t)$, $c_2(t), \ldots c_N(t)$). It can be observed that the equivalent source of noise pattern corresponds to a square signal with the same duty cycle as a single $c_i(t)$ and a frequency of $N \cdot f_c (f_c = 1/T_c)$. As a result, the interleaving is an effective harmonic cancellation method, since it presents only harmonics at every $N \cdot f_c$ frequencies, whereas individual converter shows harmonics at each f_c frequency.

The SFM consists of varying the switching frequency around a central value, f_c, according to a modulation profile, $V_m(t)$. In case of using a periodic modulation profile, the energy of interference harmonics is distributed in sidebands with sub-harmonics separated by the modulation profile frequency, f_m.

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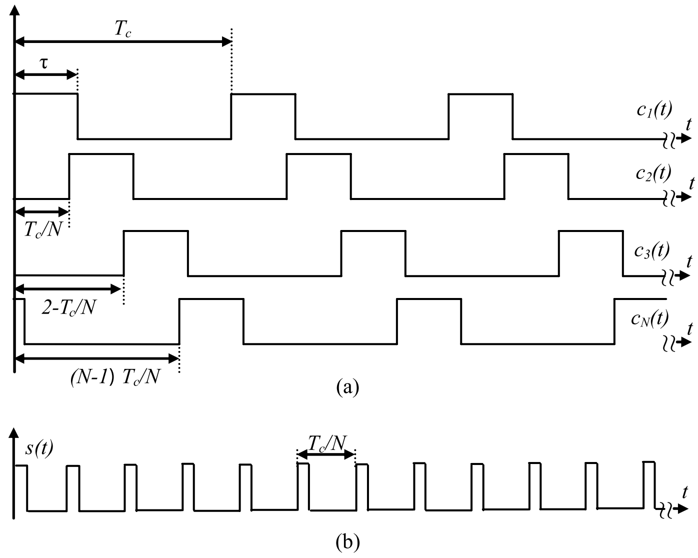

Fig. 1. Interleaving technique for N=4. (a) Switching patterns. (b) Equivalent source of noise pattern.

If SFM technique is applied at each pattern $c_i(t)$, the frequency spectrum $|S(f)|$ is shown at Fig. 2 (a). It can be observed that the f_m sub-harmonics present lower amplitude than f_c harmonics, when SFM is applied. Therefore, for N converters the total conducted EMI frequency spectrum corresponds to the frequency spectrum $N{\cdot}|C_i(f)|$.

The proposed technique combines the benefits of both previous methods: on the one hand, a reduction of the amplitude of harmonics by means of SFM and on the other hand, a suppression of all of the harmonics except for the multiples of $N{\cdot}f_c$ by using interleaving. The technique, defined as variable delay and frequency modulation (VDFM), consists of modulating in frequency the pattern of the first converter, and introduce a variable delay of pulse position, $\varepsilon_{k,i}$ in the pattern of the rest of converters (Fig. 2 (b)). This delay is updated in each switching period to ensure the interleaving in each switching cycle. This delay is given by eq. (1) where index i denotes the number of converter ($i = 1, 2, \ldots, N$).

$$\varepsilon_{k,i} = \frac{T_k}{N} \cdot (i - 1) \tag{1}$$

Fig. 2 (c) depicts the conducted EMI frequency spectrum harmonic, $|S(f)|$, obtained by simulation, when VDFM technique is used in the control of four-channel parallel converter. As expected, only harmonics located and spread around of central frequency equal to $4{\cdot}f_c$ appear.

3 Experimental results

In order to evaluate the proposed technique, a setup based on a four-channel parallel buck converter has been implemented. The switching pattern signals have been generated by means of several digital pulse width modulators (DPWM) that have been implemented in field programmable gate array (FPGA). The worst case for duty cycle has been chosen, that is, the

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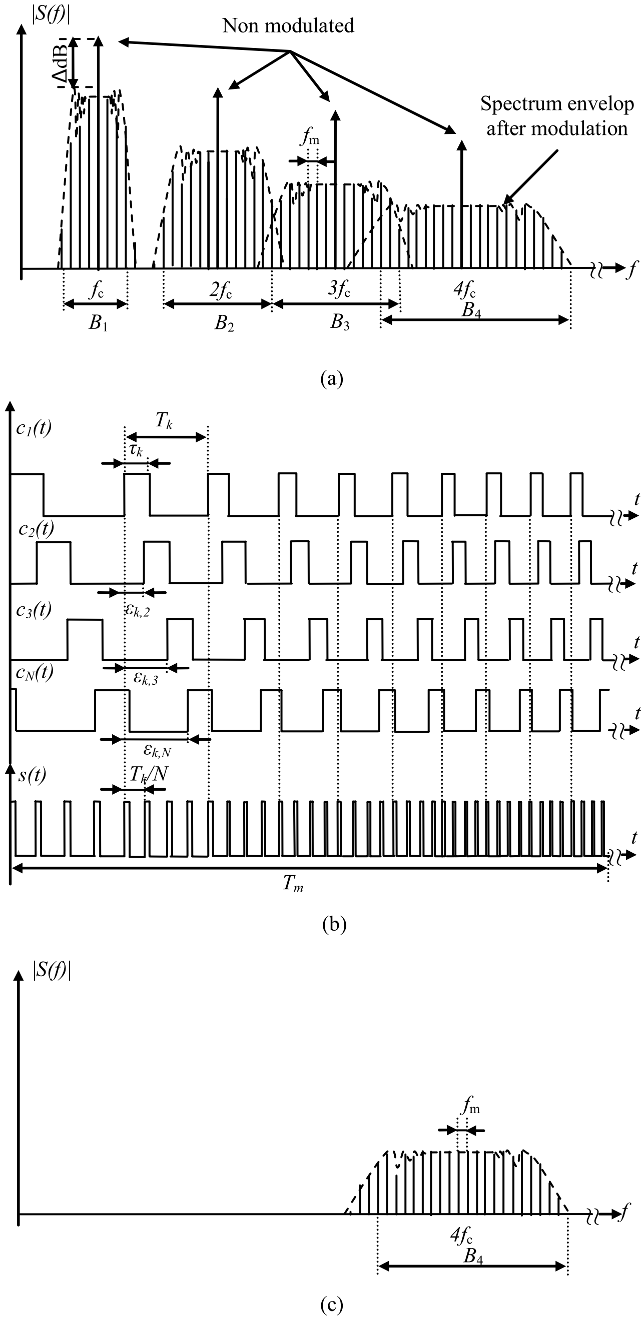

Fig. 2. (a) Spread bands of harmonics in SFM. (b) Switching patterns, $c_i(t)$, and equivalent source of noise pattern, $s(t)$, corresponding to VDFM technique for N=4. (c) Spread bands of harmonics in VDFM for N=4.

higher EMI case, D=12.5%, since it corresponds to (50/N) %. A central switching frequency f_c=400 kHz, a sawtooth as modulation profile, $V_m(t)$, with a modulation frequency f_m=10 kHz and a maximum frequency deviation Δf_c=60 kHz have been selected. Fig. 3 shows the experimental EMI spectrum results in three different cases: without any reduction technique (non-modulated case), when the SFM technique is applied and finally, the obtained one by means of the VDFM technique. By comparing the spectrum

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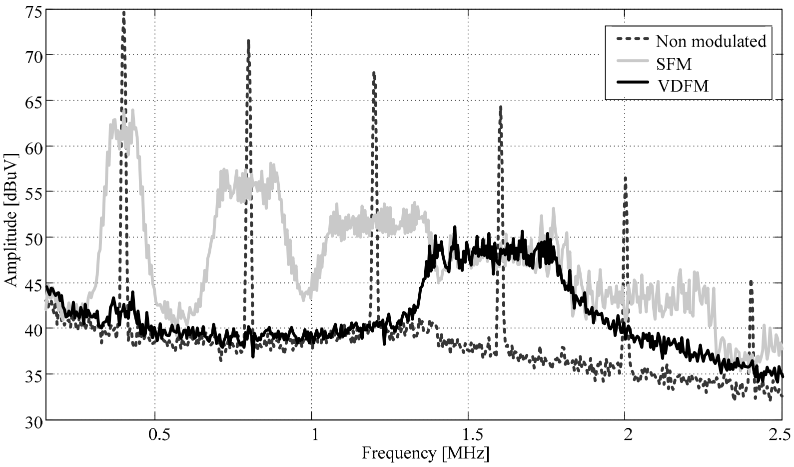

Fig. 3. Experimental EMI spectrum in three cases: Non-modulated, SFM and VDFM.

generated by power system with and without SFM, a reduction about 10 dB is achieved in all f_c harmonics. However, by applying the VDFM technique not only a higher amplitude harmonic reduction is obtained (∼20 dB) at $4f_c$, but also an effective cancellation of the remaining harmonics (f_c, $2f_c$ and $3f_c \ldots$) is measured. Moreover, only with VDFM technique, a significant reduction in the total power spectrum of the conducted EMI is observed.

4 Conclusion

In this letter, an EMI reduction method for power supply with parallel topology is proposed. The method, namely VDFM, is based on a combination of SFM and interleaving techniques. The results show an improvement in the conducted EMI spectrum in terms of EMI reduction with regard to previous techniques. In fact, most of the harmonics are cancelled. Moreover, the non-suppressed harmonics present a significant attenuation about 20 dB.

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