ANALYSIS OF SWITCHING FREQUENCY, COMMUTATION TIMES AND RESONANT TECHNIQUES FOR CONDUCTED EMI REDUCTION

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Abstract — **The aim of this paper is to evaluate the influence of switching frequency, commutation times and resonant techniques in the conducted EMI generated by a static converter. The basic EMI generation mechanism is explained. The switching frequency of an experimental converter is varied and the generated conducted EMI is measured. The commutation times (rise and fall times) are varied and the generated EMI is measured. Resonant techniques are applied and the resulting EMI is measured. At last, the efficiency of these techniques in the EMI reduction is analyzed from the EMC viewpoint.**

KEYWORDS

Electromagnetic Interference, Electromagnetic Compatibility, Power Electronics.

I. INTRODUCTION

The motivation of this work comes from the fact that many manufacturers, which produce or use static converters, only get concerned about the EMI generated by their equipment after the design and manufacturing stages. When manufacturers realize that their equipment present some problems related to EMI, they try to apply EMI reduction techniques. These techniques, when applied in finished equipments (ready to operate) turn out to be: use of an EMI filter for conducted EMI reduction and use of shielding for radiated EMI reduction; which increase the production costs. Other techniques that could be applied, as changing: switching frequency, duty cycle, dv/dt and/or di/dt, are not so effective in the final stage of manufacturing [2, 3]. Layout and/or topology changes are also difficult to implement. The adoption of new topologies could lead to a new design and a return to the initial stages of design.

This paper presents some EMI reduction techniques which can be applied even after the equipment is built. To prove this, it is done an analysis of a push-pull inverter of 150W rated power that converts 12Vdc to 220Vac. In a first moment, with a conventional push-pull inverter, two techniques of EMI reduction are applied. The first technique consists of altering the commutation times (rise and fall times), and the resulting conducted EMI is measured. The second technique consists in varying the switching frequency, and the resulting conducted EMI is measured. In a second moment, a topology change in the push-pull inverter is implemented, and the resulting conducted EMI is measured. The experimental results are compared and conclusions are presented.

II. EMI GENERATION AND REDUCTION IN STATIC CONVERTERS

A. EMI Generation in Static Converters

Static converters, in a number of topologies, are inherently EMI generators, i.e., their operating characteristics generate a rich harmonic content. The energy transfer from source to load can be controlled in various ways, but the most usual one is Pulse Width Modulation (PWM) with constant frequency, which creates waveforms as the ones presented in Figs. 1(a) and 2(a). These waveforms have a frequency spectrum that depends basically of: period (T), conduction time (τ) and commutation times from power semiconductors (t_f), as shown by Figs. 1(b) and 2(b).

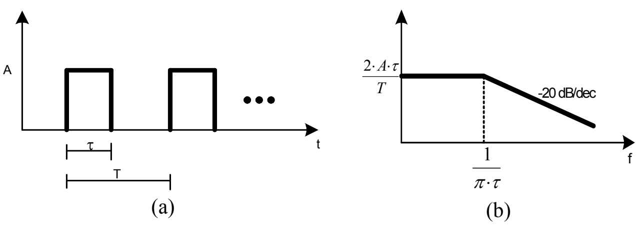

Fig. 1 – (a) A PWM signal with zero rise and fall times.
(b) Resulting frequency spectrum.

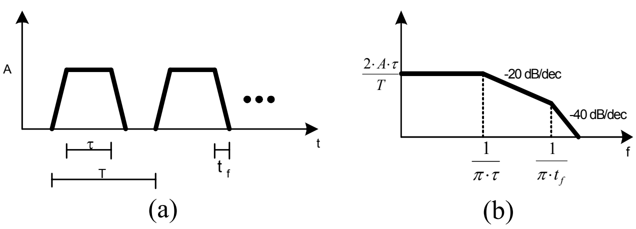

Fig. 2 – (a) A PWM signal with non-zero rise and fall times.
(b) Resulting frequency spectrum.

B. EMI Reduction in a Static Converter

From Figs. 1 and 2, one can realize that increasing commutation times (i.e. reducing dv/dt and di/dt) and reducing switching frequency can contribute for the reduction of the amplitude of the harmonic spectrum and, consequently, of generated EMI [1]. Commutation times can be increased at the command of main semiconductors, or using "slower" semiconductors. The dv/dt and di/dt can be decreased also with the use of resonant topologies with soft and non-dissipative commutation, which brings an increased efficiency of the structure. A reduction in the amplitude of the switching signal also contributes for a reduction in harmonic spectrum amplitude. Increasing commutation times and using slower semiconductors are actions that can be done after the equipment is manufactured. However, frequency and amplitude variation and utilization of resonant cells typically result in new design and layout specifications for the converter. Other techniques include placing capacitors connecting specific parts of the circuit [6], which demand layout modifications too.

III. Experimental Results

Experimental results were obtained applying three techniques of EMI reduction in a push-pull inverter, designed for input of 12Vdc, output of 220Vac, 150W of rated power, switching frequency of 24kHz and fall time (t_f) of 200ns. The techniques adopted were:

- Variation of commutation times, without changing topology and layout.
- Variation of switching frequency, changing topology and layout.
- Inclusion of resonant capacitor, which needed a little change in topology and layout.

Fig. 3 shows the power stage's schematic of the conventional push-pull inverter used in the experiments. Fig. 4 shows the voltage waveform, acquired through an oscilloscope, from one of the inverter's main switches. Fig. 5 shows the conducted EMI generated by the inverter, measured through an artificial mains network and read with an EMI Receiver.

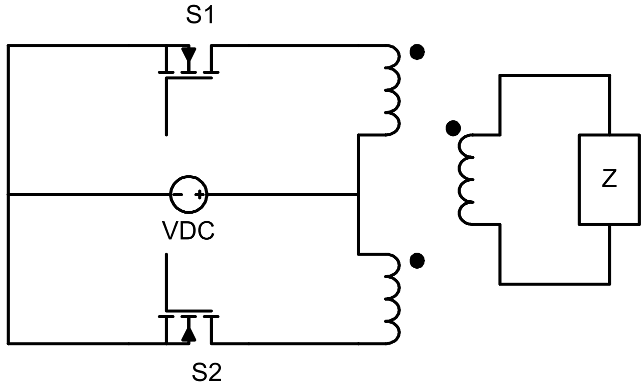

Fig. 3 – Schematic of the conventional push-pull inverter.

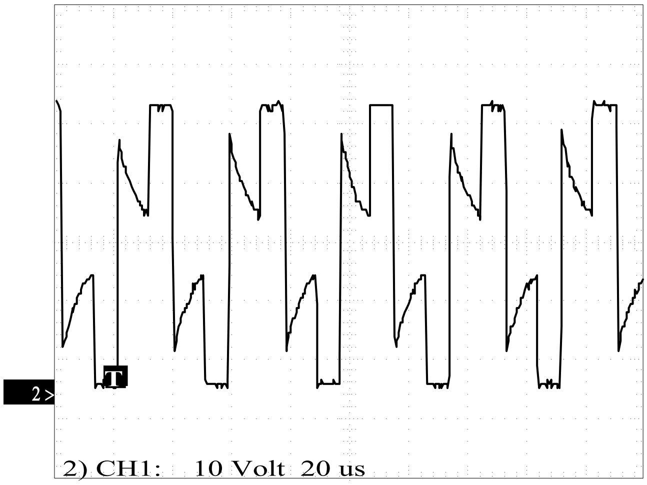

Fig. 4 – Voltage waveform acquired from one of the main semiconductors.

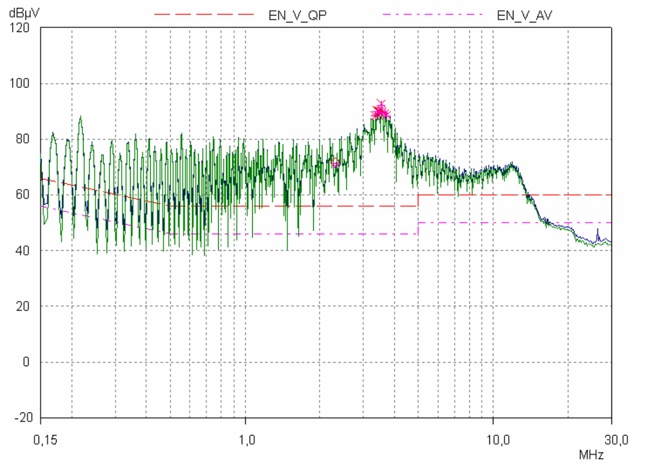

Fig. 5 – Conducted EMI generated by the conventional push-pull inverter (measured).

A. Variation of Commutation Times (Rise and Fall Times)

Figs. 6, 7, 8 and 9 show the conducted EMI measured for the push-pull inverter with values of gate resistors (Rg) and fall time (t_f) given in Table I. Through all these measurements, there is a reference measurement (shown with a weak color), which used Rg=22Ω and has a t_f=200ns.

TABLE I
R_G VALUES AND RESPECTIVE T_F

Rg (Ω)	t_f (ns)
22+37,5	500
22+50	600
22+75	1000
22+150	1400

From Figs. 6, 7, 8 and 9, one can realize that from t_f=200ns to t_f=500ns there is a reduction in the harmonic content amplitude of conducted EMI in the frequency range greater than 10MHz. From t_f=500ns to t_f=1000ns there are no sensible changes, but there is an EMI amplitude increase in the 10MHz-20MHz frequency range. When t_f=1400ns, one can realize an attenuation of about 10dB in the 3MHz-4MHz range. With the increase of t_f, the attenuation of conducted EMI was poor, and there was an increase in commutation losses in the main semiconductors, which reduced the converter's efficiency.

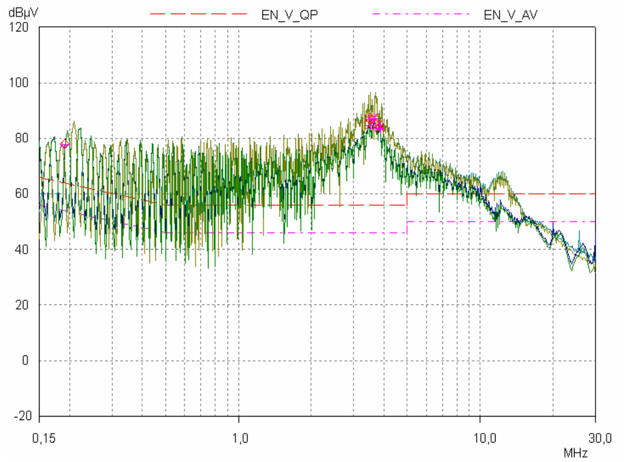

Fig. 6 – Resistor of 22+37,5Ω, t_f = 500ns.

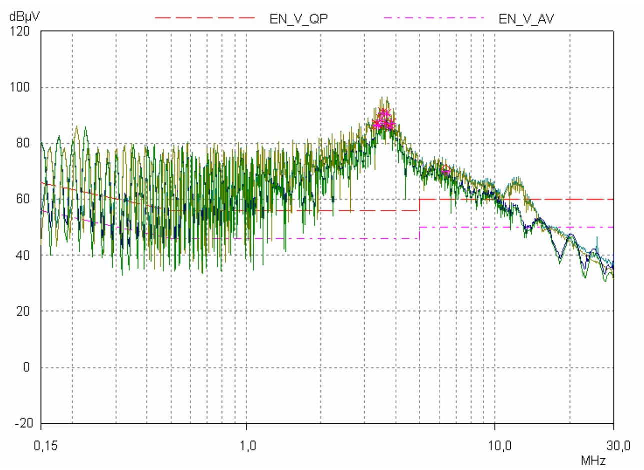

Fig. 7 – Resistor of 22+50Ω, t_f = 600ns.

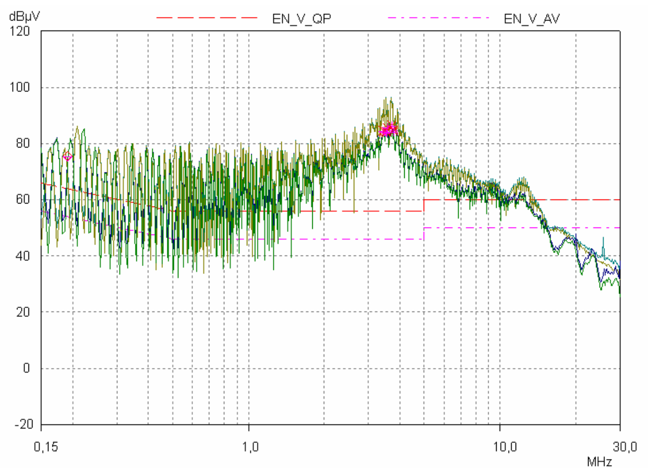

Fig. 8 – Resistor of 22+75Ω, t_f = 1000ns.

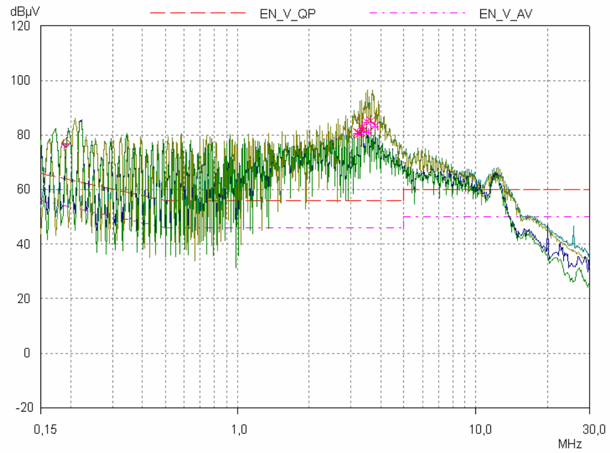

Fig. 9 – Resistor of 22+150Ω, t_f = 1400ns.

B. Insertion of Resonant Capacitor

Fig. 10 shows the push-pull conventional structure with a topology change. It was inserted a resonant capacitor, which causes a dv/dt reduction in the main switch, as shown in Fig. 11.

Fig. 12 shows the conducted EMI measured for the inverter with resonant capacitor. As one can realize, there is a reduction of about 20dB in the 3-4MHz frequency range, and a sensible attenuation in the 10-30MHz range. It's important to realize that, besides reducing the generated conducted EMI, there was an increase in the structure's efficiency, i.e., the semiconductors did not get as warm as in the case of t_f increasing.

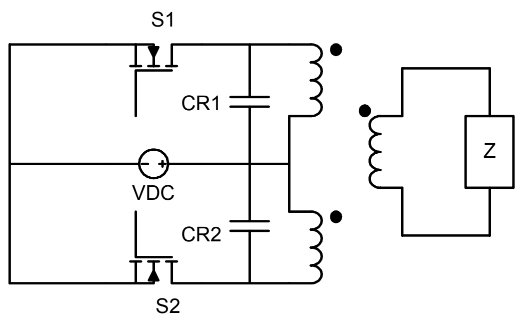

Fig. 10 – Schematic of the Push-Pull inverter with resonant capacitor.

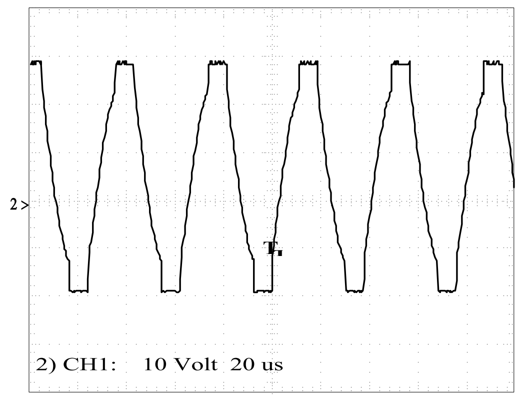

Fig. 11 – Voltage waveform acquired from one of the inverter's main semiconductors with resonant capacitor.

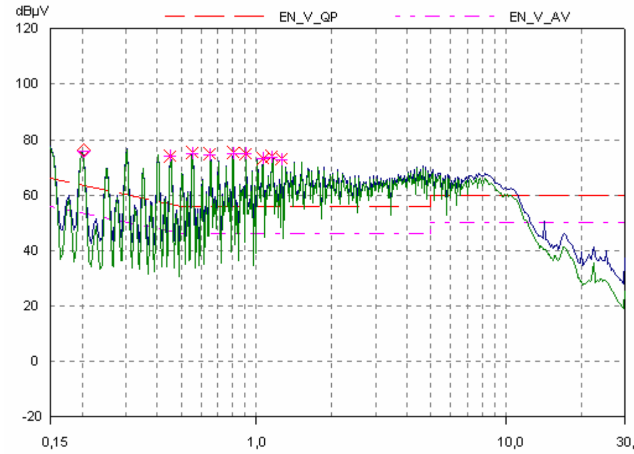

Fig. 12 – Conducted EMI generated by the push-pull with resonant capacitor (measured).

C. Switching Frequency Variation

Figs. 13, 14, 15 and 16 show the conducted EMI measured in the conventional push-pull inverter, with switching frequencies of 34kHz, 24kHz, 14kHz and 4kHz, respectively. As in the previous analysis, it was used a measurement reference of an inverter switching at 24kHz (line with a weak color).

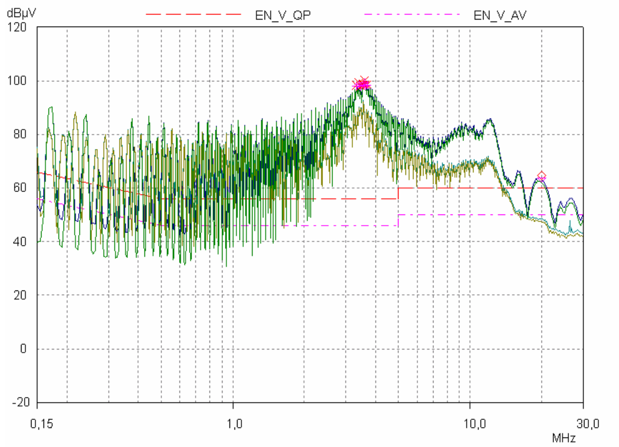

Fig. 13 – Inverter with switching frequency of 34kHz.

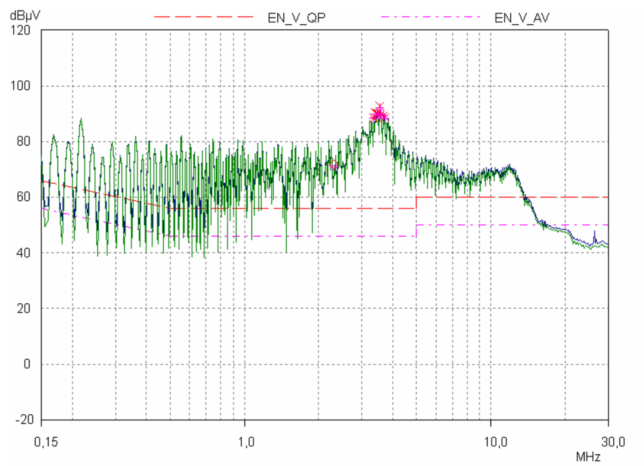

Fig. 14 – Inverter with switching frequency of 24kHz.

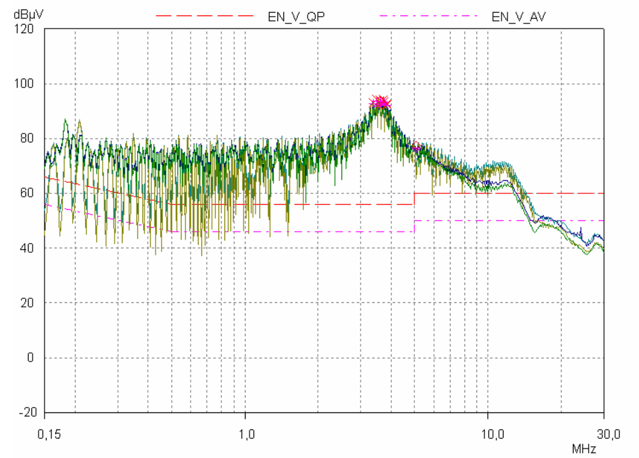

Fig. 15 – Inverter with switching frequency of 14kHz.

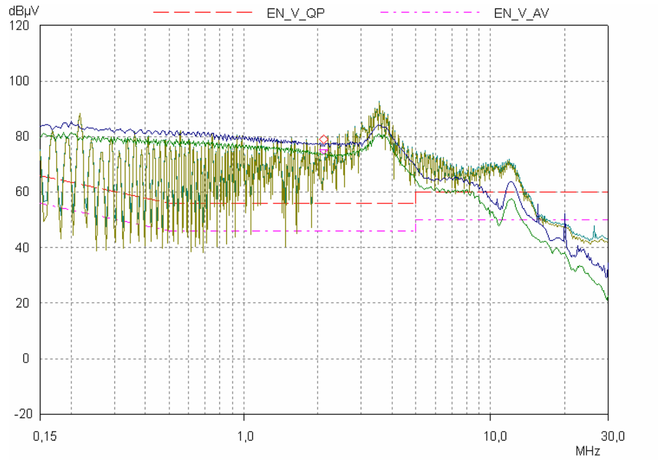

Fig. 16 – Inverter with switching frequency of 4kHz.

Looking at the conducted EMI measured shown in Figs. 13, 14, 15 and 16, one can realize that there is a sensible reduction in the harmonic content greater than 7MHz when reducing the switching frequency. Below 7MHz the EMI harmonic content reduction is poor. For switching frequencies greater than 24kHz, there was a sensible increase in the harmonic content.

IV. CONCLUSIONS

One can observe that, in the three strategies adopted for reduction of conducted EMI presented, there were different levels of reduction in the conducted EMI generated by the inverter. The strategies were more efficient for harmonics greater than 3MHz.

Referring to strategies that carried out in dv/dt decreasing (increase of t_f – use of resonant capacitor), the reduction of harmonics greater than 3MHz is due to the reduction of high frequency harmonic content, which is generated by switching. This effect it is important because the noise was reduced at its source, one of the basic principles of EMI reduction [1].

The strategy of placing a resonant capacitor was more efficient, because it simultaneously reduced the amplitude of the harmonics greater than 7MHz, reduced the amplitude of harmonics in the 3MHz-4MHz frequency range and increased the efficiency of the structure. However, this strategy brings a trouble: New layout and design are needed.

The switching frequency reduction also reduced the harmonic content greater than 7MHz. But, in this case, this fact is associated with the inter-winding parasitic capacitance. This fact can also be observed in the figures that present the inverter operating with switching frequency greater than 24kHz, where one can realize the harmonic content increase in the frequency range greater than 7MHz.

The switching frequency reduction did not reduce much the harmonic content in the 3MHz-4MHz frequency range because these harmonics are related to the LC circuit consisting of transformer inductance and output capacitance in the main semiconductors and, consequently, associated to the energy involved in the switching of these semiconductors [2, 3, 6].

For attenuating the harmonics below 3MHz, it would be necessary a radical change in the converter's design, where one should reduce the relation represented by (1).

$$\frac{A \cdot \tau}{T} \tag{1}$$

Where:

- A: Switching signal amplitude.
- τ: Conduction time.
- T: Period.

Finally, we would like to emphasize that one must look at EMI aspects since the design stage of a static converter, when one can define topology, semiconductors, switching frequency, signal's amplitude, rated power, command's strategy, layout, etc. After the equipment is ready to operate, the feasible solutions turn out to be filtering and shielding.

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