NON-LINEAR INDUCTOR CONTRIBUTION TO HARMONIC SPECTRUM IN POWER CONVERTERS

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Abstract - **The paper investigates the harmonic content in DC/DC power converters where the inductor is operated in the non-linear region. This operation is often exploited to use lighter and cheaper inductors; as a drawback, an increasing number of harmonics is noticeable. A theoretical analysis is proposed. It is based on a polynomial model of the inductor used in a boost converter. Results are given by the spectra of the output voltage performed on a circuit prototype.**

I. INTRODUCTION

The reduction of the cost and weight of the inductor employed in a DC/DC power converter can be obtained by exploiting the region in which the inductance varies, i.e., the weak-saturation region [1–4]. On the other hand, the current flowing through the inductor becomes non-linear. Usually, the inductor experiences a constant voltage. For linear operation, the current has a triangular shape; on the contrary, if the inductance depends on the current, it exhibits a pronounced peak, as shown in Fig. 1. Consequently, the harmonic contents will differ from the constant inductance behavior resulting in an increased number of frequencies. The spectrum can be calculated if a suitable model of the inductor is available. In this paper, the inductance is modeled by a polynomial expression whose parameters are experimentally identified [5-7].

An experimental analysis is performed on a boost converter considering both the current flowing through the inductor and the voltage at the load terminals.

Spectra of the output voltage obtained using FFT will be compared both for experimental and theoretical results.

II. MODEL OF THE INDUCTOR

A polynomial function has modeled the inductor since it is computationally light [4, 6]. The coefficients of this function are considered linear dependent on the temperature as in (1).

$$L(i) = L_0 + L_1 \cdot i + L_2 \cdot i^2 + \cdots = L'_0(1 + \alpha_0 T) + L'_1(1 + \alpha_1 T) \cdot i + L'_2(1 + \alpha_2 T) \cdot i^2 + \cdots \quad (1)$$

The characterization of the inductor is performed by a virtual system developed in LabVIEW® environment [5]. The inductor under test is placed in a DC/DC converter with a variable load. The LabVIEW instrument imposes the DC bias current, the frequency and the duty-cycle of the switching element, and calculates the inductance by the ratio between the voltage applied to the inductor (maintained constant) and the slope of the current.

III. BOOST CONVERTER DETAILS

The Boost converter is powered with Vs=60V, and the switching frequency is equal to 30kHz. It adopts an FDP12N60NZ MOSFET for the switch, an STTH806G rectifier for the diode. The converter scheme used for tests is shown in Fig. 2, while Fig. 3 shows the prototype.

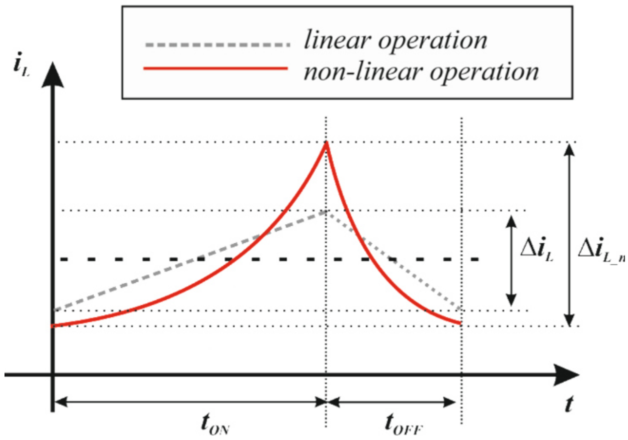

Fig.1. Theoretical waveforms of the current through the inductor

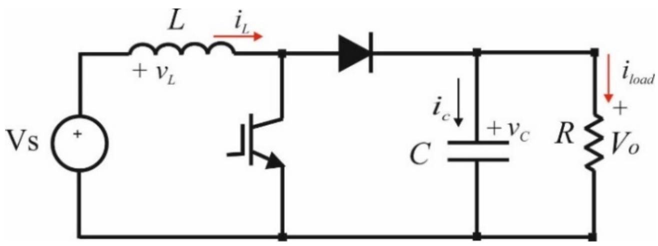

Fig.2. Scheme of the boost converter

Fig.3. Boost converter prototype

IV. RESULTS

In this section, the outcome of implementing a non-linear inductor in a boost converter has been analyzed. In particular, the input current and the output voltage have been evaluated changing the DC input current by varying the converter load. The inductor operations in the linear zone are obtained with $I_{L\,DC} \approx 2.0$A and the non-linear one with $I_{L\,DC} \geq 2.2$A. Figure 4 shows the current flowing through the switch; it should be noted that when the switch is closed, this current is equal to the input current. As the load decreases, the DC current rises, leading the inductor in the non-linear regime. This behavior worsens the ripple in the current provoking a cusp-like waveform. Such effects also impact the output voltage, increasing its AC component, as shown in Fig. 5; in fact, the output voltage spectrum contains more harmonics. This latter effect can be highlighted by analyzing the Power Spectral Density (PSD) when the inductor exploits the non-linear characteristic (Fig. 6). It is worth noting that when the DC input current raises to about 2.9A, each harmonic presents an increase in PSD of about 20 dB(mW/Hz), higher than the linear case ($I_{L\,DC} \approx 2.0$A). The mean output power is obtained by integrating the PSD in the frequency range [0, 106] Hz and summarized in Table I where the variation is compared to the linear case. It can be noted that the operation in the non-linear regime augments the mean power of 203% to the linear case.

V. CONCLUSIONS

The exploitation of the inductor in the non-linear zone introduces a different harmonic content both in output voltage and in input current. The spectrum exhibits, in general, an increase in the amplitude and high order harmonics appear; this is also confirmed by the evaluation of the experimental spectral power density. In the final paper, the experimental results will be compared with the analytic results obtained from the polynomial model of the non-linear inductor.

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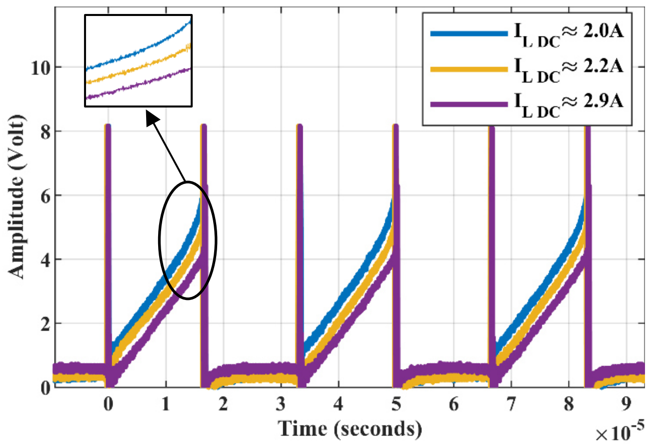

Fig.4. Current flowing through the switch for different load values, change of the slope in the current is zoomed in the inset

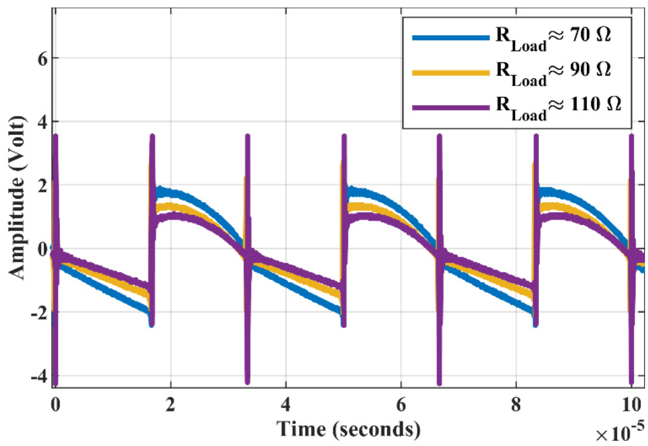

Fig.5. AC output voltage for different load values

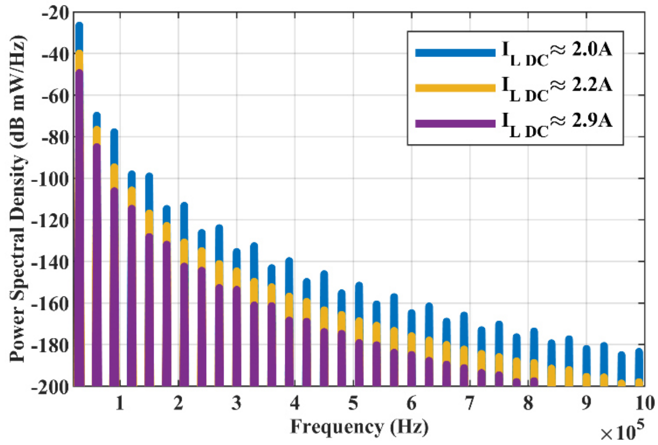

Fig.6. Power Spectral Density normalized to 1 Ω of the AC output voltage for different load conditions

TABLE I
SPECTRAL POWER DENSITY EVALUATION

$I_{L\,DC}$	Mean Power Normalized to 1Ω	Variation
2.0 A	576 mW	-
2.2 A	922 mW	**+60%**
2.9 A	1751 mW	**+203%**