A SELF COMMUTATED PWM DC-DC FULL-BRIDGE CONVERTER

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Abstract – **This paper introduces a Self-Commutated PWM DC-DC Full-Bridge Converter operating at reduced commutation losses. This converter use itself elements (bottom switches) and the phase shift control (up switches) to get the soft commutation, without using additional semiconductors or auxiliary power supplies. The self-commutation is based in the stored energy on the inductor, it is placed serially with the primary of the transformer. This energy is enough to discharge the switches of the capacitors and provides the condition for zero voltage switching (ZVS). The up switches use the phase shift control. The proposed approach allows building a converter with high frequency of operation. The output voltage is controlled by PWM. The complete theoretical analysis, operating principles, simulation results and experimental results are presented.**

KEYWORDS

PWM Full-Bridge DC-DC converter, non-dissipative commutation, voltage switching (ZVS), High power density, high switching frequency.

I. INTRODUCTION

In the last years a very high effort was moved in the sense of obtaining higher efficiency and higher power density in the switching mode power supplies. High switching frequencies are necessary to reduce the size of the filter elements and transformers of the converter. However, this, besides providing noises of electromagnetic interferences - EMI and radio frequency - RF, produces losses of significant switching and, consequently, low efficiency in a converter operation with hard-commutation. The resonant converters have attracted a high attention due of their low switching losses and low EMI [1,2], besides, soft switching PWM topologies [3,4,5] have advantages as such constant frequency of operation and simple control.

However they have load limitation and high current or voltage ratings for semiconductor devices. To alleviate these problems, the topology of the Figure 1 [6] can be used, the PWM Full-Bridge DC-DC Converter using phase-shift control and the self-resonant principle. This topology presents good results, but it has additional semiconductors (switches and diodes) and an auxiliary power supply.

Like this, the Self Commutated PWM DC-DC Full-Bridge Converter is proposed, therefore, allows to use a minimum additional components, but with the same soft switching characteristic of the earlier topologies.

The topology proposed in this paper is a simple traditional full-bridge with a inductor placed serially with the transformer and capacitors shunt with the switches. The principle of operation, simulation results and experimental results are illustrated and discussed for the new topology proposed.

II. THE PROPOSED DC-DC FULL-BRIDGE CONVERTER

For comparison effect with the converter proposed in this paper (Self-Commutated PWM DC-DC Full-Bridge Converter), the Figure 1 is shown so that it is noticed a larger number of components in your commutation cell. Figure 1 represents SR-PWM Full-Bridge DC-DC Convert (Self-Resonant Full-Bridge DC-DC Convert) with cell of commutation non dissipative, however, this commutation cell is obtained by including in the PWM Full-Bridge Converter two auxiliary switches (S_{a_1} , S_{a_2}) and two auxiliary voltage sources ($C_{aux._1}$, $C_{aux._2}$) those feed the resonant circuit (L_{r_1} , L_{r_2} , C_r).

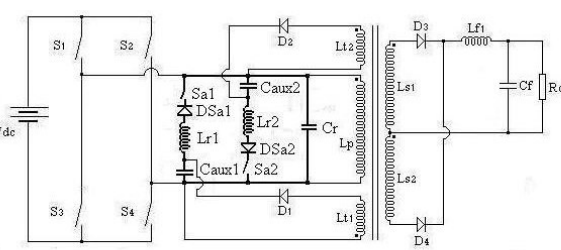


Figure 1 - The PWM Full-Bridge DC-DC Converter using phase-shift control and the self-resonant principle.

Figure 2 shows the PWM DC-DC Full-Bridge Converter operating at reduced commutation losses using phase shift control and the proposed Self-Commutated principle.

Figure 2 shows an improved converter circuit with a non-dissipative commutation. This soft commutation is obtained by the phase shift control on the S1 and S2 switches, and using the resonant circuit (L_R, C_{R1} or C_{R2} and the magnetization inductor) on the S3 or S4. The oscillation begins when S1 or S2 are turned off, thus L_R and the magnetization inductance must be discharged, and this is done by C_{R1} or C_{R2} (depends on the current direction). In a switching cycle S1, S2, S3 e S4 commutate without losses in the ZVS (Zero Voltage Switching) form.

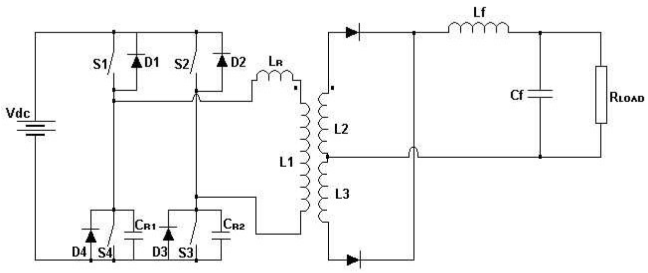


Figure 2 - The Self-Commutated PWM DC-DC Full-Bridge Converter.

How this Full-Bridge converter does not use additional elements (C_{R1} and C_{R2} can be the intrinsic capacitance of the switches and L_R can be only the magnetization inductance) it is called Self-Commutated DC-DC Full-Bridge Converter.

The Self-Commutated PWM DC-DC Full-Bridge Converter operational features give the following advantages: reduced commutation losses, high power density, high switching frequency with high efficiency, low level noise, minimum additional components.

III. PRINCIPLE OF OPERATION

Assuming that all components are ideal, the circuit operation is explained as follows. Figure 3 shows the simplified schematic circuits for each stage of operation of the Self-Commutated DC-DC Full-Bridge Converter. For this analysis S1 and S2 is initially on.

- **First Stage (t_0, t_1) -** This stage begins when the switch S2 is turned off in the ZVS form due C_{R2}. In this stage C_{R2} oscillate with L_R and the magnetization inductance up to the voltage in C_{R2} (V_{CR2}) reaches 0V. Thus the S3 can be turned on, in the ZVS form.

- **Second Stage (t_1, t_2) -** In This stage S3 is turned on in the ZVS form. The L_R current raises lineally up to the load current with the voltage approximately Vdc/2. When the L_R current reaches the load current, the current flows through S1 and S3, beginning the power transference from primary to secondary of the transformer. This is the PWM stage.

- **Third Stage (t_3, t_4) -** This stage begins when the switch S3 is turned off in the ZVS form, but the S1 switch keeps on. In this stage the input current flows through S1 and C_{R2} up to V_{CR2} reaches Vdc (input voltage).

- **Fourth Stage (t_4, t_5) -** This stage begins when V_{CR2} reaches Vdc. Thus, the diode D2 is turned on and the input current free-wheels through the switch S1 and the diode D2, up to the S1 switch be turned off in the ZVS form due C_{R1}, beginning the switching cycle for the other leg.

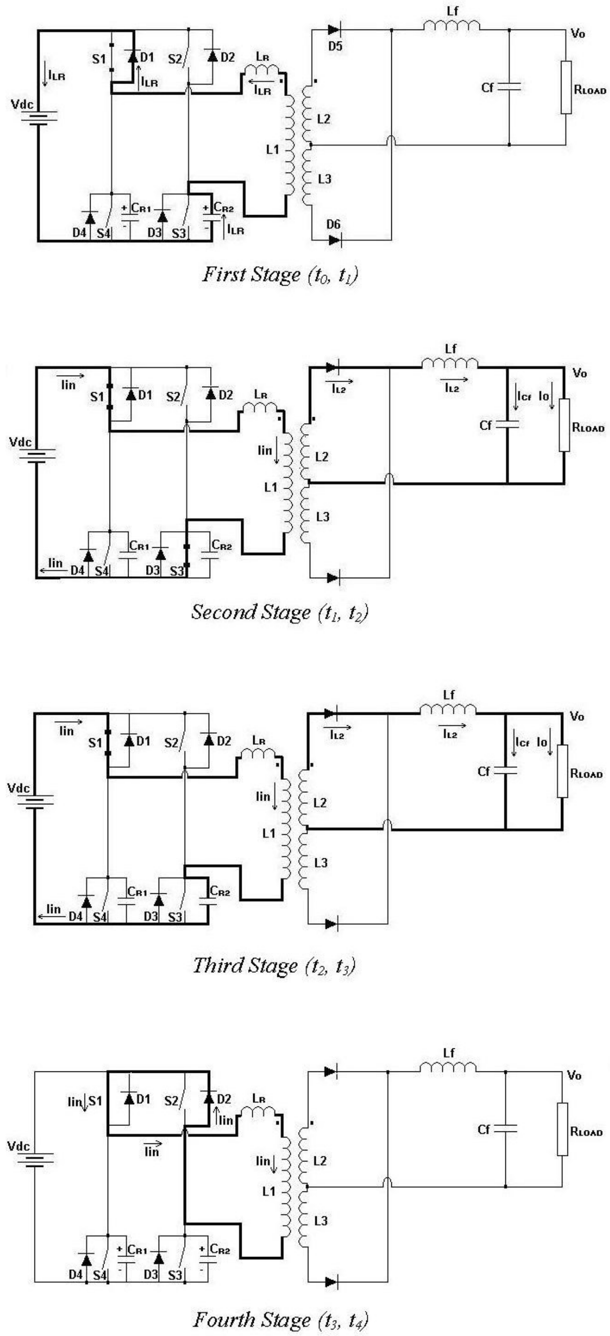


Figure 3 - Equivalent Circuits for Each Operating Stage for Self-Commutated DC-DC Full-Bridge Converter.

Figure 4 shows the principal waveforms in a half switching cycle for the switches S1, S3, voltage in C_{R2} and current in L_R.

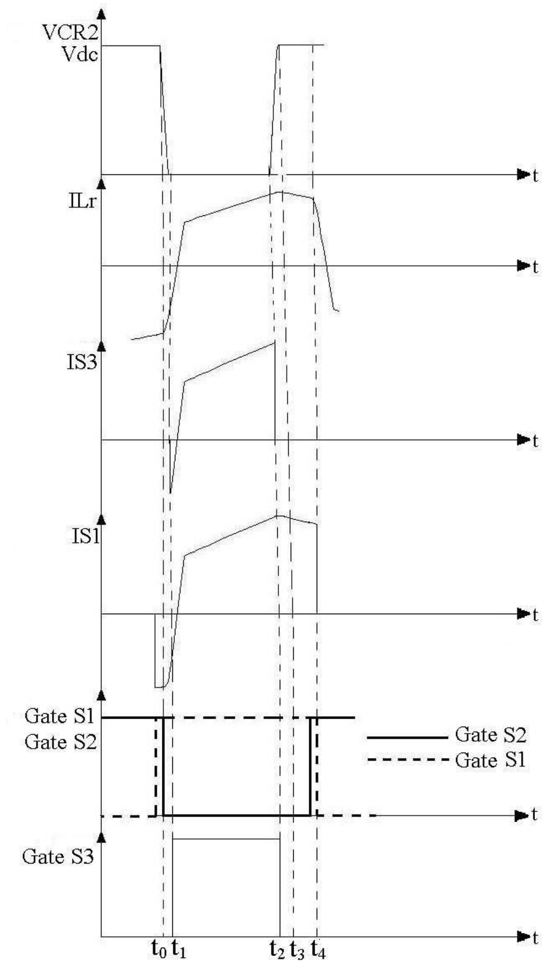


Figure 4 - Principal Waveforms for Self-Commutated DC-DC Full-Bridge Converter.

IV. ANALYSIS RESULTS

The output voltage Vo, can be obtained by the analytical study of the operating stages and with the following assumptions: all the components and switches are ideal, the output is an ideal current source (Io), the input voltage (Vdc) are ripple free, an unity turns ratio transformer (Np/Ns) is assumed, the transformer leakage inductance is negligible.

V. CIRCUIT ANALYSIS

To proceed the equations that represent the circuit are described. These calculations are distributed in four different stages, and each stage represents the respective operation state. To determine the voltage gain of the Converter, presented in this paper, the following definitions have been used:

$\text{á} = \dfrac{I_0\sqrt{L_R}}{Vdc\sqrt{C_R}}$ (1)
$G = \dfrac{V_0}{V_i} = \dfrac{V_0}{Vdc}$ (2)
$C_R = C_{R1} = C_{R2}$ (3)
First Stage (t_0, t_1): $t_1 = \dfrac{\text{sen}^{-1}\left(\dfrac{1}{\alpha}\right)}{\omega}$ (4)
Second Stage (t_1, t_2): $i(t) = -I_0.\cos\omega t$ (5) $t_2 = L.I_0\left(1+\sqrt{1-\dfrac{1}{\alpha^2}}\right)\left(\dfrac{1}{t_1}\right)$ (6)
Third Stage (t_2, t_3): $t_3 = D.T_S - \dfrac{L}{Vdc}.I_0\left(1+\sqrt{1-\dfrac{1}{\alpha^2}}\right)$ (7)
Fourth Stage (t_3, t_4): $v_{CR}(t) = \dfrac{I_0.t}{C_R}$ (8) $t_4 = \dfrac{C_R.Vdc}{I_0}$ (9)
Static Gain: $\dfrac{V_0}{Vdc} = D + \dfrac{F_S}{2.\pi.f_R}\left(\dfrac{1}{2.\alpha} - \sqrt{\alpha^2 - 1}\right)$ (10)

Figure 5 represents the Equation 10, that is, the curve of the gain static (G) dependent of the duty cycle (D), of the resonant frequency (f_R), of the switching frequency (F_S) and of the ratio (a) .

Where:

- I_0 : load current
- D : duty cycle
- F_S: switching frequency
- T_S: switching period
- f_R : resonant frequency

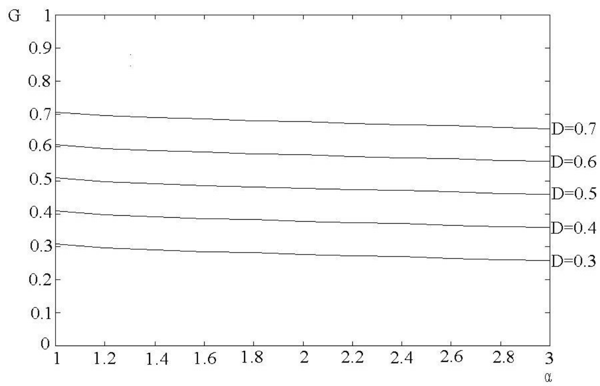
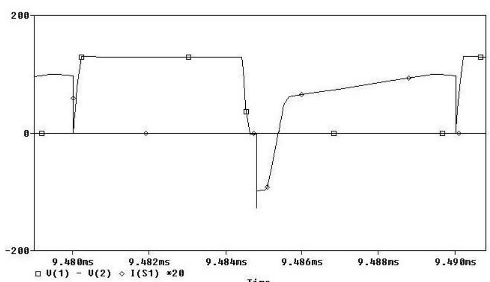


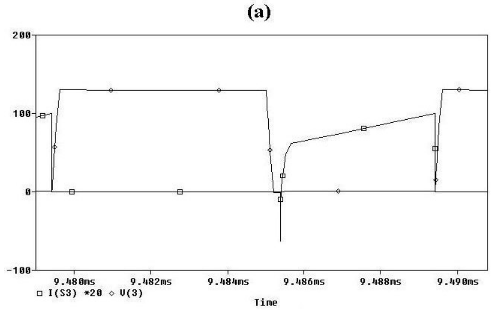
Figure 5 - Curves of the static gain.

VI. SIMULATION RESULTS

In order to confirm the effective performance, the proposed Self-Commutated DC-DC Full Bridge Converter has been studied by simulation using the following parameters set: Vdc = 130V; F_S = 100kHz; C_{R1} = C_{R2} = 3,2ηF; L_R = 10μH.



(a)



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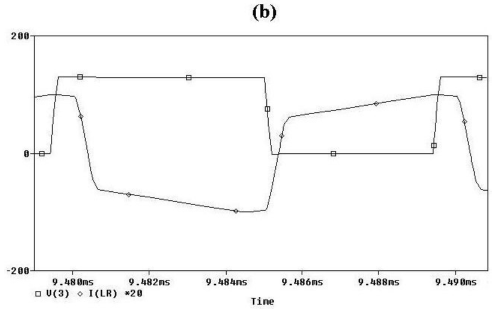
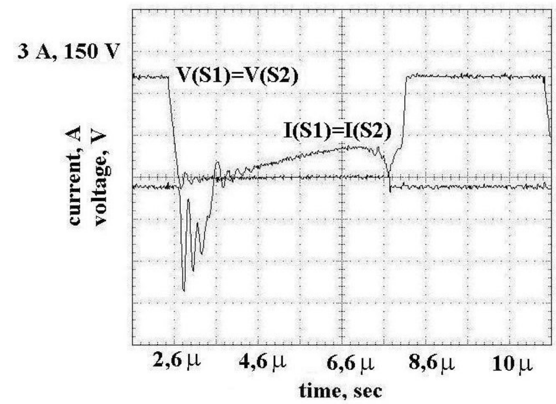


(c)

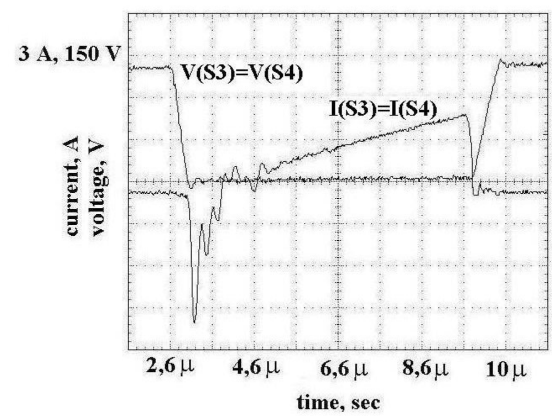
Figure 6 - Simulation Results. (a) Waveforms of the Current and Voltage in S1 and S2; (b) Waveforms of the Current and Voltage in S3 and S4; (c) Waveforms of the Current and Voltage in Lr and Cr2.

VII. EXPERIMENTAL RESULTS

The proposed Self-Commutated PWM DC-DC Full-Bridge Converter operating at reduced commutation losses was rehearsed at laboratory with the follows parameters to proceed, with the purpose of proving your accuracy and efficiency. Vdc = 130V; Vo = 66,5V; Io = 2,75A; F_S = 100kHz; C_{R1} = C_{R2} = 2,2ηF; L_R = 15μH.



(a)



(b)

Figure 7 – Experimental Results. (a)Waveforms of the Current and Voltage in S1 and S2; (b) Waveforms of the Current and Voltage in S3 and S4.

VIII. CONCLUSION

In this paper, a new and simple alternative was introduced to be reached a soft commutation through a topology that uses the minimum of additional components, the Self-Commutated DC-DC Full Bridge Converter. It is obtained by the inclusion of a commutation cell in the conventional PWM Full-Bridge DC-DC Converter. The characteristic principal of such structure are: reduced commutation losses, high switching frequency with high efficiency and low-level noise. The circuit operation has been described and discussed. Simulation and experimental results confirm the soft switching commutation in ZVS forms of the switches S1, S2, S3, and S4.

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