FULL - BRIDGE CONVERTER USING A NON - DISSIPATIVE SNUBBER

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***ABSTRACT* - This work present a contribution on the study of a soft-switching DC-DC Full-Bridge converter isolated by a high frequency transformer. The converter uses a non-dissipative snubber, that is composed by four resonant capacitors, one resonant inductor and two auxiliary switches, which work in the ZCS way. The main switches work in a ZVS way. The output voltage is controlled by PWM. The complete operating principles, theoretical analysis, relevant equations, simulation and experimental results is presented.**

1 - INTRODUCTION

Recently, there have been an increased interest in the area of soft-switching resonant converters, the tradeoffs involving these converters because they present several advantages such as: small size, light weight, higher frequency of operation, higher efficiency, reduced EMI, low-component stresses, reduction of commutation and conduction losses, etc. These features are important for power electronic circuit designers, because these converters contribute to develop high-power supplies and they are important in some application areas such as Switching Mode Power Supply (SMPS), motor drives, AC energy transmission system, etc., [1], [2], [3],[4].

Soft-switching converters can be classified as Zero-Current Switching (ZCS) and Zero-Voltage Switching (ZVS) [1]. These switching techniques present current stress or voltage stress in a ZCS or ZVS way, respectively and both are higher than that obtained in a PWM circuit. In addition these converters present load limitation due to high current and/or voltage on the main switches.

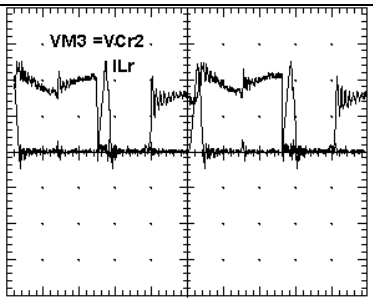
At high power levels enough to justify the use of the four controlled switches, probably the best choice is the Full-Bridge soft-switching converter. The converter controlled by phase-shifted has the circulating current flowing through the transformer and switching devices. This problem was overcame in reference [5], [10]. The Saturable reactor assisted (SRA) soft-switching PWM converters present low commutation current resulting in lower conduction losses, however due to the circulating current flowing through the converter, conduction losses are still relatively high when compared with that of conventional hard-switching PWM converters [6].

Using, resonant, quasi-resonant, soft-switching circuits or non-dissipative snubber can reduce the switching losses in converters. A good way to reach high frequency and high-power operation is to use the non-dissipative snubber presented in references [7],[8], [9].

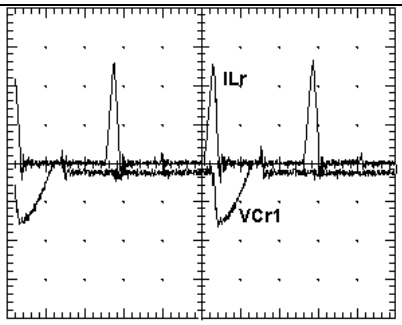
This paper proposes a Full-Bridge Converter using a non-dissipative snubber, that uses the advantages of several situation mentioned up and it contributes with general research effort.

2 - THE PROPOSED FULL-BRIGDE WITH NON-DISSIPATIVE SNUBBER

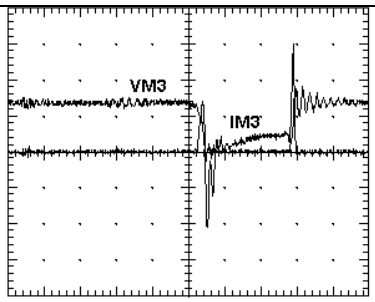
Figure 1 shows a simplified circuit of the studied the proposed Full-Bridge converter. This converter can operate with reduced commutation and conduction losses. In these converter the switches M1, M2, M3 and M4 are gated on the ZVS form due to the resonant capacitors Cr1, Cr2, Cr3 and Cr4. The switches Saux1 and Saux2 are gating on and off in the ZCS form due to the resonant inductor Lr.



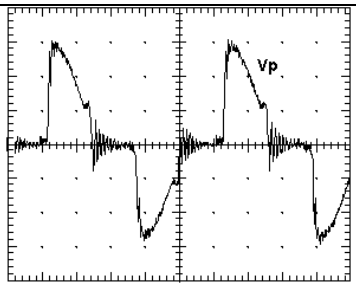
(a) Current and voltage on the resonant elements Voltage(50V/div), Current(2A/div),Time(2μ s/div).



(b) Current and voltage on the resonant elements Voltage(50V/div), Current(2A/div),Time(2μ s/div).



(c) Commutation Switch M3, Voltage(50V/div.), Current(2A/div),Time(2μ s/div).



(d) Primary side voltage (50V/div.),Time(2μ s/div).

5 - CONCLUSION

The Full-Bridge converter using a non-dissipative snubber presents features soft-switching ZVS for switches M3 and M4 and ZCS for the auxiliary switches, it operates at reduced conduction and commutation losses, it uses the resonant principle and employs a tapped inductor.

The operation and performance are verified by PSPICE simulation results, this way, confirms the soft switching commutation in ZVS and ZCS way of the switches. Theoretical results have been verified experimentally on a laboratory prototype.

6 – REFERENCES

[1] - LEE, F. C.; "High-Frequency Quasi-Resonant Converter Technologies", Proceedings on the IEEE, vol. 76, n^{0} 4, April 1988, pp. 337-389.

[2] - PRESSMAN, A. I.; "Switching Power Supply Design", McGraw Hill International Editions, Engineering Series, 1992, Singapore.

[3] - JÚNIOR, J. B. V., "Conversores Quase-Ressonantes: Novas Topologias, Projetos e análises". Tese de Doutorado - Florianópolis- SC: Universidade Federal de Santa Catarina, 1991.

[4] - BALOGH L.; REDL R.; "Power-Factor Correction with Interleaved Boost Converter in Continuos-Inductor-Current Mode", Proceedings of APEC`93 (IEEE Catalog n^{0}, pp. 168-174).

[5] - BALOGH L.; REDL R.; SOKAL, N. O.; "A Novel Soft-Switching Full-bridge DC/DC Converter: Analysis, Design Considerations, and Experimental Results at 1.5 kW, 100 kHz", IEEE Transactions on Power ELECTRONICS, VOL. 6, N^{0} 3, July 1991, pp. 408-418.

[6] - SCHWARZ, F. C.,; "An Improved Soft-Switching PWM Full-Bridge DC-DC Converter Modification Operating at Reduced Conduction Loss", IEEE PESC`93, pp. 165,170.

[7] - CORRÊA PINTO, J. A.; PEREIRA, A. A.; VIEIRA Jr., J. B.; de Freitas, L. C. and FARIAS, V. J.; "A New Boost Converter Using a Non-dissipative Snubber", Proceedings of PESC`96, pp. 397-401.

[8] - CORRÊA PINTO, J. A.; PEREIRA, A.A.; DE FREITAS, L.C.; VIEIRA JR.,J. B.; FARIAS, V.J; "A Power Factor Correction Preregulator AC-DC Interleaved Boost With Soft-Commutation", PESC'97, USA.

[9] – BARRETO, L. H. S. C.; PEREIRA, A. A.; DE FREITAS, L. C.; VIEIRA JR.,J. B.; FARIAS, V. J; "A Boost Converter Associated With A New Non-Dissipative Snubber", IEEE APEC'98, Record CD, Los Angeles, California, USA, Feb/1998.

[10] - PEREIRA, A.A.; SOUZA, J. C. S.; DE FREITAS, L.C.; VIEIRA JR.,J. B.; FARIAS, V. J; "A Full-Bridge Self Resonant PWM DC to DC Converter Operating at Reduced Conduction and Commutation Losses and Working With Three Different Transformers", PESC'97, USA.

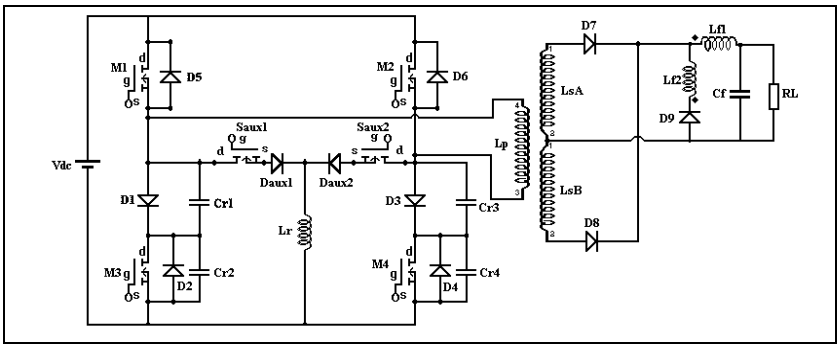


Fig.1 - The Schematic Circuit of the Full-Bridge.

3 - PRINCIPLE OF OPERATION

To simplify the study, half-switching cycle of the proposed converter was divided in seven topological modes. The figure 2 shows the equivalent circuits of the proposed converter in its seven topological modes.

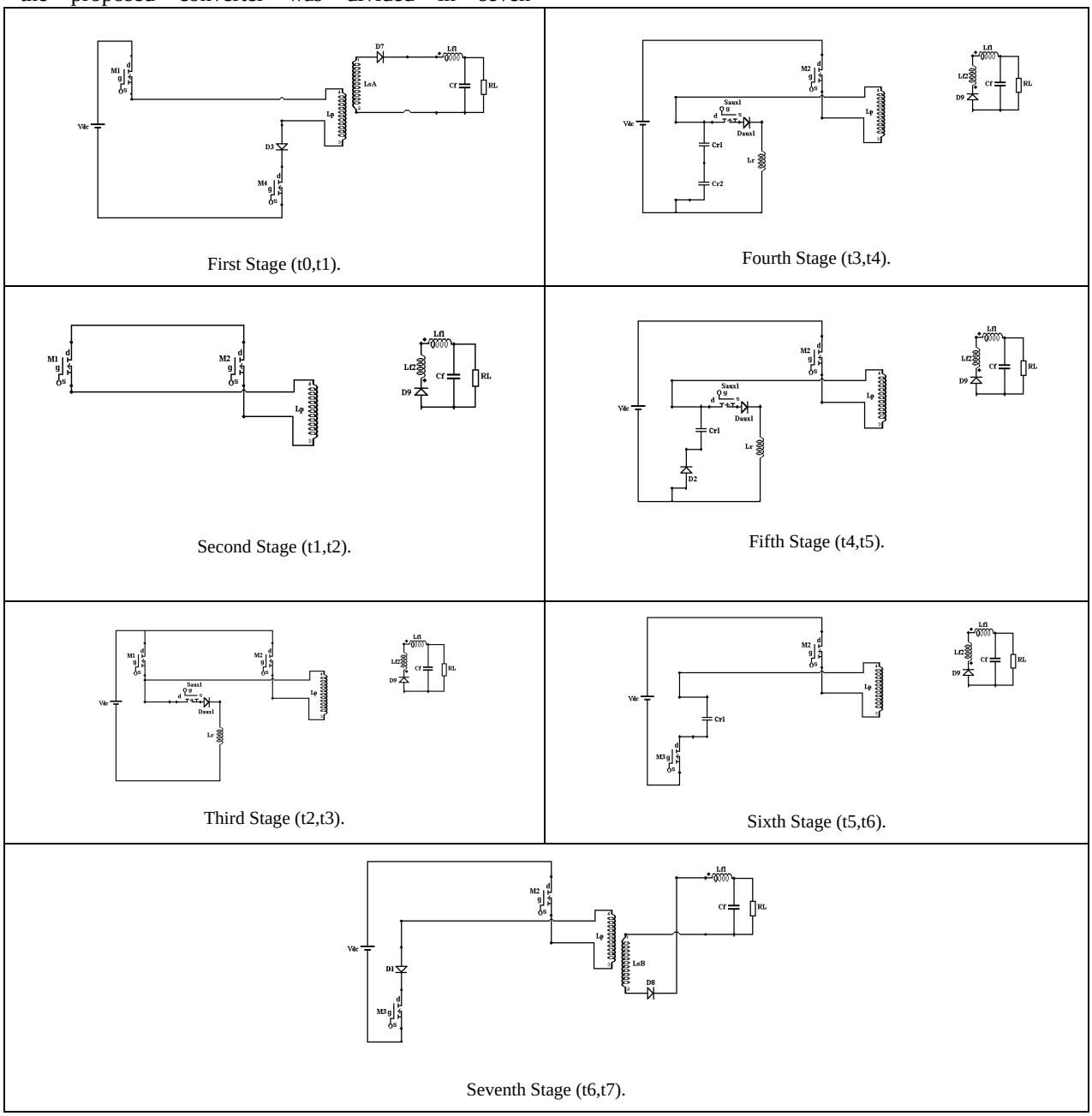


Figure 2 - Equivalent circuits for each operating stage for Fig.1 circuit.

Where:
1:n = turns ratio.

$$\alpha = \frac{Iin}{Vdc}\sqrt{\frac{Lr}{Cr}} \qquad (2)$$

$$\omega_0 = \frac{1}{\sqrt{LrCr}} \qquad (3)$$

$$X = \frac{Cr1}{Cr2} \qquad (4)$$

$$K1 = \frac{f_S}{f_O} \qquad (5)$$

$$D = \frac{\Delta T}{T_s} \qquad (6)$$

$$\Delta T = t_j - t_i \text{ (time interval)} \qquad (7)$$

f_s = switching frequency;

T_s = switching period.

From equation (1) it is observed that the converter static gain depends on the ratio between Vo and Vdc; the switch duty-cycle (D) and α is the ratio normalized load current . See figure 4.

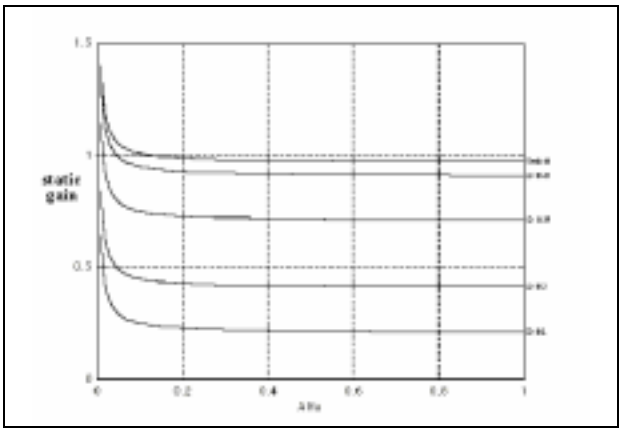


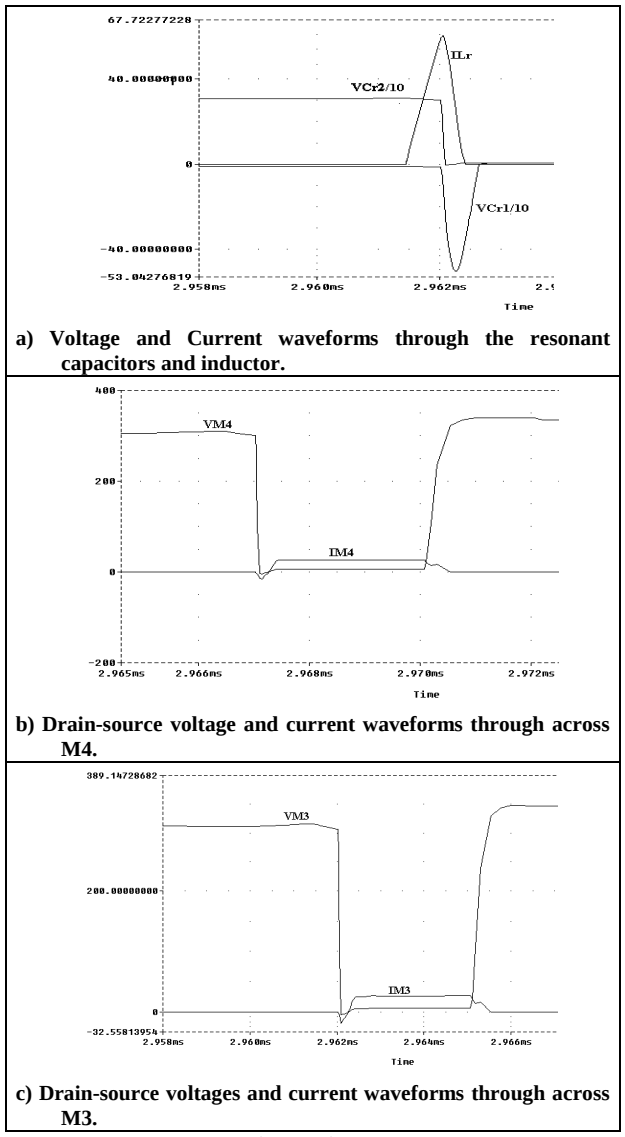
Figure 4 - Curves of duty cycle vs normalized load current, when static gain is varied.

4 - SIMULATION AND EXPERIMENTAL RESULTS

In order to illustrate the converter operation a Full-Bridge converter using a non-dissipative snubber was analyzed by simulation with the following parameters set:

Vdc=300 V;	I0 = 30 A;	f_S = 100 kHz;
Cr1 = 15.6 ηF;	Cr2 = 7.8 ηF;	ILr = 2.5 μH.

For comparison purpose, simulation results are shown in figure 5. The simulation results show the converter operating at reduced conduction and commutation losses using phase-shift with tapped inductor and soft-commutation operation.



a) Voltage and Current waveforms through the resonant capacitors and inductor.

b) Drain-source voltage and current waveforms through across M4.

c) Drain-source voltages and current waveforms through across M3.

Figure 5 - Simulated waveforms of the Full-Bridge converter using a non-dissipative snubber.

A prototype of the Full-Bridge converter using a non-dissipative snubber was built using the following set of parameters:

Vdc=50 V;	R_L = 30 Ω;
Cr1 = 15.6 ηF;	Cr2 = 7.8 ηF;
f_S = 100 kHz;	ILr = 3.3 μH.
IRFP460 (Mosfet);	Diode MUR1560

Experimental results are presented in figure 6 which demonstrates the fundamental principles of operation. As can be seen the commutations of the switches occur without losses.

The converter operating stages are as follows:

1^0 STAGE (t0,t1):

This stage begins in the time t0 when switches M1 and M4 are conducting. During this stage occurs power transference from the input voltage source to the secondary of the transformer. This stage finishes when switch M4 is turned off.

2^0 STAGE (t1,t2):

This stage begins when switch M4 is turned off. Current is flowing through the anti-parallel diode (D6) of M2 and M2 can be turned on with zero-voltage switching (ZVS) during this interval. Also during this stage the current is freewheeling in the primary of the transformer through M1 and switch M2 . The voltage on coupled inductor Lf2 forces the current to decrease quickly in the primary of the transformer, until it arrives the zero value. The current ILf2 increases until it reaches a maximum value. The time of this stage depends on the dispersion inductance of coupled inductor Lf2 and of the inductance's transformer. This stage is responsible for the phase displacement control. This stage finishes when auxiliary switch Saux1 turns on in a ZCS way, due to resonance inductor Lr that slows the di/dt. Also in this stage, the primary demagnetization occurs. The voltage in Cr2 is Vdc and in Cr1 it is zero. In the end of this stage, it exists a free wheeling stage through D9, Lf2, Lf1 and RL, but it was disregarded because it is small.

3^0 STAGE (t2,t3):

This stage begins when the auxiliary switch Saux1 is turned on in the ZCS way. During this stage the current in the inductor Lr rises lineally, until it arrives the value ILrmax, when this stage finishes.

4^0 STAGE (t3,t4):

This stage begins when current in the resonance inductor reaches IL1. At the same time there is resonance among capacitors Cr1 and Cr2 with inductor Lr. Capacitor Cr1 changed negatively while capacitor Cr2 is totally discharged, when this stage finishes and switch M3 is turned on in the ZVS way.

5^0 STAGE (t4,t5):

This stage begins when the voltage on capacitor Cr2 is zero (0). During this stage capacitor Cr1 resonates with the inductor Lr. This stage finishes when the current in inductor Lr reaches zero. Auxiliary switch Saux1 can be turned off in the ZCS way.

6^0 STAGE (t5,t6):

This stage begins when the current in resonant inductor Lr is equal to zero (0). Capacitor Cr1 is discharged lineally until the voltage in this capacitor reaches zero when this stage finishes.

7^0 STAGE (t6,t7):

This stage begins when the voltage on capacitor Cr1 reaches zero (0) and it finishes when switches M1 and M3 are turned on and turned off, respectively and simultaneously. During this stage there is the energy transference from the input voltage source to the load.

Starting from the seventh stages the operation are identical for the other arm of the converter, switches M2, M4 and Saux2, capacitors Cr3 and Cr4, inductor Lr. Therefore these stages won't be described.

Figure 3 shows the principal waveforms in a half switching cycle.

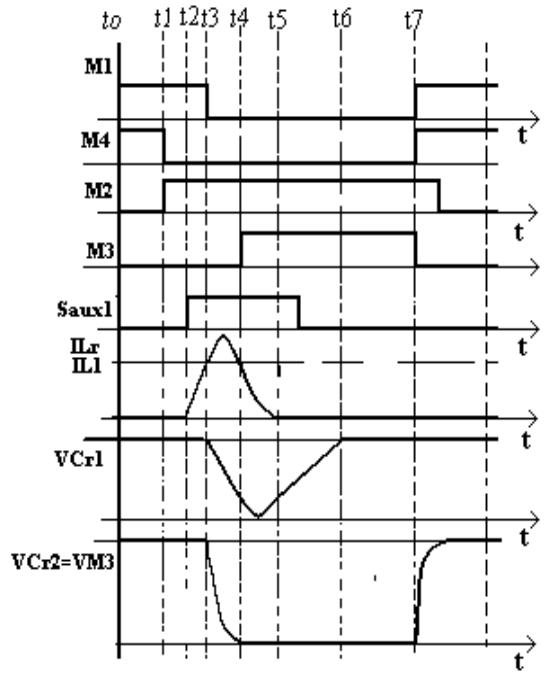


Fig.3 - Principal waveforms for figure 1 circuit.

The analysis presented in this paper is based on the following assumptions:

(1) - that switches and diodes are ideal;

(2) - The input (Vdc) and output voltage(V0) are ripple-free;

(3) - The inductors and capacitors are lossless and the current output (I) is assumed continuos during of the operation.

The transfer function between Vo and Vdc is given by equation [9]:

$$G = n.2\left\{D + \frac{K1}{2\pi}\left[\arccos\left(-\frac{1}{X}\right) + \frac{X+1}{\alpha X} + \frac{\alpha}{2}\right]\right\} \quad (1)$$