A Forward Converter Using a Soft Switching Active Cell Without Stress

E. Soares da Silva, E.A.A. Coelho, L.C. de Freitas; J.B. Vieira Jr; V.J. Farias(*)

Universidade Federal de Uberlândia
Departamento de Engenharia Elétrica
Campus Santa Mônica - Bloco 3N
38400-902 - Uberlândia-MG - BRAZIL
- Corresponding Author(*)
valdeir@ufu.br

Abstract - **This paper presents a two transistor forward converter operating in Soft Switching mode without voltage and current stresses. The use of a Stressless Soft Switching Cell allows the auxiliary switch to operate in ZCS mode at turning on and ZVS mode at turning off. The main switch S_1 operates in ZVS-ZCS at turning on and ZVS at turning off and the main switch S_2 operates in ZCS at turning on and hard switching at turning off.**

The output voltage is controlled using the PWM technique. Operating principles, simulation and experimental results are presented.

I – INTRODUCTION

Power supplies with high static and dynamic performance, low harmonic distortion and small physical size and weight, have required switching frequency increase in switched converters. High frequency in a power converter, reduce the size and weight of passive components and increase power density, making the structures cheaper. However, high switching frequency operation of converter has caused trouble due to the increase of EMI level and switching losses.

High switching frequencies with high power levels have required careful examination and control of the power dissipation during switching. Therefore, soft switching converters have been developed such as those presented in [1],[2],[3],[4], [5], [6] and [7].

In many soft switching technique applications, there are the inconvenience of voltage and/or current stress in active switches.

To overcome this drawback, several researches has been carried out, designing snubber resonant circuits cell wich do not submit the switches to high current and/or voltage stress, as in [8].

Although this converter has several advantages, it presents some drawback as follows. The presence of a coupled inductor, in series with active switch, makes ZCS turn on not so good. Furthermore the duty cycle of this converter is limited to 0.5.

Recently, other converters have been presented, as in [9] and [10]. Although these converters do not present series coupled inductor in series with active switch, they present current stress and coupled inductor.

In order to overcome these disadvantages, this work proposes a forward converter using a stressless active commutation cell, of the reference [11], operating without current and voltage stress.

The used cell is shown in Fig.1, this will be described your operation in a buck converter in the next sections.

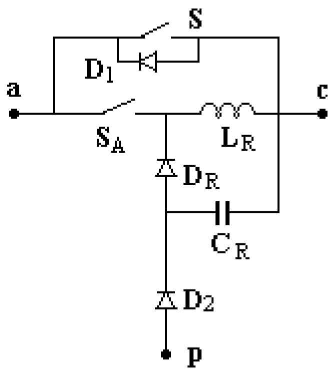


Fig. 1 – Stressless Soft Switching Cell.

II - OPERATION PRINCIPLE

For the theoretical analysis, it will be considered that the input source V_I and output current I_0 are ripple free and all devices are ideal.

A switching cycle of Buck converter will be divided in eight stages as shown in Fig.2.

First Stage: Interval $[t_o,t_1]$. This stage begins in the instant that the switch $\mathbf{S_A}$ is turned on in a ZCS mode, due to the presence of inductor *Lr*, and it finishes when i_{Lr} reaches I_0.

Second Stage: Interval $[t_1,t_2]$. It begins when i_{Lr} assumes value I_0. The current I_0 circulates through S_A and *Lr*. Before this stage to finish the switch S_1 is turned on, as shown Fig. 2, in ZCS and ZVS mode. It finishes with S_A turning off in ZVS way.

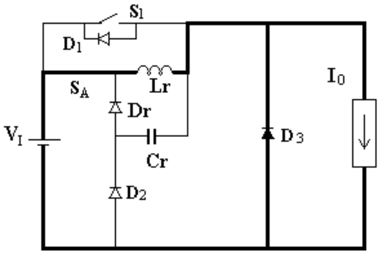
Third Stage: Interval $[t_2,t_3]$. This is a resonant stage through circuit *Cr, Lr and Dr*, where the capacitor *Cr* charges until it voltage reaches value V_I, ending this stage.

Fourth Stage: Interval [t_3-t_4]. During this stage, the inductor current decrease linerarly until it reaches zero. The switch current i_S increase until it reaches load current I_0 and the capacitor voltage value V_{Cr} remains in V_I.

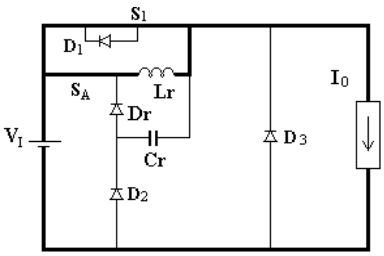
Fifth Stage: Interval [t_4,t_5]. Energy transference from source to load occurs during this stage. It finishes when the switches S_1 is turned off in ZVS mode, due to capacitor Cr.

Sixth Stage: Interval [t_5,t_6]. In this stage the capacitor linear discharge occurs. It finishes when the capacitor voltage V_{Cr} reaches zero.

Seventh Stage: [t_6,t_7]. In this stage just freewheeling occurs. It starts when the Cr voltage reaches zero. This stage finishes with the turning on of the switches S_A.



First stage.



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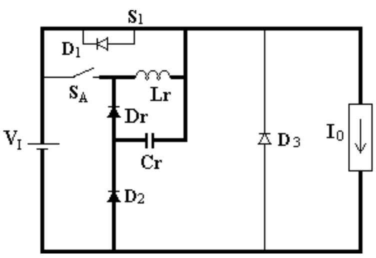
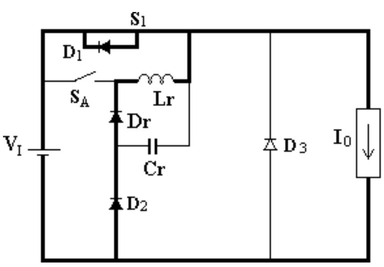
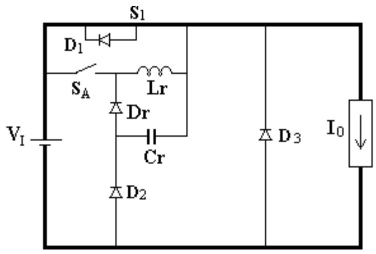


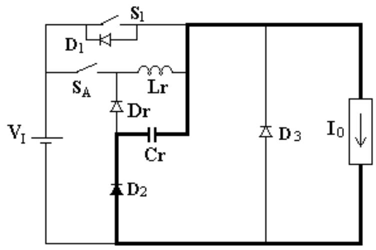
Third stage.



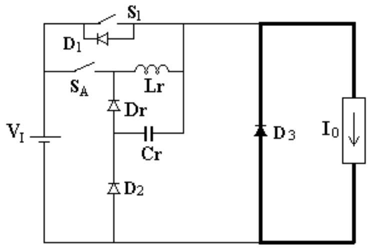
Fourth stage.



Fifth stage.



Sixth stage.



Seventh stage.

Fig.2 - Operations Stages of the Buck Converter.

In Fig. 3, the main waveforms of the operations stages are presented.

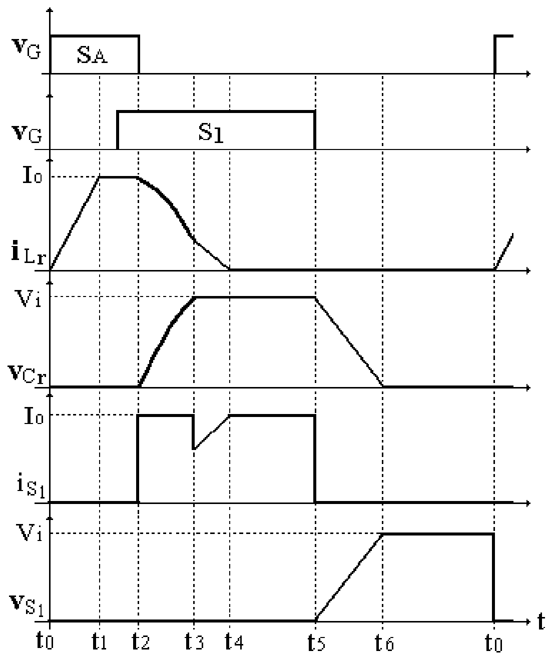


Fig.3 – Main waveforms of the Buck Converter.

In Fig. 4, it can be seen the phase diagram.

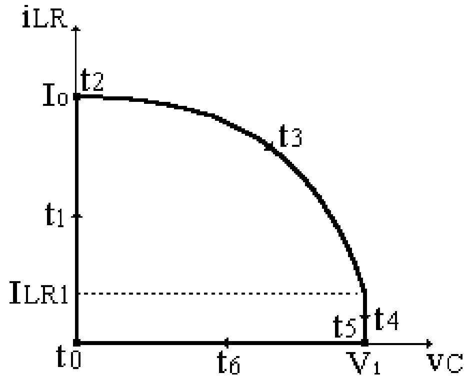


Fig.4- Phase Diagram.

Applying this Cell to one transistor forward converter some trouble are appeared. This drawback has been overcomes applying this Cell to two transistor forward converter as shows Fig. 5.

In this converter, the main swich S_2 operates in hard mode at turning off and S_2 tuning off command must be independent of switch S_1.

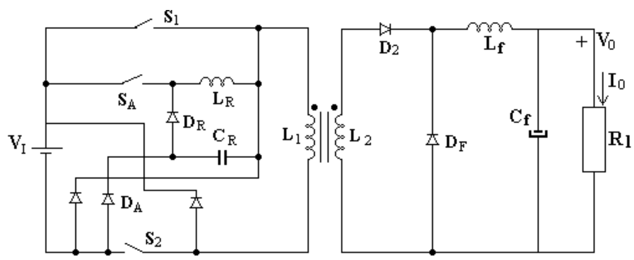


Fig. 5 – Forward Converter.

With those change, the main waveforms of this converter are shown in Fig. 6.

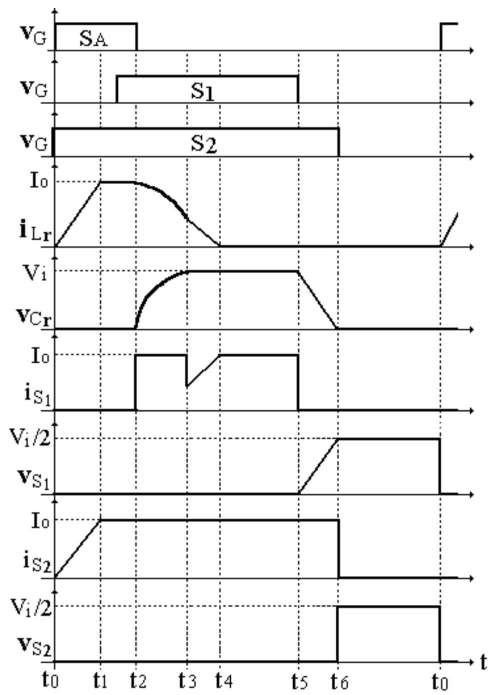


Fig.6 – Main waveforms of the Forward Converter Proposed.

As it can be seen in Fig 6, the main switch S_2 is turned off when the resonant capacitor voltage reaches zero value.

If an unity transformer turn ratio is assumed, the following gain expression can be obtained.

$$G = \frac{V_0}{V_I} = D + \frac{1}{T\omega_0}\left(\frac{1}{2\alpha} - \alpha\right) \tag{1}$$

Were:

$$\alpha = \frac{I_0}{V_0}\sqrt{\frac{Lr}{Cr}} \tag{2}$$

$$\omega_0 = 2\pi \quad f_0 = \frac{1}{\sqrt{Lr * Cr}} \tag{3}$$

fs = Switching frequency;
f_0 = resonant frequency;
α = current load normalized in relation to the resonant current peak value;
ω = resonant frequency;
I_0 = load current.

Using equation 1, it was traced the graphic of Fig. 7, which shows the static gain α versus normalized load current for several duty cycles.

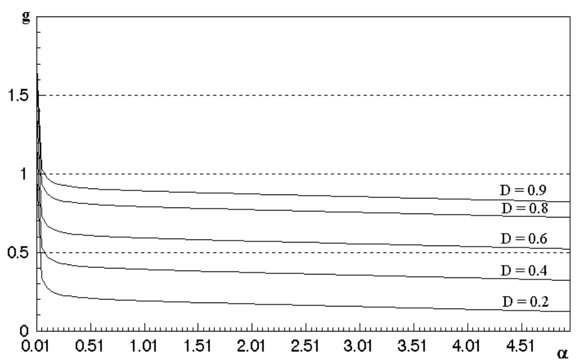


Fig.7. - Static gain(G) Versus Normalized load current (α).

Figure 8, shows the operation regions, in which the converter operates softly or hardy switched.

As it can be seen, except for light loads, the propose converter operates in soft switching mode.

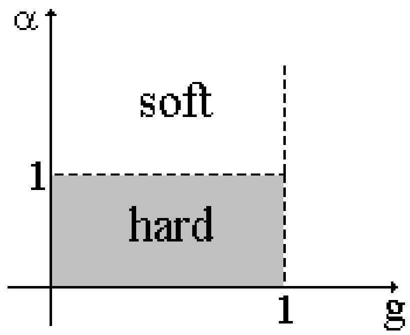


Fig. 8 – Operation Limits.

III- SIMULATION RESULTS.

In order to illustrate the converter operation, the forward converter from Fig. 1, has been analyzed by simulations (PSPICE) with the following parameter set:

V_I=150 VDC; Lf=600μH; Cl=470 μF;
Rl=8 Ω; Cr=12 ηF; Lr=7 μH;
Diodes: MUR1560 and UF5404.
fs=50 kHz; Switch IRF740

Current and voltage on the switch S_1 can be noticed in the down part of Fig. 9. Current in resonant inductor and voltage on the resonant capacitor are shown in the upper part. As it can be noticed, this converter operates softly without voltage and current stress.

Auxiliary switch voltage and current are shown in Fig. 10.

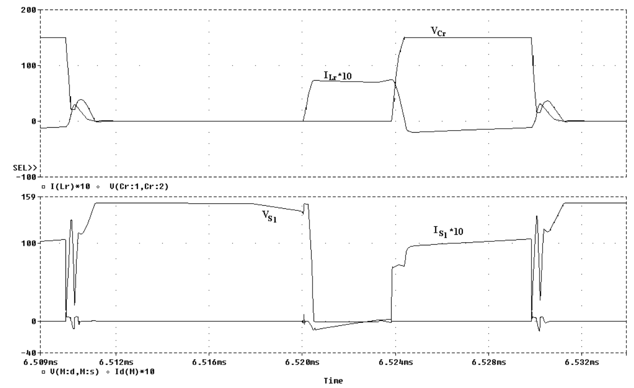


Fig. 9 – Upper - Resonant Capacitor Voltage and Resonant Inductor Current. Down – Switch Voltage and Current in Main switches

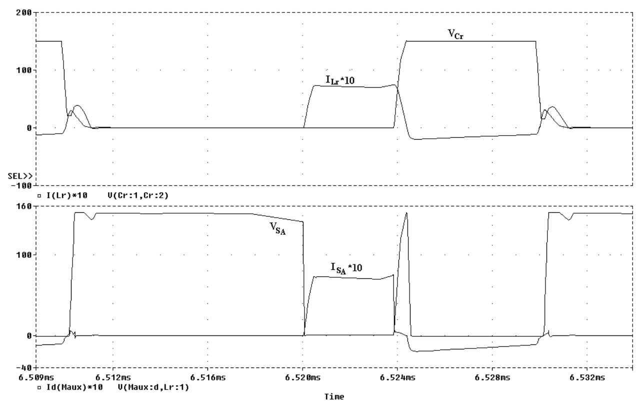


Fig. 10 - Upper - Resonant capacitor Voltage and Resonant Inductor Current. Down –Switch Voltage and Current in Auxiliary switches.

IV - EXPERIMENTAL RESULTS

To obtain some experimental results, a prototype of structure presented in Fig. 5, has been built by using the following parameter set:

V_I=100 VDC; Lf=600μH;
Cl=330 μF; Cr=4.7 ηF;
Lr=3.6 μH; fs=100 kHz;
Switch IRF740: Diodes: MUR1560 and UF5404.

Figures 11,12 and 13, show some obtained results in the experimental test. Fig. 11 is corresponding to voltage on the capacitor (V_{Cr}) and current on the resonant inductors (I_{Lr}). Fig. 12, shows voltage and current for the switch S_A. In the Fig 13 it is shown voltage and current in main switch S_1. As it can be seen the experimental waveforms are closed to those foreseen in theoretical analysis and simulation, assuring the soft switching without voltage and current stresses.

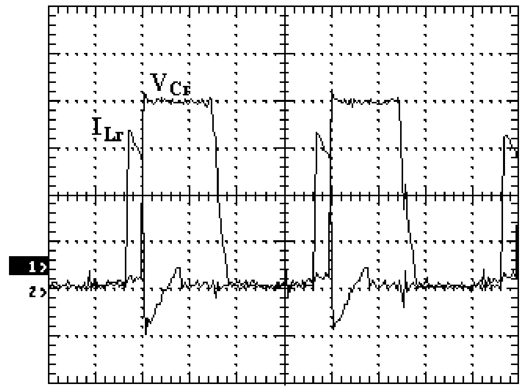


Fig.11 –Capacitor Voltage V_{Cr} (20V/div); (5 μs V/div) Inductor Current I_{LR}. (2A/div). (5 μs V/div)

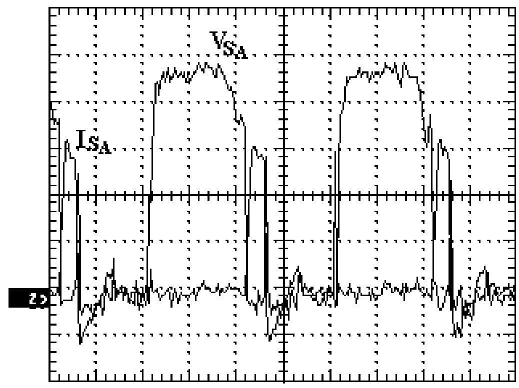


Fig.12 –Auxiliary Switch Voltage V_{SA} (20V/div); (5 μs /div) Auxiliary Switch Current I_{SA} (2A/div), (5 μs /div)

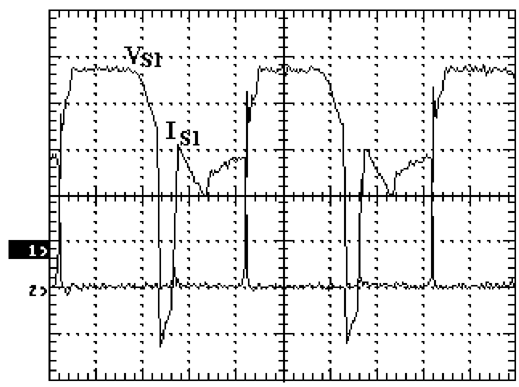


Fig.13 –Main Switch Voltage V_{S1} (20V/div); (5 μs /div). Main Switch Current I_{S1} (2A/div), (5 μs /div).

The efficiency graph has been traced for structures operating in hard and soft switching mode, as it can be seen in Fig. 14.

Although, the main switch S_2 commutes in hard mode at turning off, efficiency of this converter reaches almost 90%.

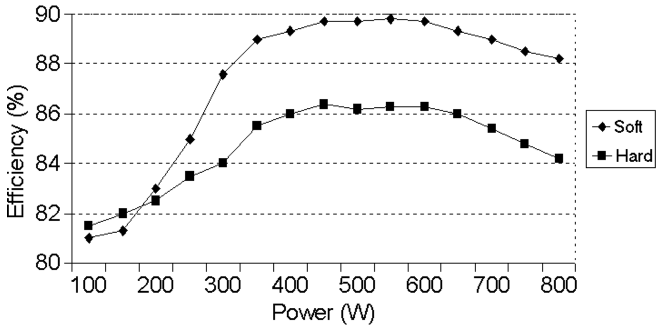


Fig.14 – Efficiency Graphic of the Converter.

V - CONCLUSION.

A *Soft Switched Forward Converter*, has been presented. It operates almost without switching losses, by using a stressless soft switching commutation cell.

The experimental and simulation results confirm the soft switching operation.

This converter operates without voltage current stresses in actives switches, to experimental results.

Although the main switch S_2 operates in hard mode at turning off, the proposed forward structure presented satisfactory efficiency, which except for light loads, is better than one of hard converter.

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REFERENCES

[1] E. T. Calkin and B.H. Hamilton, "Circuit techniques for improving the switching loci of transistor switches in switching regulators", *IEEE Trans. Industry Applications* vol. IA-12, n^o 4, 364-369, July/August 1976.

[2] W. McMurray, "Selection of Snubbers and Clamps to Optimize the Design of Transistor Switching Converters", *IEEE Trans. Industry Applications* 16 (4): 513-523, July/August 1980.

[3] Hiromichi Ohashi, "Snubber Circuit for High-Power Gate Turn-Off Thyristors", *IEEE Trans. Industry Applications* vol.Ia-19, n^{o}4, July/August 1983.

[4] J. C. Bendien, H. van der Broeck and G, Fregien, "Recovery Circuit for Snubber Energy in Power Electronics Applications with High Switching Frequencies", *IEEE Trans. Power Electronics* 3 (1): 26-30, January 1988.

[5] Lee, F.C. "High Frequency Quase-Resonant Converter Technologies", *proceeding of the IEEE*, vol. 76 N. 4, April 1988.

[6] Barbi, I.; Bolacel, J.C.; Martins D.C.; Libano F.B. "Buck Quase-Resonant Converter Operating at Constant Frequency: Analysis, Design and Experimentation", *IEEE-PESC'89*, record, pp. 873-880.

[7] Hua G.; Leu C.S.; Lee F.C. "Novel Zero-Voltage Transition PWM Converter", *IEEE-PESC'92*, Record, pp. 55-61.

[8] Barbosa, L. R.; Lambert, J. A; de Freitas, L. C.; Vieira Jr., J. B. and Farias, V. J., "A Boost PWM Soft-Single-Switched Converter with Low Voltage and Current Stresses". *Transactions on Power Electronics*. Vol. 13, n^o 1, January 1998, pp. 26-35.

[9] Lúcio R. Barbosa, E. Soares da Silva, L. C. de Freitas, J. B. Vieira Jr, V. J. Farias. "Uma Evolução de Conversores Monochaveados Suavemente". Anais CBA 2000. 11 a 14 de setembro de 2000 – Florianópolis. SC. Brasil. pp. 2323-2329.

[10] E. Soares da Silva; E. A. Rodrigues; I. S. Pacheco Jr; L. C. de Freitas, J. B. Vieira Jr, V. J. Farias. "A Soft-Single-Switched Forward Converter With Low Stresses And Two Derived". APEC 2001. March 04-08 – Anaheim – CA, USA. pp. 941-945.

[11] Vilela, M. S.; Coelho, E. A. A.; Vieira Jr., J. B.; de Freitas, L. C. and Farias, V. J.; *"A family of PWM Soft-switching Converters with Low Stresses of Voltage and Current"*, IEEE - APEC'96 Proceedings, pp. 299-304.