Soft-Single-Switched Boost PRC Using UC3854 and Special Hysteresis Current Control Technique

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***Abstract* - This paper presents a PWM Soft Single Switching Boost PRC (SSS-PWM-PRC). Using this converter, with only a single active switch, high power factor and low THD can be obtained in the rectification process. The harmonic distortion and power factor correction are based on a control strategy that forces the input current to follow a reference current. A detailed theoretical study, simulation and experimental tests, are carried out to illustrate the operating principle and to assure the correct operation of this converter.**

I. INTRODUCTION

In recent years, the technological evolution, in Power Electronics area has contributed for appearing several non-linear loads in many Electrical power plants. Since this kind of load can draw non-sinusoidal currents, or even out of phase currents, the consumers and suppliers are liable for some problems. In order to overcome this drawback and to improve the supply current quality, several researches have been carried out. One of the obtained results is the rectified PWM composed of a Boost PFC which is one of the most used topology to achieve power factor correction [1, 2, 3 and 4]. Others PFC topology are found as in[5]. There are restricted for applications that require DC voltage.

In order to improve the Boost pre regulator converter performance it is necessary to increase the switching frequency. However this causes efficiency reduction and EMI problems in hard converter. In order to overcome this drawback soft switching has been used as in [6].

Most of the proposed soft switching pre regulator have two or more active switches [7].

In this paper, it is presented a Boost PWM PRC for power factor correction and harmonic distortion compensation. This converter uses a single active switch in a soft way operating in ZCS way at the turning on and in ZVS at the turning off.

It will be presented in the following sections a detailed analysis, to emphasize such operational characteristics of this converter.

II. SOFT-SINGLE-SWITCHING BOOST PWM CONVERTER

Fig. 1 shows A soft-single-switched Boost PWM pre-regulator converter. The inductor *Lr* is used to provide ZCS of the switch S1 turning on.

As it can be seen, this converter consists of a conventional PRC Boost added by the resonant network composed by the elements *Lr* , *Cr*, D_2 and D_3 which are connected as shown.

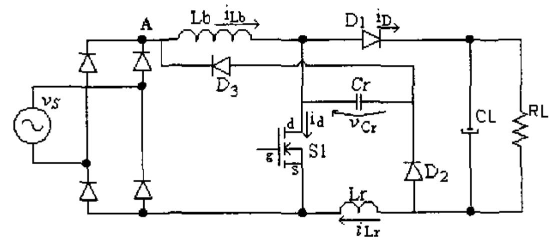

Fig. 1 - Boost PWM Soft-Single-Switched Converter.

The branch composed by *Lr*, D_2 and *Cr* is used to charge *Cr* with voltage $-V_i$ before the switch *S1* is turned off. Thus, this switch will turn off in a ZVS way.

As the switching frequency is much greater than that of the source, the voltage in node **A** will be considered constant during each switching cycle, whose operating stages are presented in Fig. 2.

In the following discussion, for simplicity, it is assume that ac ripples in filter capacitor voltage and filter inductor current are entirely negligible.

A. First Stage $[t_o, t_1]$ - When switch *S1* is turned on under ZCS condition, the *Lr* current decreases linearly to zero. The voltage across *Cr* remains in *Vo* due to the conduction of D_1.

B. Second Stage $[t_1, t_2]$ - This stage begins when diode D_1 is turned off, initiating the first resonant stage. Capacitor *Cr* discharges from Vo to -Vi. When diode D_3 turns on at instant t_3 (Fig. 3), the resonant capacitor voltage is clamped, ending this resonant period.

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C. Third Stage $[t_2, t_3]$ -This stage begins when diode D_3 is turned on. This occurs when the voltage in Cr becomes equal to input voltage. In this stage, the current following throughLr decreases linearly until it becomes zero.

D. Fourth Stage $[t_3 , t_4]$ - At instant t_4, the current through Lr becomes null and the diodes D_2 and D_3 are turned off. The duration of this stage depends on the duty cycle.

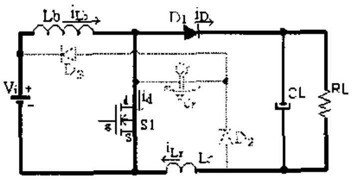
E. Fifth Stage $[t_4 , t_5]$ - Switch $S1$ is turned off with null voltage, diode D_3 provides a path for current I_{Lb}. In this stage the capacitor discharges in a linear way.

F. Sixth Stage $[t_5 , t_6]$ - When the voltage across capacitor Cr becomes $(V_0 - V_i)$ diode D_1 is turned on. In this stage , there is a new resonance between capacitor Cr and inductor L_R. This happens until voltage V_{Cr} becomes V_0.

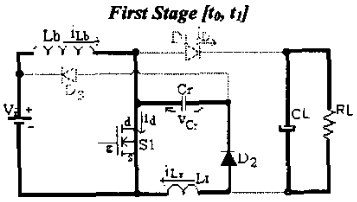
G. Seventh Stage $[t_6 , t_7]$ - When the voltage across capacitor Cr becomes V_o , diode D_2 is turned on. The Lr current increases linearly.

This stage finishes when the Lr current becomes equal to input current I_{Lb}.

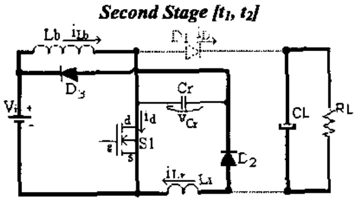
H. Eighth Stage $[t_7 , t_8]$ - During this stage, energy transference from source to load occurs through diode D_1.



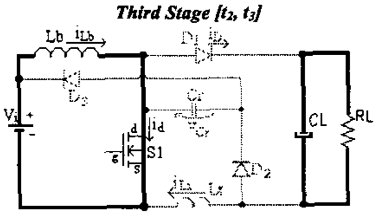
First Stage $[t_0, t_1]$



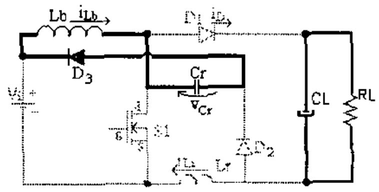
Second Stage $[t_1, t_2]$



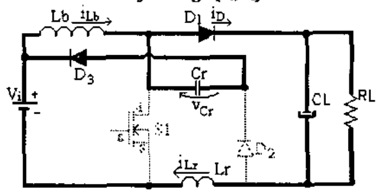
Third Stage $[t_2, t_3]$



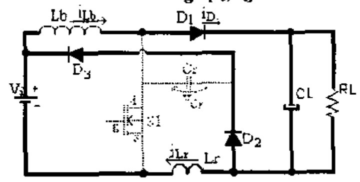
Fourth Stage $[t_3, t_4]$



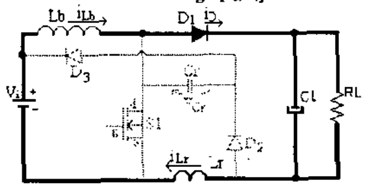
Fifth Stage $[t_4, t_5]$



Sixth Stage $[t_5, t_6]$



Seventh Stage $[t_6, t_7]$



Eighth Stage $[t_7, t_8]$

Fig. 2 - Operations Stages of the Converter

The main theoretical waveform for each switching cycle of the proposed converter are shown in Fig. 3.

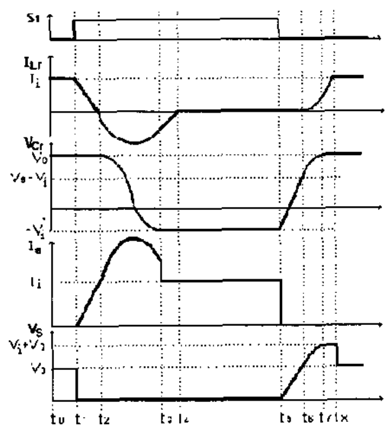


Fig. 3 - Main Theoretical Waveform of an Operation Stages.

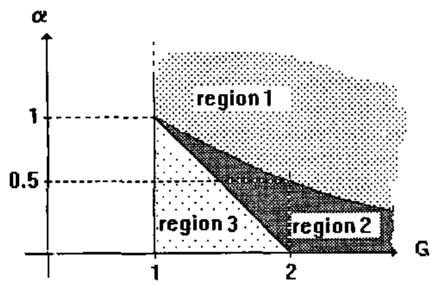


Fig. 4- Converter Operations Regions.

As it can be seen in Fig. 3, although there are switch voltage and current stresses, this converter operates in a soft switching way, ZCS on turning on and ZVS on turning off, providing high power density and low EMI.

It is important to emphasize the used commutation cell provides high converter efficiency since the commutation energy (*Wc*), equation 1,varies according to the rectified input voltage (*Vi*).

$$Wc = \frac{1}{2} Cr\, V_I^{\,2} \tag{1}$$

If the *Lr* current value at t_3 is greater than the i_{Lb} value, the AC input current will be discontinuous. This can be avoided by designing *Lr* and *Cr* adequately or by introducing a little L-C passive filter in AC side. This converter, as shown in Fig. 4, operates in three different regions of the plane $(\alpha x\ G)$, where:

$$\alpha = \frac{I_i}{V_0}\left(\frac{L_R}{C_R}\right)^{1/2} \tag{2}$$

$$G = \frac{V_o}{V_i} \tag{3}$$

In the region 3, the converter operates in hard switching and in the regions 2 and 3, the converter operates in soft switching way. It is observed this converter works hard when the normalized input current (α) and voltage gain (G) are low. This situation does not occur easily, since the α is low when G is high and vice versa, since output voltage is constant and input voltage and input current are variable and they are in phase.

III. CONTROL STRATEGY

The used control strategy causes the input current to follow a control function which is an amplified supply voltage sample plus a saw-tooth wave with low amplitude and high frequency, as shown in Fig.5, where *c(t)* is the control function and $i_{Sa}(t)$ is an input current sample. This provides high power factor and low harmonic distortion.

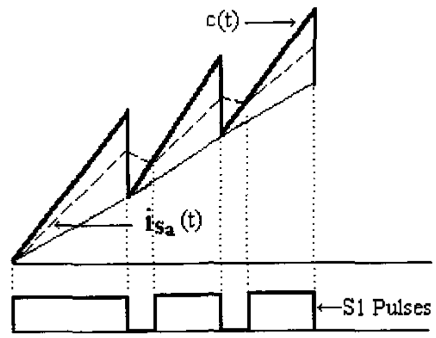


Fig. 5 - Logic of Strategy Control.

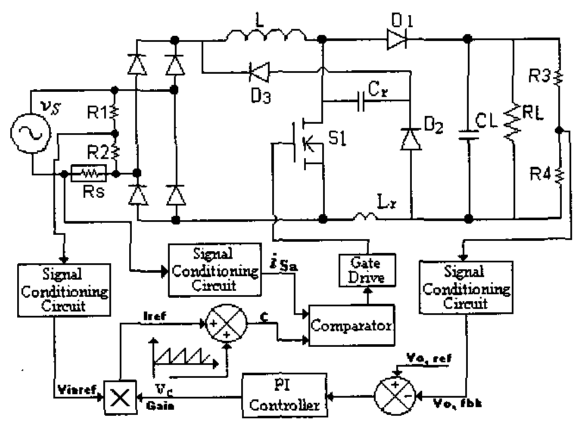


Fig. 6 - Simplified Circuit of SSS-Boost-PRC and Strategy Control.

The converter operates with fixed switching frequency which is determined by the saw-tooth frequency. Fig. 6 shows a simplified diagram illustrating all used system.

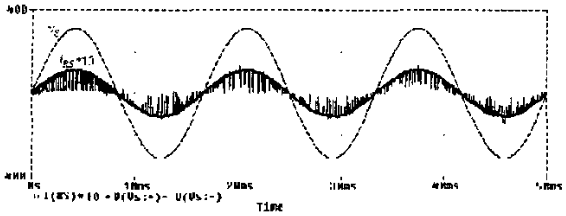
The input current and the line voltage samples are obtained from *Rs* and *R1-R2* sensors, respectively.

A PI controller is implemented to provide the control signal Vc which is multiplied by the voltage sample furnishing the sinusoidal control signal i_{ref}. This signal is added to a saw-tooth signal producing a control function c(t). The drive signal is obtained from the comparison between the control function and input current sample i_{Sa}. The signal obtained from the comparator block is isolated and amplified to drive the switch.

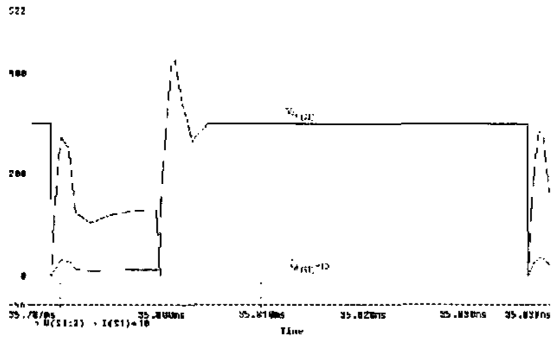
IV- SIMULATIONS AND EXPERIMANTAL RESULTS USING HYSTERESIS CURRENT CONTROL.

In order to illustrate the converter operation, an analysis was done by simulations (PSPICE) with the following parameter set:

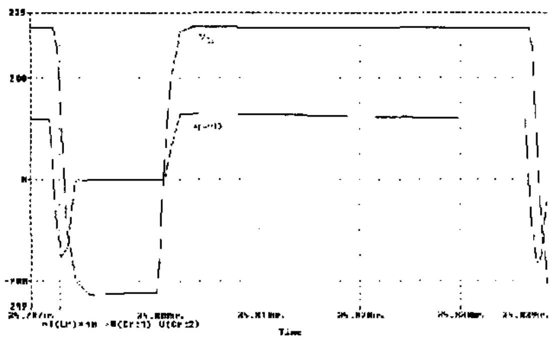
V_S=220 VCA, L=1 mH, V_0=350V, Lr=6 μH, Rl=25 Ω, Cr=18 ηF, Cl=1 mF, fs=20 kHz, Diode: MUR 1560, Switch: IRF 460.



a) Source Voltage and Current.



b)Switch Voltage and Current.



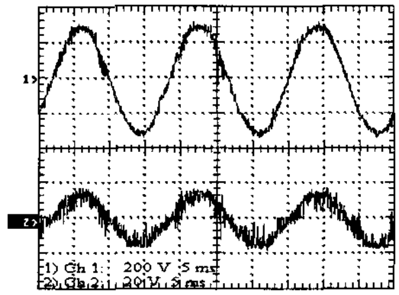
c) Voltage in Resonant capacitor and Current in Resonant Inductor.
Fig. 7- Waveform Simulations Results.

Fig. 7, shows some simulation results. It can be seen that the converter operates softly and that the input current has discontinuous form and it is in phase with the voltage supply.

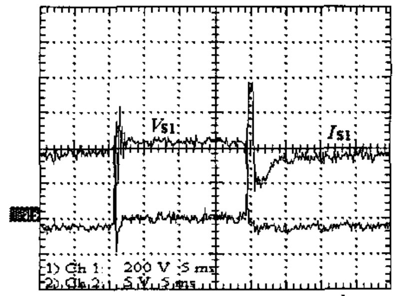
A prototype circuit was implemented to verify the waveforms predicted above. The values for the used parameters are the same as those specified in the simulation.

Fig. 8, shows the experimental waveforms correspondent to those from Fig. 7.

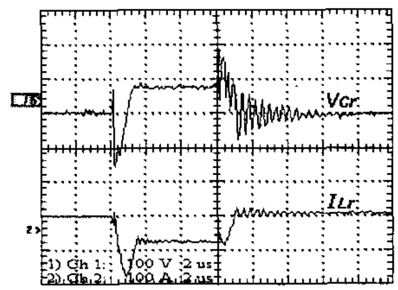
One can see the experimental results are closed to the simulation ones.



a) Voltage (200V/div) and Current (20A/div) of source.



b) Switch Voltage and Current.



c) Voltage in Resonant capacitor and Current in Resonant Inductor.
Fig.8- Waveform Experimental Results.

Figure 9 shows the power supply input current and input voltage waveforms to SSS Boost PRC using the CI3854, as shown in Fig. 10, to power factor correction.

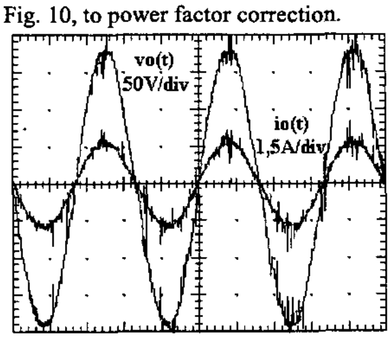


Fig.9- Waveform Experimental Results.
Voltage (50V/div) and Current (1.5A/div) of source.

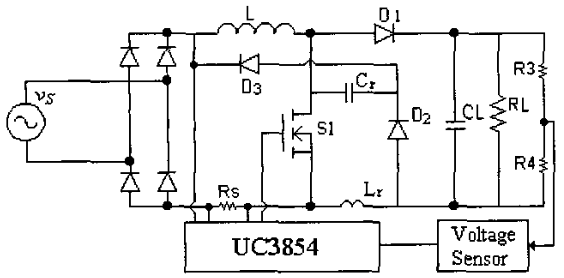


Fig.10 – SSS PRC Boost using a CI UC3854.

Fig. 11, shows the converter efficiency as a function of output power. As it can be seen the proposed soft converter achieves similar performance compared to conventional converter to some power, but for higher power the soft converter is better than conventional one.

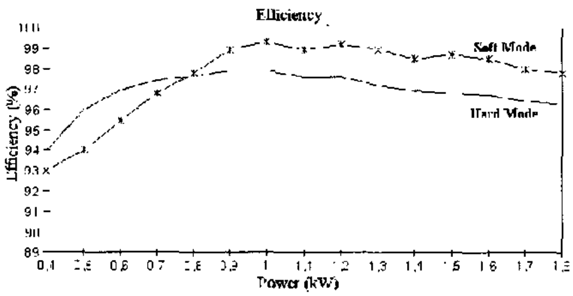
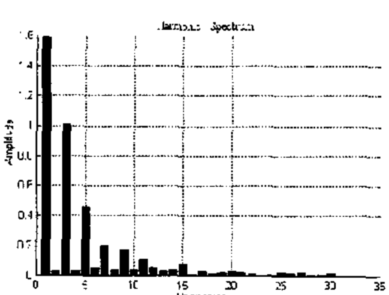
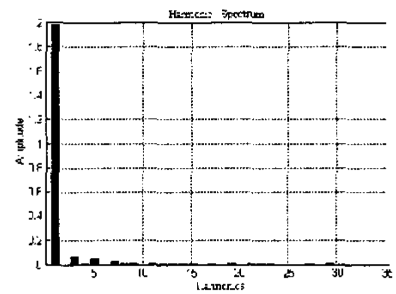


Fig. 11- PRC Efficiency graphics as output power function

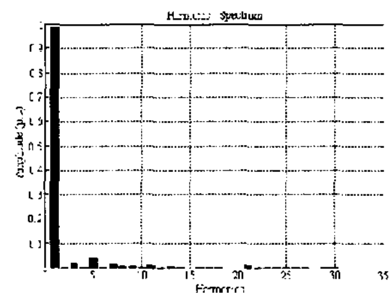
Fig. 12, shows the harmonic spectrum of the input current, in case (a) without correction, in (b) using the hard Boost converter , in (c) using soft Boost converter with Special Hysteresis Current Control Technique and in (c) using soft Boost converter with CI3854 to power factor corrétion. As it could be seen through the *Matlab and WaveStar* results, the input current THD value was 87.5% without PRC, 3.1% to conventional Boost, 3.9% to soft Boost using the Special Hysteresis Current Control Technique and 3.5% to soft Boost using the CI3854. For all Boost structures, the displacement between input current and voltage supply are 0.2 Degrees and power factor 0.99 approximately.



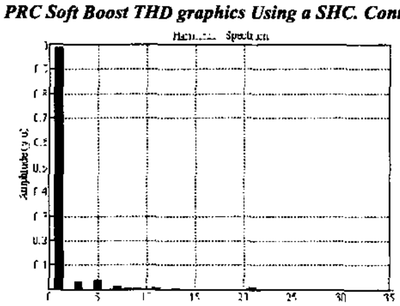
a) Load THD graphics, without PRC.



b)PRC Hard Boost THD graphics.



c) PRC Soft Boost THD graphics Using a SHC. Control.



d) PRC Soft Boost THD graphics Using the CI 3854.
Fig. 12-harmonics spectrum

V- CONCLUSION

A *Single Soft Switching Boost PWM Pre-Regulator Converter*, operating with almost unity power factor and low harmonic distortion, using a *Special Hysteresis* input current control technique, has been presented.

Although this pre-regulator has a resonant capacitor and inductor and two additional diodes compared to conventional pre-regulator, it operates with a *single active switch* and works with high power factor, low harmonic distortion and better efficiency in 20kHz and high power.

Comparing the two power factor correction strategy, can to be noticed that it not have very difference in PFC of both strategy operating with this soft switched Boost converter that use only one switch, one resonant inductor, one resonant capacitor and two diodes.

VI - REFERENCES

[1] Liy, K., Lin, Y. (1989). Current Waveform Distortion in Power Factor Correction circuits Employing Discontinous-Mode Boost converters. *Proceeding of IEEE Power Electronics Specialists Conference* , pp. 825-829.

[2] Divan, D. M., Venkataramanan, C. and Chen, C.(1992) A Unity Power Factor forward converter. *Proceeding of IAS'92. Pp 666-672.*

[3] Enjeti, N. P., Martinez, R.. High Performance Single Phase AC to DC Rectifier with Input Power Factor Correction. *Proceeding of APEC'94. Pp. 190- 195.*

[4] Salmon, J. C. Techniques for Minimizing the Input current distortion of Current-Controlled Single-Phase Boost Rectifiers. IEEE Transactions on Power Electronics. *Vol.8 nº 4, October 1993, pp. 509-520.*

[5] Barbi, Ivo and Bascopé, Grover Victor Torrico, " Single-Phase High Power Factor Variable Output Voltage Rectifier, Using the Buck+Boost Converter: Control Aspects, Design and Experimentation". COBEP'99, September 19-23, Fóz do Iguaçú PR, Brazil.

[6] Canesin, Carlos Alberto and Wakabayashi, Fabio Toshiaki, "A NEW HPF-ZCS-PWM BOOST RECTIFIER". COBEP'99, September 19-23, Fóz do Iguaçú PR, Brazil.

[7] R. Tóffano Jr., C.H.G. Treviso, V.J. Farias, J.B. Vieira Jr. And L.C. Freitas; "A Self-Resonant-PWM Boost Converter With Unity Power Factor Operation by Using Bang-Bang Current Control Strategy With Fixed Switching Frequency", ISCAS'96, Record pp. 549 – 552, Atlanta, USA, May/1996.