High Power Factor Rectifier with Reduced Conduction and Commutation Losses

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Abstract - This paper presents a high power factor rectifier with reduced conduction and commutation losses for telecommunication applications. The reduced conduction losses are obtained through the use of a single converter, instead of the conventional configuration, composed of a four-diode front-end rectifier followed by a boost converter. A non-dissipative snubber is responsible for the reduction in the commutation losses. A prototype rated at 1.6 kW, operating at 25 kHz with IGBT's has been implemented in laboratory.

I. INTRODUCTION

The conventional input stage for single-phase power supplies operates by rectifying the AC line voltage and filtering with large electrolytic capacitors. This process generates a distorted input current waveform, with large harmonic content. Thus, the resulting power factor is very poor (around 0.6).

The reduction of input current harmonics and high power factor operation are important requirements for power supplies, specially when international harmonics standards, like the IEC-61000-3-2 must be satisfied.

The technique usually employed to correct power factor of single-phase power supplies consists of a front-end full-bridge rectifier followed by a boost converter. This converter, however, presents commutation and conduction losses, contributing to reduce the overall efficiency of the power supply. The commutation losses exist because the power semiconductors undergo hard commutation. The conduction losses are significant because the current always flows through three power semiconductors simultaneously, two of them are diodes, and the other one, depending on the operation stage is a controlled switch or a diode.

In order to reduce the commutation losses, several papers proposed soft-switching techniques using auxiliary commutation circuits [1],[2],[4]. These are very efficient techniques, however, they increase the cost and complexity of the converters.

The circuit presented in [3] and [4] and shown in Fig. 1 operates with much lower conduction losses than the conventional rectifier followed by a boost converter. This occurs because the current always flows through two semiconductors simultaneously, instead of three. However, the main difficulty in these converters is that the sensoring of the input voltage and current must be isolated, carrying out additional complexity and cost.

This paper proposes a new high power factor rectifier with reduced conduction losses and a non-dissipative snubber to reduce the commutation losses, resulting in a high efficiency converter, with regulated output voltage. The proposed converter also presents non-isolated voltage and current sensing, solving the difficulties presented in previous converters.

II. THE PROPOSED RECTIFIER

The proposed rectifier is presented in Fig. 2. It is composed of two boost converters, one for each half line cycle, and an output capacitor. The first converter is composed of V_{IN}, L_{IN1}, D_1, T_1 and D_3, while the second one is composed of V_{IN}, L_{IN2}, D_2, T_2, and D_4, one for each half line cycle.

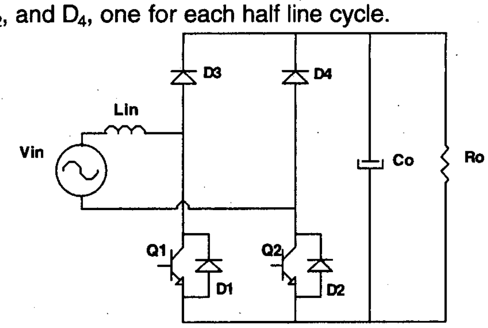

Fig. 1 – Reduced conduction losses rectifier.

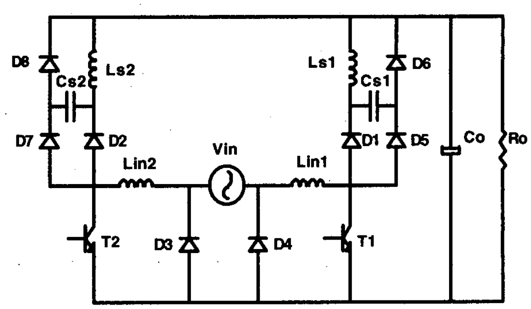

Fig. 2 – Proposed high power factor rectifier with reduced conduction and commutation losses.

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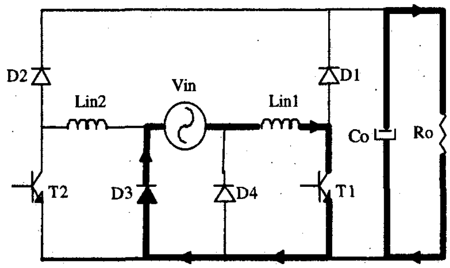
This converter presents reduced conduction losses, once there will always be two semiconductors in the current flow path.

A. Operation Stages

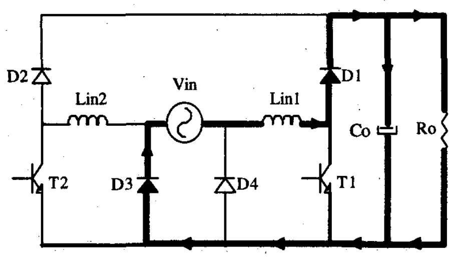
The simplified operations stages for the switching frequency are shown in Fig. 3.(a) and 3.(b). In these analysis it is not considered the non-dissipative snubber. These stages are the same stages of a boost converter. It can be noticed that there are always two semiconductors in the current flow path. Similar operation stages are obtained for the other half line cycle.

B. Commutation Analysis

The non-dissipative snubber is shown in the shadow areas of Fig. 4. The inductors L_{s1} and L_{s2} are responsible for the "lagging effect" in the reverse recovery of D_1 and D_2, reducing the turn-on losses. The current slopes in these diodes are reduced due to the insertion of these inductors.



(a)



(b)

Fig. 3 – Simplified operation stages. (a) Energy accumulation stage. (b) Energy transfer stage.

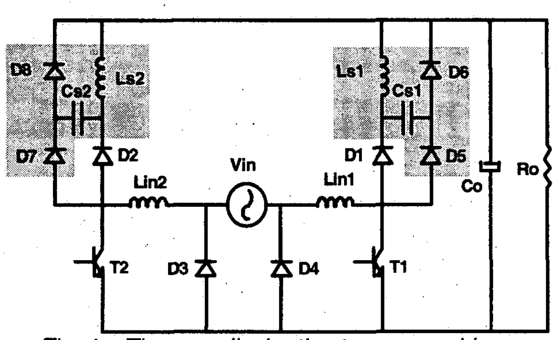


Fig. 4 – The non-dissipative turn-on snubber.

III. CONTROL STRATEGY

The main difficulty on the use of high power factor rectifiers with reduced conduction losses is the use of isolated voltage and current sensors. In order to use commercial high power factor control IC's, like UC3854, isolated voltage and current sensors followed by a rectification must be used.

A - Current Sensor

An excellent approach to perform the input current sensoring, keeping the ground reference in the negative terminal of the output capacitor, is shown in Fig. 5. It can be noticed that a resistive sensor can be used.

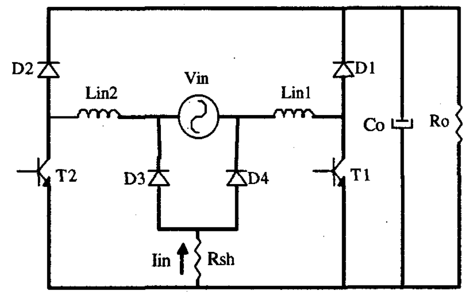


Fig. 5 – Resistive current sensor.

The resistor R_{sh} will sensor the whole input current, once D_3 and D_4 will conduct alternatively along the line cycle.

B - Voltage Sensor

The input voltage must be sensored, in order to generate a sinusoidal current reference in phase with the AC mains voltage and to establish the amplitude of the current reference due to variations of the rms value of the input voltage.

In the high power factor rectifiers with reduced conduction losses [3][4], it is necessary to use an isolation transformer and a small signal rectifier to keep all the ground reference in the negative terminal of the output capacitor.

The proposed rectifier overrides this problem, using two signal diodes and a high value resistor. The proposed solutions for the resistive current sensor and for the voltage sensor are presented in Fig. 6.

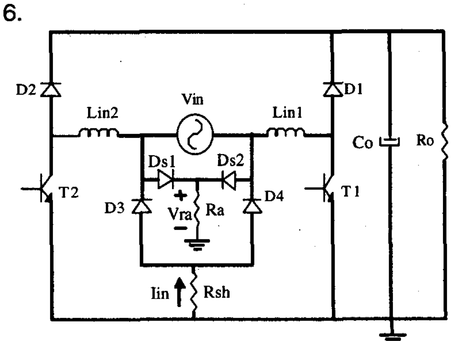


Fig. 6 – The high power factor rectifier employing non-isolated sensors.

The well-known average current mode control technique is employed in the proposed rectifier, and the block diagram of this control technique is shown in Fig. 7.

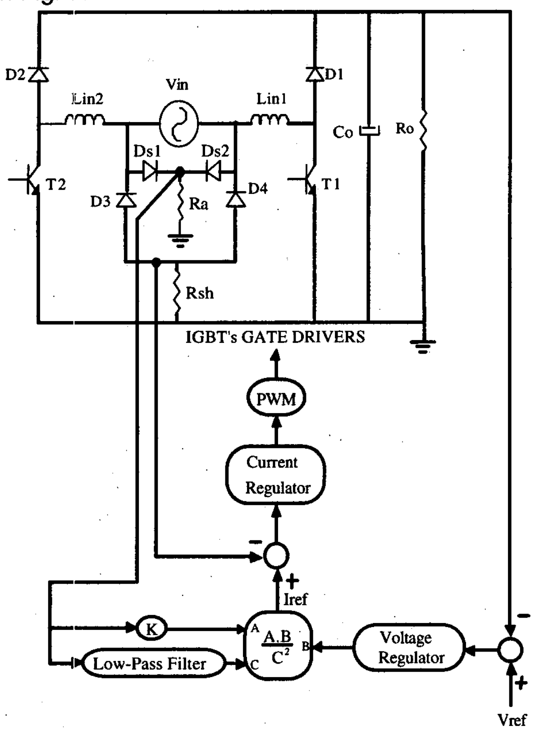


Fig. 7 – The average current mode control applied to the high power factor rectifier with reduced conduction losses.

IV. Experimental Results

A 1.6 kW prototype was built, where the specifications are as follows:

$V_o = 400$ V $V_{in} = 220\ V_{ef} \pm 15\%$

$P_o = 1600$ W $f_s = 25$ KHz

The power stage diagram of the prototype is shown in Fig. 8 and the component specifications are as follows:

- T_1, T_2 – IRG4PC50W
- D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8 – MUR850
- C_O – 470 µF
- L_{in1}, L_{in2} – 850µH – 72 turns (1×15 AWG) EE-65/26 core
- L_{S1}, L_{S2} - 4µH – 5 turns (4×24 AWG) – EE – 30/7 core
- C_{S1}, C_{S2} – 56 nF/630V

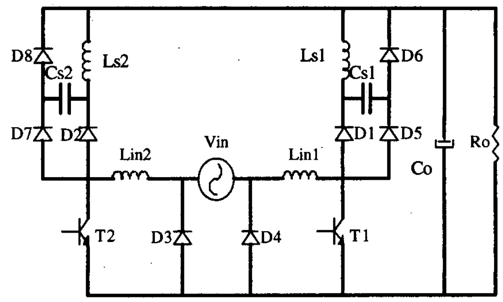


Fig. 8 – Power stage diagram of the proposed rectifier.

In Fig. 9 it is presented the line voltage and current for 1.6 kW output power. The current is practically sinusoidal with low THD and high power factor.

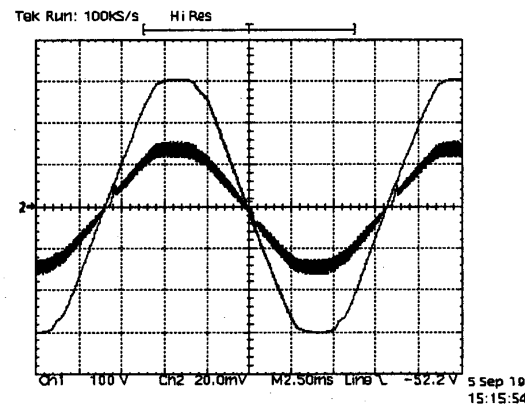


Fig. 9 – Line voltage (100V/div.) and current (10 A/div.) time (2.5 ms/div).

In Fig. 10 it is shown the voltage and current through IGBT T_1.

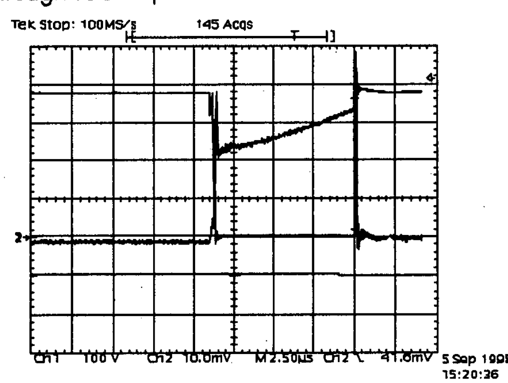


Fig. 10 – Current and Voltage in IGBT T_1.

Scales: 100V/div, 5A/div, 2.5 µs/div.

In Fig. 11 it is shown the turn-on detail of IGBT T_1. It can be noticed the reduced commutation losses, due to the presence of the turn-on snubber.

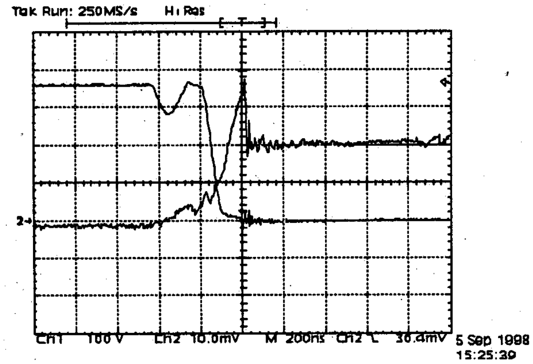


Fig. 11 – Turn-on detail of IGBT T_1. Scales : voltage: 100V/div., current: 5 A/div., time 200 ns/div.

In Fig. 12 it is shown the turn-off detail of IGBT T_1. The losses in this commutation are not significant, due to the commutation speed of the employed IGBT.

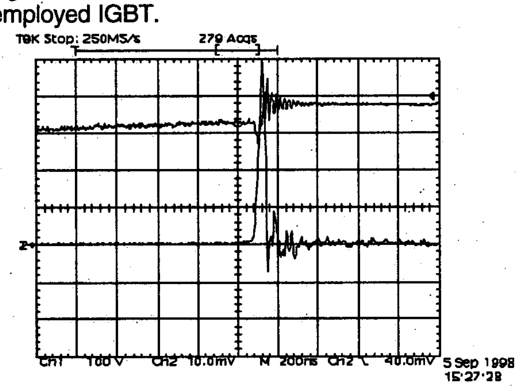


Fig.12 – Turn-off detail of IGBT T_1. Scales : voltage: 100V/div., current: 5 A/div., time 200 ns/div.

In Fig. 13 it is shown the resonant capacitor C_{S1} voltage. The voltages across these resonant capacitors are always lower than the output voltage.

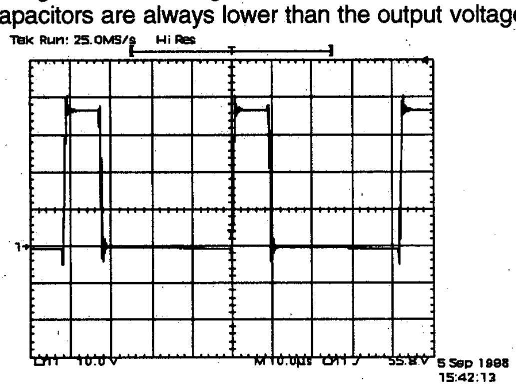


Fig. 13 – Resonant capacitor C_{S1} voltage. Scale: 10V/div., 10 μs/div.

In Fig. 14 it is shown the resonant inductor L_{S1} current. The additional stress in this current is negligible.

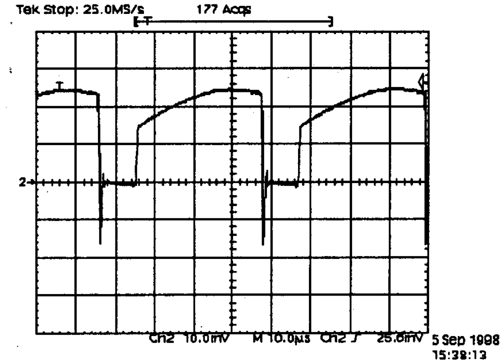


Fig. 14 – Current through Resonant inductor L_{S1}. Scale: 5 A/div., 10 μs/div.

In Fig. 15 it is presented the current through inductor L_{IN1}. It can be noticed that the input current flows through this inductor only in half line cycle.

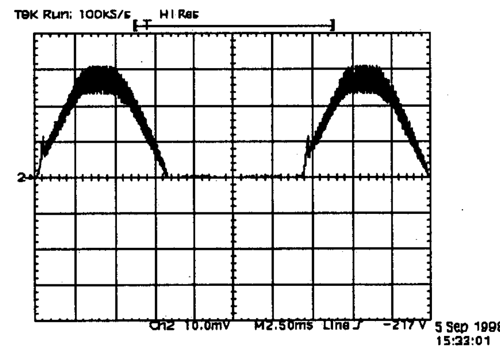


Fig. 15 – Current through input inductor L_{in1} Scale: 5 A/div., 2.5 ms/div.

In Fig. 16 it is shown the efficiency of the rectifier. A very high efficiency (about 97%) was obtained, showing the high performance of the proposed rectifier.

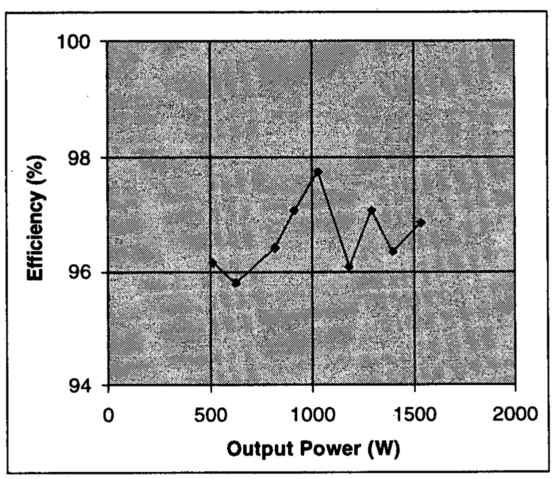


Fig. 16 – Obtained efficiency.

V. Conclusion

The results obtained by the proposed high power factor rectifier show that a very high efficiency is achieved due to the following factors:

- Reduced conduction losses due to the fact that there are only two semiconductor voltage drops in the current flow path;
- Reduced commutation losses due to the employment of a non-dissipative snubber.

Another important characteristics for these rectifiers are:

- The voltage stresses for all the semiconductors are limited to the output voltage.
- The employment of resistive sensor simplifies the circuitry and reduces the cost and size of the converter.

This rectifier is a very suitable alternative for high power factor rectifiers, particularly 1.5 kW and 3 kW power supplies, which are standard values for telecommunication applications.

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