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# Novelty Technique for Power factor Improvement by a Single phase Rectifier

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**Abstract**– A new technique is implemented to improve the input power factor of a single-phase rectifier followed by an inductive filter. It consists in the employment of a two-quadrant active power filter, based on a conventional bidirectional DC-DC converter, connected to the output side of the diode bridge. This technique allows the extension of this rectifier range operation in the continuous conduction mode. A laboratory prototype was designed and built, with the following specifications: input voltage: 220 VRMS; output voltage: 200 VDC; rated power: 3 kW; switching frequency: 100 kHz. By the experimental results obtained, the system presented a unity power factor and an efficiency of 95% at full load, while the maximum efficiency value was 98% at 2 kW.

**Index Terms** - Active power filter, Total Harmonic Distortion, power factor correction, single-phase inductive filter rectifier.

## 1 INTRODUCTION

The increasing of the electronic devices in industry and residences has created a major concern on the electric power quality issue, due to the fact that these equipments draw a current with high harmonic content from the grid. The devices which present this characteristic are known as nonlinear loads. The active power filters have been considered a dynamic and adjustable solution to the power quality issue. Shunt active power filters (APF) consist of a power electronic converter which injects a compensating current to the grid, with the harmonic contents equal to the nonlinear load, but with opposite phase resulting in a sinusoidal grid current in phase with the voltage achieving an unity input power factor.

The single-phase diode rectifier is a usual nonlinear load, which is widely used in industry for providing DC loads or DC-DC converters and inverters. The conventional single-phase rectifier topology consists of a full-bridge diode rectifier followed by a capacitive filter, presents an input current with impulsive characteristic, resulting in a high Total Harmonic Distortion (THD) and a poor input power factor.


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Many passive and active methods for the input current harmonic distortion reduction applied to this rectifier topology have been already presented in literature. Another example of usual nonlinear load is the single-phase rectifier with output inductor, which is commonly used in industry applications where high output current is demanded.

The addition of an inductor on the diode bridge output allows the rectifier input current peak reduction and therefore, its total harmonic distortion reduction and the input power factor improvement. Thus the reactive power flow from this rectifier is smaller than the conventional one. However, two drawbacks of this rectifier topology must be emphasized, the inductor large size and the possible resonance between the output capacitor and inductor.

A passive method for input current harmonic mitigation was proposed for the inductive filter rectifier to improve the power factor. Nevertheless, the rectifier operation was in the Discontinuous Conduction Mode (DCM) not allowing the output voltage regulation. An active power filter was used for input current harmonic reduction applied to this rectifier topology operating as the nonlinear load. The APF was connected to the Alternating Current (AC) side of the rectifier for a load value in which the original rectifier operated in the DCM, the APF insertion to the system was not capable of changing the rectifier operation mode resulting in no output voltage regulation. The application of a shunt active power filter for current harmonics reduction applied to an inductive filter rectifier will process a smaller amount of reactive power than in the case of a conventional rectifier. Then the APF converter may be designed for smaller power operation and control effort. In this paper, a new technique to improve the input

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power factor of a single-phase rectifier with output inductor based on a two-quadrant shunt active power filter. Still, the application of the proposed APF to this rectifier topology enabled the extension of the rectifier operation range in the Continuous Conduction Mode (CCM).

## 2 PROPOSED SINGLE-PHASE SHUNT ACTIVE FILTER

The proposed active power filter (APF) topology shown in figure 1 consists of a bidirectional DC-DC converter with capacitive energy storage. This converter presents the same operation stages of a VSI converter used on conventional single-phase APF application for the positive half-cycle of input voltage. The proposed APF converter is connected on the DC side of a rectifier followed by an inductive filter.

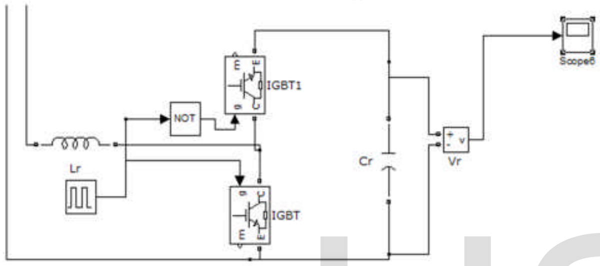


Figure 1. Proposed active power filter structure.



## 3 LOAD CHARACTERISTICS – SINGLE PHASE RECTIFIER WITH INDUCTIVE FILTER

The non-unit power factor load employed in this work is composed by a single-phase rectifier followed by an inductive filter, as per Figure 2. It is commonly used on applications that demand high output current. Also, this rectifier presents a higher input side power factor than the rectifier followed by a capacitive filter, since the last one presents an input current with impulsive characteristic, resulting in a high Total Harmonic Distortion (THD). Even though, the load introduced on Figure 2 contains some disadvantages as the inductor volume and the load inductor-capacitor resonance issue.

This rectifier can operate in the continuous conduction mode (CCM) when the load inductor current never reaches zero and consequently, the diode bridge is always conducting. When operating in this mode, the load output voltage is obtained.

On the other hand, the operation in the discontinuous conduction mode (DCM) occurs when the load inductor current goes to zero for a period of time, resulting on the diodes conduction block.

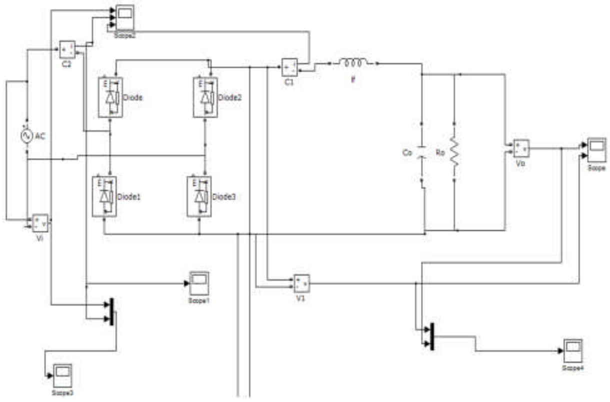

Figure 2. Single Phase Diode Bridge Rectifier Circuit

When operating in the DCM, this rectifier presents a varying load output voltage characteristic which depends on two parameters: the effective input voltage as shown in expression

$$V_o\,(CCM) = 0.9 V_{oref} \qquad (1)$$

The DCM rectifier operation analysis is detailed on the Appendix section. For very low current load values, the output voltage can achieve the input voltage peak. The main theoretical waveforms for the inductive filter rectifier on both operation modes. However, in order to obtain a constant output load voltage for several load current values, the operation in the CCM is shown in figure 3.

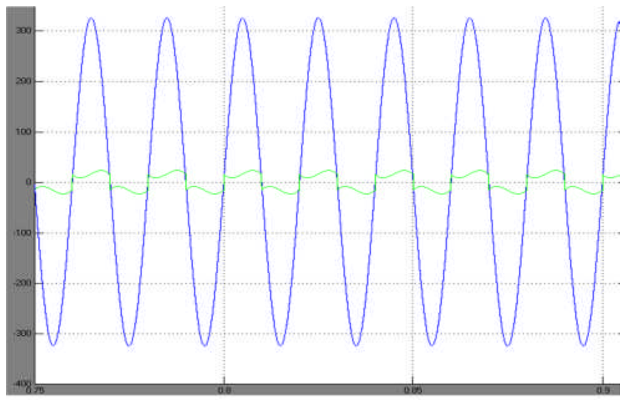

Figure 3. Unity Power Factor

## 4 SYSTEM CHARACTERISTICS WITH THE PROPOSED ACTIVE FILTER

By the exposed, the aims of the proposed APF application are input power factor correction, input current harmonic

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content reduction and the extension of the CCM range operation for the inductive filter rectifier.

The two quadrants operation feature of the APF converter results in its power topology simplification, as can be seen in Figure 1, and enables the UC3854B Integrated Circuit (IC) utilization. This IC is commonly applied in power factor correction control. Since the internal UC3854B multiplier operates only in one quadrant, its usage for the four-quadrant APF is not possible.

The output diode bridge current, is the rectified input current. For power factor correction achievement, the input current must be a sine wave in phase with the input voltage, thus the output diode bridge current ought to be a rectified sine. The main theoretical currents waveforms, for the circuit presented in Figure 3, are shown along with the input voltage. From the proper APF operation, the input current is a sine wave, allowing input side high power factor and low input current THD. Additionally, the diode bridge is operating in the CCM, independent from the load current value ensuring a load output voltage (Vo) independent of the load power. Therefore, even for load current values for which the original inductive filter rectifier operates in the DCM, with the proposed APF application the system operation in the CCM is obtained, resulting in the extension of the CCM range operation.

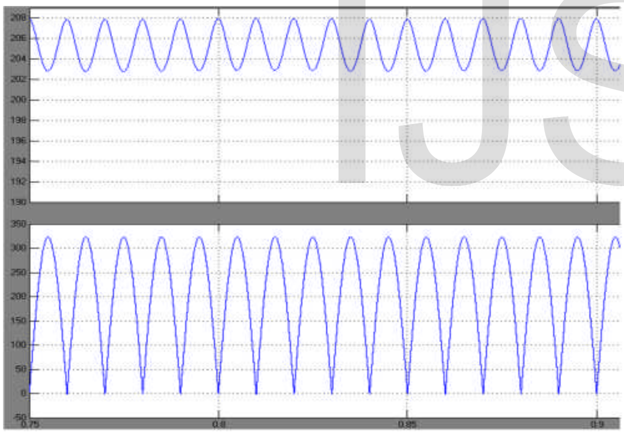

Figure 4. Output Voltage with Power correction and the FWR output

## 5 SYSTEM MODELLING AND CONTROL STRATEGY

There are two main control strategies used in single-phase active power filter control are control and input current control. The APF DC-link voltage control is responsible for the system active power flow control, since the APF active power flow must be zero, besides the components losses. The current control is responsible for the input current shape control, which must be a sine waveform in phase with the input voltage. The control strategy is based on the average current mode using the rectified input current as the control variable which is similar to the input current control strategy. This strategy is effective and simple because it uses only one current sensor and load current harmonic contents calculation is not necessary.

A few changes on this strategy were needed due to the inductor-capacitor load resonance issue. For solving this problem, a band-stop filter with the rejection center frequency tuned in the load resonance frequency was used in the APF DC-link voltage monitoring.

Therefore, the signal applied on voltage loop control is resonance frequency oscillations attenuated, not interfering on the system control. The voltage controller also had to be configured with a low cutoff frequency, resulting in an active power flow control strongly slow. By that, the transient voltage and current oscillations were increased, exceeding design limits and compromising the system operation. For solving the dynamic active power flow control problem, a feed forward control of the load output current was necessary.

Due to the low components losses in the APF converter, it is considered that the load average active power is the same as the input .The system active power flow can be controlled through the load output current value. The constant gain used in the feed forward output current loop for the system active power flow control. In addition, the APF DC-link voltage control is used for APF losses compensation.

### 5.1 CURRENT TRANSFER FUNCTION MODELLING

After established the system control strategy, current and voltage transfer functions models must be defined. As the current loop control must be fast, since it is responsible for the input current waveform control, the obtained rectified input current model is high frequency defined, being based on small-signal average current modeling, for switching periods. The APF converter equivalent circuit shown in Figure 5, in which the average voltage is shown. From this equivalent circuit, the rectified input current transfer function model is obtained.

### 5.2 VOLTAGE TRANSFER FUNCTION MODELLING

On the other hand, the APF DC-link voltage control must be slow, even slower than the input source frequency. Its transfer function model is obtained by the average values of the APF variables accounted in one input source half-period. Figure 5 presents the equivalent circuit for voltage transfer function modeling, resulting in which each variable is defined for its average value in one input source half-period.

Power Components Determination Load inductance (Lo), was designed for original inductive filter rectifier CCM operation from 30% to 100% of the nominal load value. The APF inductance (Lf), was designed based on the maximum input current high frequency ripple value. It defines the APF inductance value from the specified maximum input current high frequency ripple value. Load and APF capacitors (Co, Cf) were designed for low DC-link voltage

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### 5.3 UC3854B USAGE FOR INPUT CURRENT CONTROL

As mentioned previously, one of the main highlights of this work is the UC3854B Integrated Circuit usage for the system current control. Unlike most APF applications, this active filter is connected on the DC side of the load, and then the APF converter operates only in two quadrants, allowing this IC application. Among existing ICs that accomplish average current model control for power factor correction, the UC3854B is quiet required.

Some of these IC key features were used are over current protection, PWM modulator, two quadrants analog multiplier/divider and the current amplifier.

As the active power flow control is made by the sum of the APF DC-link voltage regulation signal and the load output current loop signal. The resulting signal is generated externally from the UC3854B and forced into the "A" input of its internal multiplier. The multiplier "B" input is a current signal responsible for the shape of the controlled current. It must be an image of the rectified input voltage. The last multiplier input, "C", is for the effective input voltage feed-forward control. The multiplier output is the current reference signal for the rectified input current control.

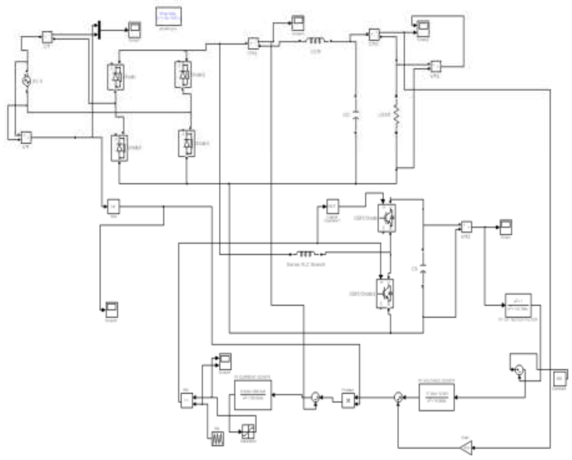

Figure 5. Closed Loop Circuit Diagram

## 6 EXPERIMENTAL RESULTS

The implemented system was tested for different load values. The main waveforms obtained from this prototype are presented in this section.

Figure 4 shows the output voltage waveform and the load output voltage for the inductive filter rectifier operation without and with the proposed APF respectively in nominal load value. For this load value, the original rectifier operates in CCM; therefore the load output voltage remains the same in both cases. However, with the APF operation, the input power factor correction is achieved from 0.88 to 1 and the input current harmonic contents are reduced from 43% to 4% as expected.

Figure 3 - Steady state waveforms for nominal load for unity power factor - (a) input voltage (200V/div) and current (20A/div), output voltage (100V/div) for load operation; (b) input voltage (200V/div) and current (20A/div), output voltage (100V/div) for load operation with the proposed APF.

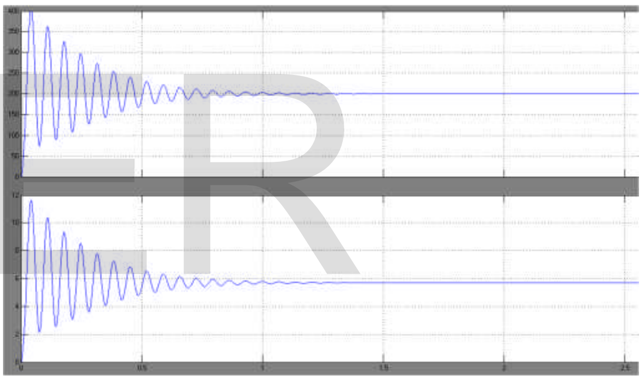

Figure 6. Load Voltage Waveforms

Figure 6 - Steady state waveforms for the rectifier operation with the proposed APF (Scales: 100V/div, 10A/div) - (a) input voltage and current; (b) input voltage and rectified input current; (c) input voltage and inductor load current; (d) input voltage and inductor filter current.

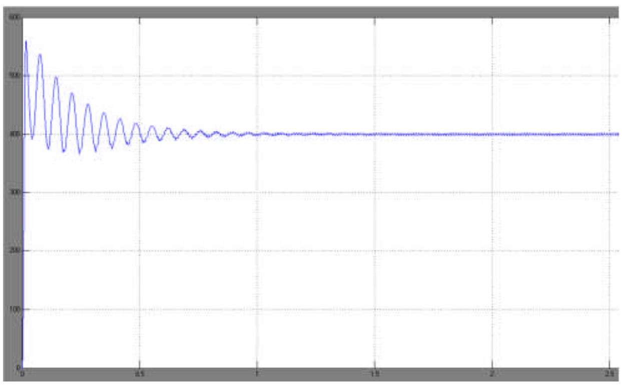

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Figure 7. Voltage Output for Shunt Active Filter

The output voltage harmonic spectrum for the load operation with and without the proposed APF in nominal load value is presented in Figure 7. It can be seen that the voltage harmonic contents were substantially reduced.

## 7 CONCLUSION

This paper has presented an active power filter topology based on a bidirectional DC-DC two-quadrant converter applied for the power factor correction of a single-phase rectifier followed by an inductive filter. Theoretical analyses were detailed, summarizing the main load characteristics and the load operation with the APF. Moreover, the proposed control strategy, system modeling and prototype design were shown. Finally, the experimental results obtained by the implemented prototype validated the theoretical analysis. Unity power factor and input current, THD reduction were achieved for nominal load value and both were improved for a large load values. In addition, the APF application allowed the rectifier CCM operation extension, presenting an output voltage load regulation for a wide load value range.

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