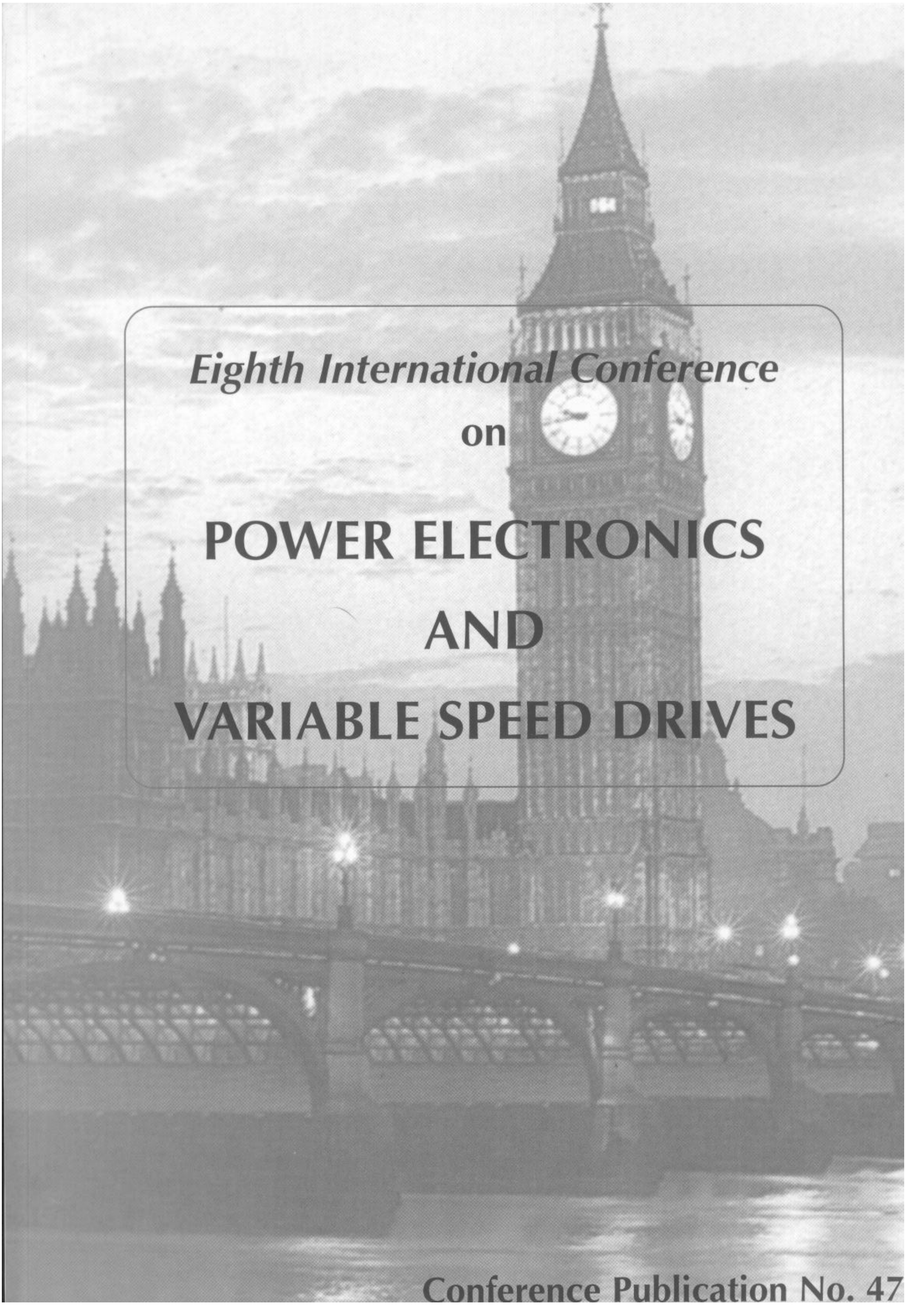

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ACTIVE FILTERING AND POWER FACTOR CORRECTION USING A DSP CONTROLLED RECTIFIER BRIDGE

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ABSTRACT

The capacity of performing active filtering while feeding and controlling a dc link is described in this paper. The implemented scheme uses a controlled rectifier bridge for both tasks. The protection sensors are used in the control scheme to reduce the amount of sensor employed for the system. Also, due to the structural characteristic of the control used, it operates at a fixed switching frequency.

INTRODUCTION

AC-DC converters are used as dc power supplies in many practical power applications. Excessive harmonic currents generated by such converters on the ac side may cause system power quality degradation. Hence power system harmonics regulations are being progressively applied. Recently, PWM converters have been introduced to improve power factor and ac-side current harmonic distortion [1][2]. PWM rectification schemes allow the application of accurate control strategies to control magnitude, power factor and wave form of the input current. With the adequate control strategy it is possible to use a PWM controlled rectifier bridge to perform active rectification, power factor correction and active filtering tasks. In this work a space vector control scheme on a three-phase PWM controlled rectifier bridge to perform simultaneously the active rectification, power factor correction and active filtering tasks are developed. The proposed control scheme was tested by simulation and experimentally by means of a DSP controlled three-phase IGBT bridge.

SPACE VECTOR MODEL FOR A THREE PHASE CONTROLLED RECTIFIER BRIDGE

The space vector model of the rectifier bridge is simple when three switches are simultaneously on [3]. In this case, the rectifier can be modeled using two simplifying considerations: Feeding a constant voltage or a constant current source. When the rectifier feeds a voltage source, the bridge connectivity directly defines the space vector $\overrightarrow{v_{rec}}$. The relationship between the rectifier variables is described by the following equation:

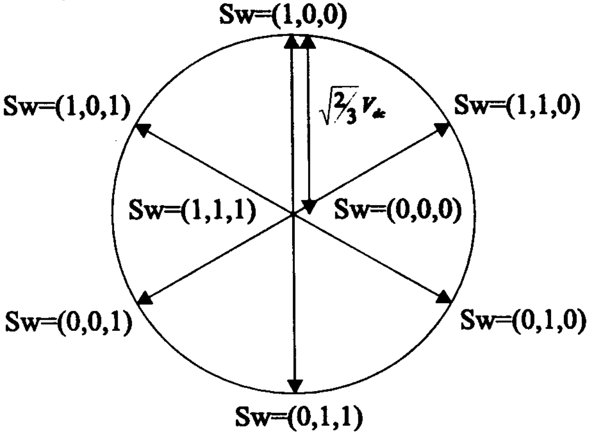

Figure 1: Voltage space vector $\overrightarrow{v_{ref}}$ as a function of the switching vector **Sw**.

$$\overrightarrow{v_{sys}} = \overrightarrow{v_{rec}} + L_{rec}\frac{d}{dt}\overrightarrow{i_{rec}} + R_{rec}\overrightarrow{i_{rec}} \qquad (1)$$

where:

$$\begin{aligned}\overrightarrow{i_{rec}} &= \sqrt{\frac{2}{3}}\begin{bmatrix}1 & e^{j\frac{2\pi}{3}} & e^{j\frac{4\pi}{3}}\end{bmatrix}\begin{bmatrix}i_a\\ i_b\\ i_c\end{bmatrix}\\ \overrightarrow{v_{rec}} &= \sqrt{\frac{2}{3}}\begin{bmatrix}1 & e^{j\frac{2\pi}{3}} & e^{j\frac{4\pi}{3}}\end{bmatrix}\begin{bmatrix}v_a\\ v_b\\ v_c\end{bmatrix} \qquad (2)\\ &= \sqrt{\frac{2}{3}}\begin{bmatrix}1 & e^{j\frac{2\pi}{3}} & e^{j\frac{4\pi}{3}}\end{bmatrix}\mathbf{Sw}V_{DC}\end{aligned}$$

and **Sw** is the connectivity vector, whose elements are "one" if the upper switch is on and "zero" if the lower is on for each bridge branch. The rectifier space vector $\overrightarrow{v_{rec}}$ has only seven possible states, as

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shown in figure 1. In rectifiers feeding a constant current source, the rectifier current space vector $\overrightarrow{i_{rec}}$ has the same behavior shown in figure 1, for the voltage space vector in the rectifier feeding a constant voltage source.

For the implemented rectifier, feeding a voltage source, during the commutation intervals the current space vector can not change instantaneously between two positions. There is a smoother variation along the space circle path caused by the inductance *Lrec*. During commutations, the line current changes continuously, reducing its magnitude in one phase and increasing in another phase. In these conditions, the magnitude of the current space vector $|\overrightarrow{i_{rec}}|$ is dependent on the switching strategy. For example, in a delta current controlled bridge, the current space vector draws a circle at constant angular speed. In any other case, a more detailed circuit analysis of the commutation process must be performed in order to evaluate the current space vector trajectory. The analysis of power system including rectifier bridges requires an accurate bridge control system modeling.

RECTIFIER BRIDGE'S CONTROL THEORY

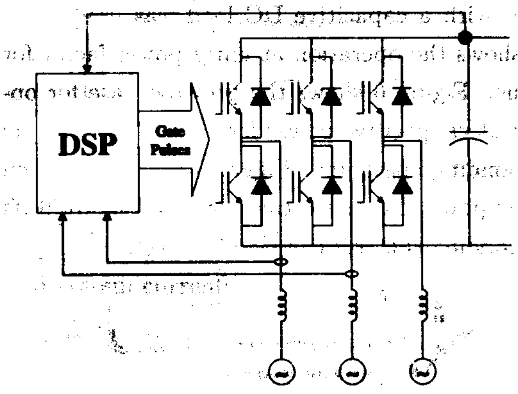

Figure 2: Three phase controlled rectifier bridge.

There are two principal tasks that an active filter can perform. The first is to compensate the harmonic components in the voltage waveform at a certain system node which have a distorted voltage. This is achieved injecting a certain content of the selected harmonic currents to produce a voltage drop in the system impedance with a magnitude and phase angle chosen to cancel the harmonic components in the system voltage. The second task, implemented in this work, is to compensate the harmonic components of the current injected by a non-linear load. This can be done injecting exactly the same amount of harmonic current components in the load but with opposite phase.

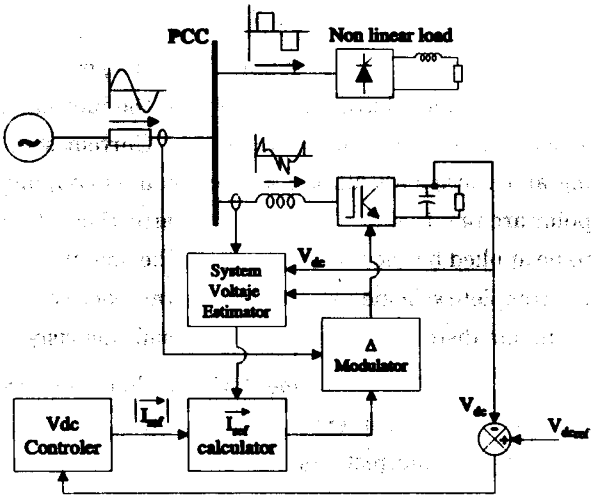

Figure 3: Proposed scheme for the active filter and power factor correction system.

The proposed active filter scheme is based on a three phase current controlled rectifier bridge (figure 2), this bridge is controlled to follow a sinusoidal reference current in each phase. The reference current space vector is calculated to be phase displaced with the system voltage space vector in the desired power factor angle. The magnitude of the reference current space vector is adjusted by the Vdc controller, since the AC current magnitude determines the power driven by the rectifier, and hence the Vdc voltage equilibrium. A DSP programmed to perform the desired control strategy determines the optimal commutation state every control cycle. The described control strategy performs active rectification driving sinusoidal current from the system.

The proposed filter scheme differs slightly from the rectifier scheme. In the filter scheme the current to be controlled is the system's current, accordingly with the diagram shown in figure 3. The reference current spatial vector magnitude is again adjusted by the Vdc controller, and the reference current phase angle is determined to leading or lagging the system voltage, in the angle required to obtain the desired power factor.

In the proposed scheme, described in figure 3, the filter's current measurement is used for the protection circuits. By means of Ec.1 the filter's current space vector is used to estimate the system's voltage space vector, reducing in this way the amount of sensors employed. To improve the quality of the estimated system's voltage, the signal obtained from equation 1 is filtered using a cascade of band pass filters centered around the supply frequency, ensuring in this way a low harmonic content on the internally generated system's current reference. Current sensing and voltage estimation at the common coupling point are required to determine the corrective action to be applied by the rectifier bridge. The operation of the complete scheme permits to perform reactive and harmonic distortion compensation simultaneously.

Usually active filter implementation is done measuring the spectral content in the non-linear current, obtaining an indirect control of the system's current. For the proposed scheme, the current sensors are placed directly on the main feeder, obtaining in this way a direct control of the system's current.

In this scheme the active and reactive power in the AC side is determined by the total current drawn by the non-linear load and the controlled rectifier bridge. Since the system current is controlled directly by the bridge, if a change in active power consumption of the non-linear load is suddenly produced the injected system current will remain constant while the Vdc controller reacts producing a change in the DC voltage. That means, the active power variation is supplied for a short time by the DC capacitor.

The capacitor's size must be chosen according to the switching frequency, amount of harmonic compensation, reactive compensation and DC load.

EXPERIMENTAL RESULTS

For the experimental tests a DSP based work bench was used[4]. A picture of the test rig is shown in Fig. 4. The controlled rectifier bridge uses six 50A and 1200V IGBT's as the switching elements. For limiting the incoming $\frac{di}{dt}$ on the rectifier, a three phase series inductor array (10mH) was employed. The controller was implemented on an ADSP-21061 DSP card. The control algorithm cycle was synchronized to the analog signals' acquisition at a 10kHz sampling rate.

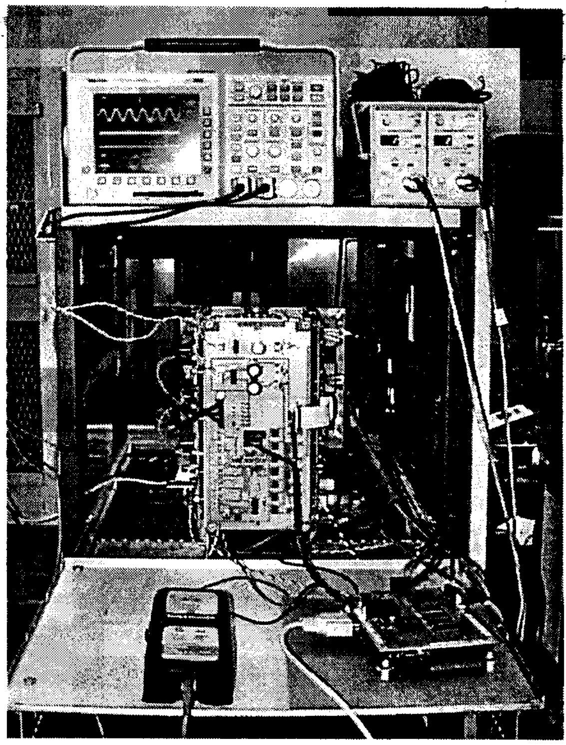

Figure 4: Experimental test rig

Two diffent kind of non-linear loads were tested; in the case one the non-linear load used was a non-controlled rectifier bridge supplying an inductive DC load, for the second case the same non-controlled rectifier with a capacitive DC load was used. Figure 5 shows the operation at unity power factor for case one. Figure 6 shows the previous case for operation at cappacitive power factor and Figure 7 its corresponding spectrum. Figure 8 shows operation at unity power factor for case two, and figure 9 its corresponding spectrum.

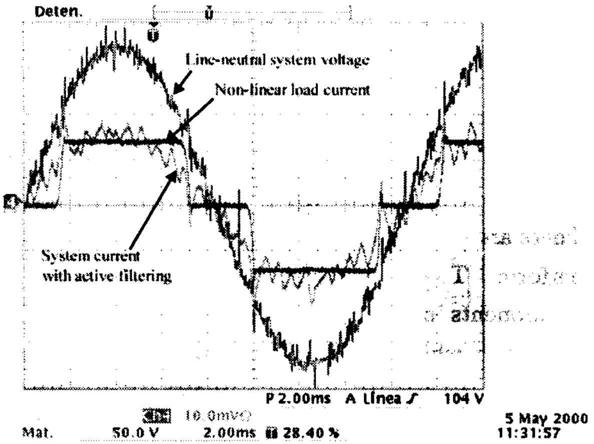

Figure 5: Case 1, Non-linear load current and unity power factor system current (5A/Div and 50V/Div).

The spectrums for the tested cases show a lack of compensation for high frequencies. This can be clearly seen from the time waveform in the second case.

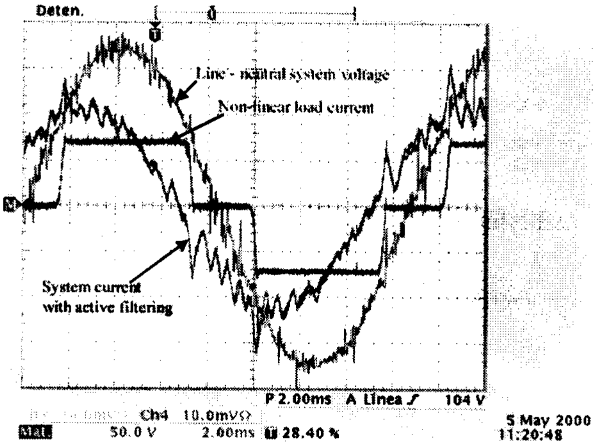

Figure 6: Non-linear load current and capacitive power factor system current (5A/Div and 50V/Div).

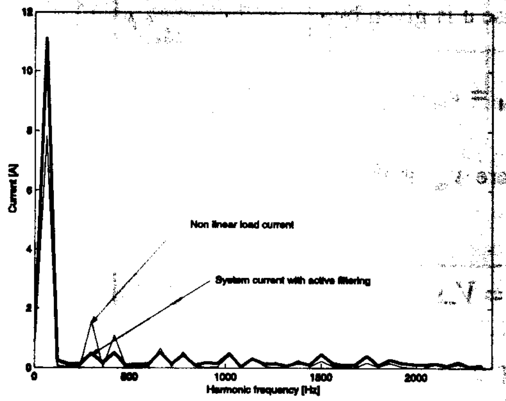

Figure 7: Case 1, Spectrum for the non linear load and system currents

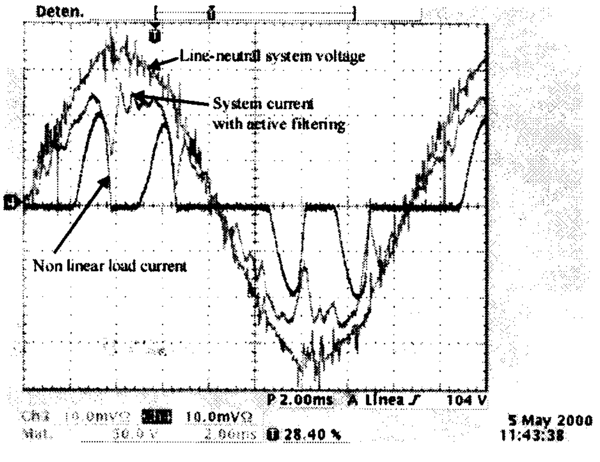

Figure 8: Case 2, Non-linear load current and filtered system current (5A/Div and 50V/Div).

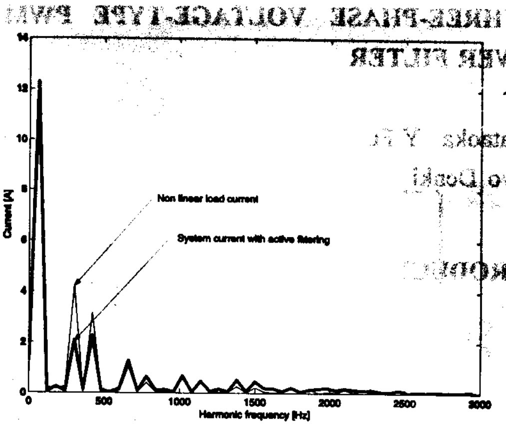

Figure 9: Case 2, Spectrum for the non linear load and system currents.

The results show a high frequency component on the system's current, that can be easily removed with a small low pass passive filter. The current waveform can still be improved using a higher commutation frequency, reducing in this way the current ripple.

CONCLUSIONS

A spatial vector control scheme applied to a three phase controlled rectifier bridge for active filtering and power factor control is proposed and implemented. Models in space vector coordinates of the system and the bridge, and the theory of the control scheme are presented. The proposed scheme is tested by simulation and experimentally by means of a DSP controlled IGBT three phase rectifier bridge. The results obtained show the viability and performance of the proposed scheme and strategies.

REFERENCES

1. Nishida Y., Miyashita O., Haneyoshi T., Tomita H., and Maeda A., 1997, IEEE Transactions on Industrial Electronics, 337-343

2. Ohnuki T., Miyashita O., Lataire Ph., and Maggetto G., 1999, IEEE Transactions on Power Electronics, 222-226

3. Aller J. M., Restrepo J., Bueno A., Giménez M. and Guzmán V., 1999, IEEE Power Engineering Review, 49-50

4. Restrepo J., Cabello A., Aller J. M., Giménez M. I., Guzmán V. and Bueno A., 1999, Proceedings of the 34nd Universities Power Engineering Conference UPEC'99, 612-615