DC Link Fuzzy Control for an Active Power Filter, Sensing the Line Current Only.

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Abstract. A different approach for controlling a shunt active power filter is presented. The dc link is controlled with fuzzy logic, and the current generated for the filter to compensate harmonics and power factor is not sensed. The sensors acts directly on the mains line currents, forcing them to be sinusoidal, and in phase with the mains voltage supply. The amplitude of the current is controlled by the fuzzy system, which operates through the error between the dc link voltage of the PWM modulator (active power filter), and a pre-established reference voltage, Vref. The main advantages of this approach are the following: a) the control block becomes simpler because there is no need to evaluate the current template for the filter currents, b) the dc link fuzzy control has better dynamic behavior than conventional PI control, and c) the filter can operate simultaneously as a power factor compensator, and as a four quadrant rectifier-inverter system.

I. INTRODUCTION

Conventionally, passive LC filters have been used to eliminate line current harmonics, and to improve the load power factor. However, in practical applications these passive second order filters present many disadvantages such as aging and tuning problems, series and parallel resonance, and others. In order to overcome these problems, active power filters have been researched and developed [1,2]. In recent years, shunt active power filters, based on current-controlled PWM converters have been widely investigated. They have gradually been recognized as a viable solution to the problems created by high-power nonlinear loads [3,4]. These filters work as current sources, connected in parallel with the non-linear load, generating the harmonic currents the load requires. In this form the mains only needs to supply the fundamental, avoiding contamination problems along the transmission lines. However, shunt active filters have some drawbacks, because until now they are difficult to implement in large scale, the control is complicated, and the cost is high. For example, to get the current reference template in shunt active power filters, the load current, and the filter current have to be sensed. From the load current, a complicated hardware has to be implemented to extract the signal of the harmonic content [5, 6]. With this signal, the filter current is controlled to inject the harmonics back to the system, but with 180 degrees phase-shift. In this way, the harmonics from the load are canceled. However, if the signal template of the harmonic content is not properly evaluated, the compensation becomes inadequate.

One solution proposed in this paper is to use a conventional, four-quadrant PWM rectifier as a shunt active power filter. This is accomplished by simply connecting the non-linear loads between this rectifier and their line current sensors. This solution reduces cost and allows an important simplification in control. Besides, the system can be controlled by fuzzy logic [7]. This approach presents the following particular characteristics: a) the four quadrant rectifier-inverter system can operate as an active filter, and as a power factor compensator simultaneously, b) the dc link fuzzy control has better dynamic behavior than conventional PI control, and c) the control block is simpler because there is no need to evaluate the current template for the filtering currents, because it follows a sinusoidal template in phase with the voltage supply.

II. THE PROPOSED SYSTEM

The figure 1 shows the schematic of the shunt active power filter proposed. It only measures the dc link voltage, and the mains line current. As it can be observed, almost any current-controlled PWM converter can be used as a shunt active power filter, without additional electronic circuitry.

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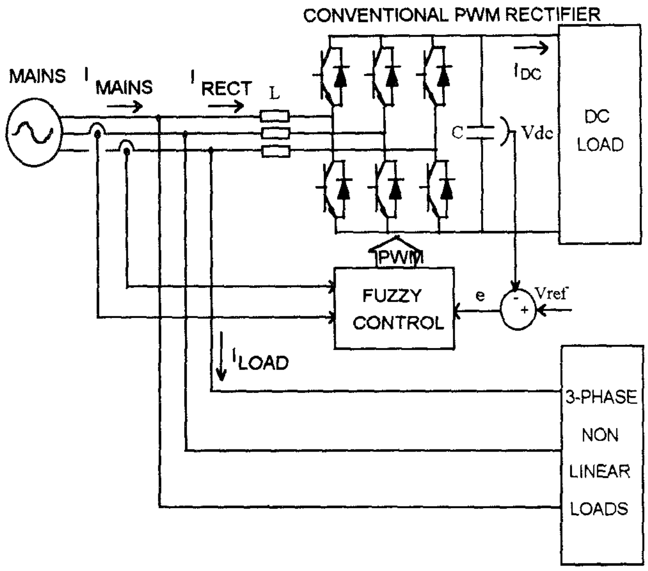

Fig. 1. Active power filter proposed

In the control strategy presented here, the active power filter has been implemented with a four-quadrant, current controlled PWM rectifier, in which a non-linear load has been connected between it and their current sensors. Doing that, the rectifier begins to behave as a shunt active power filter, but without loosing its characteristics as a four-quadrant rectifier. The current-controlled rectifier does not detect the presence of the non-linear load. It simply try to keep the mains current sinusoidal. In this way, there is no need to sense, neither the non-linear load current nor the filter current.

In this way, the PWM converter can work as a four quadrant rectifier, as a power factor compensator, and as a filter simultaneously. In other words, is a Multiple-Function System. The control strategy is conventional in the sense that the dc link voltage of the converter is controlled by adjusting the amplitude of the input ac currents. Due to the multiple capability of this approach, a good dynamic behavior is desirable. For this reason, a fuzzy control in the dc link has been implemented, which allows more flexibility and better dynamic response.

III. Hardware Implementation

The hardware was implemented with a 2-kVA, four-quadrant, current hysteresis controlled, IGBT converter. As a non-linear load, a diode rectifier with input inductance, and RL dc load was used. The block called FUZZY CONTROL in figure 1, generates the sinusoidal templates to control the magnitude of the mains current, **Imax.** They are controlled through the error between the dc link voltage Vdc of the PWM rectifier, and a pre-established reference voltage Vref. The phase of the sinusoidal template is adjusted through the mains voltage supply.

The fuzzy controller has been implemented with a "Freedom16" v2.1 board from Intec Inoventures Inc. [8]. This board is built around Motorola's 16 bit 68HC16 microcontroler wich not only has more computer power than a PC-AT, but, also features digital signal processing (DSP) capabilities and a host of specific features such as pulse counting, high speed inputs and outputs and 8 channnels of 10 A/D conversion. The board has the advantage that can be programmed in C language through a PC serial interface, and can be debuged through the parallel port. Once the programe is finished, the Freedom16 can be programed in ROM for a stand alone operation.

Despite the F16 has 8 A/D converters, the implemented control was built with an external 8 bit converter. In this form, was possible to increase the conversion time and produce a faster response in the control loop. As the F16 does not suport D/A convertion, the output was also implemented with an external 8 bit DA converter. The figure 2 shows the hardware implementation for the fuzzy control loop, and figure 3 shows the PC interface for programing and debuging in F16.

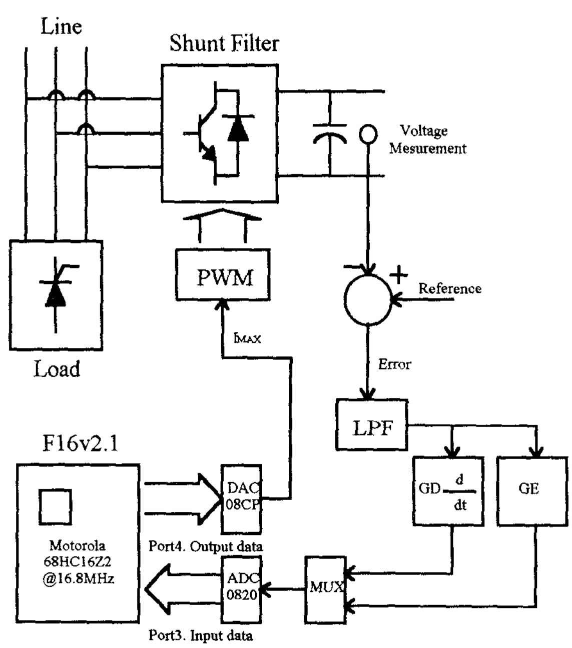

Fig. 2. Fuzzy control loop

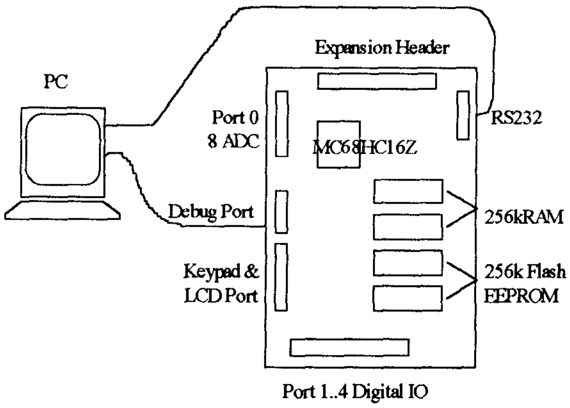

Fig. 3. PC interface for programing and debuging

IV. Software Implementation

To implement the fuzzy control strategy, a PI fuzzy control with 49 rules has been selected [7, 9]. The inputs are the error voltage **e(k),** and its incremental variation **de(k)**. The output is the amplitude of the mains current, **Imax(k)**. To make the system work at unity power factor (power factor compensator), the mains current is kept in phase with the mains voltage. The Fig. 4 shows the fuzzy control block implemented.

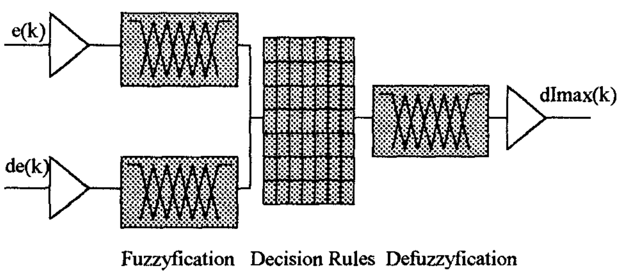

Fig. 4. Fuzzy control block

The fuzzy controller is characterized for the following:

- Seven fuzzy sets for each input
- Seven fuzzy sets for the output
- Triangular membership functions
- Fuzzyfication using continuous universe of discourse
- Implication using the *"min"* operator
- Inference mechanism based on fuzzy implication
- Defuzzyfication using the *"centroid"* method

All fuzzy variables have the same partition and membership functions. The fuzzy control has 7 membership functions called from Negative Big (NB) to Positive Big (PB). The figure 5 shows a unitary discusion universe wich can be modified by simple gain on each variable. The idea of this partition is to simplify the number of calibration variables, reducing them to one gain for each variable: GE for error, GD for derror and finaly GU for DImax.

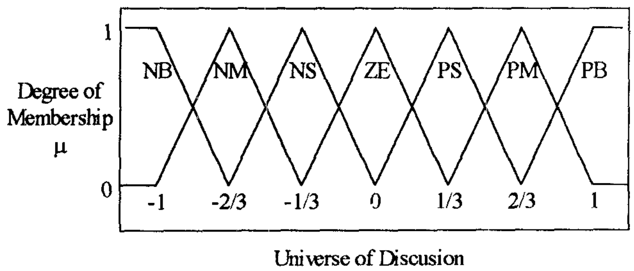

Fig. 5. Unitary discusion universe

The final output to the system is calculated as Imax(k) = GU*DImax(k) + Imax(k-1). Figure 6 shows the flow chart for the software implementation.

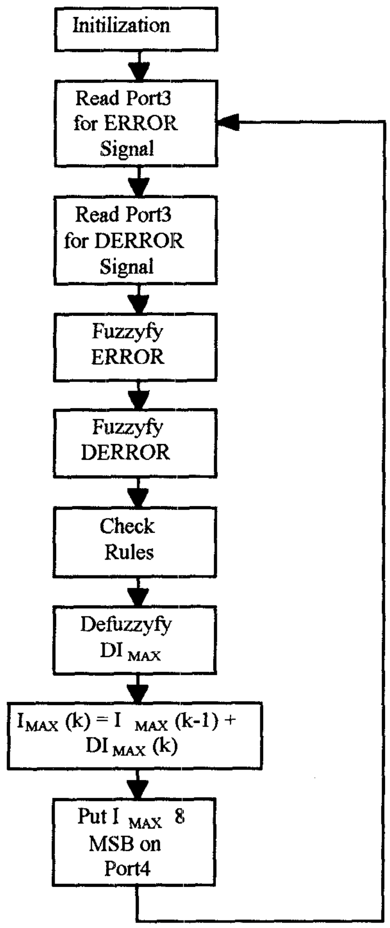

Fig. 6. Flow chart of the fuzzy control.

V. SIMULATION RESULTS

Some simulations were performed using Mathlab. The Figures 7 and 8 shows a comparison between PI Control and Fuzzy Control. The load is a thyristor rectifier, working with $\alpha = 30^{o}$. The parameters of the filter are: Vdc=250 [V], L=2.5 [mH], C=10,000 [uF]. In a), a step from 0 to 20 [A] change in the load current (thyristor bridge rectifier) is displayed. In b) the opposite situation has been simulated.

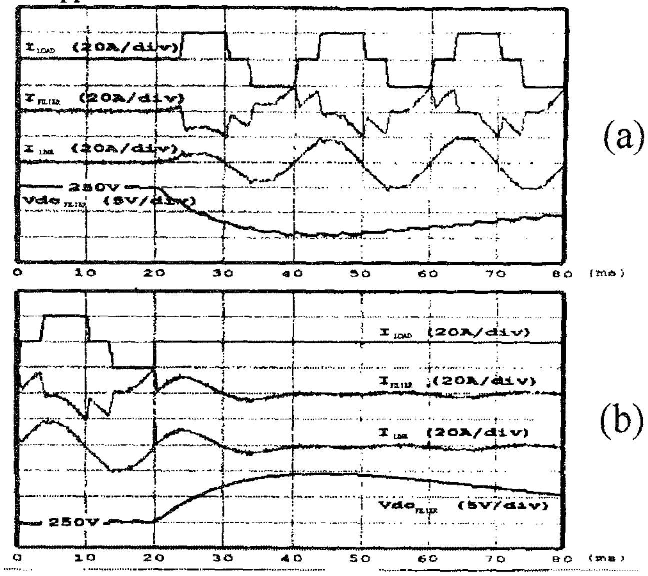

Fig. 7. Transient response with PI Control
a) from 0 to 20 [A] load current
b) from 20 to 0[A] load current

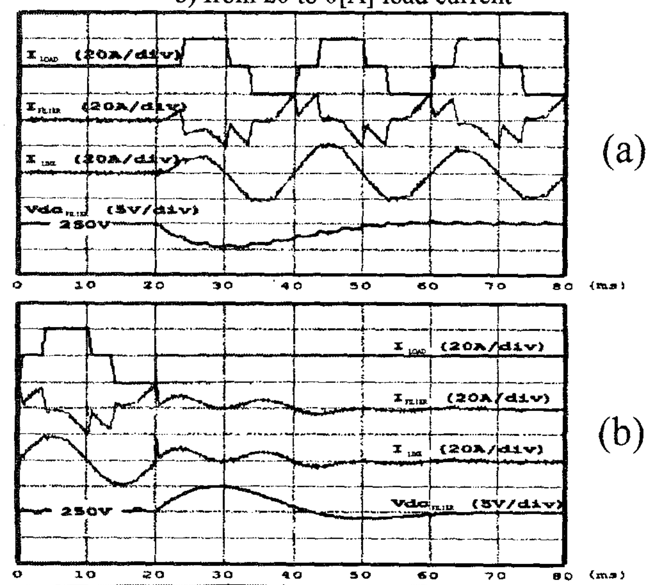

Fig. 8. Transient response with Fuzzy Control
a) from 0 to 20 [A] load current
b) from 20 to 0[A] load current

It is clear that the transient response in the mains current, and in the dc link voltage, is faster in the fuzzy alternative. With fuzzy, the dc voltage in the filter (Vdc) is recovered in less than 40 [ms] (two cycles), but with conventional PI the same situation takes more than 60 [ms]. The load is a rectifier with firing angle $\alpha = 30^{o}$.

VI. EXPERIMENTAL RESULTS

For the experiments, a 2-kVA, four-quadrant, current-controlled PWM rectifier was used. The rectifier was implemented with IGBTs, and their main components were: C=4,400 μF, and L=2.5 mH. The dc voltage was adjusted to three different values: 100, 150 and 200 volts.

The figure 9 shows the waveforms obtained for steady-state operation. The first oscillogram (a) shows the source current. The second (b), shows the current through the non-linear load (diode rectifier), and the third (c) shows the current through the active power filter (four-quadrant PWM rectifier). It can be observed that the waveform of the line current is quite sinusoidal, showing the good performance of the proposed control strategy.

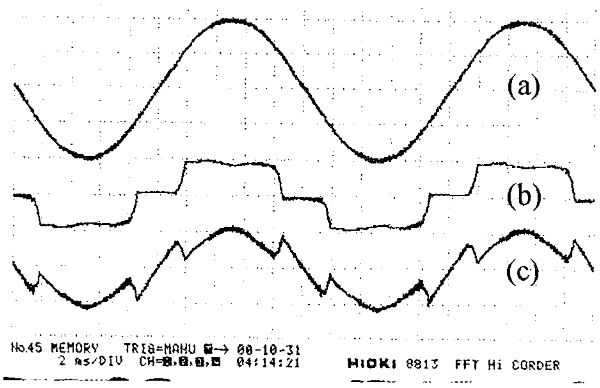

Fig. 9. Steady-state operation
(a) line current (4 A/div)
(b) load current (4 A/div)
(c) filter current (4 A/div)

The figure 10 shows the in-phase operation of the input current respect to the mains voltage supply (unity power factor operation). The first oscillogram (a) shows the source voltage. The second (b), shows the source current. The third (c) shows the current through the non-linear load (diode rectifier), and the fourth (d) shows the current through the active power filter (four-quadrant PWM rectifier).

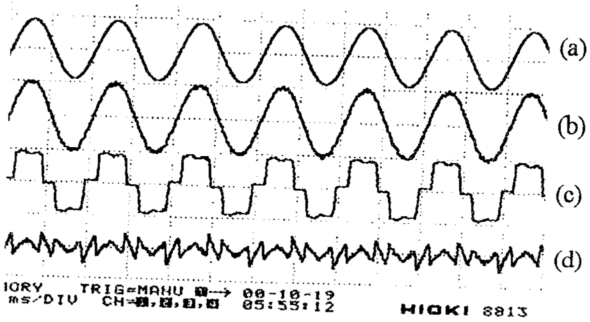

Fig. 10. In-phase operation of the system
(a) phase-to-neutral source voltage [50 V/div]
(b) source current [4 A/div]
(c) current through the non-linear load
(d) current through the active power filter

The figure 11 shows a comparison between PI control (upper signals), and fuzzy control. The first oscillogram of each experiment (a) shows the dc voltage drop when Vref=100 volts. The letters (b), (c) and (d) show the source current, the non-linear current, and the filter current respectively. In this experiment, two step changes have been generated. In the first step, a dc load at the diode rectifier output terminals is connected. In the second step a dc load is directly connected at the dc link of the active power filter (four-quadrant PWM rectifier). The oscillograms show that the fuzzy control recovers the steady-state in a shorter time. The scales are: V=25 V/div, and I=4 A/div. The source frequency is 50 Hz.

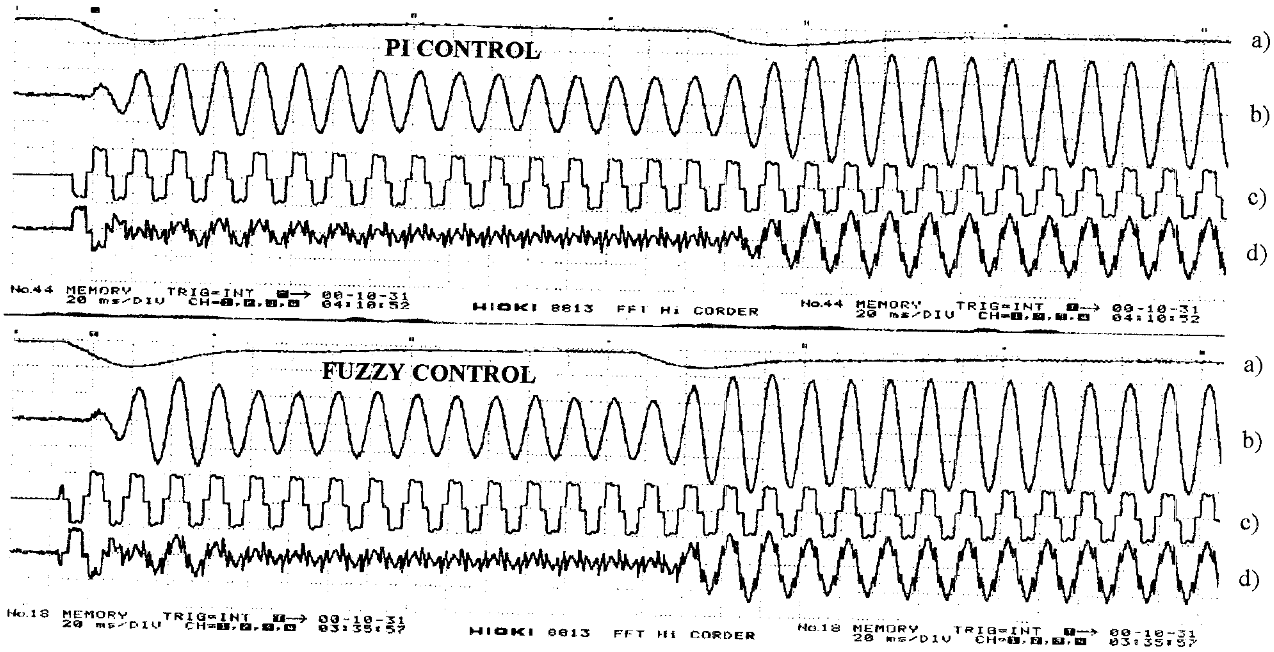

Fig. 11. Comparison between PI Control (upper signals), and Fuzzy Control (lower signals)
(a) dc voltage drop [25 V/div]; (b) source current [4 A/div]
(c) non-linear load current [4 A/div] (d) filter current [4 A/div]

The figure 12 shows the transient response obtained for a sudden disconnection of the load at the active power filter dc link. The upper oscillograms are for PI Control, and the lower correspond to Fuzzy Control. Again it is possible to realize that fuzzy has better dynamic behavior than PI control. It can be noticed a power reversal in the load current, to allow fast recovery of the dc link capacitor voltage. The oscillograms show: (a) the dc voltage error (25 V/div), and (b) the input source current (4 A/div). The diode rectifier was not connected, but the transient response in that case is very similar

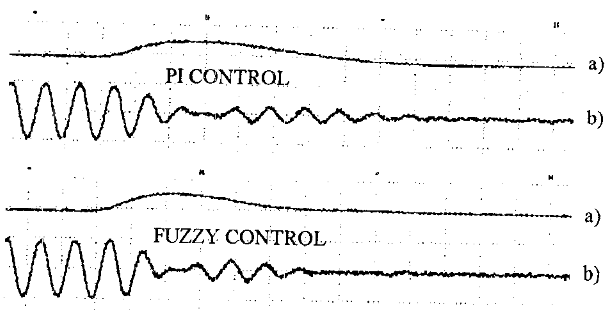

Fig. 12 Transient response for a sudden disconnection of the load at the active filter dc link

CONCLUSIONS

A different approach for controlling a shunt active power filter has been presented. The dc link is controlled with fuzzy logic, and the current generated for the filter to compensate harmonics and power factor is not sensed. The amplitude of the mains current is controlled by the fuzzy system, through the error between the dc link voltage of the PWM modulator (active power filter), and a reference voltage, Vref. The main advantages of this approach are the following: a) the control block becomes simpler because there is no need to evaluate the current template for the filter currents, b) the dc link fuzzy control has better dynamic behavior than conventional PI control, and c) the filter can operate simultaneously as a power compensator, and as a four quadrant rectifier-inverter system.

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REFERENCES

[1] Akagi, H. Kanazawa, Y. y Nabae, A. "*Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components*", IEEE Trans. on Ind. Appl., Vol IA-20 N°3, May/June 1984, pp. 625-630.

[2] Akagi, H., Nabae, A. y Atoh, S., "*Control Strategy of Active Power Filters Using Multiple-Voltage Source PWM Converters*", IEEE Trans. on Ind. Appl., Vol. IA-20 N°3, May/June 1986, pp. 460-465.

[3] W. M. Grady, M. J. Samotyj, and A. H. Noyola, "Survey of Actve Power Line Conditioning Methodologies", IEEE Trans. on Power Delivery, Vol. 5, N° 3. July 1990, pp. 1536-1542.

[4] L. Malesani, L. Rosseto, and P. Tenti, "Active Filters for Reactive Power and Harmonic Compensation", Proc. of The IEEE PESC'86, June 1986, pp. 321-330.

[5] Dixon, J., García J., y Morán, L., "*A control System for Three Phase Active Power Filter, which Simultaneously Compensates Power Factor and Unbalanced Loads*", Proceedings of the IECON'93, Nov. 15-19 1993, Hawaii, USA, pp.1083-1087.

[6] Tepper, S., Dixon, J., Venegas, G., y Morán, L.,"*A Simple Frequency Independent Method for Calculating the Reactive And Harmonic Current in a Nonlinear Load*" International Power Electronic Conference, IPEC'95, Yokohama, Japan, April 3-7 1995.

[7] Bose, B. K., "*Expert System, Fuzzy Logic, and Neural Network Applications in Power Electronics and Motion Control*", Proceedings of the IEEE, Vol. 82, N° 8, August 1994, pp. 1303-1323.

[8] Freedom 16 Advanced 16 bit Controller, User's Manual. Intec Inoventures Inc., 2751 Arbutus Road, Victoria, B. C., Canada, V8N-5X7.

[9] Dorf, R., "*Modern Control Systems*", Addison-Wesley 1989.