CIEP 98

Single–Phase Active Power Filter for Reactive Power and Harmonic Compensation.

Leobardo Cortés B., Sergio Horta M *., Abraham Claudio S., Víctor M. Cárdenas G.

Centro Nacional de Investigación y Desarrollo Tecnológico
Interior Internado Palmira s/n, PO. Box 5-164
Fax +(73) 122434 Cuernavaca, Mor. , México.

* Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Ciudad de México
Calle del Puente 222, Esquina Periférico Sur, C.P. 14380.
Fax: 673-25-00, D.F. México.

ABSTRACT. This paper presents design considerations of an Active Power Filter and a simple method to calculate reactive power components and current harmonics for single-phase no linear loads. This allows compensation of harmonic currents into the utility power. Simulations and experimental results are shown for a non linear load of 1kVA.

I. Introduction.

Harmonic contamination in power systems is a serious problem due to the increase of nonlinear loads. The problem of nonsinusoidal line currents created by nonlinear power electronic loads is well documented. This kind of loads generates non desired phenomena, such as:

- generation of harmonics currents
- critical values for THD voltage
- efficiency reduction in electrical equipment.

Conventionally, a passive L-C filter are used to suppress harmonics components. The capacitor are used to compensate the lag power factor. However, passive filter have many disadvantages, such as large size, resonance, and fixed compensation characteristics. Therefore, conventional passive power filters cannot provide a complete solution[1,2].

Another more efficient solution is the utilization of Active Power Filters (APF). The main advantages of using an Active Power Filter are: a) elimination of unwanted harmonics; b) power factor compensation; and c) redistribution of power to keep the system balanced.

II. Single phase Active Power Filter description.

II.1. The proposed Method

In the practical implementantion of this kind of filter, forced conmutated, current-controlled voltage source inverters (CC-VSI) are widely used. The quality and performance of the active power filter depend mainly on three considerations[3]: the design of the power inverter, b) the modulation method used to follow the current template (hysteresis, triangular carrier, deadbeat) c) the method implemented to generate the reference template, which is the topic of this work. The proposed solution, to solve the problems above mentioned, for single-phase non linear loads, is to use a single-phase parallel active power filter, shown in fig. 1.

II.2. Principles of operation

It is well known that active power filters correct current system distortion caused by non linear loads by injecting equal-but-opposite current harmonic components at a specific point of utility[4]. The APF behavior under steady state and transient operating conditions depends mainly on the control strategy.

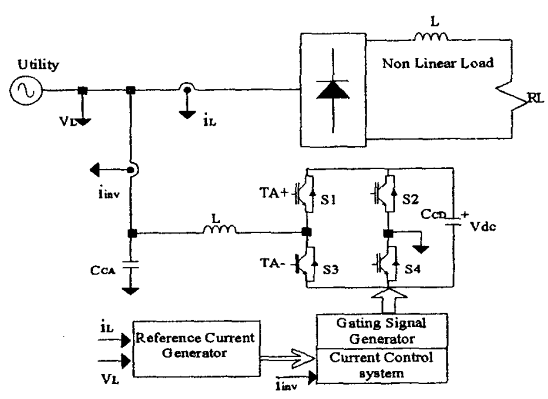


Fig. 1 Single phase active power filter (APF) and simplified analog.

0-7803-5006-5/98/$10.00©1998 IEEE.

III. Design control system

III.1. Block diagram of active filter control

The control system has to be able to generate the current reference waveform for APF and also has to produce the gating signals. This control system is shown in fig. 2.

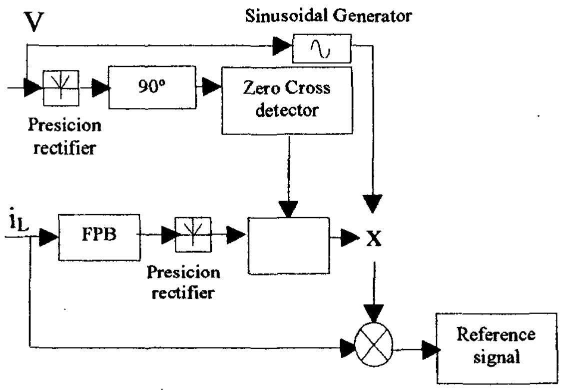


Figura 2. Block diagram of the fast calculation circuit for the reference current.

The control system is based on the assume that I_L is the total load current. This current contains basically three components: $I_L = I_P + I_Q + I_H$, where I_P, I_Q, I_H, are the fundamental active current, reactive current and the harmonic currents components, respectively. The proposed method is based on the recovering of the fundamental active current in the current load. Once this current is obtained, it is substraeted from the total load currents to get the desired reference waveform. In this circuit (fig. 2), the load current (I_L) is filtered through a Band-Pass filter to obtain the fundamental phase-current. This current is rectified and used as an input signal for a "Sample and Hold" circuit. The "Sample and Hold" circuit, synchronized with the peak value of the phase to neutral voltage, generates a dc signal, proportional to the amplitude of the active component of the current I_P in DC. Now, the value of the signal I_P in DC has to be multiplied by an unit-amplitude sinusoidal waveform in phase with the mains voltage. Therefore, the reference signal is $I_{ref} = I_L - I_P$.

III.2. Current controller scheme.

On the order hand, the block diagram in the fig. 3 shows the current controller scheme, its principal objetive is to force at the current APF to follow the reference current. The signal generated to active power filter control [TA+, TA-], (shown in fig. 3), are obtained from the difference between the signal reference (i_{ref}) and the output current of the APF (i_{inv}). This error signal (i_{error}) input, to a PI control that allows to elimitate the steady state error, in order to obtain a fast response due to for load pertubations. Next, the output signal of PI control is modulated by a triangular signal and finally, a hysteresis control generates the signal APF control [TA+, TA-], with the commutation frequency as a function of the triangular signal.

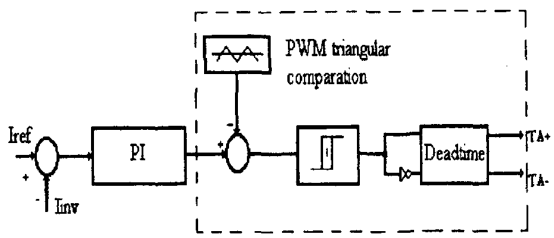


Fig 3. PI basically current controller.

IV. Simulation Results

Fig. 4 shows the simulation results using the PSpice software, with an analog control: linear PI control and triangular comparison. This simulation has been done with the following parameters:

Active filter: L=2.3mH, C=1465μF, fc= 7.68KHz.

Non linear load (RL load after rectifier bridge): Lc = 1H, Rc = 6.4Ω.

Fig. 4a. Shows the source voltage and current. It can be observed that the harmonic currents are compensated by the active power filter. These harmonic currents depend on the reference signal quality which is obtained by the control circuit (figs. 4b). In the fig. 4a shows the current ripple at the switching frequency (fc), which can be reduced when the switching frequency is increased with a natural reduction of the output APF inductor (L), can be observed.

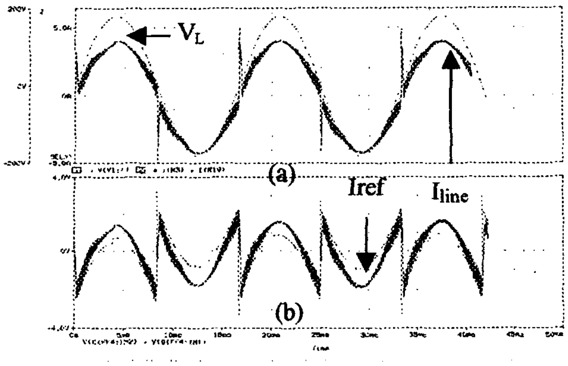


Fig. 4. Preliminary results: a) current and voltage in AC line; b) Reference signal control and APF current.

The fig. 5 show simulation results of the APF transient response. This simulation considers only the feedback loop current, it can be observed that the capacitor voltage (V_{CAP}) decreases with an increase of the load current. In consequence, a higher error is present in the generated current (peaks level increase on fig. 5 shows).

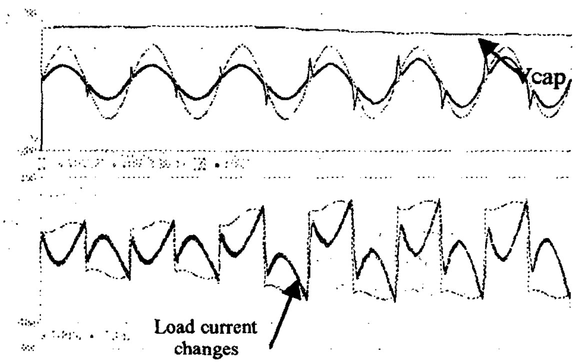


Fig.5. Simulated current and voltage waveforms for steady state and transient response.

IV. Experimental results

The reference signal control (i_{ref}) together with inverter current output are shown in fig. 6a, the ripple current depends basically on following parameters: APF inductor (L), switching frequency (fc), and the voltage applied to the inductor (L). Fig. 6b shows a zoom of fig. 6a, where it can be observed a reduction of the spike current at the instant when the current crosses zero and consequently, a reduction of the flowing error between the reference current (*Iref*) and the inductor current (*Iinv*).

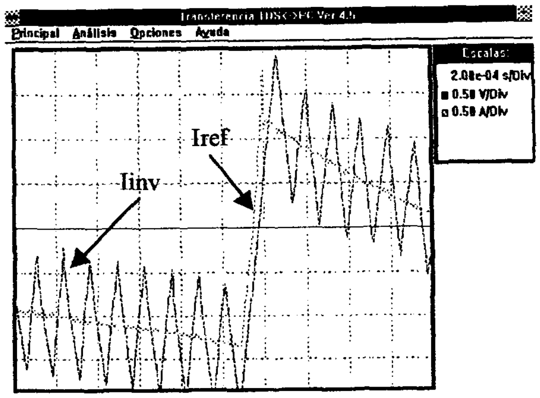
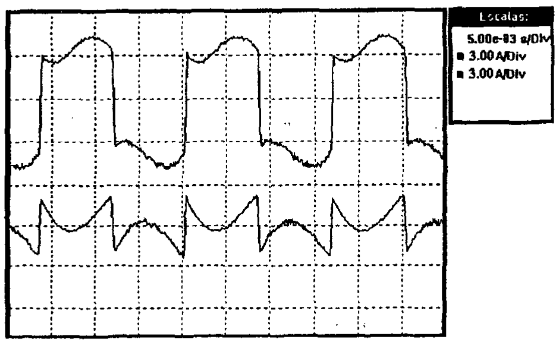
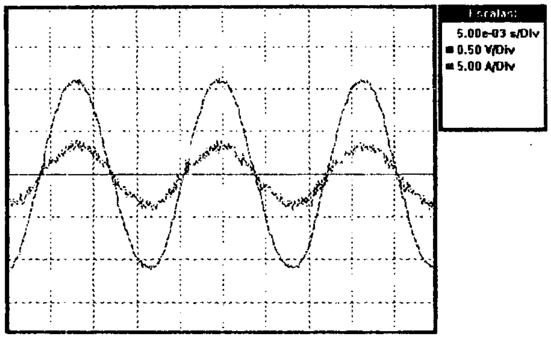


Fig. 6. Experimental results: Reference signal control and APF current outcomes.

Fig. 7a shows the non linear load demand current and the reference signal generated by the APF control, necessary to accomplish harmonic currents compensation. Outcomes of current and voltage are shown in fig. 7b, where it can be observed a reduction of the THD (6%) and an increase of power factor correction (PF ≈ 0.99) in the current line AC. Fig. 8 shows the transient experimental result.

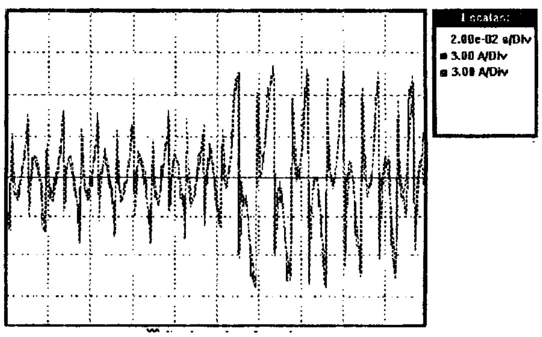


(a)

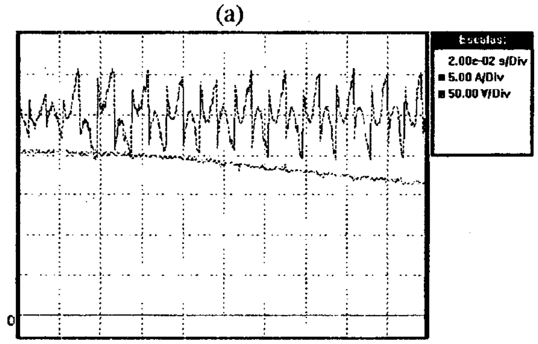


(b)

Figura 7. Steady state experimental results (a) The phase to neutral source voltage and the respective load current. (b) The phase to neutral source voltage and the respective source current.



(a)



(b)

Figura 8. Transient experimental results. (a) Reference current and APF current. (b)APF current and Capacitor (C_{CD}) voltage.

Conclusions:

- The merits of this single-phase APF are the following:
  - Simplifying the calculation of the reference signal current required for APF.
  - Energy balance concept is used to simplify the design of the conventional APF capacitor.
  - The results demonstrate harmonics suppression and a nearly unity power factor is obtained.
- The results that have been achieved so far, are very interesting and show that APF is a good solution for the harmonic currents compesation and power factor correction and transient response becomes fast and good.
- It can be shown that the analog control technique proposed is a simple solution but very suitable for this application because THD lower than 6% has been obtained.
- A compromise has to be made between design parameter of an APF, as a function of the load power, load dynamic response and line impedance. For example, choice of a small L low implies an increase of frequency for same power load. It's necesary to have a good response in case of non linear load with higher di/dt.
- The closed agreement between the analytical and the experimental results proves the validity of the analysis and the feasible of the proposed system.

References

1. S.M. Peeran, C. W. P. Cascadden "Application, Design and Specification of Harmonics Filter for Variable Frequency Drives"PESC'94, pp. 909-916.
2. W.M. Grady, M.J. Samotyj, A.H. Noyola, "Survey of Active Power Line Conditioning Methodologies", in IEEE Trans. On Power Delivery, Vol. 5, No. 3, July, pp. 1536-1542.
3. F. Pôttker and I. Barbi, "Power factor correction of non-linear loads employing a simple a single phase power filter: Control strategy, Design methodology and experimetation", in PESC'97, Vol.1. pp. 412-417.
4. H. Akagi. "Trends in Active Power Line Conditioners", in Proc. IEEE Industrial Electronics, Control, Instrumentation and Automation, 1993, pp. 19-24.
5. J.S. Tepper, J.W. Dixon, G. Venegas and L. T. Morán, "A simple frequency – independent method for calculating the reactive and harmonic current in a nonlinear load", in IEEE Transactions on industrial electronics, Vol 43, No. 6, December 1996, pp. 647-65.