Improved Injection Current Controller in Single-Phase Shunt Active Power Filters

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Abstract. Nowadays shunt active power filters (SAPFs) are one of the most versatile and efficient solutions in the correction of the load power factor and the compensation of current harmonics generated by non-linear loads. The injection current controller, which must achieve that the compensation current track the reference one, is one of the basic components of the controller of a SAPF. This work presents a new method to control the injection current using a digital predictive algorithm, which allows an optimal compensation in stationary state and during variations in the load current and in the source voltage. Results obtained in simulation tests and experimentally on a laboratory prototype confirm and validate the proposed technique.

Key words: Current harmonics, reactive current, shunt active power filter, injection current control, Kalman filtering,

1. Introduction

Non-linear loads connected to the electrical grid cause voltage and current harmonics which can reduce the efficiency and capability of the transport and distribution lines due to the presence of reactive power current components.

The power system efficiency can be improved using passive filters, active filters or both solutions simultaneously: hybrid filters. Active power filters and hybrid filters are the most efficient and versatile ones, avoiding problems associated to passive solutions as resonances.

The general structure of the compensation by means of a SAPF is shown in figure 1. The SAPF is composed by an IGBT H-Bridge, a floating capacitor (V_{dc}) and a current link (L_i). The SAPF current consumption allows the compensation of the non-desirable components of the load current instantaneously. Its controller must determine the compensation reference current, which is composed by the non-desirable load current component and a current to compensate the power converter switching losses, and ensures that the instantaneous compensation current corresponds to the reference current [1].

The injection current controller must ensure that the compensation current tracks the reference current taking into account the characteristics of the link inductor and the voltage in point of common coupling (PCC).

Different methods to control the injection current have been proposed: hysteresis [2], PI, deadbeat, adaptative [3], fuzzy, ANN but probably, the most applied one, is a PI-controller due to its simplicity. The fundamental drawback of this controller is that is not capable of track sinusoidal signals without stationary error, which generates a poor SAPF performance [4], due to this fact resonant controllers have been applied [5] to electrical drives but in the case of SAPF, with reference currents composed of diverse harmonic components, the structure of the full controller can be very complex, with a resonant control block for each harmonic component in the error signal.

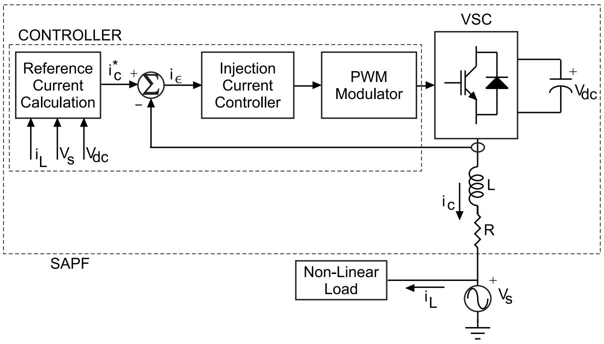

Fig. 1. General structure of a shunt active power filter

This paper proposes a new injection current controller which improves the results obtained with PI controllers and simplifies the controller design. The proposed current controller takes advantage of the predictive capability of discrete Kalman filtering and has been tested in simulation and on a laboratory prototype, verifying its optimal behavior under stationary and dynamical conditions.

2. Proposed Current Controller

The controller in figure 1, after determining the compensation reference current, $i_C^*(t)$, must ensure that the current through the current link, $i_C(t)$, corresponds to the compensation reference current. The reference current, $i_C^*(t)$, is compared with the injection current, $i_C(t)$, and the error current, $i_\varepsilon(t)$, is applied to the injection current controller which establishes the new output voltage of the voltage source converter (VSC). This voltage must be traduced to switching states of the VSC by means of a modulator, which establishes the time in each switching state. Finally, the voltage across the current link establishes the injection current $i_C(t)$.

Using a digital controller, this control loop can be analyzed as shown in figure 2, where the effect of the analog-to-digital and digital-to-analog interfaces is introduced. The transfer functions $G_{c1}(z)$ is applied to the control of the injection current of the current controller and $G_{C2}(z)$ is employed to minimize the effect of the source voltage in the injection current controller. On the other hand $G_M(s)$ is the modulator transfer function, $G_I(s)$ is the power converter transfer function and $G_L(s)$ is the current link transfer function.

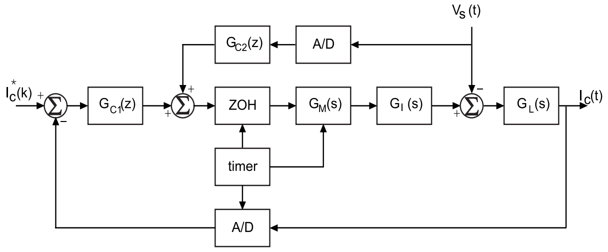

Fig. 2. Discrete current control loop

Where the continuous blocks have been modeled as:

$$G_L(s) = \frac{1}{Ls + R} \tag{1}$$

$$G_I(s) = V_{dc}(s) \tag{2}$$

$$G_M(s) = \frac{1}{G_I(s)} \tag{3}$$

where must be appointed that the effect of oscillations on the DC bus voltage are neglected due to the different frequencies of the DC bus voltage controller and the injection current controller, being faster the last one. The effect of the source voltage is treated as a disturbance on the controller, then, the injection current controller without disturbances can be analyzed as it is shown in figure 3. This figure shows the proposed control loop where the acquisition delays are modeled by means of z^{-r} and the predictive effect of the applied Kalman filters is modeled through z^{+b}.

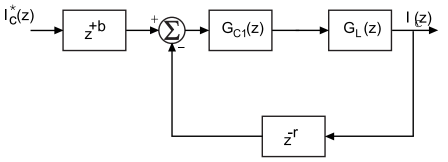

Fig. 3. Simplified current control loop

Then, establishing that the error in the compensation must be 0, the current controller transfer function will be:

$$G_{C1}(z) = \frac{1}{\left(z^b - z^{-r}\right)G_L(z)} = \frac{R\left(1 - az^{-1}\right)}{(1-a)\left(z^{b-1} - z^{-(r+1)}\right)} \tag{4}$$

Where $a = e^{-\frac{RT_S}{L}}$, R and L model the linking inductance and T_S is the sampling interval employed by the digital controller.

As consequence, the controller only can be feasible, independently of the time delays in the acquisition of the injection current, if b=1. Then, the application of a predictive Kalman filtering loop on the reference current with one sample in advance allows the development of this controller. Due to equation 3 $G_{C2}(z)$ only has to compensate r delays in the acquisition of the source voltage, so other Kalman filter with predictive capability can be applied to obtain this signal.

3. Simulation Results

A full SAPF has been modeled to test the proposed injection current controller. This SAPF is connected to the grid and to a non-linear load which is a full bridge diode rectifier with a RC load, R=64 Ω and C=1000 μF. The source voltage corresponds to 25 V_{rms} at 50 Hz. The SAPF is composed of one H-bridge with IGBTs and diodes in anti-parallel, a DC capacitor C=2200 μF at 160 V and a current link L=12 mH and R=1.6 Ω.

Figure 4 shows the obtained results in stationary state during the compensation. The injection current matches the reference signal, including the higher frequency components which correspond to the reference current peak.

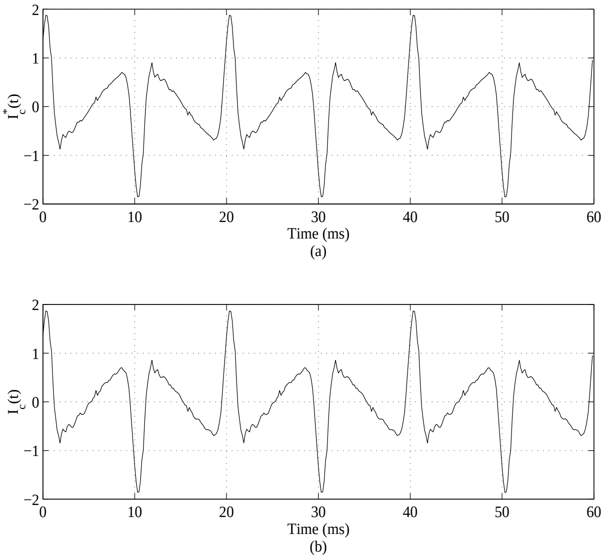

Fig. 4. a) Reference and b) compensation currents. Stationary state.

Figure 5 shows the reference current and the injection current during the charging transient of the SAPF capacitor. In this case, low frequency components in the reference signal, due to the charging process of the DC capacitor, are tracked maintaining the good performance of the proposed current controller.

4. Experimental Results

A laboratory prototype of SAPF has been developed to test the proposed current controller. The power converter of the SAPF is an H-Bridge made up of IGBTs with anti-parallel diodes IRG4PC50UD and an IR2130 control circuit is employed to apply the gate signals to the converter. A DSP target board based on a TMS320C31 processor runs the SAPF control algorithm with a sampling interval of 156 μs, which corresponds to 128 samples per cycle at the fundamental grid frequency. Power signals conditioning and isolation is obtained using effect Hall transformers to measure voltage and currents in the PCC and an isolation amplifier to measure the DC voltage in the SAPF. The test conditions correspond to the described ones in the simulation tests.

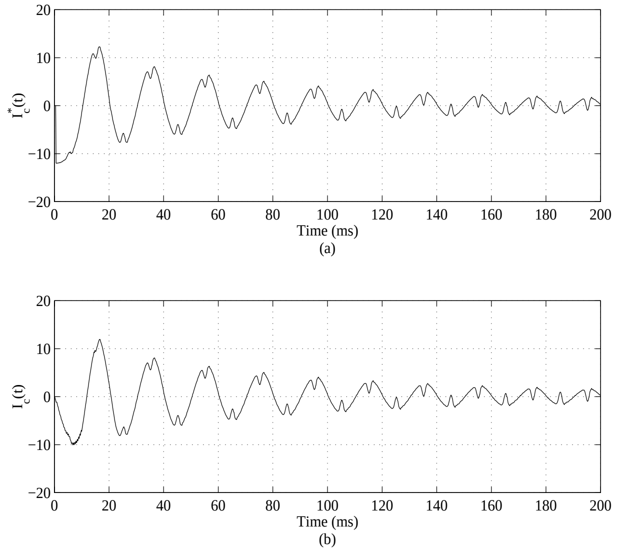

Fig. 5. a) Reference and b) compensation currents. DC capacitor charging transient.

Figure 6 shows the frequency spectra of the load current and the source current during the compensation. The compensation objective is the minimization of the first 5 odd harmonics of the load current in the source current. As can be seen, these harmonic components are reduced below the 5% of the fundamental frequency, which demonstrates that the proposed controller is working properly. In this compensation mode, the ITHD is reduced from 123.38% to 12.80%

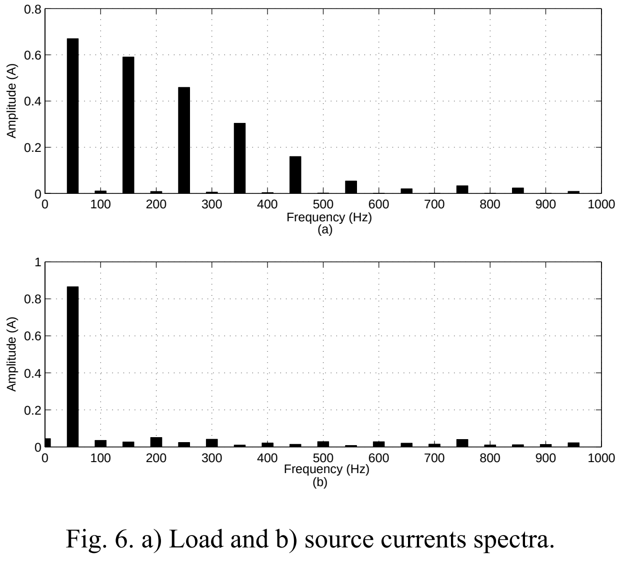

Fig. 6. a) Load and b) source currents spectra.

Figure 7 shows waveforms of the load current, taken as compensation reference, and the source current during a transient in the load current consumption due to the variation of the DC resistance from 68 Ω to 34 Ω. As can be seen, the source current maintains its sinusoidal waveform in despite of this load change. This is due to the structure of the proposed current controller which is based on the model of the current link and not on the characteristics of the error signal.

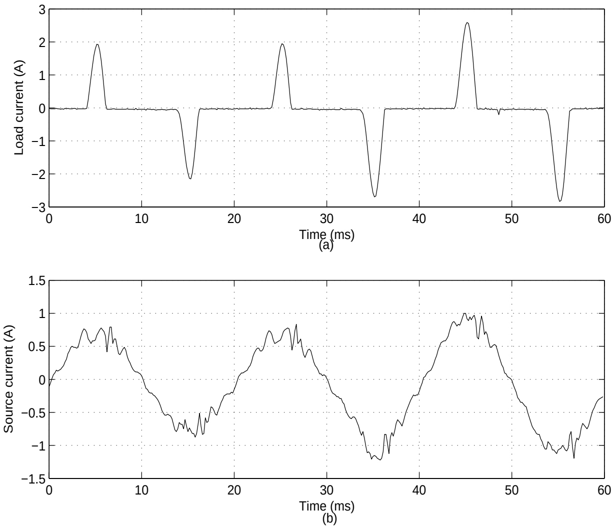

Fig. 7. a) Load and a) source currents during a load transient

5. Conclusions

A new current controller for single phase shunt active power filters has been proposed. The use of a digital algorithm with predictive capability allows obtaining an optimal FIR controller. This controller simplifies the design of the present current controllers and improves their behavior.

Obtained results in simulation test and employing a laboratory prototype allows the evaluation and validation the proposed control method in stationary state and under load transients.

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