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NEW INJECTION CURRENT CONTROLLER IN THREE-PHASE ACTIVE POWER FILTERS

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ABSTRACT

Nowadays shunt active power filters (SAPFs), due to their flexibility and reliability, are one of the most versatile and efficient solutions in the compensation of the load power factor and current harmonics.

The fundamental functional blocks of a SAPF controller are the calculus of the injection reference current, the control of the DC bus and the control of the injection current. This last controller subsystem, which must achieve that the compensation current tracks the reference one, is a critical component of the controller of a SAPF.

This work presents a new method to control the injection current in three-phase SAPFs using a digital predictive algorithm, which allows an optimal compensation in stationary state and during transients in the load current and variations in the source voltage.

Results obtained in simulation tests and experimentally on a laboratory prototype confirm and validate the proposed technique.

KEYWORDS

Current harmonics, shunt active power filter, injection current control, Kalman filtering,

1. INTRODUCTION

The presence of reactive power and harmonic current components in transmission and distribution lines reduce their efficiency and capability.

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 filters as network conditions dependency and resonances.

The general structure of a three-phase SAPF, the disturbing non-linear load and the electrical grid are shown in figure 1. The SAPF is composed by an IGBT H-Bridge (VSC), a floating capacitor with voltage Vdc and three current links represented by series L and R. The SAPF current consumption allows the compensation of the non-desirable load current components. Its controller must determine the compensation reference current, which is composed by the selected load current components and an active current component to compensate the power converter switching losses, and ensures that the instantaneous compensation current corresponds to the reference current [1].

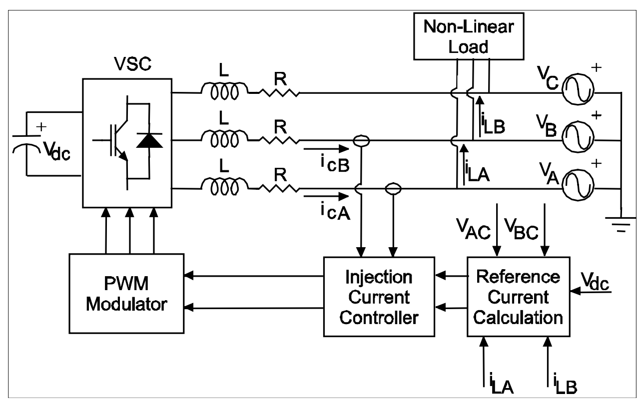

Figure 1 . General structure of a shunt active power filter

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

Different methods to control the injection current have been proposed: hysteresis [2], PI in the stationary reference frame and in the synchronous rotating frame (SRF) [4], deadbeat, adaptative [3], fuzzy and 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 in the stationary reference frame, which deteriorates the SAPF performance [5].

Due to this fact resonant controllers have been applied to electrical drives [6] 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 case of PI controllers in the SRF the main problem is the requirement of a transformation to the SRF axes for each harmonic component [7].

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 recursive Kalman filtering and has been tested in simulation and on a laboratory prototype, verifying its optimal behavior under stationary and dynamical conditions.

2. PROPOSED THREE-PHASE CURRENT CONTROLLER

The SAPF controller in figure 1, after determining the compensation reference signal using the load currents $i_{LA}(t)$ and $i_{LB}(t)$, must ensure that the currents through the current link, $i_{CA}(t)$ and $i_{CB}(t)$, corresponds to the compensation reference current. The reference signal is instantaneously compared to the injection current. The error signal 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 drops across the current links establish the injection currents $i_{CA}(t)$ and $i_{CB}(t)$.

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 function $G_{C1}(z)$ is applied to the control of the injection current and $G_{C2}(z)$ is employed to minimize the effect of the source voltage in the controller, which is considered as a disturbance. The current link transfer function is $G_L(s)$, the power converter transfer function is $G_I(s)$ and the modulator transfer function is $G_M(s)$. Their values are:

$$G_L(s) = \frac{1}{3}\frac{1}{Ls+R}\begin{pmatrix} 2 & -1 \\ -1 & 2 \end{pmatrix} \quad (1)$$

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

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

Where is considered that only two currents are measured (in lines A and B) and the current in line C is obtained using the Kirchhoff law.

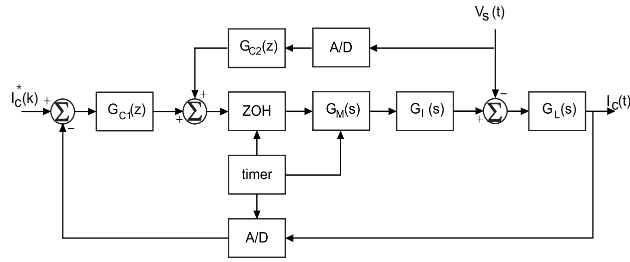

Figure 2 . Discrete current control loop

The control loop of the DC voltage is executed at a very low frequency in comparison with the frequency of the injection current controller: the first one is executed at the grid voltage fundamental frequency while the current controller is executed at each sampling interval. Then, oscillations on the DC bus voltage can be neglected during the analysis of the proposed current controller. 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 where z^{-r} corresponds to the acquisition delays and z^{+b} is a predictive block which allows the implementation of $G_{C1}(z)$.

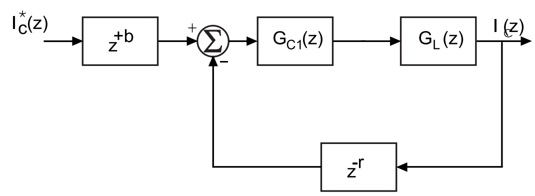

Figure 3 . Simplified current control loop

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

$$\begin{aligned} G_{C1}(z) &= \frac{1}{\left(z^b - z^{-r}\right)\; G_L(z)} \\ &= \frac{3R\left(1-az^{-1}\right)}{(1-a)\;\left(z^{b-1} - z^{-(r+1)}\right)}\begin{pmatrix} 2 & -1 \\ -1 & 2 \end{pmatrix}^{-1} \end{aligned} \quad (4)$$

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. This condition is accomplished applying a predictive Kalman filtering loop on the reference current calculation with one sample in advance. This filtering loop is implemented in $G_{C3}(z)$. The transfer function $G_{C2}(z)$ must compensate r delays in the acquisition of the source voltage signal, so $G_{C2}(z)$ can be implemented as another Kalman filter with r-samples predictive capability. Figure 4 shows the described structure.

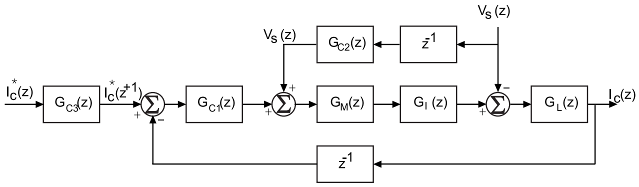

Figure 4. Proposed current controller

In the case of resonant controllers [8], the stationary error associated at each harmonic current component can be minimized using different resonant blocks but this solution reduces the controller stability. Using a PI controller, one SRF must be synchronized at each harmonic component frequency allowing a properly compensation of non-active load currents. The proposed structure simplifies the current controller minimizing the error signal.

3. SIMULATION RESULTS

A full three-phase 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 RL load, R=34 Ω and L=100 mH. The source voltage corresponds to 25 Vrms at 50 Hz. The SAPF is composed of one three-phase H-bridge with IGBTs and diodes in anti-parallel, a DC capacitor C=550 μF at 180 V, to allow the compensation of high frequency load current components, and a current link L=12 mH and R=1.6 Ω. The employed sampling frequency is 6.4 kHz.

Figure 5 shows the obtained stationary state results during the compensation in phase A. The injection current matches the reference signal including its higher frequency components, which correspond to the reference current peaks, due to the switching of the load diodes. The error current in figure 5.c. shows the difference between the reference current and the injection one. Spikes are due to delays in equation 4 during the signal processing.

Figure 6 shows the reference current and the injection current during a load variation where the current consumption is doubled. The good performance of the proposed controlled can be seen during the transient at 100 ms. Tacking into account the response time of the reference signal estimator, the controller tracks the reference signal in less than 10 samples. Moreover, the error signal in figure 6.c. is similar to 5.c., with mean value zero. The difference before and after the transient is the presence of higher spikes due to the processing delays.

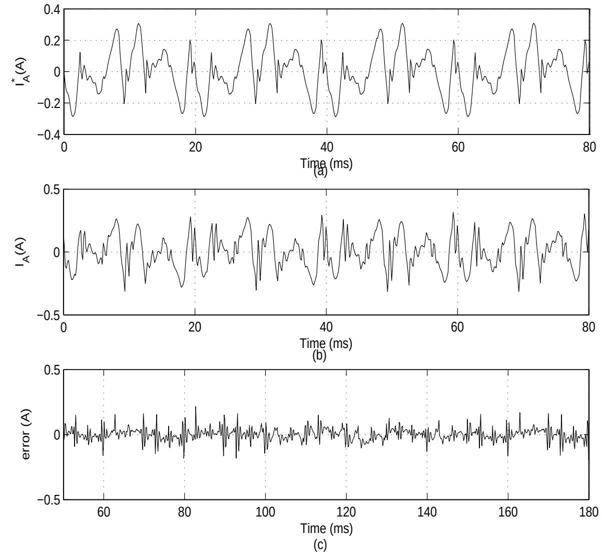

Figure 5 . a) Reference, b) compensation and c) error currents in phase A. Stationary state.

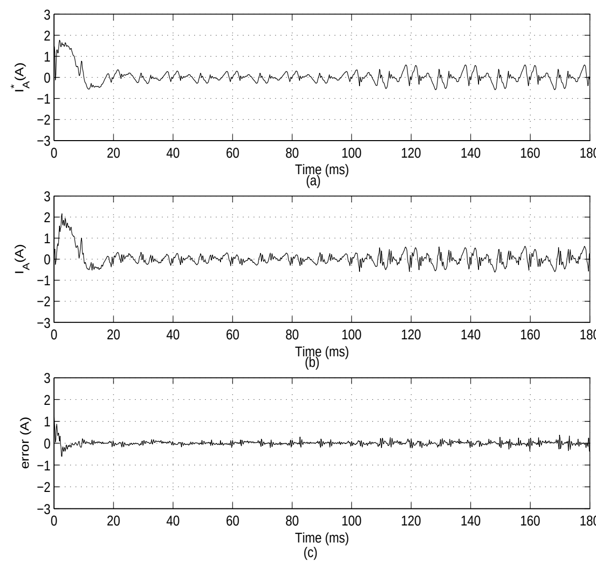

Figure 6 . a) Reference, b) compensation and c) error currents in phase A. Load transient.

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 a IGBTs module BSM74GD120DN2 from SIEMENS and controlled using a TPD-1 card from CONCEPT. 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.

Figure 7 shows the frequency spectra of the load current and the source current in phase A during the compensation. These signals have been selected due to the fact that the compensation reference signal can not been measured externally. The compensation objective is to obtain sinusoidal signals en each phase, proportional to the voltage waveforms and with PF=1. As can be seen, in the source current harmonic spectrum, only the fundamental component is present, which demonstrates that the proposed controller is working properly and tracks the harmonic components at 250 Hz and 350 Hz.

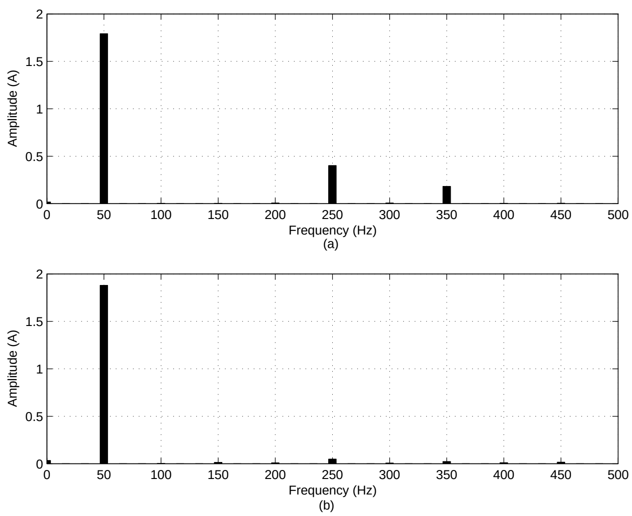

Figure 7 . Phase A a) load and b) source currents spectra.

Figure 8 shows the waveforms of the load current and the source current in phase A during a load current transient due to the change of the DC resistance in the load. 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.

5. CONCLUSIONS

A new injection current controller for three-phase shunt active power filters has been proposed. The use of a digital algorithm with predictive capability allows an optimal reference signal tracking, simplifying its design and improving its performance.

Obtained results in simulation test and employing a laboratory prototype of a three-phase shunt active power filter allow the evaluation and the validation of the developed controller in stationary state and under load transients.

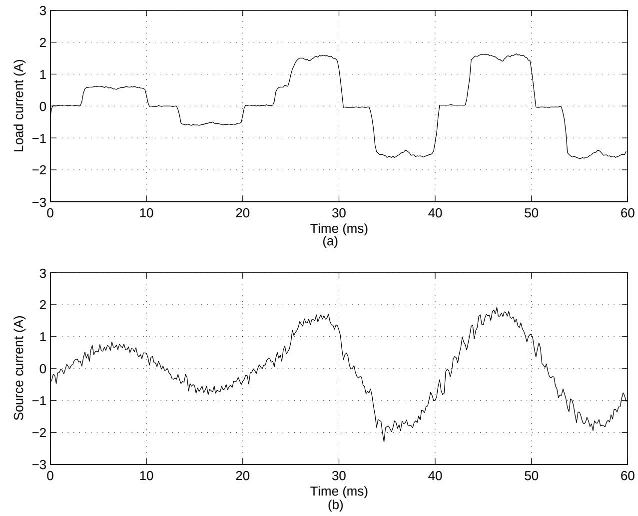

Figure 8 . Phase A a) load current and b) source currents during a load transient

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