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Comparative Analysis in the Case of Indirect Current Control in a Shunt Active Filtering System

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***Abstract* - In this paper, the performance of a three-phase four wire shunt active power filter (APF) using indirect current control with active load current calculation was compared with that corresponding to using indirect current control with prescribed current calculation from the voltage controller. It is clear that, under balanced and sinusoidal voltage conditions, these two methods give similar results. The variant of the indirect current control with prescribed current calculation from the voltage controller has the advantage of simplicity, but exhibits increased sensitivity to voltage ripples on the compensation capacitor, as they are reflected in the output of the voltage controller. The whole system was modeled using MATLAB-SIMULINK software. The simulation results demonstrate the applicability of both methods for APF control.**

Cuvinte cheie: *Filtru activ de putere, control indirect al curentului, calculul curentului activ al sarcinii.*

Keywords: *Shunt Active Power Filter, Indirect current control, Active Load Current Calculation*

I. INTRODUCTION

After identifying the existence of current and/or voltage harmonics in an electrical system, the problem arises of finding and implementing solutions to solve the problems they generate. In adopting them, the possibility of compensating the reactive power and imbalances generated by the load is also taken into account.

Active Power Filters (APF) are inverter-type static converters, bidirectional in current and voltage, controlled in such a way as to absorb the harmonics that must be eliminated from the network and equipped with a circuit component for energy storage on the DC side [1], [2].

Because of their particular objective of improving the current waveform rather than controlling the transferred power, active power filters have also been called "Active Harmonics Conditioners" (AHC) or "Active Power Line Conditioners" (APLC).

There are many control methods of the current in the shunt APF, so that the current injected into the power supply follows its reference value [3]–[5].

The need to control also the voltage across the compensation capacitor in the DC side must be mentioned [1]–[8].

Clearly, the control system of an APF contains an outer loop for regulating the voltage on the compensation capacitor and an inner loop for regulating the current. The output of the current controller determines the sequences of gate drive signals for APF's semiconductor devices.

On the other hand, the structure of the current control loop is determined by the adopted control algorithm.

The performance of the active filtering is significantly affected, both by the technique adopted for the reference currents generation and by the current control technique [1], [4], [6], [9].

Depending on the controlled current in the regulation scheme, there are two control methods, the direct control and the indirect control, respectively.

The direct current control involves the direct regulation of the current at the output of the inverter.

In this case, the main component of the current prescribed to the current controller is the compensating reference current, to which the active component necessary to cover the losses in the system is added. The latter causes the voltage on the compensation capacitor to be maintained at the prescribed value [1], [10]–[14].

The indirect control consists of controlling the supply current and involves prescribing its waveform that corresponds to the desired supply current.

The advantage consists in the simpler way of calculation and in the fact that the current controller operates with sinusoidal signals having the pulsation of the power supply network [1], [15]–[18].

Referring to the objectives of active filtering, the indirect current control is preferable when zero current distortion or unity power factor is desired after compensation.

In this case, it can lead to a simpler control structure by significantly reducing the computational requirements and time.

There are two ways to obtain the active load current, either based on the output of the voltage controller, or by extracting it from the total load current [1].

Following the numerical simulation study of the two compensating current calculation methods, for a typical nonlinear load topology, some comparative conclusions could be drawn.

The remaining of the paper is organized as follows. Section II presents the algorithm for the indirect current control for the two ways of obtaining the active current of the load. Section III is dedicated to the presentation of the virtual implementation of the whole active filtering system. The simulation results are illustrated in Section IV.

Some final conclusions are formulated at the end of the paper.

II. The Algorithm for the Indirect Current Control

A. *The Indirect Current Control Based on the Voltage Controller Output*

The first variant of the active power filter control algorithm is the indirect current control based on the voltage controller output [1], [17], [19]. It contains two cascaded control loops, the desired grid current being obtained from the voltage controller (the amplitude) and its waveform and phase is provided by a phase locked loop (PLL) circuit from the supply voltages (Fig. 1). Fig. 1 illustrates:

- The control loop for the DC-voltage across the compensating capacitor, which gives the desired amplitude of the power supply current;
- The power supply current control loop, whose operation determines the necessary gating signals for the APF's semiconductor devices, so as to obtain the desired current absorbed from the network. Therefore, the filter current is obtained intrinsically, not being directly controlled by the current control loop. The following notations are used in Fig. 1:

VC - compensating capacitor voltage (the voltage transducer measured the voltage across both capacitors, connected in series; the central socket is connected to the power grid neutral point;

APF - active power filter power section;

VT - voltage transducer;

CT - current transducer;

i* - prescribed power supply instantaneous current;

i - power supply instantaneous current.

B. *The Indirect Current Control with Load Active Current Computation*

The control scheme associated to the indirect current control with load active current computation is shown in Fig. 2. In this case, only the component of the prescribed current associated of the power losses (I_{Fa}) is provided by the voltage controller.

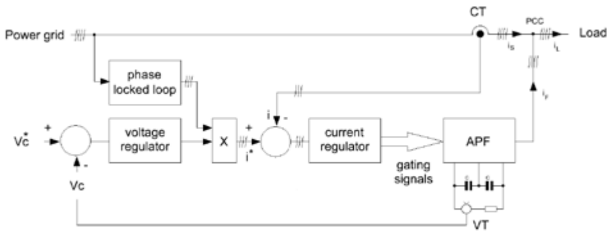


Fig. 1. Diagram of the indirect current control based on the voltage controller output.

Thus, to reduce the negative effect of the voltage controller output ripple on the compensated current shape (given the high value of this signal), the power supply desired current amplitude is computed as the sum of the voltage controller output (I_{Fa}) and the load active current amplitude (I_{La}).

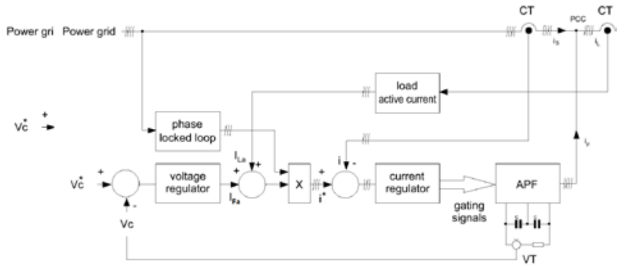


Fig. 2. Diagram of the indirect current control with load active current computation.

The load active current is obtained based on the load active power:

$$I_{LaRMS} = \frac{\sum_{k=1}^{3} \frac{1}{T} \int_{0}^{T} u_{sk} \cdot i_{Lk} dt}{\sum_{k=1}^{3} U_{sk}} \tag{1}$$

where:

- I_{LaRMS} - load current active component, RMS value;
- U_{sk} - power supply voltage RMS value of phase k;
- u_{sk} - power supply instantaneous voltage on phase k;
- i_{Lk} - load instantaneous current on phase k.

For the both current control methods, the voltage controller of PI (proportional-integrative) type is tuned based on the modulus criterion [20], [21].

Considering the adaptive capacitor voltage control, the voltage controller parameters are real-time adapted to the non-active power to be compensated [22].

The power supply current control loop uses hysteresis type controllers which gives the gating signals for the active filter power transistors. The switching frequency is limited by the hysteresis band on one hand and by the time sample (simulation step) on the other hand.

III. Virtual Implementation

For the simulation of the entire active filtering system operation, both variants of the control algorithm were implemented in the Matlab-Simulink environment. The load was the same in all studied cases, namely an uncontrolled three-phase bridge rectifier, with an RLC load. The specific sections of the scheme have been grouped into masked subsystems. The control section was also grouped in a Simulink subsystem, for easy migration from one algorithm variant to the other. The complete active filtering virtual system is illustrated in Fig. 3.

The initialization of the active power filter is done according to the typical steps [1]:

- the power section is connected to the grid by means of current limiting resistors (the capacitor is charged via the power inverter anti-parallel diodes);
- the resistors are short circuited when the compensating capacitor voltage reaches about 80% of the maximum voltage;
- the compensating capacitor is actively charged to the working voltage (the control loops are active), by absorbing from the power grid the necessary active current;

- the initial capacitor voltage is the voltage on the capacitor at the closed loop control system startup time.

The desired power grid current is obtained by multiplying the voltage controller output signal with the voltage template, received from the PLL circuit:

- for the control method based on the voltage controller, the power supply desired current amplitude is given only by the voltage controller (Fig. 4);

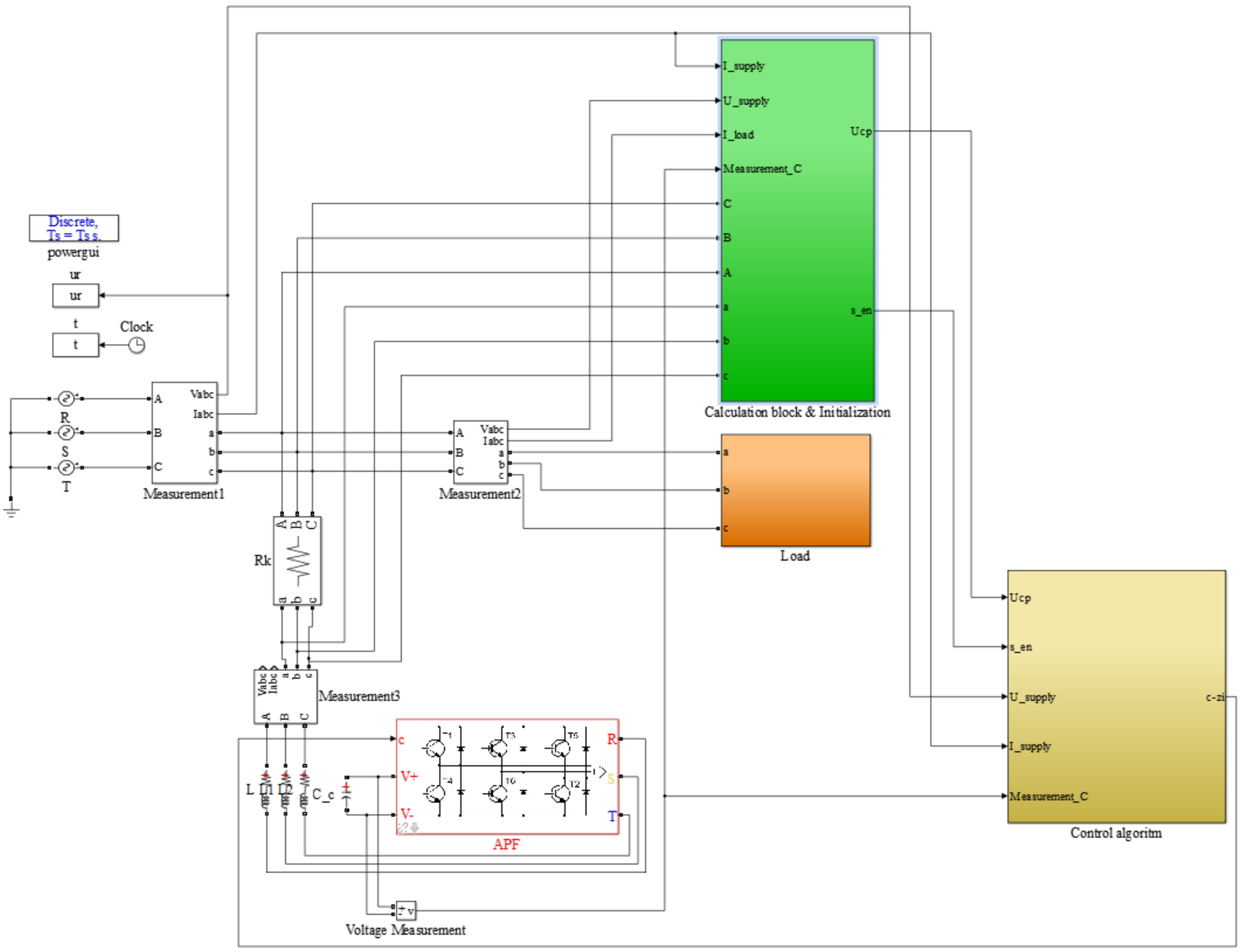


Fig. 3. Virtual model for the active power filtering system.

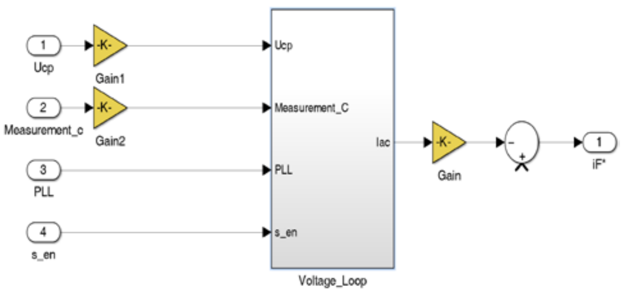


Fig. 4. Indirect current control method based on the voltage controller output.

- for the control method based on the load current active component, the desired power supply current is given by the sum between the load current active component (which is also the desired compensating current) and the voltage controller output (which gives the active current drawn from the power supply to charge the compensating capacitor and to cover the active power filter losses (Fig. 5);

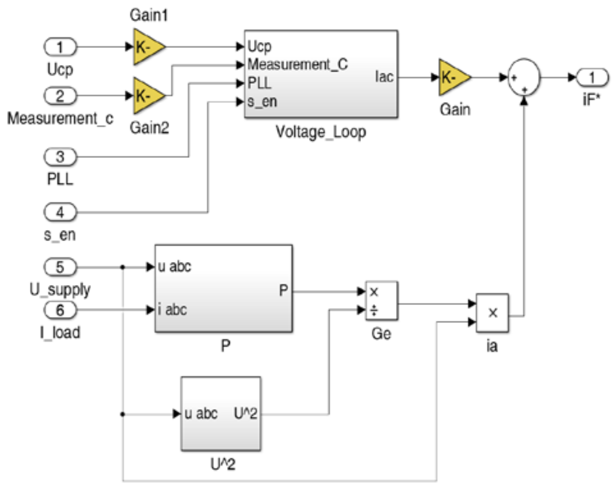
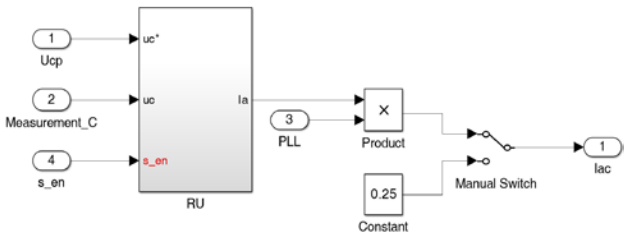


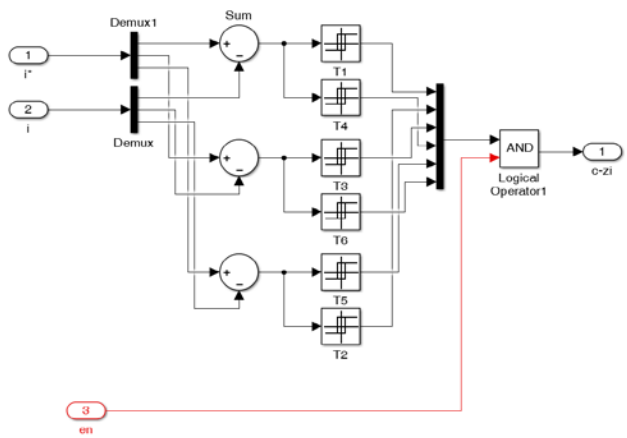
Fig. 5. Indirect current control method based on the load current active component.

The algorithm was modified to allow compensation validation from an external signal for both indirect current control approaches, even though this cannot be done natively.

Fig. 6 (a and b) illustrates the voltage control loop and the current control loop in detail.



a)



b)

Fig. 6. Virtual model for: a) the compensating capacitor voltage control loop; b) the desired supply current control loop.

IV. Simulation Results

A. *The Indirect Current Control Based on the Voltage Controller Output*

Fig. 7 shows the waveforms of the supply voltage (in black) and the power supply current (in red). It can be seen that the simulation is done for total compensation, the fundamental component of the current being in phase with the voltage.

Fig. 8 shows the waveforms of the real supply current (in blue) and the prescribed supply current (in red).

The evolutions of the voltage on the compensation capacitor (in blue) and its prescribed value (in red) are shown in Fig. 9 for the entire charging process of the capacitor. The same voltages in steady state regime are illustrated in Fig. 10.

Table I shows the energy indicators specific to the simulation in the case of indirect current control with the calculation of the prescribed current from the voltage controller.

The total harmonic distortion factor (THD) is calculated taking into account all harmonics of the current and the partial harmonic distortion factor (PHD) is calculated taking into account the harmonics up to order 51.

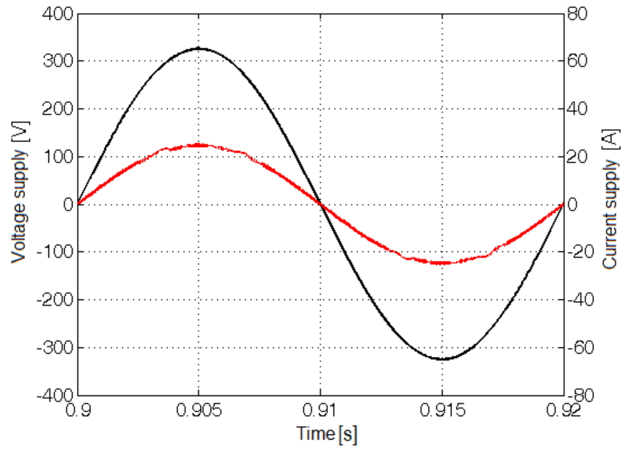


Fig. 7. The waveforms of the supply voltage (in black) and the power supply current (in red) for the indirect current control method based on the voltage controller output.

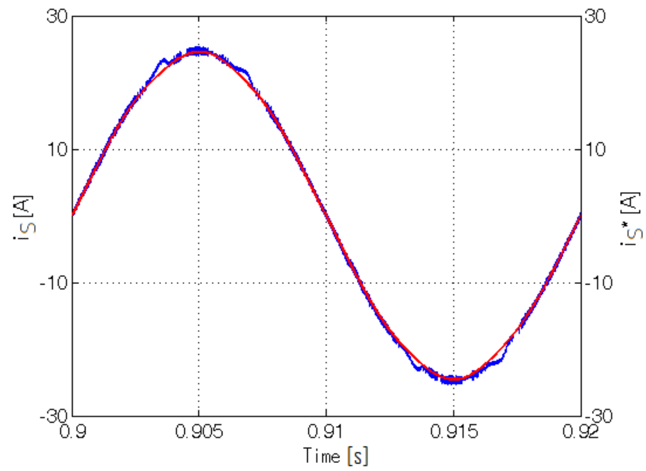


Fig. 8. The waveforms of the obtain supply current (in blue) and the prescribed current (in red) for the indirect current control method based on the voltage controller output.

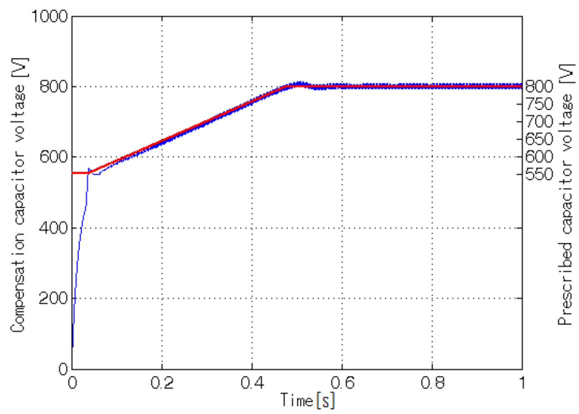


Fig. 9. Waveforms of the compensation capacitor voltage (in blue) and the prescribed capacitor voltage (in red) for the indirect current control method based on the voltage controller output.

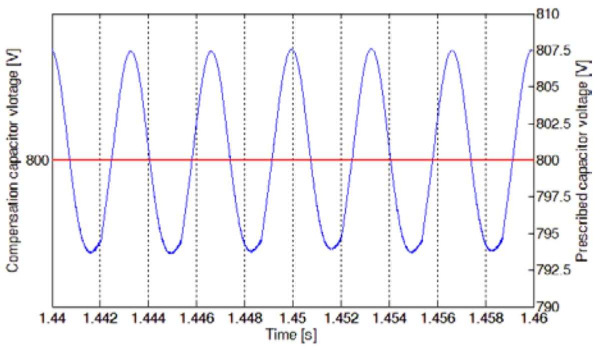


Fig. 10. Waveforms of the compensation capacitor voltage (in blue) and the prescribed DC voltage (in red) for the indirect current control method based on the voltage controller output.

TABLE I.
ENERGY INDICATORS WHEN THE CALCULATION OF THE PRESCRIBED CURRENT IS FROM THE VOLTAGE CONTROLLER

Load current (RMS)	20 A
Power supply current (RMS)	17.49 A
Active power	12.08 kW
Apparent power	12.09 kVA
Load current THD	75.4 %
Power supply current THD	2.04 %
Load current PHD	1.17 %
Power supply current PHD	75.4 %
Efficiency	89.74 %

B. *The Indirect Current Control with Load Active Current Computation*

In this case, the waveforms of the supply voltage and the power supply current are shown in Fig. 11. It can be seen that the current is almost sinusoidal and in phase with the supply voltage.

Fig. 12 illustrates the real current together with the compensating current.

The time evolution of the voltage on the compensation capacitor compared with the prescribed DC voltage is shown in Fig. 13. Their waveforms in steady state regime are illustrated in Fig. 14.

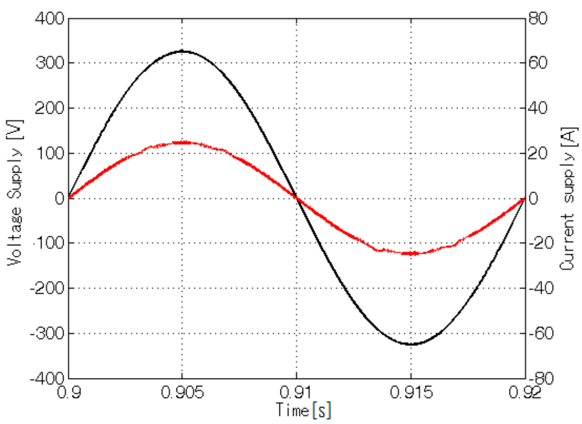


Fig. 11. The waveforms of the supply voltage (in black) and the power supply current (in red) for the indirect current control method based on the load current active component.

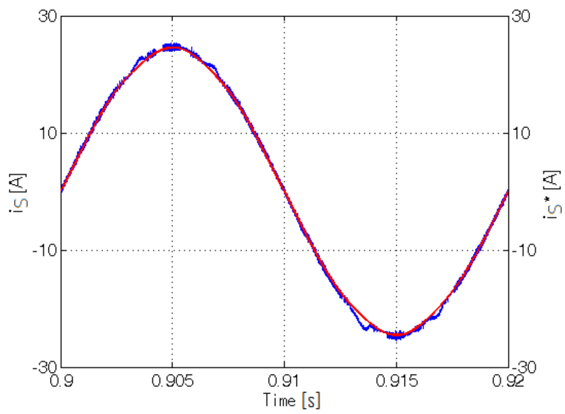


Fig. 12. The waveforms of the obtain supply current (in blue) and the prescribed current (in red) for the indirect control method based on the load current active component.

Table II synthesizes the energy indicators specific to the simulation in the case of the indirect current control with load active current computation.

TABLE II.
ENERGY INDICATORS WHEN THE CALCULATION OF THE PRESCRIBED CURRENT IS WITH LOAD ACTIVE CURRENT COMPUTATION

Load current (RMS)	20 A
Power supply current (RMS)	17.48 A
Active power	12.051 kW
Apparent power	12.054 kVA
Load current THD	75.4 %
Power supply current THD	2.1 %
Load current PHD	1.29 %
Power supply current PHD	75.4 %
Efficiency	89.98 %

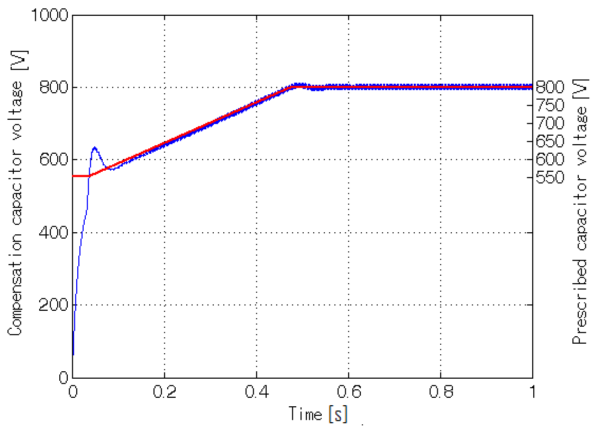


Fig. 13. Waveforms of the compensation capacitor voltage (in blue) and the prescribed voltage (in red) for the indirect current control method based on the load current active component.

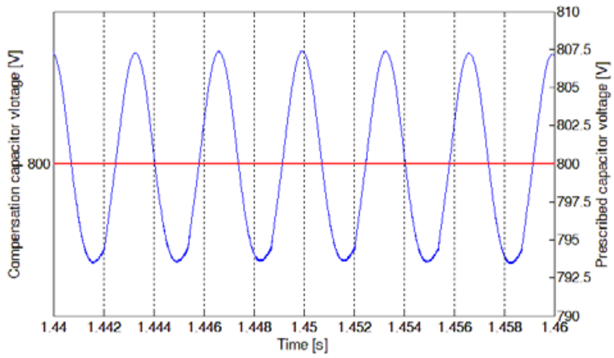


Fig. 14. Waveforms of the compensation capacitor voltage (in blue) and the prescribed DC voltage (in red) for the indirect current control method based on the load current active component.

It can be seen that, the indirect control with the calculation of the prescribed current from the voltage controller leads to a slight increase in active filtering efficiency (36.9, compared to 35.9 in the case of the indirect control with the calculation of the active current of the load). It must be specified that the active filtering efficiency has been calculated as the ratio of the distorted load current THD and supply current THD after compensation.

V. Conclusions

The control algorithm for the three phase four wire active power filter was implemented in the Matlab-Simulink environment for the two indirect current control methods.

Following the numerical simulation study of the two methods of indirect current control, some comparative conclusions could be drawn. From a qualitative point of view, the waveform of the compensated current was almost sinusoidal in both cases. It remains a harmonic current distortion due to the switching operation of the active power filter, specific to the current control with hysteresis controller.

Differences between the performances obtained by the two current control methods could be observed quantitatively based on power quality indicators.

The indirect control without extracting the active load current naturally allows the operation of the active power filter in regeneration mode, sending an active current into the power supply.

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Second coauthor – 20%
Third coauthor – 20%
Fourth coauthor – 20%

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