

Implementation and Experimental Validation of Shunt Active Filter Control Strategies on dSPACE Prototyping System

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Abstract - This paper presents a comparative analysis of control strategies applied to active power filtering, aiming to compensate a nonlinear three-phase load with a current of 20 A per phase. The study focuses on the comparison between direct power control (DPC) and indirect current control, analyzed in two distinct configurations: (i) reference current calculation based solely on the voltage regulator, and (ii) reference current calculation including the active component of the load current. The active power filter system is modeled and simulated in the Matlab/Simulink environment and subsequently implemented in real time on the dSPACE DS1103 platform for experimental validation. The evaluations are carried out under identical load conditions, allowing for a relevant and fair performance comparison. Experimental results highlight the ability of both strategies to reduce harmonic distortions and compensate reactive power, while showing notable differences in terms of total harmonic distortion (THD), DC-link voltage stability, and dynamic response to load variations. The comparative analysis provides a clear perspective on the advantages and limitations of each method, emphasizing the impact of the reference current calculation approach on the overall performance of the active power filter and its relevance for practical power quality compensation applications.

Cuvinte cheie: filtru activ de putere, control direct al puterii (DPC), control indirect al curentului, sarcină neliniară trifazată, factor total de distorsiune armonică (THD), compensarea puterii reactive, implementare în timp real.

Keywords: active power filter, direct power control (DPC), indirect current control, nonlinear three-phase load, total harmonic distortion (THD), reactive power compensation, real-time implementation.

I. INTRODUCTION

The increasing use of power-electronic-based equipment has led to a proliferation of nonlinear loads in distribution networks, generating harmonic and reactive currents that degrade power quality, increase system losses, and affect the operation of sensitive equipment [1], [2].

Active Power Filters (APFs) have emerged as an effective solution for compensating harmonic and reactive currents, offering superior performance compared to passive filters and rapid adaptability to load variations [3]-[6]. The performance of an APF strongly depends on the control strategy employed.

This paper focuses on a comparative analysis between indirect current control (ICI) and direct power control (DPC), two efficient methods for active power filtering [7]-[12], [16], [17]. Indirect current control is investigated in two configurations: (i) with the reference current calculated solely from the DC-link voltage regulator, and (ii) with the reference current calculated based on the active load current [16].

The system is modeled and simulated in Matlab/Simulink and implemented in real time on the dSPACE DS1103 platform [13]-[15]. The comparative analysis evaluates the performance of both strategies in terms of harmonic reduction, reactive power compensation, and dynamic response, providing relevant conclusions for practical applications in power quality improvement.

II. THEORETICAL BACKGROUND

Nonlinear loads degrade power quality by introducing harmonics, reactive power, and voltage distortion. Unlike passive filters, active power filters use power electronics to inject controlled compensating currents, maintaining nearly sinusoidal supply currents in phase with the grid voltage and thus reducing THD.

A. Concept of Indirect Current Control

Indirect current control (ICC) is an effective method for operating APFs by regulating the reference compensating current calculated from the DC-link voltage and/or the active load current. The ICC principle is illustrated in the block diagram in Fig. 1 [6], [13]-[20], where:

- I.F. – interface filter;
- TU – voltage transducer;

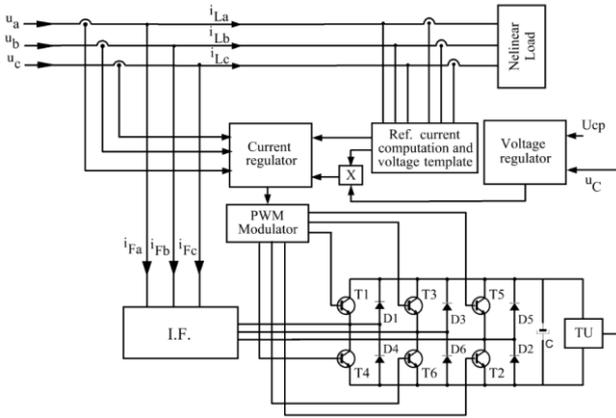


Fig. 1. Single-line diagram of a parallel three-phase active power filter with indirect current control.

- X – multiplication block which multiplies the voltage controller output with the voltage template.

In this work, ICC has been implemented on the dSPACE DS1103 platform, ensuring sinusoidal supply currents in phase with the grid voltage while effectively compensating harmonic and reactive components.

B. Direct Power Control

The Direct Power Control algorithm its described in Fig.2.

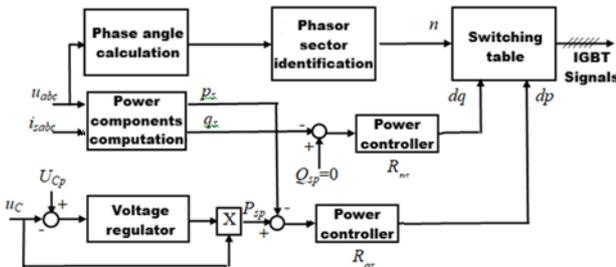


Fig. 2. Block diagram for direct power control

The power components (instantaneous active and reactive powers, p and q) are computed from the supply voltages and the grid currents. The reference reactive power is set to zero in order to ensure reactive power compensation, whereas the reference active power is defined as the product of the voltage controller output and the DC-link voltage across the compensation capacitor (Fig. 2). The power controllers are implemented as hysteresis-band controllers [17].

In the design of the switching table, twelve sectors corresponding to the possible positions of the voltage space vector in the fixed (α, β) reference frame are considered, as a function of the angle θ (Fig. 3).

TABLE I. SWITCHING TABLE FOR THE ADOPTED DPC [17]

dp	dq	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}
1	0	101	111	100	000	110	111	010	000	011	111	001	000
	1	111	111	000	000	111	111	000	000	111	111	000	000
0	0	101	100	100	110	110	010	010	011	011	001	001	101
	1	100	110	110	010	010	011	011	001	011	101	101	100

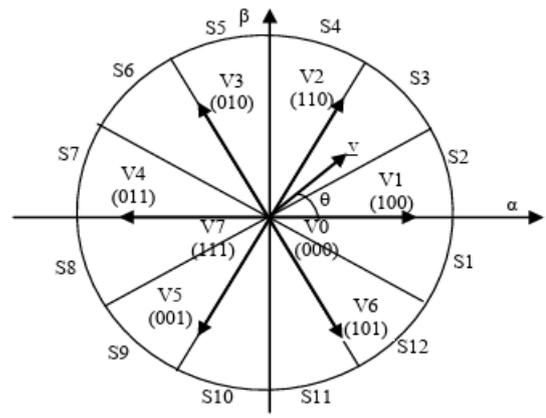


Fig. 3. Sectors and voltage vectors in the stationary reference frame [17]

Based on the outputs dp and dq of the hysteresis controllers and on the identified sector number (n) of the voltage vector, the inverter transistor switching states are determined according to the adopted switching table (Table I).

III. MODELING OF THE ACTIVE FILTERING SYSTEM

A. Modeling of the Active Filtering System in the Case of Indirect Current Control

The gating signals for the inverter transistors are generated by the three-phase hysteresis current regulator. The reference current is obtained in two variants:

- from the voltage controller – the reference currents are obtained by multiplying the output of the voltage controller with the voltage template (three-phase unitary amplitude signals synchronized with the grid voltages, given by the phase locked loop, PLL) (Fig. 4);
- from the load active current – the reference current are obtained by the sum of two components (Fig. 5):

- o the active filter charging current – obtained like in the previous case;
- o the load active current – obtained from the load computed active power.

The advantage of the second control system is given by the fact that the voltage controller output gives the amplitude of the active filter charging current and not the amplitude of the current absorbed from the grid by the entire active filtering system like in the first control system. This is because the controller output ripple is much smaller, given the fact that the output magnitude is smaller. This way the distortion introduced by the voltage controller itself two the compensated current is reduced [21]-[24].

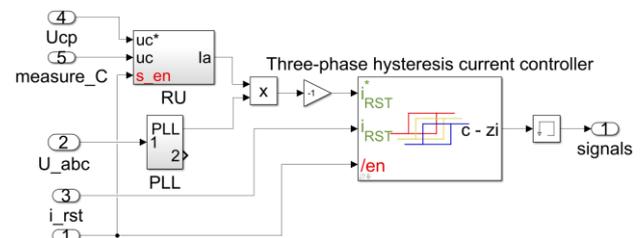


Fig. 4. Block structure in the case of indirect control with the reference current computed solely from the voltage controller

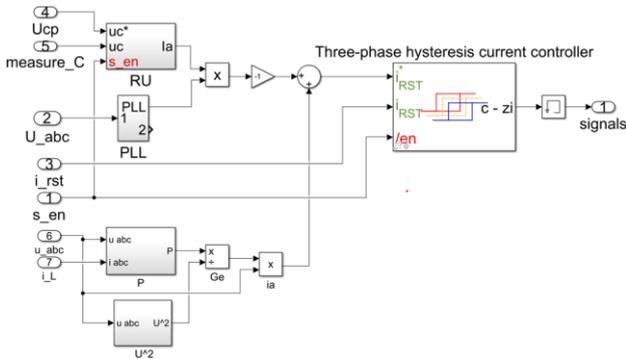


Fig. 5. Block structure in the case of indirect control with the computation of the load active current

B. Modeling of the Active Filtering System in the Case of Direct Power Control

For direct power control, the Simulink model developed based on the principles of the method is shown in Fig. 6. The instantaneous active and reactive powers are calculated using the supply voltages and the grid currents, inside the block “Calculation of p and q ”, which also provides the phase angle, θ (Fig. 7). The sector number corresponding to the position of the voltage space vector is obtained at the output of the “Sector Determination” block (Fig. 8).

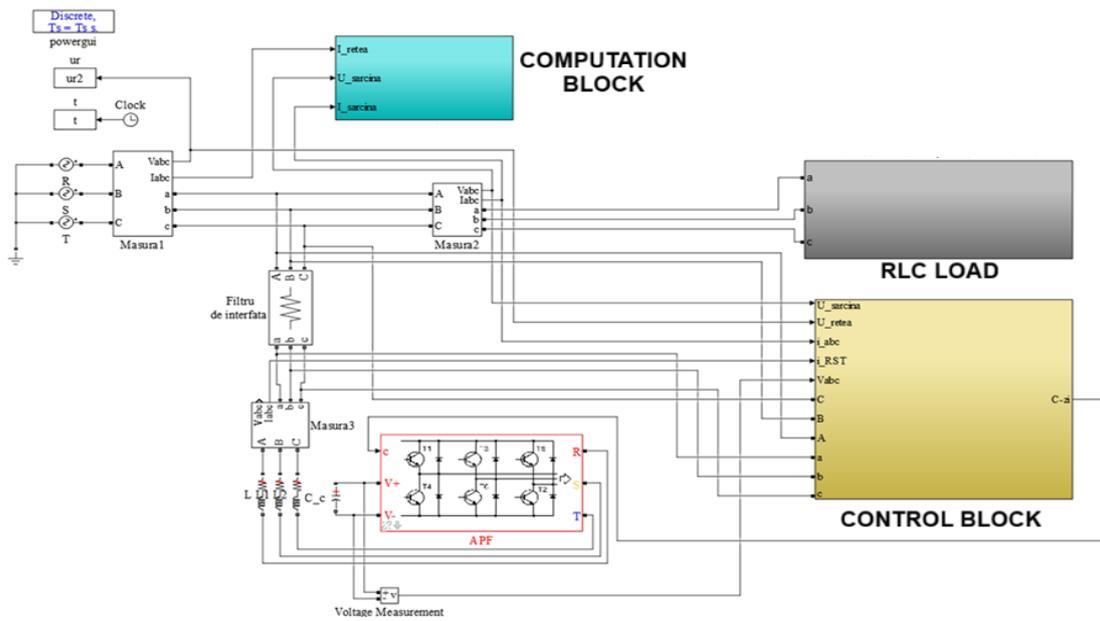


Fig. 6. Simulink model of the whole active filtering system.

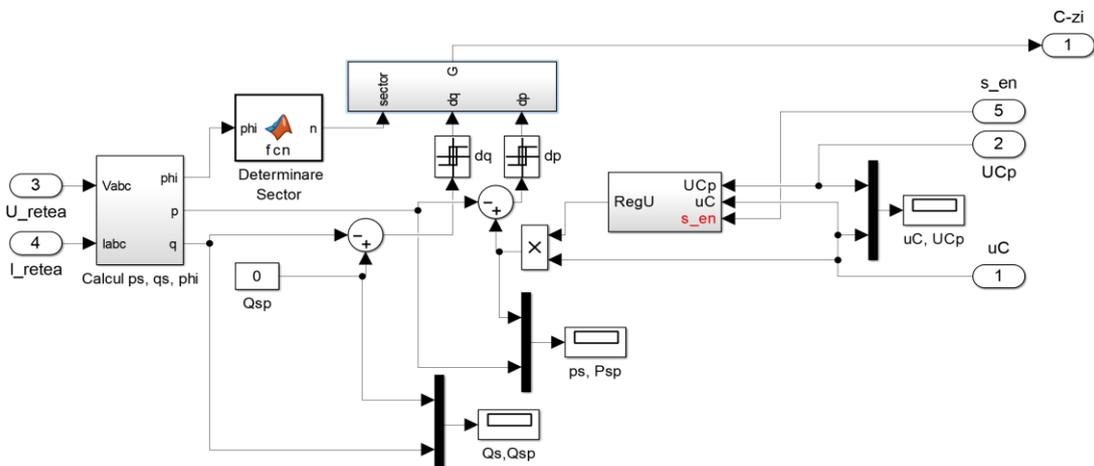


Fig. 7. SIMULINK model of the control block for Direct Power Control

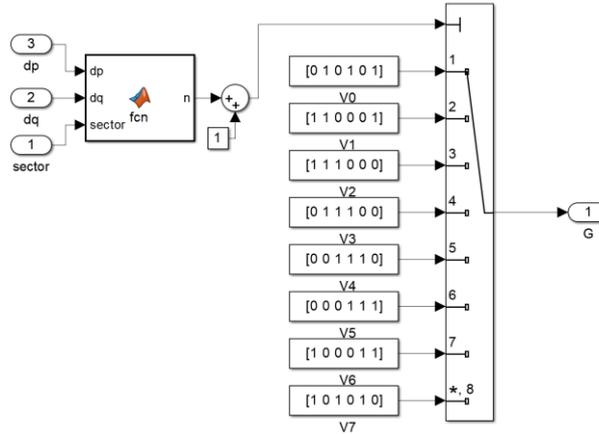


Fig. 8. SIMULINK model of the transistor gate control block based on the outputs of the hysteresis controllers and the identified sector number

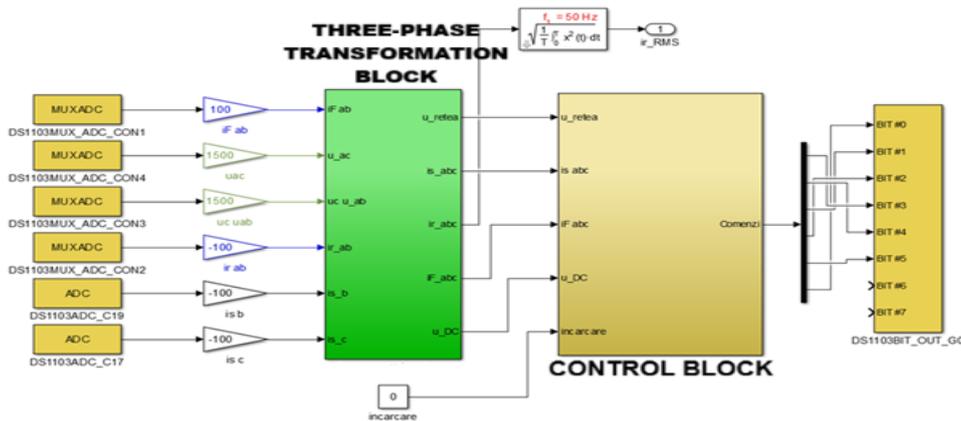


Fig. 9. The real-time control SIMULINK block of the active power filter.

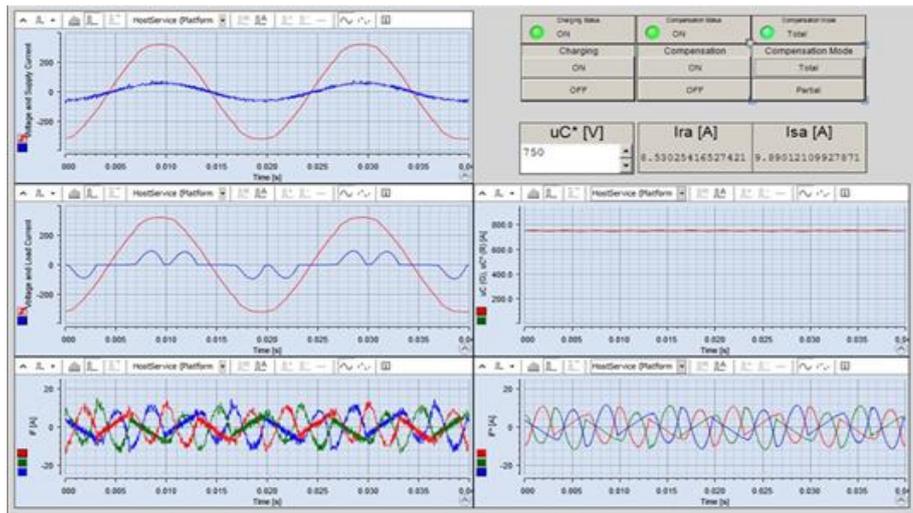


Fig. 10. The virtual ControlDesk panel for the active power filter control.

IV. EXPERIMENTAL VALIDATION

The development of the SIMULINK control model of the experimental active power filter is based on extracting the control algorithm sub-model of the virtual active filter from the active filtering system complete model (presented in Section III), and replacing the virtual power-section with the dSpace library blocks. These blocks are the link between the dSpace board hardware

resources and the SIMULINK environment. Accordingly, the SIMULINK control model of the active power filter is shown in Fig. 9.

To achieve the real-time execution machine code, the control model was compiled with the sampling time of 30 μ s. This value represents a compromise between accuracy and computational load, given the complexity of the implemented algorithms.

The virtual control panel developed for this approach, in ControlDesk NG is illustrated in Fig. 10.

To evaluate the performance of the active filtering system, the operating point was set for a load current of 20 A RMS.

A. Active Filtering System in the Case of Indirect Current Control

1) Active Filtering System under Indirect Current Control Based on the Reference Current Computed Solely from the Voltage Controller

The voltage and current waveforms for phase 'a' drawn from the grid by the active filtering system, had been measured with a Tektronix TPS2024 oscilloscope (Fig. 11). The current was measured with the Fluke 80i-500s Current clamp (1mV/1A transfer ratio). The same quantities had been acquired with the dSpace board analog to digital converters and plotted in MATLAB (Fig. 12).

Fig. 13 shows the harmonic spectrum of the grid current under total p-q compensation for a 20 A load current. The current THD for phase 'a' is 5.25%, and for phases 'b' and 'c' is 5.8% and 5.81%..

Furthermore, the comparison between the oscilloscope and dSPACE measurements shows good agreement, with minor differences mainly due to sampling and signal conditioning. The harmonic spectrum confirms the effectiveness of the p-q compensation strategy, reducing the grid current distortion and ensuring a nearly sinusoidal waveform. The similar THD values across all phases indicate balanced operation and stable controller performance.



Fig. 11. Experimental voltage (green) and current (orange) waveforms at the grid side sampled with the Tektronix oscilloscope. TPS2024

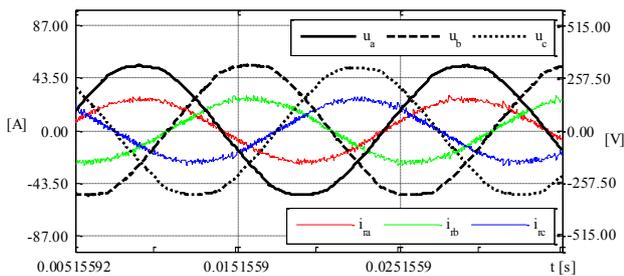


Fig. 12. Grid voltage and current waveforms sampled with the dSpace DS1103 ADCs.

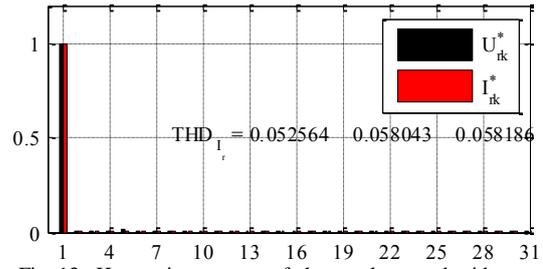


Fig. 13. Harmonic spectrum of phase voltage and grid current.

2) Active Filtering System under Indirect Current Control Based on the Computation of the Load Active Current

For this case, the grid voltage and compensated current are illustrated in Fig. 14 (sampled with the Tektronix TPS2024 digital oscilloscope) and in Fig. 15 (sampled with the dSpace board analog to digital converters and plotted in MATLAB, respectively).

Fig. 16 shows the harmonic spectrum of the grid current under total p-q compensation for the same load. The current THD for phase 'a' is 5.63%, and for phases 'b' and 'c' it is 4.92% and 5.2%, respectively.

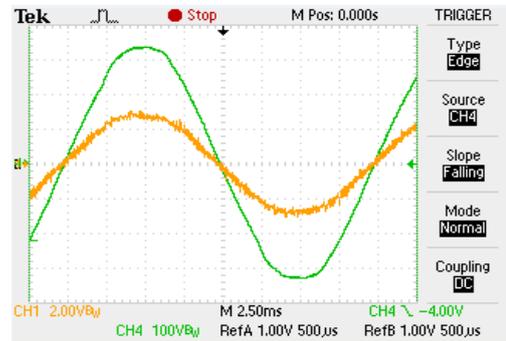


Fig. 14. Experimental voltage (green) and current (orange) waveforms at the grid, for phase 'a', acquired with a Tektronix TPS2024

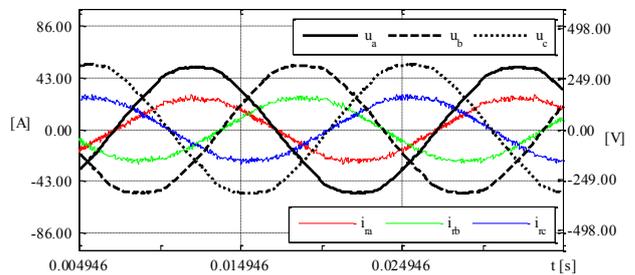


Fig. 15. Grid voltage and current waveforms

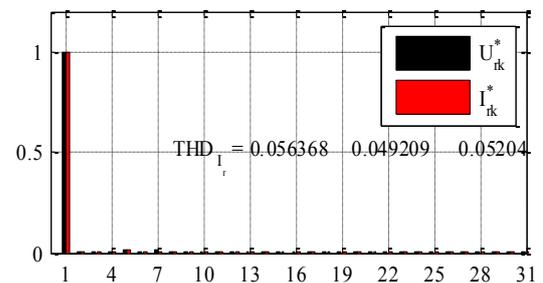


Fig. 16. Harmonic spectrum of phase voltage and grid current.

B. Active Filtering System in the Case of Direct Power Control

The Tektronix TPS2024 oscilloscope screen in Fig. 17 shows the grid voltage and current waveforms for phase 'a'. Fig. 18 shows the phase voltages and currents at the grid side after total compensation for a 20 A load current, sampled by the dSpace board. Fig. 19 presents the harmonic spectrum of phase 'a' grid current and phase voltage. The phase current THD values are: phase 'a' – 5.82%, phase 'b' – 5.79%, and phase 'c' – 5.56%.

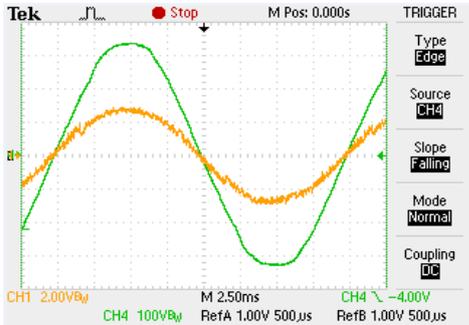


Fig. 17. Experimental voltage (green) and current (orange) waveforms at the grid, for phase 'a', acquired with a Tektronix TPS2024

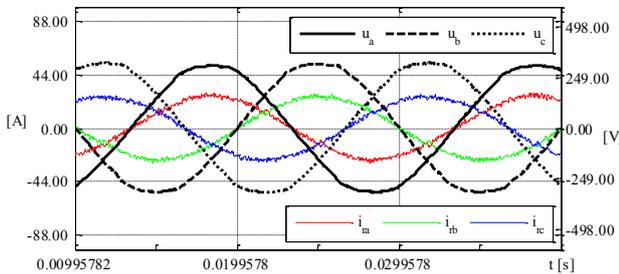


Fig. 18. Grid voltage and current waveforms.

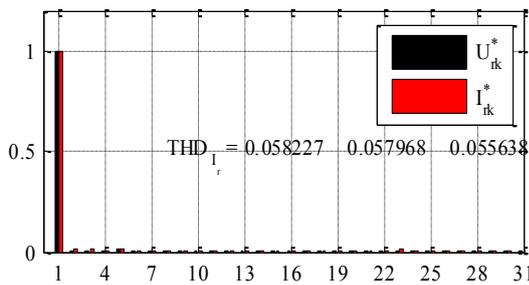


Fig. 19. Harmonic spectrum of phase voltage and grid current.

Table II summarizes the performance of three control methods applied to the active power filter under total compensation conditions: the classical indirect current control (Yvc), the indirect current control based on the active component of the load current (Iac), and the direct power control (DPC).

TABLE II. PERFORMANCE COMPARISON FOR A LOAD CURRENT OF 20 A

Control Method	Compensation Strategy	EF _{avr}	η [%]	PF
Yvc	Total Compensation	7,51	95,98	0,997
Iac		7,9	97,17	0,997
DPC		7,32	96,94	0,998

The classical indirect current control (Yvc), in which the reference grid current amplitude is generated exclusively by the compensating capacitor voltage controller, achieves an average filtering efficiency (EF_{avr} of 7.51, an overall efficiency of 95.98%, and a power factor of 0.997. Although this strategy ensures stable operation and near-unity power factor, its filtering performance and efficiency are slightly inferior compared to the other investigated methods.

The indirect current control strategy based on the active component of the load current (Iac), where the reference grid current amplitude is obtained by combining the active component of the load current with the output of the compensating capacitor voltage controller, exhibits the best overall performance. This method achieves the highest average filtering efficiency (EF_{avr} = 7.9) and the highest system efficiency (97.17%), while maintaining a power factor of 0.997. These results indicate an improved harmonic compensation capability and reduced power losses.

The direct power control (DPC) method provides the highest power factor (0.998), demonstrating superior control of active and reactive power exchange with the grid. However, its average filtering efficiency (EF_{avr} = 7.32) is slightly lower than that obtained with the indirect current control strategies, although the overall efficiency remains high (96.94%).

Overall, all three control methods ensure effective total compensation, with power factor values close to unity and efficiencies exceeding 95%. Among them, the Iac-based indirect current control offers the best compromise between filtering performance, efficiency, and power factor, making it a suitable candidate for high-performance active power filter applications.

V. CONCLUSIONS

The performance obtained by the classical indirect current control, in which the reference grid current amplitude is generated exclusively by the compensating capacitor voltage controller is the lowest of the three investigated methods given the high effect of the voltage controller output ripple in the reference current. The indirect current control strategy based on the active component of the load current, exhibits the best overall performance, achieving the highest average filtering efficiency and the highest system efficiency. The direct power control method provides the highest power factor, demonstrating superior control of active and reactive power exchange with the grid.

Overall, all three control methods ensure effective total compensation, with power factor values close to unity and efficiencies exceeding 95%.

ACKNOWLEDGMENT

The authors would like to acknowledge the support provided by INCESA, within Laboratory 103 – Active Filtering and High-Performance Static Converters, where the experimental measurements and determinations were carried out. The work was conducted within the same research group, and the authors appreciate the technical assistance and collaborative environment provided by the laboratory staff. This work was supported by the Research

Program of the Electrical Engineering Department, financed by the University of Craiova.

Contribution of authors:

First author – 30%

Second author – 25%

Third author – 15%

Fourth author – 15%

Fifth author – 15%

Received on September 27, 2025

Editorial Approval on December 10, 2025

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