

## COMPARISON OF THREE PHASE 4-LEG SHUNT ACTIVE POWER FILTER USING DQ, INDIRECT AND MAXIMUM CONTROL METHOD

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**Abstract:** In this paper is presented a comparative analysis of three control methods for a three-phase active power filter (APF) with four legs, aiming at the power quality indicators: THD, power factor, unbalance. The results are obtained by simulation in Matlab/Simulink of a three-phase electrical system supplied by four wires.

**Keywords:** active power filter (APF), control method, power quality.

### INTRODUCTION

For this study is used a three-phase APF with four legs in order to improve the three indicators of power quality: THD, power factor, unbalance.

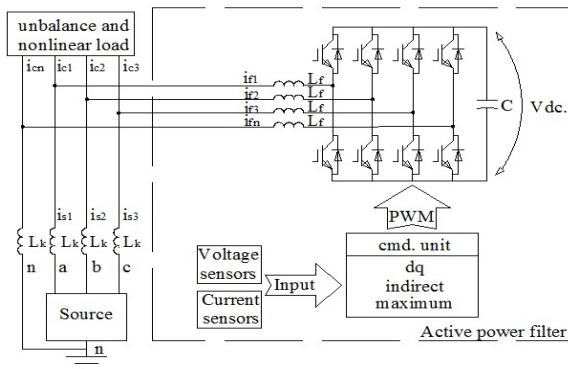


Fig.1. APF connection.

The topology with 4 legs (Fig. 1) was used to have control on the neutral wire, because most of the electrical systems are connected by four wires.

### THEORETICAL CONSIDERATIONS

#### 1.1. Synchronous reference system control method

The real currents are transformed into synchronous reference system DQ synchronized with the voltage source and it rotates with the same frequency. This transformation is defined by: [1].

$$(1) \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ \sin(\omega t) & \cos(\omega t) \end{bmatrix} \times \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

Reference signals in DQ plan are:

$$(2) \begin{cases} i_{dref} = -i_{dac} \\ i_{qref} = -i_{qdc} - i_{qac} \end{cases}$$

#### 1.2. Indirect control

Indirect control is a strategy that does not require knowledge of the spectrum of load current.

This algorithm was proposed in [2]:

$$(3) i_{s1} = i_{C1} + i_{F1}$$

where:

- $i_{S1} = \sqrt{2}I_{SA} \cdot \sin \omega t$ , source current,  $I_{RA}$  rms value;
- $i_{C1} = \sqrt{2}I_{CA} \cdot \sin \omega t + \tilde{i}_{C1}$ , load current,  $I_{CA}$  rms value,  $\tilde{i}_{C1}$  - polluting component;
- $i_{F1} = \sqrt{2}I_{FA} \cdot \sin \omega t + \tilde{i}_{F1}$ , injected current filter,  $I_{FA}$  rms value,  $\tilde{i}_{F1}$  - polluting component.

The reference currents are:

$$(4) \begin{cases} i_{F1}^* = \varepsilon \cdot \sin \omega t \\ i_{F2}^* = \varepsilon \cdot \sin \left( \omega t - \frac{2\pi}{3} \right) \\ i_{F3}^* = \varepsilon \cdot \sin \left( \omega t - \frac{4\pi}{3} \right) \end{cases}$$

### 1.3. Maximum control method

The distorted load current is filtered to extract the fundamental component, using a band-pass filter set on the frequency of 50 Hz. Output signal attenuation will be equal to 0 and phase shift will be 180°. [3]. Thus the filter output will be equal to the fundamental load current but in phase shift opposition. If load current is summed to the output band-pass filter current, is obtained the current waveform reference.

## SIMULATION RESULTS

### 1.4. Define the system

For this study, it was simulated in Matlab / Simulink an electrical system with two loads:

- nonlinear – bridge rectifier, that supplies a resistor  $R = 30\Omega$ ;
- inductive unbalanced star connected load  $L = 100mH$ ,  $R = 40\Omega$ .

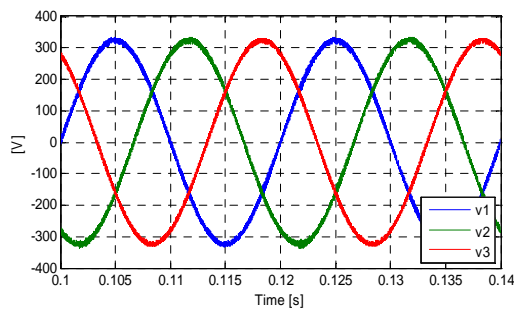


Fig.2. Voltage supply

Being supplied with sinusoidal voltage (Fig. 2), the electrical system draws non sinusoidal electrical current (Fig. 3), where it can be observed also the neutral current.

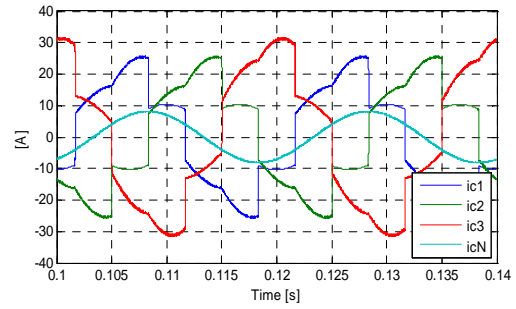


Fig.3. Total system currents.

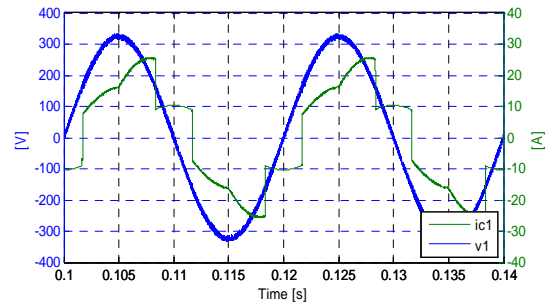


Fig.4. Supply voltage and current for phase 1.

The waveforms of voltage and current for phase 1 are shown in Fig. 4, where can be observed the inductive shift phase. Table 1 provides data on the power quality indicators of the implemented system.

Table 1 Input data.

Quality indicator	THDi	Power	Unbalance
Consumer type	[%]	factor	[%]
Unbalanced	24.74	0.89	18.86

### 1.5. Active power filter control through Synchronous reference system method

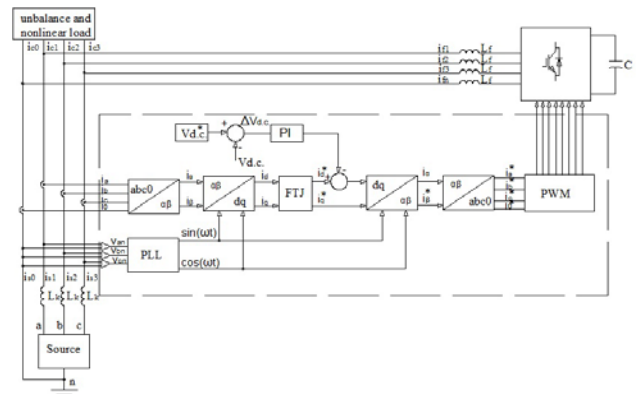


Fig.5. Control diagram - synchronous algorithm (d-q)

To implement the control method of a three phase four-leg parallel APF with synchronous algorithm, it was built in Matlab/Simulink the model, based on Fig. 5. The regulator design parameters, the filter

inductance  $L_f$  and the storage capacitor  $C$  values are given in Table 2.

Table 2 The main parameters used to control an active power filter by DQ method.

L <sub>f</sub> [mH]	C [mF]	PI		Hysteresis band	V <sub>d.c.</sub> setpoint [V]
		K <sub>p</sub>	K <sub>i</sub>		
1	20	10	2	0.5	750

After connecting the APF from the source is absorbed an electric current as in Fig. 6, where it can be seen the sinusoidal phase current shape and the cancellation of the neutral current.

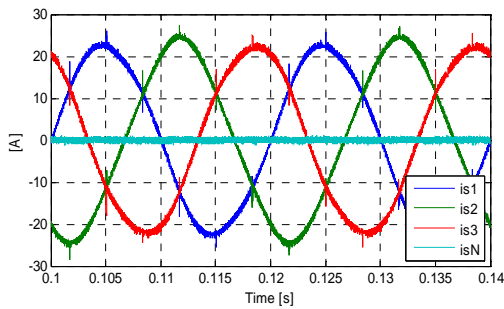


Fig.6. Supply currents after APF connection

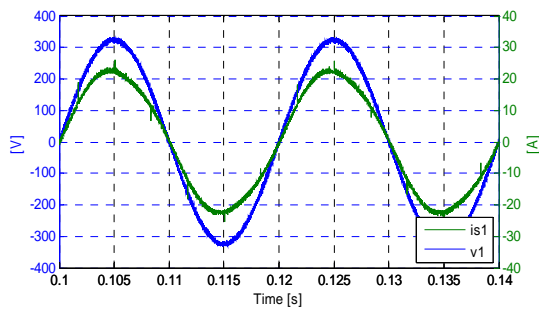


Fig.7. Voltage and current

The APF injected current for compensation is presented in Fig. 8 and in Fig. 9 is presented graphically the charging regime of the active power filter DC capacitor.

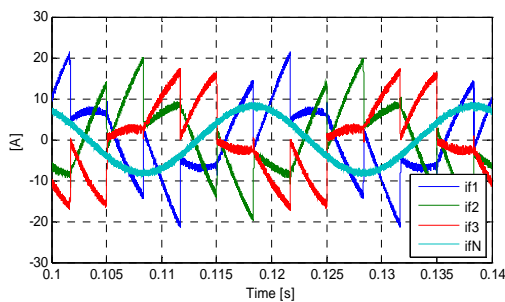


Fig.8. Current injected by the active power filter

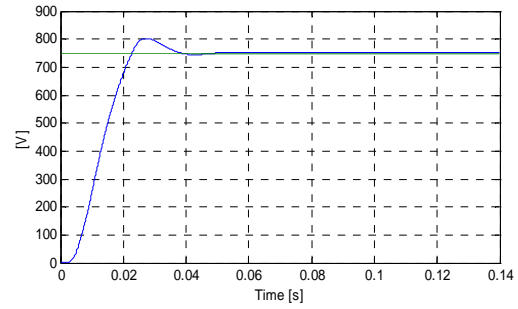


Fig.9. DC voltage evolution

Table 3 Results obtained by DQ control method.

Quality indicator	THDi	Power	Unbalance
Consumer type	[%]	factor	[%]
Unbalanced	4.39	0.99	3.44

### 1.6. Active power filter control through indirect method

To study the influence of connecting a parallel APF controlled by indirect control method, has been implemented in Matlab / Simulink the diagram in Fig. 10.

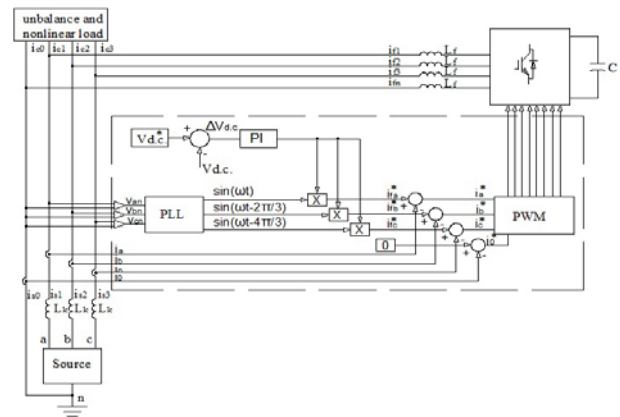


Fig.10. Control diagram – indirect method

Table 4 The main parameters used to control an active power filter by indirect method.

L <sub>f</sub> [mH]	C [mF]	PI		Hysteresis band	V <sub>d.c.</sub> setpoint [V]
		K <sub>p</sub>	K <sub>i</sub>		
1	20	5	4	0.5	750

After connecting the APF it can be observed an improvement of the current source waveform Fig. 11 and in Fig. 12, and it can be seen that the current and source voltage are in phase.

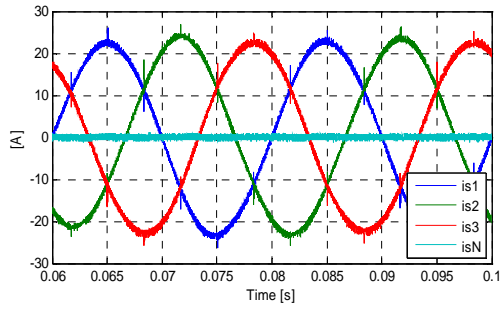


Fig.11. Supply currents after APF connection

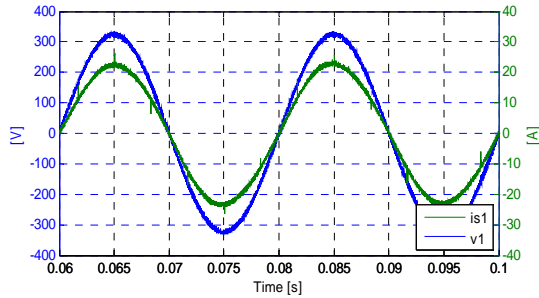


Fig.12. Voltage and current

Table 5 Results obtained by indirect control method.

Quality indicator	THDi	Power	Unbalance
Consumer type	[%]	factor	[%]
Unbalanced	3.13	1	1.07

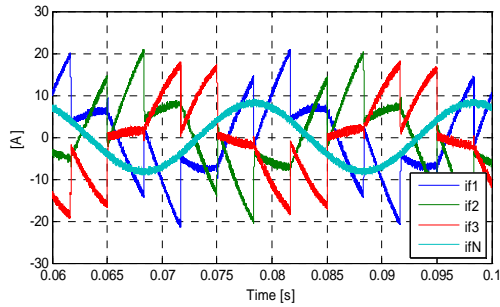


Fig.13. Current injected by the active power filter

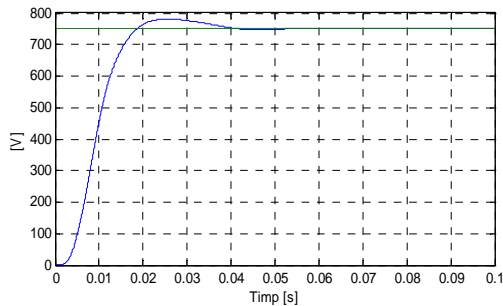


Fig.14. DC voltage evolution

The injected current by the APF for compensation is illustrated in Fig. 13, and in Fig. 14 is shown the evolution of DC voltage across the capacitor.

1.7. Active power filter control through maximum method

The control scheme behind the Matlab/Simulink model for studying the electrical system where it has been connected an APF controlled by maximum method is shown in Fig. 15.

Table 6 The main parameters used to control an active power filter by maximum method.

Lf	C	PI		Hysteresis	Vd.c.
[mH]	[mF]	Kp	Ki	band	setpoint
1	20	20	7	0.5	750

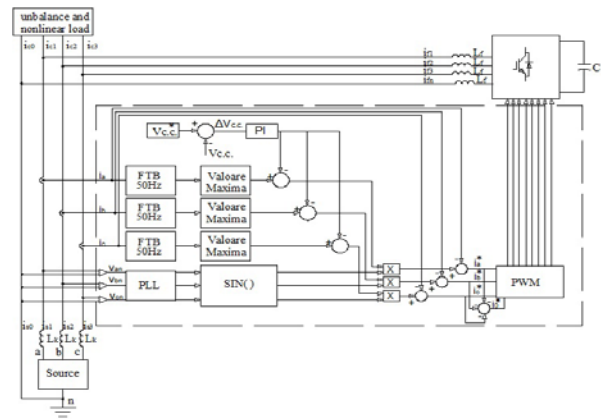


Fig.15. Control scheme – maximum method

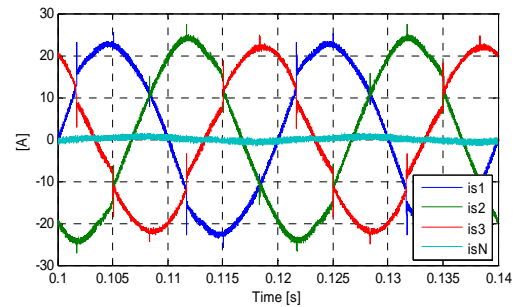


Fig.16. Supply currents after APF connection

In Fig. 16 are shown the waveforms of source current, and it can be seen a reduction in harmonic content.

Table 7 Results obtained by indirect control method.

Quality indicator	THDi	Power	Unbalance
Consumer type	[%]	factor	[%]
Unbalanced	6.40	0.99	2.64

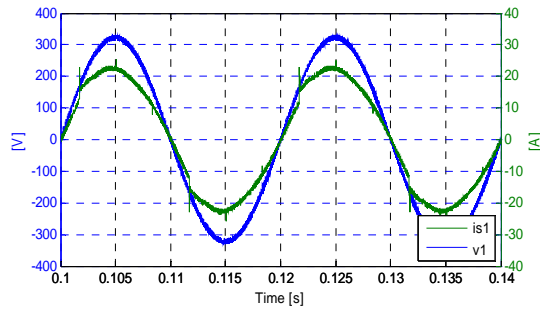


Fig.17. Voltage and current

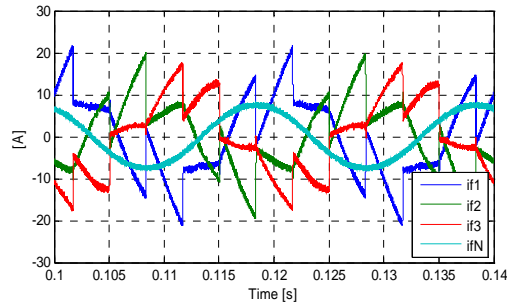


Fig.18. Current injected by the active power filter

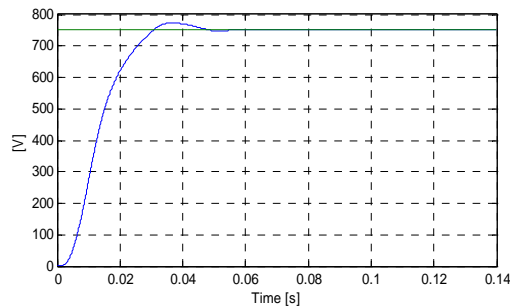


Fig.19. DC voltage evolution

**CONCLUSION**

In Table 8 are listed the values of the analyzed power quality indicators, obtained from Matlab/Simulink simulation.

Table 8 Output data.

Control method	Quality indicator Consumer type	THDi [%]	Power factor	Unbalance [%]
Without AF	Unbalanced	24.74	0.89	18.86
d-q	Unbalanced	4.39	0.99	3.44
Indirect	Unbalanced	3.13	1	1.07
Maximum	Unbalanced	6.40	0.99	2.64

Table 9 Obtained rating.

Quality indicator	dq	Indirect	Maximum
THDi	Good	Very good	Weak
Power factor	Excellent	Excellent	Excellent
Unbalance	Good	Excellent	Very good

**Appendix (Acknowledgments)**

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