Power Active Filter Based on Synchronous Reference System Theory

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Abstract:-The paper presents the structure of an active parallel filter for distorting regime and reactive power compensation. The active power filter control is based on synchronous reference system theory. The authors present the modeling of parallel active filter based on this theory and the simulation results in MATLAB-SIMULINK for two methods of power filter regulator. One of this is based on instantaneous reactive power (SRS_Q) and the other is based on instantaneous active power (SRS_P).

Keywords:- Power active filter, distorting regime, reactive power, active power, simulation

1 Introduction

More than 60% of power system is feed by power static converters. There are well known advantages of power static converters, but there are some disadvantages such as distortion of the waveforms of voltages and currents of the power supply, which is equivalent with presence of fundamental harmonic and superior harmonics in electrical networks.

In consequence of that, there is necessary development of some solutions to compensate the voltage and current harmonics. Those solutions are represented by passive and active filters.

Power active filters (PAF) represent for the network a changeable inductance with a determined value needed for harmonics discharge. These filters didn’t base on a rigid structure and are appropriate for complex waveforms, which have a complex mathematic model.

In the latest years, there were a large variety of PAF topologies [2], [16], [19], due to the development in power converters and power static elements with a better performance in control, current and voltage rated values and reduced switching times. All of these associated with a development of digital techniques and a Digital Signal Processors (DSP) leaded to the PAF methods improvement.

PAF can be classified in [13], [15]:

- Parallel active filters;
- Serial active filters;
- Serial-parallel active filters;
- Hybrid active filters.

The parallel active filters represents the well-known structure and improve the distorting regime, power factor, balanced the network currents and made the null phase current to zero value.

The PAF is connected in parallel with the non-linear load. The basic function consists in injection of currents which are load currents in opposite-phase, so that the load harmonic currents are canceled [8], [9].

The PAF consists in a DC static converter and an element to stock the energy. The static converter is controlled with a high frequency and with an algorithm which measures the load current and generates switching signals for the semiconductors elements to inject appropriate currents in the network.

The most used structure of PAF is based on voltage converter controlled in voltage where the energy is stocked in a capacitor installed on dc part of the converter (Fig.1).

There are other methods to control the parallel active filter, but this control method will be presented in this paper due to their advantages.

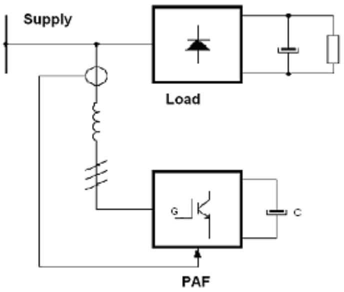


Fig.1. Parallel active filter

2 Modeling of power active filters based on synchronous reference system theory

The synchronous reference system method consist in conversion between three-phase reference system and synchronous reference system using Park transformation method, which is used in electrical drives systems [1], [7], [18].

The synchronous reference system is a two-phase and orthogonal system which have an angular speed given by the angular frequency of the voltage.

This method, named Synchronous Reference System (SRS), applied to the reactive energy compensation and distorting regime didn't demand the instantaneous values of the power [10], [11], [12].

The orthogonal reference system, will be given by the angle θ between axis d and axis α (Fig.2).

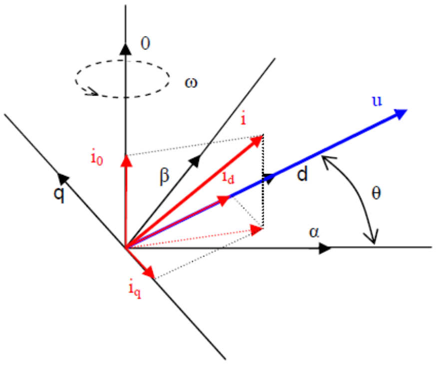


Fig.2. Coordinates α-β-0 and d-q-0, axis d orientaded with voltage vector.

To develop this method we use the rotating matrix ρ(θ), so the Park components are obtained tacking into account the α-β-0 components.

$$x_{dq0} = [\rho(\theta)]\cdot x_{\alpha\beta 0} \qquad (1)$$

The 0 component given by the homopolar system is unchanging due to the rotating transformation.

The polar projection of the voltage is:

$$u_{\alpha\beta} = u\cdot e^{j\delta} = u\cdot\cos(\delta) + ju\cdot\sin(\delta) = x_\alpha + jx_\beta \quad (2)$$

Where u represent the modulus of the voltage vector:

$$\left|u_{\alpha\beta}\right| = u = \sqrt{x^2{}_\alpha + x^2{}_\beta} \qquad (3)$$

$$x_\alpha = u\cdot\cos(\delta) \qquad (3.a)$$

$$x_\beta = u\cdot\sin(\delta) \qquad (3.b)$$

In d-q coordinate system we obtain:

$$\begin{aligned} u_{dq} &= u\cdot e^{j(\delta-\partial)} = u_{\alpha\beta}\cdot e^{-j\partial} = \\ &= u\cdot\cos(\delta-\theta) + ju\cdot\sin(\delta-\theta) = x_d + jx_q \end{aligned} \qquad (4)$$

$$x_d = u\cdot\cos(\delta-\theta) \qquad (4.a)$$

$$x_q = u\cdot\sin(\delta-\theta) \qquad (4.b)$$

Where:

$$x_d = u\cdot\cos(\delta)\cdot\cos(\theta) - u\cdot\sin(\delta)\cdot\sin[\theta] \qquad (5.a)$$

$$x_q = u\cdot\sin(\delta)\cdot\cos(\theta) - u\cdot\cos(\delta)\cdot\sin(\theta) \qquad (5.b)$$

And tacking into account x_d and x_q:

$$x_d = u_\alpha\cdot\cos(\theta) + u_\beta\cdot\sin(\theta) \qquad (6.a)$$

$$x_q = u_\alpha\cdot\cos(\theta) - u_\beta\cdot\sin(\theta) \qquad (7.a)$$

If, in the above equations we consider the 0 component constant, result:

$$x_{dq0} = \begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_\alpha \\ x_\beta \\ x_0 \end{bmatrix} \qquad (8)$$

And:

$$x_{\alpha\beta 0} = \begin{bmatrix} x_\alpha \\ x_\beta \\ x_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} \qquad (9)$$

3. SIMULATION OF THE POWER ACTIVE FILTER

We will present the working regime of the compensation method based on synchronous reference system theory by simulation results.

The synchronous reference system method is developed in time domain and gives the power, voltage and current [3], [5], [6], [17].

The simulations are made using Matlab-Simulink [20] software, which permits simulation for control blocks and the power converters in the same time.

In the PAF simulations the network, the load and the converter of the filter are the same, changing only the control circuit of the filter in concordance with the control method.

3.1. Load circuit

The load used in the simulations consists in a three phase rectifier (REDT), permanently connected and a single phase rectifier connected to phase R after 0.3 seconds.

3.1.1. The three-phase load (REDT):

Consists in a full bridge rectifier with a d.c. R-L load and an R-L circuit on a.c. side with 2mH and Q=30, like in Fig. 3.

The control angle of the rectifier is 30^0 and the voltage average value is with THD = 28,78%.

3.1.2. The single-phase load (REDM):

Consists in a diode bridge with THD = 32,7%, which is connected after 0.3 s and an R-L circuit on the a.c. side, with 2mH and Q=30.

Connecting and disconnecting of the single-phase load permit study of the dynamic work of the active filter.

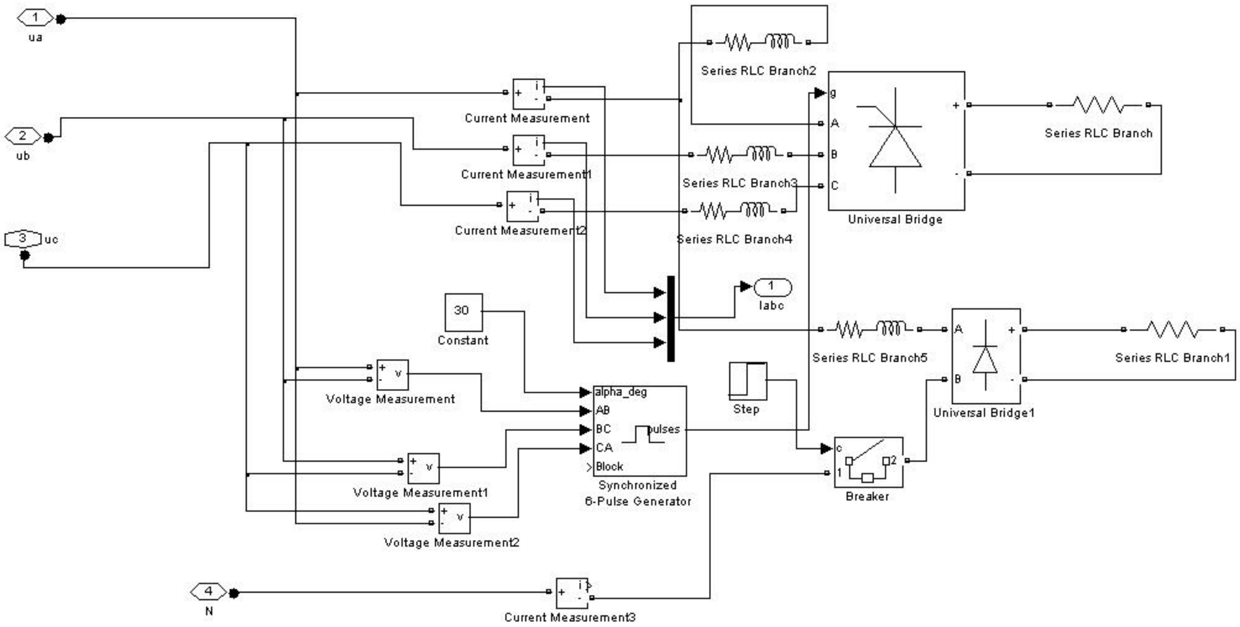


Fig.3. Simulation scheme for load circuit

The currents on phase a, b and c, when both loads are connected have an THD with: 17,4%, 23,4% and 23,4%.

The waveforms for currents and instantaneous powers are presented in the following diagrams (figures 4-6):

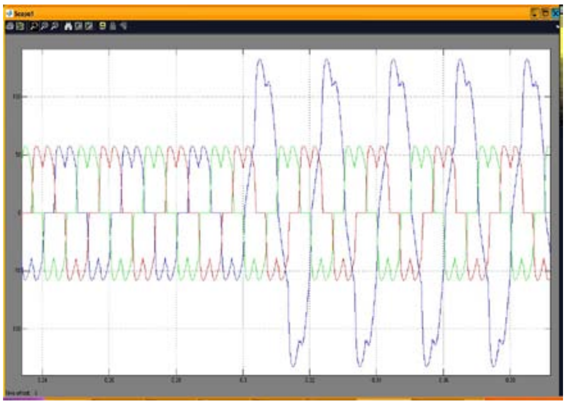
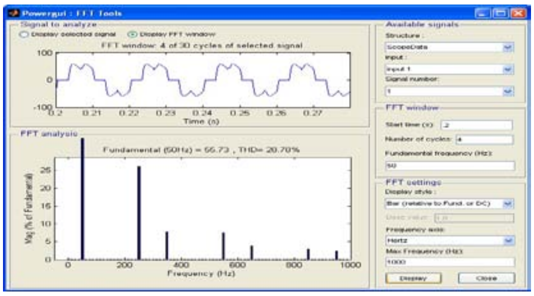


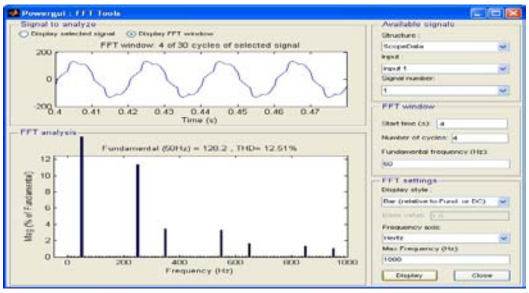
Fig.4. Diagram of the phase currents



Fundamental (50Hz) = 55.73 , THD= 20.70%

Structure : ScopeData
Input : input 1
Signal number: 1
Start time (s): .2
Number of cycles: 4
Fundamental frequency (Hz): 50
Display style : Bar (relative to Fund. or DC)
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig.5. Current harmonics with three-phase load



Fundamental (50Hz) = 120.2 , THD= 12.51%

Structure : ScopeData
Input : input 1
Signal number: 1
Start time (s): .4
Number of cycles: 4
Fundamental frequency (Hz): 50
Display style : Bar (relative to Fund. or DC)
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig.6. Current harmonics with both loads

3.2. The PAF circuit

The power active filter (PAF) circuit consists in DC converter and an element to stock the energy. The DC converter is controlled with a high frequency and with an algorithm which measures the load current and generates switching signals for the semiconductors elements to inject appropriate currents in the network.

In Fig.7. is shown the power active filter circuit used for simulation of the control method.

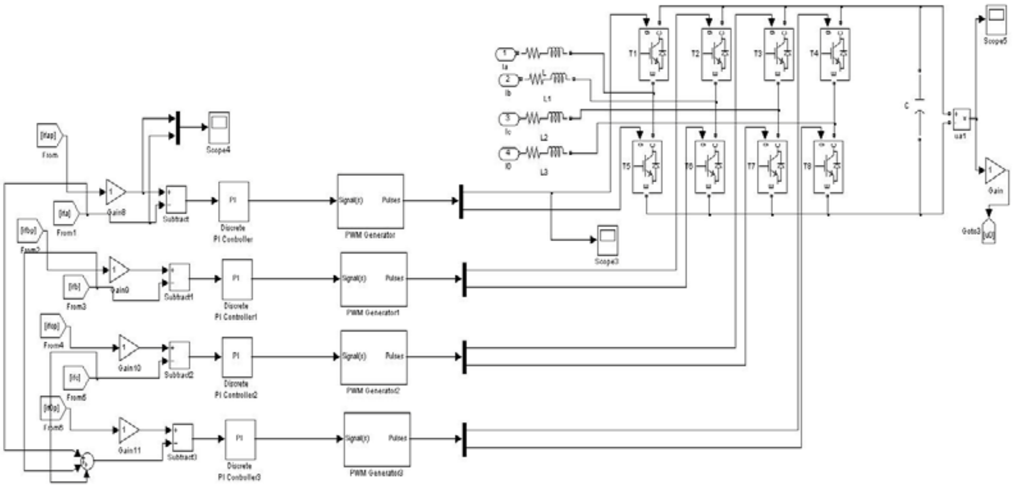


Fig.7. The PAF circuit

The inverter is a PWM one, and the controlled method for the inverter uses a PI controller with an 8 kHz carrier frequency.

The PI controller transfer function is:

$$\frac{K \cdot (1 + s \cdot T)}{s \cdot T}\text{,where: } K = 10\text{, and } T = 10ms$$

3.3. Compensation methods based synchronous reference system theory

There are two methods to determine the compensation current, both based on the same theory, described in the above section:

- SRS_Q method, computes the compensation current from reactive and homopolar components and PAF losses;
- SRS_P method computes the compensation current from active components and PAF losses.

The simulation blocks for control methods are described in Fig.8 for the SRS_Q method and in Fig.9 for the SRS_P method.

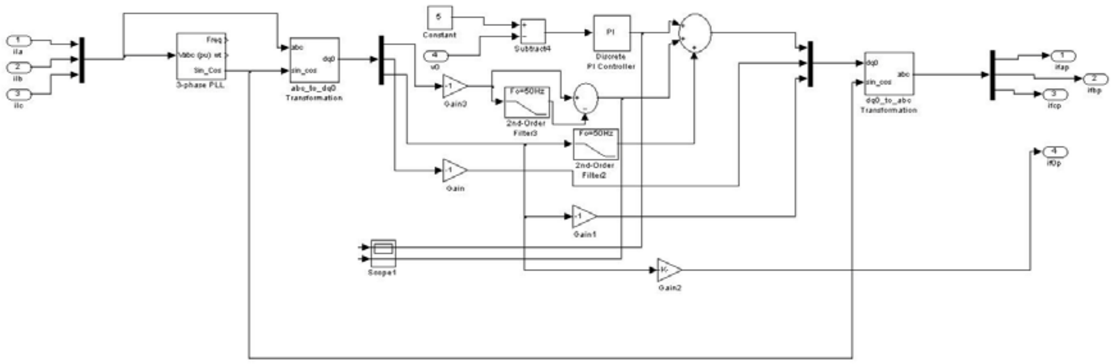


Fig.8. Control circuit for SRS_Q method

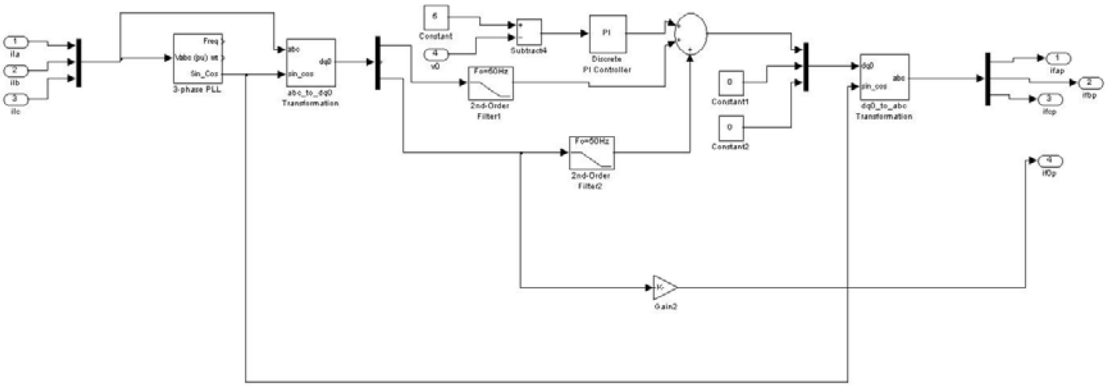


Fig.9. Control circuit for SRS_P method

The results for simulation in both cases are presented in the following diagrams (Fig. 10- 15).

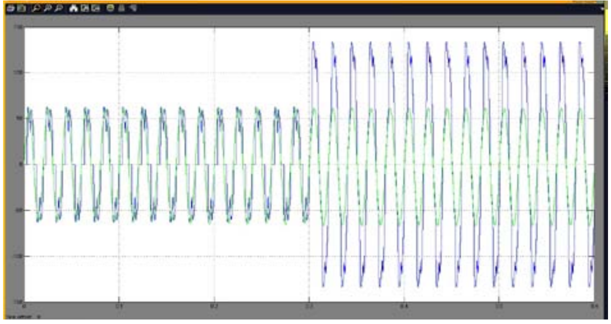


Fig.10. The unfiltered and filtered currents on phase “a” (SRS_Q)

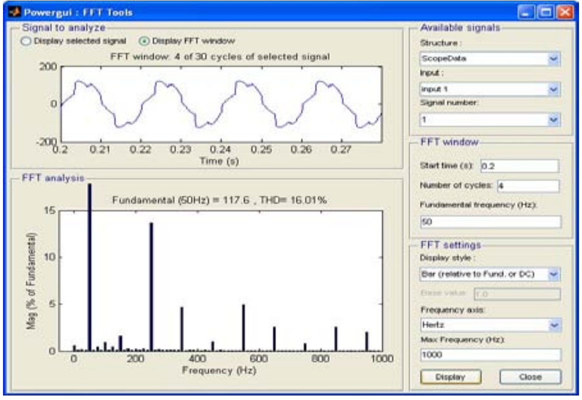

Powergui : FFT Tools
Signal to analyze
○ Display selected signal ● Display FFT window
FFT window: 4 of 30 cycles of selected signal
FFT analysis
Fundamental (50Hz) = 117.6 , THD= 16.01%
Available signals
Structure : ScopeData
Input : input 1
Signal number: 1
FFT window
Start time (s): 0.2
Number of cycles: 4
Fundamental frequency (Hz): 50
FFT settings
Display style : Bar (relative to Fund. or DC)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig.11. Current harmonics with three-phase load (SRS_Q)

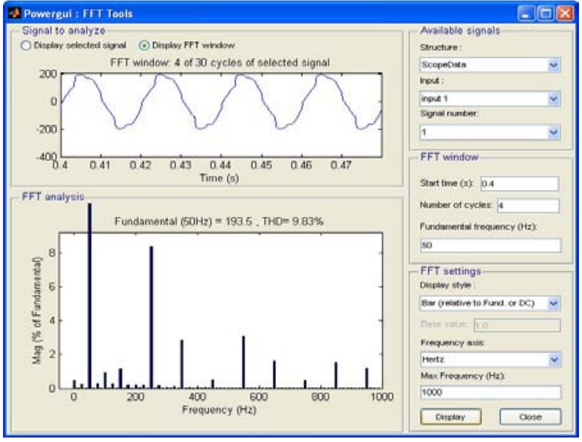

Powergui : FFT Tools
Signal to analyze
○ Display selected signal ● Display FFT window
FFT window: 4 of 30 cycles of selected signal
FFT analysis
Fundamental (50Hz) = 193.5 , THD= 9.83%
Available signals
Structure : ScopeData
Input : input 1
Signal number: 1
FFT window
Start time (s): 0.4
Number of cycles: 4
Fundamental frequency (Hz): 50
FFT settings
Display style : Bar (relative to Fund. or DC)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig.12. Current harmonics with both loads (SRS_Q)

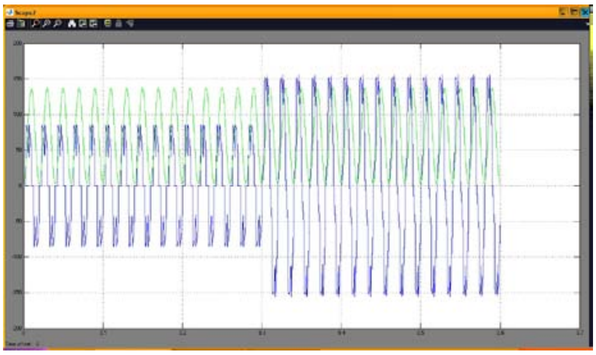


Fig.13. The unfiltered and filtered currents on phase “a” (SRS_P)

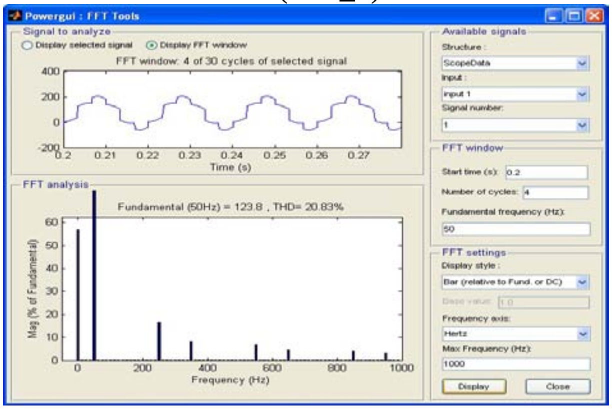

Powergui : FFT Tools
Signal to analyze
○ Display selected signal ● Display FFT window
FFT window: 4 of 30 cycles of selected signal
FFT analysis
Fundamental (50Hz) = 123.8 , THD= 20.83%
Available signals
Structure : ScopeData
Input : input 1
Signal number: 1
FFT window
Start time (s): 0.2
Number of cycles: 4
Fundamental frequency (Hz): 50
FFT settings
Display style : Bar (relative to Fund. or DC)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig.14. Current harmonics with three-phase load (SRS_P)

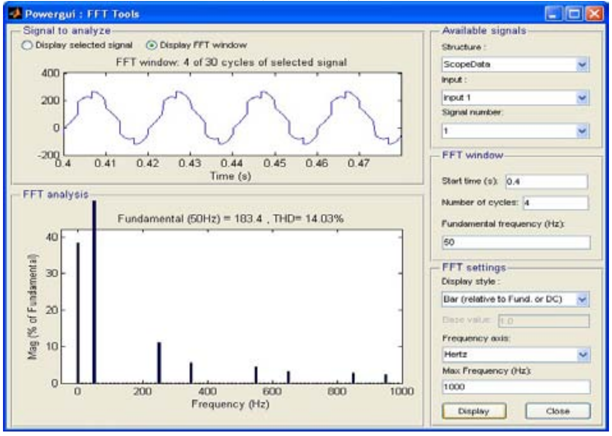

Powergui : FFT Tools
Signal to analyze
○ Display selected signal ● Display FFT window
FFT window: 4 of 30 cycles of selected signal
FFT analysis
Fundamental (50Hz) = 183.4 , THD= 14.03%
Available signals
Structure : ScopeData
Input : input 1
Signal number: 1
FFT window
Start time (s): 0.4
Number of cycles: 4
Fundamental frequency (Hz): 50
FFT settings
Display style : Bar (relative to Fund. or DC)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig.15. Current harmonics with both loads (SRS_P)

4. CONCLUSIONS

The paper takes into account the methods for control the PAF described in the references [1],[2],[8], and modeling the works of the circuits to obtain the equations used for simulation.

There are studied two methods based on synchronous reference system theory, one named SRS_Q in which the control reference value is reactive current component, and the other SRS_P, where the control reference value is active current component.

It can be observed that is necessary the coordinate reference system changing, the values used for computation of the compensation currents can be determined from the two-phase system.

From the simulation result, we can observe:

- The THD without compensation is 28.78 % in case of three-phase load, and 12.61 % in case of unbalanced loads,
- Using the SRS _Q method of control for the PAF, the THD falls to 16.01 % for balanced load, and 9.83 % for unbalanced loads,

In case of SRS _P method of control for the PAF, the THD is 20.83 % for three-phase load, and 14.03 % for both loads (three-phase and two phase)

The result of the simulations for both methods: one based on reactive current component (SRS _Q) and the others based on active current component (SRS _P), are similar, but the second one gives better results and

From the simulation result we can observe that the SRS method permits the selective compensation of the harmonics and reactive power.

References:

[1] Adkins B., Harley R. G. “The General Theory of Alternating Current Machines”. Chapman & Hall, London, 1975.

[2] Akagi, H. “Trends in active power line conditioners”. IEEE Transactions on Power Electronics, Vol.9, No.3, May 1994 Pages: 263-268.

[3] Akagi H., Kim H. “The theory of instantaneous power in three-phase four-wire systems: A comprehensive approach”. Conf. Rec. IEEE-IAS Annu. Meeting, 1999, Pages: 431-439.

[4] Arad, S., Arad, V., Lupu, L., “The remote control of Electric Devices, Protection, Control and Monitoring Systems.”, 2006 IEEE International Symposium , IEEE Conference Publications, vol I, pp 267-272, Montreal, Que, ISSN 0018-9219, ISBN 1-4244-0497-5. Indexed by Inspec, IEEE Xplore, INSPEC Accession Number: 9132144, Digital Object Identifier 10.1109/ISIE.2006.295604, 2006, ISI Web of Scienece, 2006

[5] Aredes M., Watanabe E.H. “New control algorithms for series and shunt three-phase four-wire active power filters”. IEEE Transactions on Power Delivery, Vol. 10, No. 3, July 1995, Pages: 1649-1656.

[6] Aredes M., Häfner J., Heumann K. ”Three-phase four-wire shunt active filter control strategies”. IEEE Transaction on Power Electronics, Vol. 12, No. 2, March 1997, Pages: 311-318.

[7] Bose B.K. “Power Electronics and AC Drives”. Prentice-Hall. New Jersey, 1986.

[8] Chiuţă I., Conecini I. “Compensarea regimului energetic deformant”. Editura Tehnică, Bucureşti, 1989.

[9] Conecini I. ”Îmbunătăţirea calităţii energiei electrice”. Editura. AGIR, Bucureşti 1999.

[10] Kim H., Akagi H. “The instantaneous power theory on the rotating p-q-r reference frames”. IEEE 1999 International conference on power electronics and drive systems, PEDS´99, July 1999, Hong Kong, Pages: 422-427.

[11] Kim H., Blaabjerg, F., Bak-Jensen, B., Jaeho Choi. “Instantaneous power compensation in three-phase systems by using p-q-r theory”. IEEE Transactions on Power Electronics, Vol. 17, No. 5, Sept. 2002, Pages: 701-710.

[12] Nabae A., Tanaka T. “A new definition of instantaneous active-reactive current and power base on instantaneous space vector on polar coordinates in thee-phase circuits”. IEEE Transactions on Power Delivery, Vol. 11, No. 3, July 1996, Pages: 1238-1243.

[13] Pătrăşcoiu N., *Modeling and Simulation of the DC Motor Using Matlab* *and LabVIEW* The International Journal of Engineering Education. Volume21, Number 1/2005, Dublin Institute of Technology, pag. 49-54, ISSN 0949-149x

[14] Roman M. “Filtros activos de potencia para compensación instantánea de armónicos”. 3ª Jornadas Técnicas de Redes Eléctricas de Distribución e Instalaciones de Usuarios. Innovaciones. Matelec 94. Madrid.

[15] Roman M. “Filtros activos de potencia para la cancelación de armónicos”. II Seminario Anual de Automática y Electrónica Industrial. SAAEI 95, Universitat Rovira i Virgili Tarragona,1995.

[16] Singh B., Kamala-Haddad. “A review of active filters for power quality improvement”. IEEE Transactions on Industrial Electronics, Vol. 46, No. 5, October 1999, Pages: 960-971.

[17] Tolbet L.M., Habetler T.G. “Comparison of time-based non-active power definitions for active filters”. CIEP 2000, Acapulco, MEXICO, October 15-19, Pages: 73-79.

[18] Vas P. “Vector Control of AC Machines”. Clarendon Press, Oxford, 1990.

[19] Zhuo F., Yue-Wang, Zhaoan-Wang. “The configuration of main circuit and control strategy for active power filter in three-phase four-wire system”. IEEE 32 Annual Power Electronics Specialists Conference, 2001. PESC. 2001, Vol. 3, June 2001, Pages: 1615-1618.

[20] * * * Software Matlab 6.5.