THE CONSERVATIVE POWER THEORY AND THE ACTIVE FILTERING

Eng. **Alexandra PĂTRAŞCU**, PhD. Student, Prof. Eng. **Mihaela POPESCU**, PhD,
Assis. Eng. **Vlad SURU,** PhD

University of Craiova, Electrical Engineering Faculty.

REZUMAT. Această lucrare analizează posibilitatea descompunerii curentului în circuite trifazate fără fir de nul pe baza Teoriei Conservative a Puterii. În acest scop au fost analizate mai multe studii de caz prin simulare, în Matlab/Simulink, pentru tensiune nesinusoidală şi pentru sarcini liniare, respectiv, neliniare. După interpretarea rezultatelor obținute prin simulare, modelele de calcul create au fost verificate experimental, pe baza unui sistem real de filtrare activă.

Cuvinte cheie: Teoria Conservativă a Puterilor, tensine nesinusoidală, filtru activ paralel, calitatea energiei

ABSTRACT. This paper analyzes the feasibility of decomposing the current in three-phase, three-wire systems using the Conservative Power Theory. Several case studies were created to be analyzed by simulation in Matlab/Simulink environment, under non-sinusoidal voltage conditions, taking into consideration linear and non-linear loads. After interpreting the results obtained by simulation, the implemented computation models have been investigated using an experimental active filtration system.

Keywords: Conservative Power Theory, non-sinusoidal voltage, shunt active filter, power quality.

1. INTRODUCTION

Most of industrial, commercial and home loads have non-linear character, this way harmonic distortion level in power grids has become a serious issue.

Negative aspects which could be determined by the high level of harmonics presence in the power grid are well known and there were introduced standards in order to limit these harmonic distortions.

Therefore, customers must limit the harmonic current absorbed from the power grid. Accordingly, they have to insure that harmonics filtering is provided.

Shunt active filters developed once with the new standards imposed to the equipments, in the context of technology evolution and power semiconductor elements performances, but also due to the progress in the DSP, numerical methods and control algorithm domain [1]-[6].

2. BASIC DEFINITIONS

This section presents some basic definitions which appear in the Conservative Power Theory defined by Paolo Tenti [7], [8].

Starting from a set of real variables, continuous in time and periodic of period T, Tenti defined their internal product and the norm of x(t) as:

$$x \circ y = \frac{1}{T}\int_0^T x(t)y(t)dt \qquad (1)$$

$$\|x\| = \sqrt{x \circ x} = \sqrt{\frac{1}{T}\int_0^T x^2(t)dt} = X \qquad (2)$$

Given a periodic function x(t) of period T and angular frequency $\omega = 2\pi/T$ it was defined the derivative operator, $\breve{x}$, and the integral operator, $\hat{x}$, as follows:

$$\breve{x} = \frac{1}{\omega}\frac{dx}{dt} \qquad (3)$$

$$\hat{x} = \omega(x' - \overline{x}') \qquad (4)$$

where:

$$x'(t) = \int_0^t x(\tau)d\tau \text{ and } \overline{x}'(t) = \frac{1}{T}\int_0^T x'(t)dt \qquad (5)$$

3. CURRENT DECOMPOSITION USING THE CONSERVATIVE POWER THEORY

In this section it will be presented an orthogonal decomposition of the current into active and reactive components. Each current term relates to some energy phenomenon, taking into account supply voltage and load current distortion [7], [8].

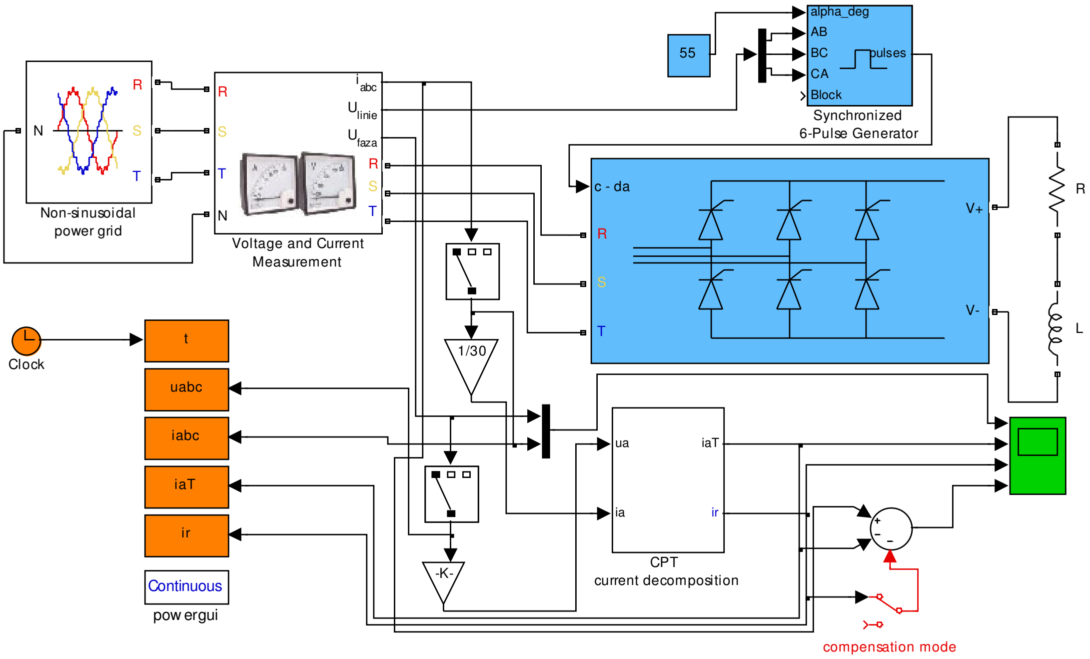

Fig. 1. The virtual filtration system

The active current is defined as the minimum current conveying active power P absorbed from the network. It is given by [7], [8]:

$$\underline{i}_a = \frac{\underline{i} \circ \underline{u}}{\|\underline{u}\|^2}\underline{u} = \frac{P}{\|\underline{u}\|^2}\underline{u} \tag{6}$$

The reactive current component, i_r, was split into two orthogonal terms i_q (main reactive current) and i_s (secondary reactive current), where current i_q is defined as the minimum current accounting for reactive power, which relates to the energy stored in the network.

The two components are defined as follows [7], [8]:

$$\underline{i}_q = \frac{\underline{i} \circ \hat{\underline{u}}}{\|\hat{\underline{u}}\|^2}\hat{\underline{u}} \tag{7}$$

being the main reactive current vector, and:

$$\underline{i}_s = (\underline{i} \circ \underline{v})\underline{v} \tag{8}$$

being the secondary reactive current vector.

4. OBTAINED RESULTS

In order to validate the correct implementation of the CPT based compensating current calculation algorithm, one typical nonlinear load was used, i.e. a three-phase full wave controlled rectifier with a passive RL load.

A. Simulation results

In the first stage, the CPT based current computation model was verified by simulation, using the model presented in Fig. 1.

The grid voltage and current waveforms for the studied nonlinear load is shown in Fig. 2.

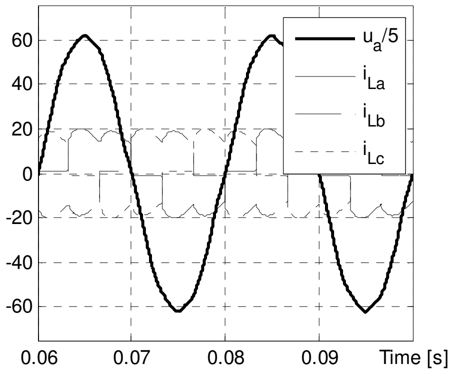

Fig. 2. The grid voltage and load current waveforms for the three-phase bridge rectifier

The current computation model gives at its output the active and the reactive current components. By subtracting the first or the both components, the active filter compensating current has been obtained, for the total compensation in the first case, and the partial compensation in the second case.

The nonlinear load active current obtained by (6) is illustrated in Fig. 3. Considering the ideal filtration system, the presented active current is exactly the compensated current absorbed from the power grid (in total compensation mode), because:

$$i_{Source} = i_{Load} - i_{Filter} = i_{Load} - i_{Load} + i_a = i_a \tag{9}$$

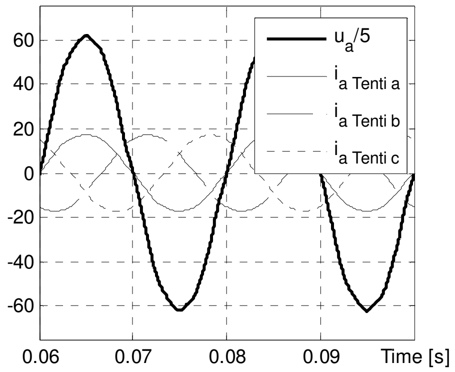

Fig. 3. The grid voltage and the Tenti's active current waveforms

B. Experimental results

In the 2^{nd} stage, the presented algorithm has been experimentally verified on an active filtering system consisting of:

- the three-wire power inverter;
- the 1st order interface filter;
- the dSPACE DS1103 control platform;
- three phase full wave controlled rectifier.

The current absorbed by the real nonlinear load, is illustrated in Fig. 4, for a RMS value of 14.51 A.

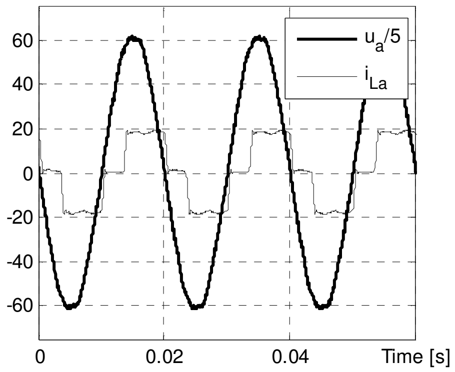

Fig. 4. The grid voltage and load current waveforms for the experimental three-phase bridge rectifier

The compensated current absorbed from the power grid, in case of total compensation, is illustrated in Fig. 5. It can be observed that the current and the voltage have similar shapes, the phase shift between the voltage and current being eliminated. Also, after the compensation, the grid current RMS value has been reduced to 12.01 A, due to the elimination of the reactive and distortion components. Regarding the compensated current harmonic distortion, the current THD has been reduced from 28.39% to 10.1%, giving a filtration efficiency of 2.81. It must be mentioned that the power grid voltage THD had the value of 1.77% at the time of the experiment.

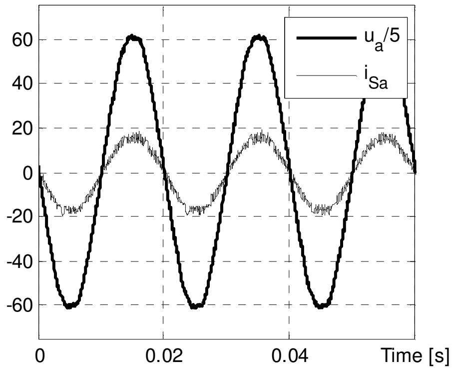

Fig. 5. The grid voltage and the total compensated current waveforms

In the case of partial compensation (Fig. 6), only the void current has been compensated, so the current keeps its reactive phase shift and the RMS value changes from 14.34 A to 14.55 A. This is because the reactive components is much higher than the void component, so the compensation has little effect regarding to the current RMS value, and more than that the RMS value slightly increases due to the active filter switching operation. However, the harmonic distortion of the compensated current decreases from 28.33 % to 8.58 %, giving a filtration efficiency of 3.29, which explains the almost sinusoidal shape of the grid current.

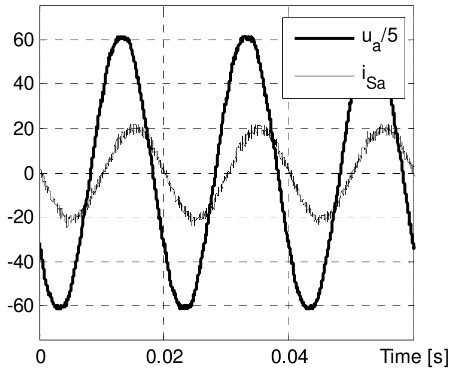

Fig. 6. The grid voltage and the partial compensated current waveforms

5. CONCLUSIONS

The implementation of the CPT in the active filtering gave good results for the investigated nonlinear load, not only by simulation, but also in the experimental studies. This decomposition method allowed the implementation of total and partial compensation, being convenient when the reactive power compensation is not necessary.

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About the authors

Eng. **Alexandra PĂTRAŞCU**, PhD. Student
University of Craiova, Romania
email:alexandra_2585@yahoo.com

She was born in Craiova, Romania, in 1985. She graduated the Faculty of Electrical Engineering, and also obtained the Master Degree in Electrical Engineering at the University of Craiova. Since 2009 she joined the PhD School of Electrical Engineering Sciences at the University of Craiova and she is in the 2nd stage of her thesis titled “Power Definitions under Non-Sinusoidal Conditions and Their Application for Active Power Filters Control”.

Prof. Eng. **Mihaela POPESCU**, PhD
University of Craiova, Romania
email: mpopescu@em.ucv.ro

She was born in Craiova, Romania, in 1965 and received the Engineering degree and the Ph.D. degree in electrical engineering from the University of Craiova, Romania, in 1988 and 2001, respectively. In 1992, she joined the Department of Electric Drives of Electromechanical Faculty, University of Craiova, as an Assistant. She is currently a Professor at Faculty of Electrical Engineering and Director of Department of Electromechanics, Environment and Industrial Informatics. Her main field of interest includes power quality in static converters driving systems, with over 100 technical publications. She is a member of the IEEE Power & Energy Society.

Assis. Eng. **Vlad SURU,** PhD
University of Craiova, Romania
email: vsuru@em.ucv.ro

He was born in Iaşi, Romania, in 1982 and received the Engineering degree in Electrical Engineering from the University of Craiova, Romania, in 2007. The Ph.D. degree was received in 2012, also from the University of Craiova. In 2007, he joined the Department of Electric Drives and Industrial Informatics of the Electromechanical Faculty, University of Craiova, as an Assistant. He is currently an Assistant at the Faculty of Electrical Engineering, Department of Electromechanics, Environment and Industrial Informatics. His main field of interest includes the power electronics and static converters based driving systems. He is a member of the AGIR Engineering Society, and of the Robotics Society.