THE CONSERVATIVE POWER THEORY AND THE ACTIVE FILTERING

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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:

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

(1)

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

(2)

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

\[ \ddot{x} = \frac{1}{\omega} \frac{dx}{dt} \]  

(3)

\[ \int x = \omega(x' - \ddot{x}') \]  

(4)

where:

\[ x'(t) = \int_0^t x(\tau)d\tau \quad \text{and} \quad \ddot{x}(t) = \frac{1}{T} \int_0^T x'(t)dt \]  

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

$$i_a = \frac{i \circ u}{\|u\|^2} = \frac{P}{\|u\|^2} u$$  \hspace{1cm} (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]:

$$i_q = \frac{i \circ u}{\|u\|^2} u$$  \hspace{1cm} (7)

being the main reactive current vector, and:

$$i_s = (i \circ v) v$$  \hspace{1cm} (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.

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:

$$i_{Source} = i_{Load} - i_{Filter} = i_{Load} - i_{Load} + i_a = i_a$$  \hspace{1cm} (9)
B. Experimental results

In the 2nd 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.

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.

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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