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# A Simulation Case Study of a Control Algorithm for UPQC Using Instantaneous Power Tensor Formulation and UVTG

KEYWORDS


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**ABSTRACT** *In this paper we present a modified algorithm to generate the reference signals to control the series and parallel power inverters in an unified power quality conditioner "UPQC" to enhance power quality. The algorithm is based in the instantaneous power tensor formulation which it is obtained by the dyadic product between the instantaneous vectors of voltage and current in n-phase systems. The perfect harmonic cancellation algorithm "PHC" to estimate the current reference in a shunt active power filter was modified to make it hardy to voltage sags through unit vector template generation "UVGT" while from the same algorithm it extracts the voltage reference for series active power filter. The model was validated by mean of simulations in Matlab-Simulink R .*


## I. INTRODUCTION

The UPQC are power electronic devices that acts like controlled voltage and current sources in power systems so that it can remove or reduce the effect of power quality issues like harmonics, sags, swells, imbalances in power source or loads and also lead to improve the power factor.

The growing interest in UPQCs come from last century, and since the concept of "power quality" has been gaining increasing popularity in the field of electrical engineering, today, has become a great topic for companies providing electricity service, equipment manufacturers and end users, that leading to solutions searching to solve the problems of power quality (Khadem, 2013; Pe´rez Litra´n, 2011; Teke,2011; Li, 2010; Peng et al., 1990b,a).

Regarding the estimation algorithms of reference signal, many theories and methods have been proposed to define the reference signals to correct the problems of power quality either voltage or current, which highlights the use of the instantaneous active and reactive power theory or pq theory, as one of the theories most used in order to generate reference currents in the shunt active power filters and UPQC; while of- ten the estimation of sequence components and phase-looked- loops "PLL" are used for the voltage reference estimation and the grid synchronization with the filters, respectively (Tekel,2011; Khadkikar, 2012).

Furthermore, the interest in distributed generation systems such as wind and solar power is increasing, so has raised the use of one or more distributed generation systems in UPQCs that require injection of active power to the compensated system (Khadkikar, 2012; Park et al., 2003; Han et al., 2006; Mastromauro et al., 2009; Davari et al., 2009; Toodeji et al., 2009; Mokhtarpour et al., 2012; Saudin et al., 2012). This type of systems has the advantage that can to control power quality problems either in voltage and current, besides it can also mitigate sags and swells, even it can acts like a power source to provide energy to load in blackouts if there is integrated with a storage power system like a battery bank. The basic configuration of those systems is illustrated in Figure 1. Here we show the distributed generation system connected to DC bus of UPQC.

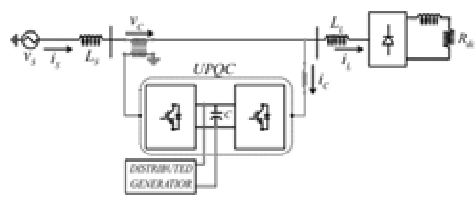


**Figure 1. UPQC-DG System configuration.**

## II. INSTANTANEOUS POWER TENSOR FORM ULATION

The tensor formulation of instantaneous power was proposed in 2007 (Herrera et al., 2007; Salmero´ n and Herrera, 2009), and thereafter defined like "Instantaneous Power Tensor Theory" in 2010 (Ustariz et al., 2010a,b), is based on the interpretation of the instantaneous voltage and current vectors like first order tensors, then to define the power components by the dyadic product in a n-phase system, and proposing compensation models for shunt active power filter to compensate the same type of systems.

From the tensor formulation (Herrera et al., 2007)-(Ustariz et al., 2010b), several techniques have been proposed for

$$q(t) = \mathbf{i}(t) \wedge \mathbf{u}(t) \quad (2)$$

where, $\wedge$ denotes the outer product, that is an antisymmetrization of dyadic product denoted by the operator $\otimes$, so that:

$$q(t) = \mathbf{i}(t) \wedge \mathbf{u}(t) = (\mathbf{i} \otimes \mathbf{u}) - (\mathbf{u} \otimes \mathbf{i}) \quad (3)$$

Besides the components of the current is defined as follows:

$$\mathbf{i}_p = \frac{p(t)}{u^T u} u = \frac{(u_1 i_1 + u_2 i_2 + \ldots + u_n i_n)}{\mathbf{u} \cdot \mathbf{u}} \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix} \quad (4)$$

expression equivalent to:

$$\mathbf{i}_{\sim} = \frac{(\mathbf{u} \otimes \mathbf{i})}{\mathbf{u} \cdot \mathbf{u}} \mathbf{u} \quad (5)$$

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$$= \frac{(u \otimes i)}{u \cdot u} u + \frac{[(i \otimes u) - (u \otimes i)]}{u \cdot u} u \qquad (6)$$

Finally, the decomposition of the current leads to the expression 7:

$$\vec{i} = \vec{i}_p + \vec{i}_q \qquad (7)$$

The power and current components definition in (Ustariz

et al., 2010a,b) are selfsame to defined in (Herrera et al., 2007;

Salmero´ n and Herrera, 2009), although the first one development shown at a slightly form more elegant the tensorial formulation from the definition of the instantaneous power

tensor ℘8. Thus, for a n-phase system, the instantaneous-power tensor is given by:

$$\wp_{ij} = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_n \end{bmatrix} \otimes \begin{bmatrix} i_1 & i_2 & \cdots & i_n \end{bmatrix} = \begin{bmatrix} v_1 i_1 & v_1 i_2 & \cdots & v_1 i_n \\ v_2 i_1 & v_2 i_2 & \cdots & v_2 i_n \\ \vdots & & \ddots & \vdots \\ v_n i_1 & v_n i_2 & \cdots & v_n i_n \end{bmatrix} \qquad (8)$$

From 7 and 8, they performing the decomposition of one instantaneous power tensor in two, called active power tensor

of a block called "DSFC" (direct sequence and fundamental component estimation algorithm) for t ng the fundamental frequency defined by the fast Fourier transform. The algorithm

$$= (u \otimes \vec{i}_p) + (u \otimes \vec{i}_q) = {}^p\wp_{ij} + {}^q\wp_{ij} \qquad (9)$$

$$\vec{i}_p = \frac{(u \cdot i)}{\|u\|^2} u, \quad \vec{i}_q = \frac{\left[(i \otimes u) - (u \otimes i)\right]}{\|u\|^2} u \qquad (10)$$

becoming clear, the expressions in 10 by Ustariz, are the same defined in 5 and 6 by Herrera.

## III. SHUNT INVERTER REFERENCE GENERATION ALGORITHM

From the tensor formulation (Herrera et al., 2007)-(Ustariz et al., 2010b), several techniques have been proposed for compensation in shunt active filters, one of these is the technique of the perfect harmonic cancellation "PHC" at source. Estimation of reference for this control strategy for the active filter is given by:

$$\vec{i}_{ref} = \vec{i} - \vec{i}^{+}_{p\_f} \qquad (11)$$

$i_{p\_f}$ is the direct sequence and fundamental frequency active instantaneous current vector, defined by:

$$i_{p\_f} = \frac{tr(\bar{\wp}_{ij})}{T \; v_f \cdot v_f} v_f \qquad (12)$$

to 13 proposed by Herrera:

$$\frac{P}{U^2}$$

Where U is the average norm of the voltage instaneous vector, and P = tr(℘¯ij ) is named like average active power by Herrera or average instantaneous power tensor by Ustariz.

Block diagram for current reference estimation by PHC technique is shown in Figure 2 (Ustariz et al., 2010b).

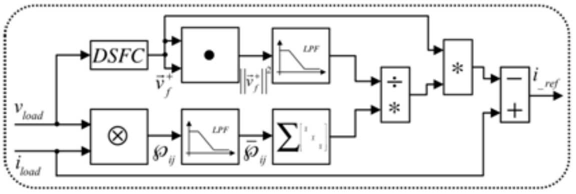


**Figure 2. Block diagram for current reference estimation by PHC tech- nique(Ustariz et al., 2010b).**

he load voltage (Ustariz et al., 2010b). This algorithm uses the inverse transform of Fortescue for determining direct sequence and trigonometric operations for extraction.

For compensation of the reactive power at a fundamental frequency, the algorithm described in Figure 2 makes use p ℘ij and reactive power tensor q ℘ij , like in 9:

℘ij = ~u ⊗~i = ~u ⊗ (~ip + ~iq )

supports wave forms unbalanced and non - sinusoidal, but does not support sags and swells in voltage. This is due the Fourier transform calculates the amplitude of the fundamental component in any condition regardless of if this is or not the nominal amplitude of the load. It has been verified by simulation that, in voltage sags, the algorithm decreases proportionally the reference current, and therefore, does not have the expected complete compensation.

## IV. PHC WITH TENSOR FORMULATION AND UVTG TO CONTROL SERIES INVERTER

As mentioned in the previous section, the PHC algorithm reported in (Ustariz et al., 2010b) is not tolerant to variations in the power supply, such as sags and swells, which is why this algorithm has been modified to make it tolerant to these perturbations.

The modification to the referenced, uses Unit Vector Template Generation (UVTG) for obtaining direct sequence volt- ages and fundamental frequency with a PLL in the syn- chronous reference system (SRF-PLL) to determine the phase of the reference. The "UVTG" technique is well described in (Khadkikar et al., 2004; Vadirajacharya et al., 2007; PAL et al., 2013).

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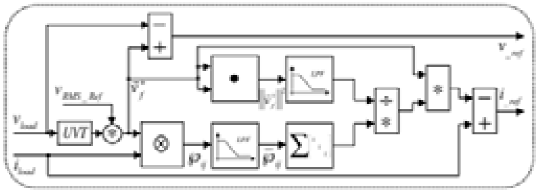


**Figure 3. Block Diagram for reference signal estimation of Series and Shunt inverters of the UPQC.**

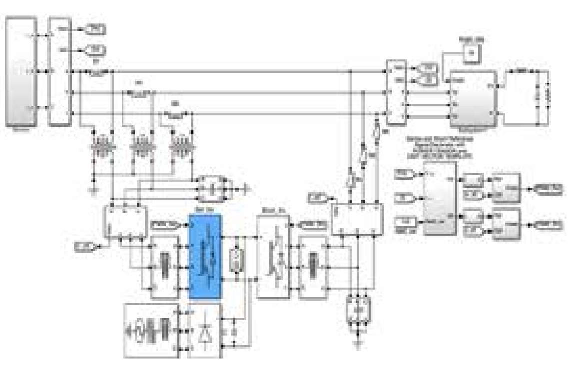
Extracting reference signals from the PLL and SFR-UVTG technique is sufficient to extract the reference signals of the active filter in series UPQC-DG inverter. In Figure 3 the complete diagram estimation references for unified power quality conditioner is illustrated. The voltage reference is set at 14.

~v ref = ~v+ − ~vload (14)

In the diagram of Figure 3 the "UVT" block provides sinusoidal signals at unit value in phase with the fundamental component of the source voltage independent of its magnitude or harmonics condition.

### V. NUMERIC SOLUTION AND RESULTS

The simulation corresponding to check the algorithm regarding the generation of the reference was implemented in Matlab-Simulink R . The model has a voltage source distorted with harmonics for feeding a nonlinear load with a given current displacement factor to ensure control of the reactive power, the supply voltage also applied to the system at some point of a voltage sag to verify that the algorithm is tolerant to these (Figure 4).



The inverters control loop has been made by hysteresis with fixed switching frequency (Akagi et al., 1986) with the same frequency in both switching inverter bridges , the model

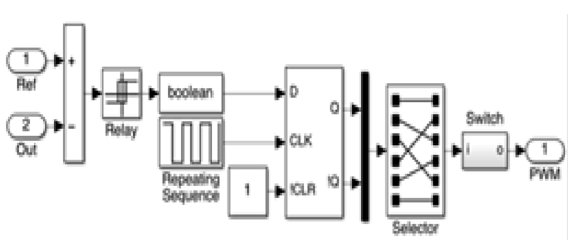



**Figure 5. Hysteresis control with fixed switching frequency.**

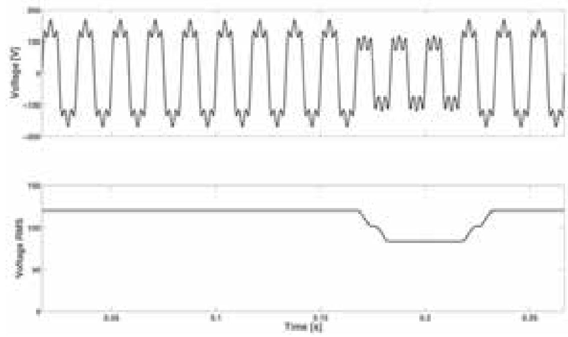


**Figure 6. Harmonic polluted voltage source, with SAG. A) Waveform, B) RMS Value.**

implemented for this control is illustrated in Figure 5. The first part is the error which is passed through a system that converts the error to binary values as stated in equation 15:

(ref − out) ≥ 0 ⇒ Boolean = 1 (15)

(ref − out) < 0 ⇒ Boolean = 0

Although the switching output of Boolean type, is variable and depends on the dynamics of change in the measured error, in the D-type flip-flop, switching frequency is fixed at a constant value given by the block sequence (serving as clock) and can be set according to the inverters design criteria. Although the literature has reported many methods of controlling inverters, we have implemented this model because it has a quick response and a low computational cost, which allows it to be easily programmed in current DSP based development systems.

In Figure 6, the waveform of one phase of the power supply and the RMS value over time of simulation are illustrated, it is heavily contaminated by harmonics, illustrating the effect of distorting the current loads on source impedances. Further- more, a voltage sag of three cycles is shown to verify that the algorithm can compensate for such transients on the network. In this case we have simulated a drop in the RMS value of 30%.

The UPQC is operated in four time intervals: in the first 3 cycles is not given compensation in voltage or current, in the second time interval, beginning at the 4rd cycle, the voltage compensation is only activated, in this range the series active filter compensates harmonics, isolating the load (Figure 7).

In the next interval, from the 6th cycle, compensation of harmonics and reactive power in current is activated,

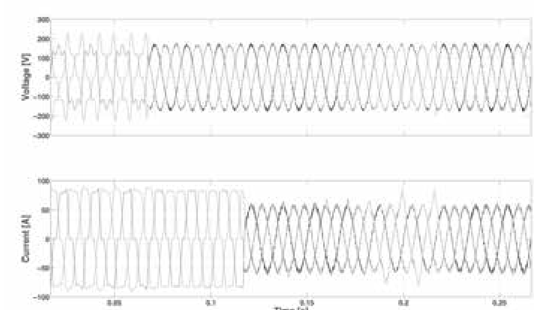


**Figure 7. UPQC-DG waveform. A) Compensation voltages, B) Compensation currents.**

in this case, the parallel inverter injects the compensation current needed to eliminate harmonics generated by the load and to carry the power factor to the unit. In the signals of reference can be seen that the length of the voltage sag time is compensated by an increase of the voltage signal reference.

The compensation signal that UPQC generates are presented in Figure 7. At the time where the sag in source is generated it is observed that the compensation voltage of series compensator increases to supply in the load the required magnitude.

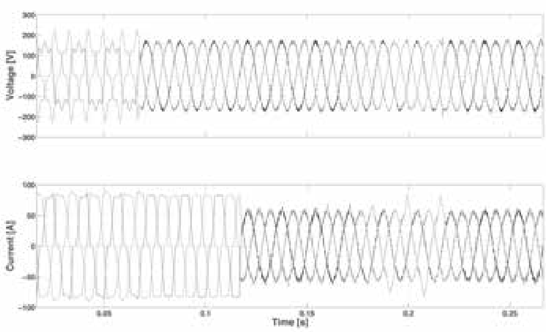



**Figure 8 illustrates the voltage signals of the load and supply current throughout the simulation time.**

compensation, the ripple of the active and reactive power is decreased, then the reactive power and the oscillating part of the active power are removed. At the time of the voltage sag, one component of active power and reactive oscillating arise due to the lack of compensation current produced by harmon- ics for having limited power in the distributed generator.

Finally, in Table I the most important simulation results are presented before and after compensation and during the voltage sag.

**VI. ACKNOWLEDGEM ENTS**

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