Author(s): Hosny, W., Dubrucky, B., Pokorny, M.
Article Title: Enhancement of the Dynamic Performance of Single Phase Active Power Filters Using Virtual Two Axis Strategy Publication
Type: Conference Paper
Year of publication: 2009
Citation: Hosny, W., Dobrucky, B. Pokorny, M. (2009) 'Enhancement of the Dynamic Performance of Single Phase Active Power Filters Using Virtual Two Axis Strategy Publication', Proceedings of the 44th International Universities Power Engineering Conference (UPEC 2009), University of Strathclyde, Glasgow.
Link to conference website:
http://www.upec2009.org/content/node/308
DOI: (not stated)

Dynamic Performance of Single Phase Active Power Filters Using Virtual Two Axis Strategy

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***Abstract*-In this paper the orthogonal transformation technique or virtual two axis strategy which was instigated by Akagi et al in 1984 for three phase power systems has been extended by Dobrucky and Pokorny in 1999 for the determination of instantaneous power in single phase power systems. This technique is described in detail in two of the authors' previous publications,[2] and [3], by adopting this technique, an expression for the reference current used in an active power filter for the compensation of harmonic distortion and reactive power is derived. This expression is implemented by a digital signal processor and results in providing an excellent transient response of the filter which is demonstrated experimentally. This excellent response is realized due to the fast evaluation of the filter reference current when the two axis strategy described in this paper is used.**

***Index Terms*—Dynamic performance of active power filters, harmonic distortion and reactive power compensation, orthogonal transformation technique, single phase power systems**

I. INTRODUCTION

In this section orthogonal transformation technique or virtual two axis strategy instigated by Akagi et al, [1] and applied to a single phase power system is briefly explained. This technique was described in detail in two of the authors' previous publication, [2]. By adopting this technique, an expression for the reference current used in an active power filter for the compensation of harmonic distortion and reactive power is derived.

Consider a single phase power system feeding a non-linear load in the form of a solid state diode bridge rectifier with an inductive load connected the dc side. Adopting the virtual two axis strategy, the real and virtual components of the supply voltage and current can be represented in vector forms in the Gaussian complex domain as a symmetrical trajectory, Fig.1. The complex voltage is represented by the broken circular trajectory whilst the complex current trajectory, assuming a square real current waveform, is represented by the four-sided trajectory. Because of the symmetry of both trajectories shown in Fig.1, it is evident that the investigation of the voltage and current for the complex power system, including both of the real and virtual voltage and current components, could be carried out within a quarter of the periodic time of the real and current waveforms. Thus Fourier transforms applied for the harmonic analysis of the non-sinusoidal current could be carried out during this interval.

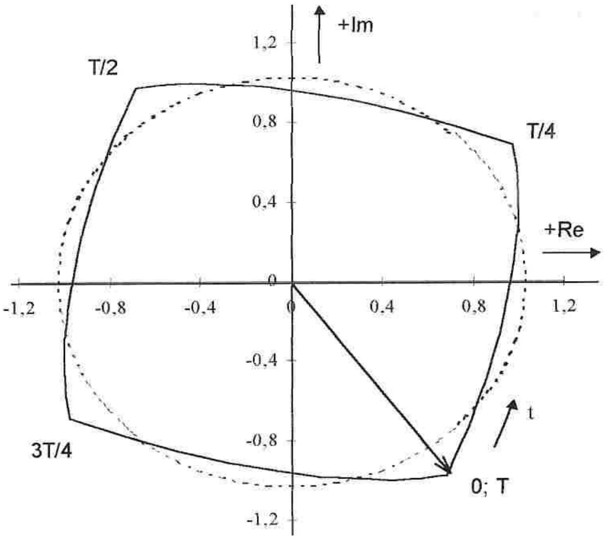

Fig.1. Trajectory of the complex single phase power system voltage and current in the Gaussian complex domain

Fig.2 shows the arrangement of the real and virtual circuits of the complex single phase power systems under investigation. As it is shown in this figure, the real and virtual circuits should be synchronised by the "SYNC" signal. This implies that both of the real and virtual components are initially equal to zero.

II. INSTANTANEOUS ACTIVE AND REACTIVE POWER

In this section the use of p-q-r instantaneous reactive power method described in [1] and [3] for the compensation of reactive power and harmonic filtering is explained. The instantaneous active and reactive power equations for the complex power system under consideration are given in the α-β domain, as described in [1] as follows:

$$\begin{aligned} p &= v_\alpha i_\alpha + v_\beta i_\beta \\ q &= v_\alpha i_\beta - v_\beta i_\alpha \end{aligned} \qquad (1)$$

Where p and q respectively are the instantaneous active and reactive powers, v_α and v_β respectively are the real and virtual (imaginary) supply voltage components and i_α and i_β respectively are the real and virtual (imaginary) supply current components.

Fig.3 depicts the time variation of p and q for the complex single phase power system under consideration. In this figure P_{AV} and Q_{AV} respectively are the average values of the active and reactive power. The instantaneous power factor, Φ, is defined as:

$$\Phi = \tan^{-1} (q/p) \qquad (2)$$

It is important to point out that the values of p, q and Φ in (1) and (2) are instantaneous values.

The p-q-r theory is introduced in [4] where the current, voltage and power equations are projected in p-q-r rotating frame of reference. Fig.4 shows the voltage components in both of the fixed α-β and rotating p-q frame of reference for a single phase power system. The r-axis is considered to be the zero axis.

In Fig.4, $v_{\alpha\beta}$ is defined as:

$$v_{\alpha\beta} = \sqrt{v_\alpha^{\,2} + v_\beta^{\,2}} \qquad (3)$$

Angle, θ is defined as:

$$\Theta = \tan^{-1} (v_\alpha/v_\beta) \qquad (4)$$

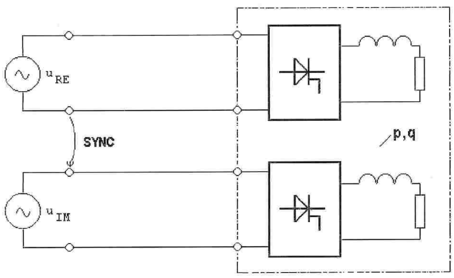

Fig.2. Real and virtual circuits of the complex power system under investigation

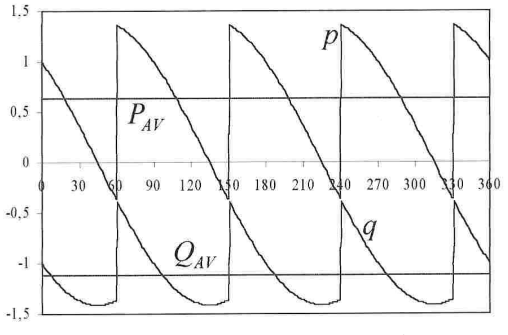

Fig.3. Instantaneous and average values for the active, p, and reactive power ,q, of the complex single phase power system under consideration

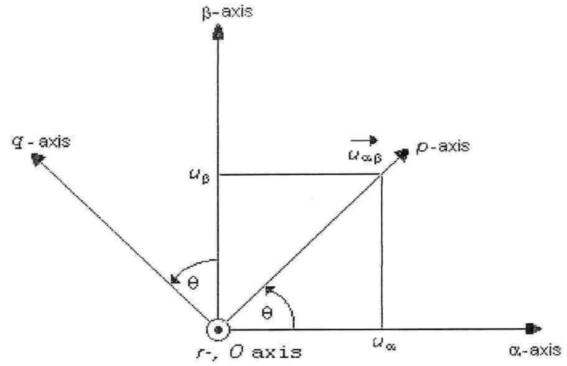

Fig.4. Supply voltage in the complex single phase power system under consideration represented in the fixed and rotating frame of reference

III REFERENCE CURRENT EXPRESSION FOR THE ACTIVE POWER FILTER

In this section instantaneous expressions for the reference currents for an active power filter to compensate for the harmonic distortion and reactive power in the single phase power system under investigation are derived. Because of the symmetry of the complex voltage and current vectors trajectories, Fig.1, the average value of the active and reactive powers for both of the real and virtual phases can be evaluated from (1) as follows:

$$P_{RE\ AV} = P_{AV}/2 = 2/T \int_0^{T/4} (v_\alpha i_\alpha + v_\beta i_\beta)dt$$

$$(5)$$

$$Q_{RE\ AV} = Q_{AV}/2 = 2/T \int_0^{T/4} (v_\alpha i_\beta - v_\beta i_\alpha)dt$$

The real current, i_α, can be derived from (1) and (3) as follows:

$$i_\alpha = 1/v_{\alpha\beta}^{\,2} (v_\alpha\, p - v_\beta\, q)$$

$$= 1/v_{\alpha\beta} (v_\alpha (P_{AV} + p_\sim) - v_\beta (Q_{AV} + q_\sim)) \qquad (6)$$

In (6), $p_\sim$ and $q_\sim$ respectively are the ripple active and reactive power components, P_{AV} and Q_{AV} respectively are the average active and reactive power of the complex power system under consideration.

IV EXPERIMENTAL RESULTS

A test rig was set up to verify the theoretical derivations above. An active power filter is implemented with the current reference in (6) used as an input to the filter and the digital signal processing of the voltages and currents is implemented using a 32 bit floating point DSP,TMS320C31. The configuration of the experimental setting is shown in Fig.5.

The single phase power system under experimentation is a sinusoidal supply voltage feeding a diode bridge rectifier with an RL load connected to the dc side.

The active power filter is a shunt type comprising of a fully-controlled ac to dc IGBT bridge rectifier together with a passive filter in the form of an input inductor L of 1.2 mH and a capacitor of 10,000 μF connected to the output. Both the load and the active power filter are rated at 25 kVA. The output current of the active power filter is controlled by a hysteresis comparator to confine the switching frequency to 15 kHz.

A Steady State Operation

Fig.6 shows the waveforms of the load current, the compensating current of the active power filter and the supply current. The active power filter performed its task of compensating for the harmonic distortion as the supply current is converted to a pseudo-sinusoidal waveform. The top waveform in Fig.6 shows the original supply current waveform and the bottom waveform shows the supply current waveform after the implementation of the active power filter. The middle waveform is the filter reference or compensating current.

B Dynamic Operation

The dynamic properties of the active power filter are mainly determined by the time required for the computation of the reference current for the active power filter and the cycle time of the digital signal processor implemented in order to execute these computations. Due to the symmetry of the complex voltage and current trajectories in the Gaussian domain within the proposed two virtual axis strategy, Fig.1, the reference current computation time is limited to a quarter of the periodic time of the supply voltage. This leads to improvement of the dynamic performance of the active power filter due to adopting the reference current computation strategy explained in this paper.

The transient response of the voltage across the filtering capacitor when the load is applied is shown in Fig.7.
As it can be seen in Fig.7, the capacitor voltage dips to about 600 V upon the application of the load but the voltage controller responds quickly and brings it back to the reference voltage value of 900 V. the voltage axis in Fig.7 is scaled as 300 V per division.

Fig.8 shows the transient waveforms of the supply current, the load current and the compensating or reference current of the active power filter.

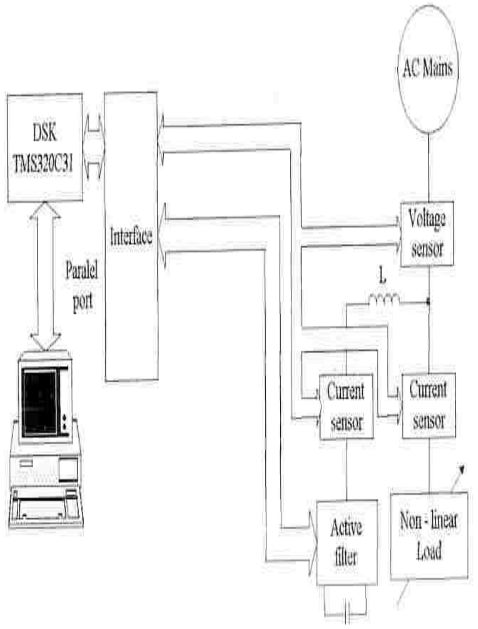

Fig.5. Block diagram of the experimental setting

This figure demonstrates the superior dynamic properties of the active power filter under consideration, using the current reference expression referred to earlier. In Fig.8, the supply current response illustrates a time lag, starting from the moment of the full load application. This time lag is caused by the filter inductance, L.

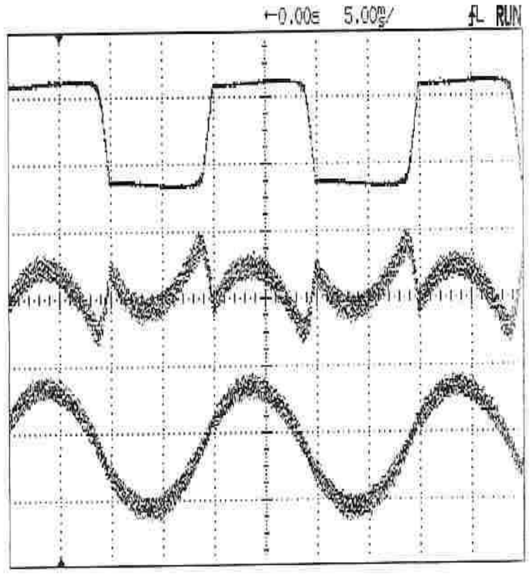

Fig.6. Waveforms of the supply current of the single phase power system under consideration before (top) and after (bottom) the implantation of the active power filter with the shown (middle) reference or compensating current

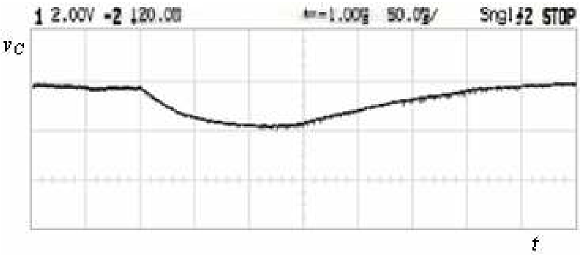

Fig.7. Capacitor voltage of the active power filter upon the load application

V CONCLUSIONS

A novel strategy, virtual two axes or orthogonal transformation technique, is used to yield the compensating current expressions for the active power filter of a single phase power supply feeding a solid state power converter connected to an inductive load. The compensating current equations are expressed in terms of the real and virtual supply voltages and currents. Experimental results demonstrated the effectiveness of the novel active power filter control strategy. In particular, the fast dynamic response achieved by the methodology described in this paper has been highlighted.

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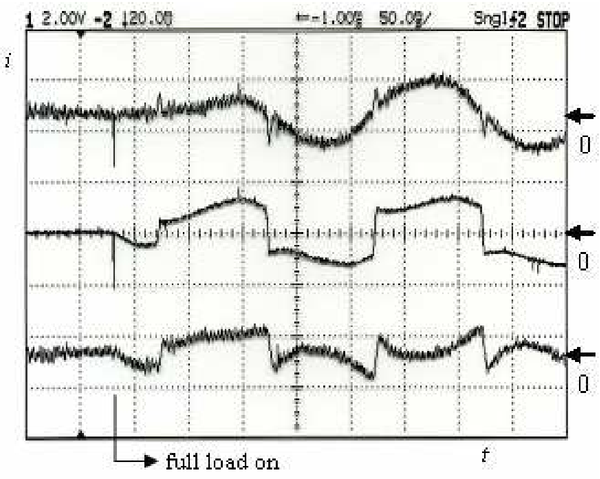

Fig.8. Transient waveforms of the supply current to the single phase power system under consideration after (top) and before (middle) the implementation of the active power filter supplying the filter reference current (bottom)