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Power Quality Improvement Using Hybrid Power Filter Based On Dual Instantaneous Reactive Power Theory With Hysteresis Current Controller

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Abstract : In this paper control algorithm for a three phase hybrid power filter is proposed. It is constituted by a series active filter and a passive filter connected in parallel with the load. The control strategy is based on the vectorial theory dual formulation of instantaneous reactive power, so that the voltage waveform injected by the active filter is able to compensate the reactive power and the load current harmonics and to balance asymmetrical loads. The proposed algorithm also improves the behavior of the passive filter. Here the control scheme is given to Hysterisis current controller in the place of PWM generator for removing very small distortions in waveforms. Simulations have been carried out on the MATLAB-Simulink platform with different loads and with variation in the source impedance. This analysis allowed an experimental prototype to bedeveloped. Experimental and simulation results are presented.

Key words : Active power filters, instantaneous reactive power theory, harmonics, hybrid filter,hysteresis current controller, power quality.

INTRODUCTION

Power Quality is of key concern for the industry nowadays.The presence of harmonics in the power electrical systems is the main cause of the electrical wave pollution that so many problems carry. The indiscriminate increase of non-linear loads has given rise to investigation into new compensation equipment based on power electronics. The main design target for this equipment is the elimination of the harmonics present in the system. Depending on the application type, series or parallel configurations or combinations of active and passive filters can be proposed. The presence of harmonics in power lines results in greater power losses in the distribution system, interference problems in communication systems and, sometimes, in operation failures of electronic equipments, which are more and more sensitive since they include micro-electronic control systems, which work with very low energy levels. So, for the better performance of the system it should be free from harmonics. For that purpose filters are used,Because of these problems, the issue of the power quality delivered to the end consumers is, more than ever, an object of great concern. The combination of series active filter and shunt passive filter called as Hybrid filter, which uses Instantaneous Power Theory is presented in the following paper. The series active filter presents functionalities to improve the system stability and to suppress distortions at the system voltages. The shunt passive filter is designed to drain the harmonic currents generated by the non-linear load. The control strategy applied in this network is based on the definitions for instantaneous powers in the reference frame (p-q theory). The compensated electric system was simulated in MATLAB-Simulink, and the strategy was applied to a three-phase system with balanced and unbalanced loads.The simulation results used to verify the theoretical behaviour are presented.

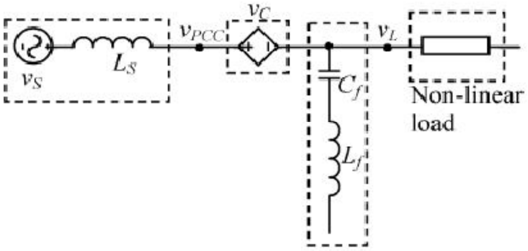

Fig.1: series active filter and parallel passive filter

DUAL INSTANTANEOUS REACTIVE POWER THEORY

The instantaneous reactive power theory is the most widely used as a control strategy fo the APF. It is mainly applied to compensation equipment in parallel connection. For this, a balanced and resistive load is considered as reference load.This theory is based on a Clarke coordinate transformation from the phase coordinates (see Fig.2) below

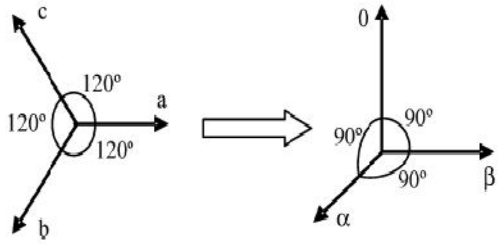

Fig.2: Transformation from the phase reference system (abc) to the 0αβ system

In a three-phase system such as that presented in voltage and current vectors can be defined by

$$v = [v_a \quad v_b \quad v_c]^T \qquad i = [i_a \quad i_b \quad i_c]^T \tag{1}$$

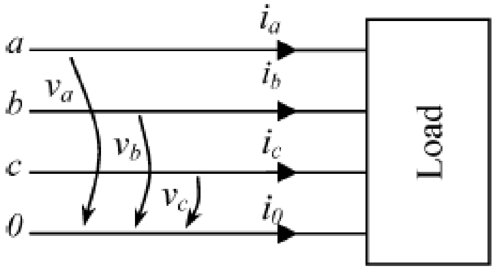

Fig.3: Three-Phase System

The vector transformations from the phase reference system a-b-c to α-β-0 coordinates can be obtained, thus

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}. \tag{3}$$

The instantaneous real power in the α-β-0 frame is cal-culated as follows

$$p_{3\phi}(t) = v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0 \tag{4}$$

This power can be written as

$$p_{3\phi}(t) = p + p_0 \tag{5}$$

where is the instantaneous real power without zero sequence component and given by

$$p = v_\alpha i_\alpha + v_\beta i_\beta \tag{6}$$

It can be written in vectorial form by means of dot product

$$p = \boldsymbol{i}^T_{\alpha\beta} \boldsymbol{v}_{\alpha\beta} \tag{7}$$

Where $\boldsymbol{i}^T_{\alpha\beta}$ is the transposed current vector in α-βcoordinates

$$\boldsymbol{i}_{\alpha\beta} = [i_\alpha \quad i_\beta]^T \tag{8}$$

In the same way, $\boldsymbol{v}_{\alpha\beta}$ is the voltage vector in the same coordinates

$$\boldsymbol{v}_{\alpha\beta} = [v_\alpha \quad v_\beta]^T \tag{9}$$

In (5), p_0 is the zero sequence instantaneous power, calculated as follows

$$p_0 = v_0 i_0 \tag{10}$$

In a three-wire system there are no zero-sequence current components, that is, $i_0 = 0$ In this case,only the instantaneous power defined on the α-β axes exists, because the product $v_0 i_0$ is the always zero.

The imaginary instantaneous power is defined by the equation

$$q \hat{=} v_\alpha i_\beta - v_\beta i_\alpha \tag{11}$$

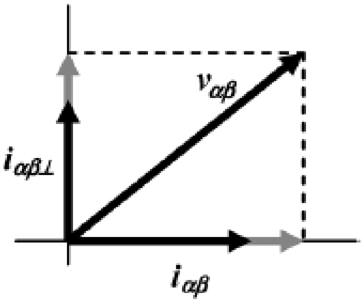

Fig.4: Decomposition of the voltage vector

In accordance with (7), this can be expressed by means of the dot product

$$q = \boldsymbol{i}^T_{\alpha\beta\perp} \boldsymbol{v}_{\alpha\beta} \tag{12}$$

where $\boldsymbol{i}^T_{\alpha\beta\perp}$ is the transposed current vector perpendicular to $\boldsymbol{i}_{\alpha\beta}$ and it can be defined as follows

$$\boldsymbol{i}_{\alpha\beta\perp} = [i_\beta \quad -i_\alpha]^T \tag{13}$$

Both power variables previously defined can be expressed as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \boldsymbol{i}^T_{\alpha\beta} \\ \boldsymbol{i}^T_{\alpha\beta\perp} \end{bmatrix} \boldsymbol{v}_{\alpha\beta} \tag{14}$$

In the αβ plane, $\boldsymbol{i}_{\alpha\beta}$ and $\boldsymbol{i}_{\alpha\beta\perp}$ vectors establish two coordinates axes. The voltage vector $\boldsymbol{v}_{\alpha\beta}$ can be decomposed in its orthogonal projection on the axis defined by the currents vectors,Fig.4.By means of the current vectors and the real and imaginary instantaneous power, the voltage vector can be calculated

$$\boldsymbol{v}_{\alpha\beta} = \frac{p}{i^2_{\alpha\beta}} \boldsymbol{i}_{\alpha\beta} + \frac{q}{i^2_{\alpha\beta}} \boldsymbol{i}_{\alpha\beta\perp} \tag{15}$$

COMPENSATION STRATEGY

Electric companies try to generate electrical power as sinusoidal and balanced voltages so it has been obtained as a reference condition in the supply. Due to this fact, the compensation target is based on an ideal reference load which must be resistive, balanced and linear. It means that the source currents are collinear to the supply voltages and the system will have unity power factor. If, in Fig. 3, voltages are considered as balanced and sinusoidal, ideal currents will be proportional to the supply voltages

$$\boldsymbol{v} = R_e \boldsymbol{i} \tag{16}$$

R_e is the equivalent resistance, $\boldsymbol{v}$ the load voltage vector and $\boldsymbol{i}$ the load current vector.

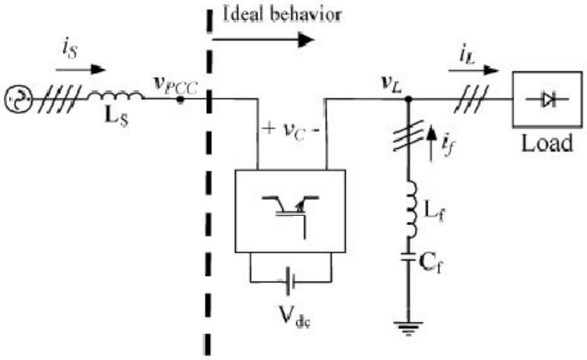

Fig.5: System with compensation equipment

The average power supplied by the source will be

$$P_S = I_1^2 R_e \tag{17}$$

In this equation, I_1^2 is the square rms value of the fundamental harmonics of the source current vector. It must be supposed that when voltage is sinusoidal and balanced, only the current fundamental component transports the power consumed by the load. Compensator instantaneous power is the difference between the total real instantaneous power required by the load and the instantaneous power supplied by the source

$$p_C(t) = p_L(t) - p_S(t) \tag{18}$$

In this equation, the average power exchanged by the compensator has to be null, that is

$$P_C = \frac{1}{T}\int p_C(t)dt = 0 \tag{19}$$

When average values are calculated in (18), and (17) and (19) are taken into account

$$0 = \frac{1}{T}\int p_L(t)dt - I_1^2 R_e \tag{20}$$

Therefore, the equivalent resistance can be calculated as

$$R_e = \frac{P_L}{I_1^2} \tag{21}$$

Where P_L is the load average power, defined as

$$P_L = \frac{1}{T}\int p_L(t)dt \tag{22}$$

Fig. 5 shows the system with series active filter, parallel passive filter and unbalanced and nonsinusoidal load. The aim is that the set compensation equipment and load has an ideal behaviour from the PCC. The voltage at the active filter connection point in 0αβ coordinates can be calculated as follows

$$\boldsymbol{v}_{PCC\boldsymbol{\alpha\beta}} = \frac{P_L}{I_1^2}\boldsymbol{i}_{\boldsymbol{\alpha\beta}} \tag{23}$$

$\boldsymbol{i}_{\boldsymbol{\alpha\beta}}$ is the source current in 0αβ coordinates. In this equation, the restriction of null average power exchanged by the active filter is imposed.
The load voltage is given according to (15) by

$$\boldsymbol{v}_{\boldsymbol{L\alpha\beta}} = \frac{p_L}{i_{\alpha\beta}^2}\boldsymbol{i}_{\boldsymbol{\alpha\beta}} + \frac{q_L}{i_{\alpha\beta}^2}\boldsymbol{i}_{\boldsymbol{\alpha\beta}\perp} \tag{24}$$

where p_L is the real instantaneous power and q_L is the load Imaginary instantaneous power.
The reference signal for the output voltage of the active filter is $\boldsymbol{v}^*_{\boldsymbol{C\alpha}\beta} - \boldsymbol{v}_{\boldsymbol{PCC}\alpha\beta} - \boldsymbol{v}_{\boldsymbol{L\alpha}\beta}$ (25)

Considering (23) and (24), the compensation voltage is

$$\boldsymbol{v}^*_{\boldsymbol{C\alpha}\beta} = \left(\frac{P_L}{I_1^2} - \frac{p_L}{i_{\alpha\beta}^2}\right)\boldsymbol{i}_{\boldsymbol{\alpha\beta}} - \frac{q_L}{i_{\alpha\beta}^2}\boldsymbol{i}_{\boldsymbol{\alpha\beta}\perp} \tag{26}$$

When the active filter supplies this compensation voltage, the set load and compensation equipment behaves as a resistor R_e.Finally, if currents are unbalanced and nonsinusoidal, a balanced resistive load is considered as ideal reference load. Therefore,the equivalent resistance must be defined by the equation

$$R_e = \frac{P_L}{I_1^{+2}}. \tag{27}$$

Here, I_1^{+2} is the square rms value of the positive sequence fundamental component. In this case, (26) is modified, where

$$\boldsymbol{v}^*_{\boldsymbol{C\alpha}\beta} = \left(\frac{P_L}{I_1^{+2}} - \frac{p_L}{i_{\alpha\beta}^2}\right)\boldsymbol{i}_{\boldsymbol{\alpha\beta}} - \frac{q_L}{i_{\alpha\beta}^2}\boldsymbol{i}_{\boldsymbol{\alpha\beta}\perp} \tag{28}$$

Reference signals are obtained by means of the reference calculator shown in Fig. 7 and Fig. 9. In the case of unbalanced loads, the block “fundamental component calculation” in Fig.7 is replaced by the scheme shown in Fig. 8,which calculates the current positive sequence fundamental component.The compensation target imposed on a four-wire system is the one presented in (16). However, a modification in the control scheme of Fig. 9 is necessary. This consists in including a third input signal from the zero sequence power p_0 in the control block where is generated. The proposed control strategy may be suitable in a stiff feeder, Where $v^*_{0\alpha\beta}$ voltage could be considered undistorted.

HYBRID FILTER

There are two approaches to the mitigation of power quality problems.The first approach is called load conditioning,which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. A flexible and versatile solution to voltage quality problems is offered by active power filter. Currently, active power filters are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. This combination of a shunt passive filter and a series active filter is generally called a hybrid filter. The series active filter generates harmonic voltages to cancel the harmonic voltages produced by the non-linear load and the shunt passive filter eliminates harmonic currents generated by the non-linear load. The hybrid filter presented in this paper compensates for the voltage harmonics produced by the non-linear load and also improves the source currents by eliminating the current harmonics to a certain extent. The control technique used in this paper is based on instantaneous power theory.The system shown in Fig. 6 has been simulated in the Matlab-Simulink platform to verify the proposed control. Each power device has been modeled using the SimPowerSystem toolbox library. The power circuit is a three-phase system supplied by a sinusoidal balanced three-phase voltage source with a source inductance of and a source resistance . The inverter consists of an Insulated Gate Bipolar Transistor (IGBT) bridge. On the dc side, two 100-V dc sources are connected.An LC filter has been included to eliminate the high frequency components at the output of the inverter. This set is connected to the power system by means of three single-phase transformers with a turn ratio of 1:1.

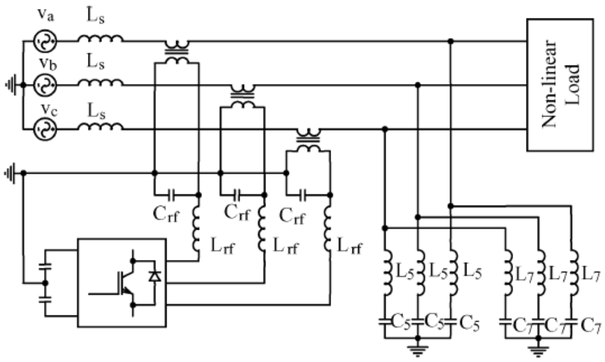

Fig.6: Series active power and passive filter topology

The series active filter consists of a three-phase voltage-fed PWM inverter connected in series with the power grid through three single-phase transformers. The power converter is a standard 3-leg voltage controlled Voltage Source Inverter (VSI) with a capacitor on the dc side. A shunt passive filter is connected to the output of the series active filter inverter in order to smooth the ripples on the generated compensating voltages. The passive filter is constituted by two LC branches tuned to the fifth and seventh harmonics.

Table.1: System Parameters

Parameter	Ratings	
Source Voltage	100v	
Transformer	10kva , 50Hz	
Source Impedance	L_S =5.8mH , R_S =3.6Ω	
Dc Voltage	100v	
Non Linear Load	L=55mH , R=25Ω	
Ripple Filter	L_{rf} =13.5mH	C_{rf} =50µF
Passive Filter	L_5=13.5mH	C_5=30µF
	L_7=6.75mH	C_7=30µF

The fundamental component is obtained by means of a block with the scheme shown in Fig.7 below

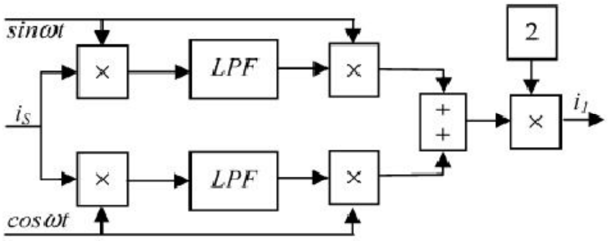

Fig.7: Calculation of fundamental component

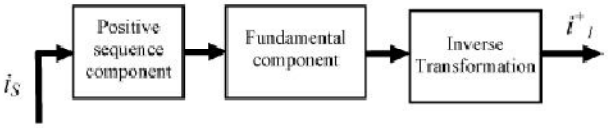

Fig.8: Modification in the contol scheme for unbalanced load

The control scheme used here is shown in below fig.9

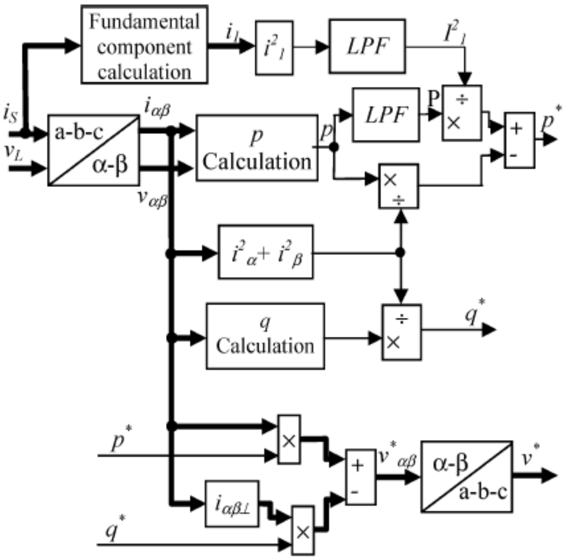

Fig.9: Control Scheme

Table.2: Passive Element Values of The Load

Phases	C	R
a	2200µF	16.67Ω
b	2200µF	25Ω
c	2200µF	50Ω

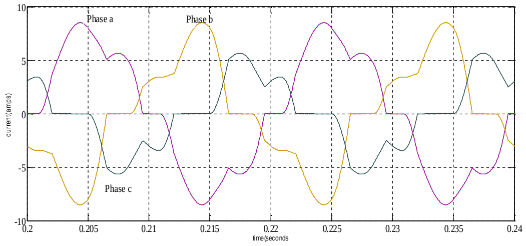

Fig.10: source current without filters & unbalanced load

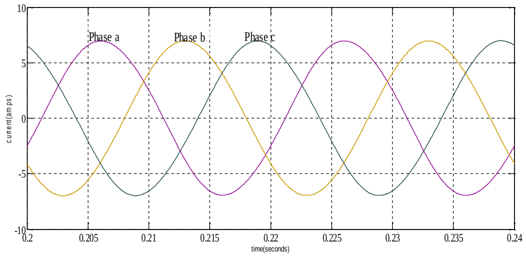

Fig.11: source current with active filters & unbalanced load

HYSTERESIS CURRENT CONTROLLER

Hysteresis is the dependence of a system not only on its current environment but also on its past environment. This dependence arises because the system can be in more than one internal state. To predict its future development, either its internal state or its history must be known. If a given input alternately increases and decreases, the output tends to form a loop.However, loops may also occur because of a dynamic lag between input and output. Often, this effect is also referred to as hysteresis, or rate-dependent hysteresis. This effect disappears as the input changes more slowly, so many experts do not regard it as true hysteresis.

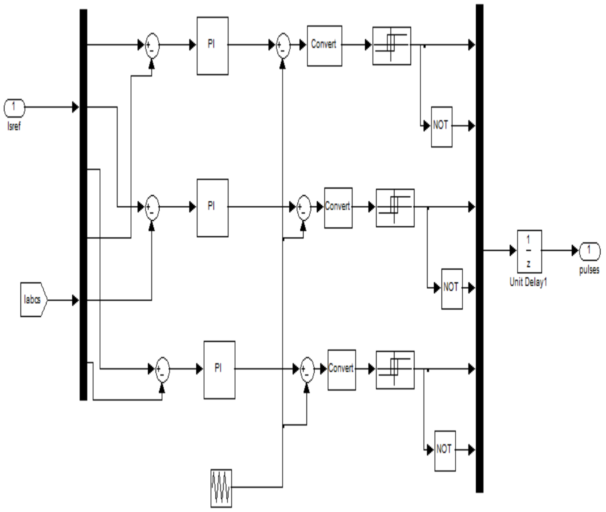

Fig.12: Hysteresis Current Controller

Hysteresis current control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform Hysteresis current control is the easiest control method to implement One disadvantage is that there is no limit to the switching frequency, but additional circuitry can be used to limit the maximum switching frequency. Here the control scheme is given to Hysterisis current controller in the place of PWM generator for removing very small distortions in waveforms.Simulations have been carried out on the MATLAB-Simulink platform with different loads and with variation in the source impedance.

CONCLUSIONS

A control algorithm for a hybrid power filter constituted by a series active filter and a passive filter connected in parallel with the load is proposed. The control strategy is based on the dual vectorial theory of electric power. The new control approach achieves the following targets.

—The compensation characteristics of the hybrid compensator do not depend on the system impedance.
—The set hybrid filter and load presents a resistive behavior. This fact eliminates the risk of overload due to the current harmonics of nonlinear loads close to the compensated system.
—This compensator can be applied to loads with random power variation as it is not affected by changes in the tuning frequency of the passive filter. Furthermore, the reactive power variation is compensated by the active filter.
—Series and/or parallel resonances with the rest of the system are avoided because compensation equipment and load presents resistive behavior.

Therefore, with the proposed control algorithm, the active filter improves the harmonic compensation features of the passive filter and the power factor of the load. Simulations with the MATLAB-Simulink platform were performed with different loads and with variation in the source impedance.

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