DIFFERENT VIEW ON PQ THEORY USED IN THE CONTROL ALGORITHM OF ACTIVE POWER FILTERS

R. Pavlanin[1], M. Marinelli[2], B. Zigmund[1]

[1]*University of Zilina in Zilina, Faculty of Electrical Engineering, Department of Mechatronics and Electronics, Univerzitna 8, 010 26 Zilina, Slovakia, pavlanin@fel.utc.sk, brano.zigmund@gmail.com,*
[2]*Politecnico di Bari, Dipartimento di Elettrotecnica ed Elettronica, V. Orabona 4, 70125 Bari, Italy, marinelli@deemail.poliba.it*

Summary The improvement of power quality is a frequently discussed issue, which still requires a considerable research effort to be devoted to the study of the problem. The aim of this paper is to describe some problems related to the control of switching compensators, commonly known as active power filters. It also includes some shortcomings of pq theory regarded as three phase instantaneous power theory. The term “shortcomings” means that the pq theory does not provide a proper description of power properties. Moreover the control algorithm based on this theory only achieves satisfactory results for sinusoidal balanced voltage system. Nevertheless it can still be considered a helpful approach to the problem under study. The simulation results presented in this paper illustrate the weaknesses of the pq theory.

1. INTRODUCTION

Increasing number of power electrical and electronic equipment which affect negatively the AC main caused the question of power quality became very important. Reactive power, harmonics and also unbalance are coupled with low level of power quality. Nevertheless, a lot of equipment needs reactive power (electrical motors, transformers etc.) or harmonics (semiconductor converters, induction furnaces, lighting and heating equipment etc.) in order to work properly. Consequences of the negative effects of such disturbances are increasing costs for delivering power (higher losses, lower efficiency), faster ageing process of equipment, unpredicted faults in power supply, communication interference and so on. Therefore it is desirable to compensate these negative effects as much as possible and also as closest as possible to the source of disturbances. In general it is possible to say that an ideal load has to draw from main only active power. This means all loads connect to the mains have to behave like a resistor (current has to follow the voltage waveform and has to be in phase with voltage). These properties can be described by power factor given by:

$$\Lambda = \frac{P}{S} \tag{1}$$

where P is active power and S is apparent power. That means it is desirable to connect to the mains only loads with unity power factor. The apparent power is in this case defined as:

$$S = \sqrt{P^2 + Q^2 + D^2} \tag{2}$$

Where Q is reactive power and D is distortion power. Nevertheless, real loads need reactive and distortion (harmonics) power for their correct operation. It is necessary to compensate required reactive and distortion power through the use of dedicated devices. Nowadays many compensation techniques are presented. Passives techniques as capacitors battery for a compensation of reactive power, or passive serial filters tuned for compensation specific harmonic have a lot of disadvantage, for example: massiveness, unexpectedly resonances coupled with another device and so on. Diode rectifiers with boot chopper (also power factor corrected AC-DC converters) and PWM converters as line-side rectifiers can work with unity power factor. These converters are inseparable input part of inverters, so they can compensate only this device. Providing compensation of several devices together is desirable to use active power filter (APF). Considering a progress in development of semiconductor components is possible to use APF in higher power systems (also considering multilevel topologies etc.), but usually as medium power compensator. Shunt APF provides compensation of nonlinear load to unity power factor (but usually only displacement power factor and lower current harmonics of nonlinear load). Finally result is that the current drawn from main is sinusoidal.

2. SHUNT ACTIVE POWER FILTER TOPOLOGY

As fig.1 shows shunt active power filter is connected in parallel to nonlinear load and to main. Normally works as voltage source inverter VSI with current control loop.

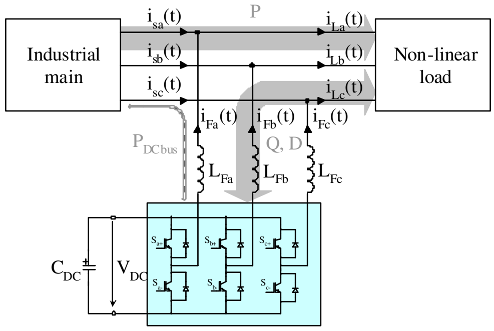

Fig. 1 The general configuration of shunt active filter

It is necessary to connect this inverter to main through the reactors (shown in fig.1). On DC side of inverter is capacitor which in connection with control keeps constant voltage on DC bus. Thus, the main function of active filter is draw reactive and distortion power to nonlinear load. This can be also illustrated by the form of currents. On the base of Kirchhof’s law for each phase is filter current given as:

$$i_F(t) = i_L(t) - i_s(t) \tag{3}$$

According to Fourier’s analysis distorted periodic function (non-harmonic current of load) can be given by sum of sinusoidal functions (sum of harmonics), after load current is:

$$i_L(t) = I_0 + \sum_{i=1}^{n} I_{mi} \sin(i.\omega t - \varphi_i) \tag{4}$$

where I_0 is DC component of current (we will not consider it), I_{mi} is amplitude of i^{th} harmonic, i is harmonic order and φ_i is phase angle of i^{th} harmonic. In general we can consider for line current the following equation:

$$i_s(t) = I_{m1A} \sin(\omega t) \tag{5}$$

where I_{m1A} is the amplitude of active part of current fundamental component. Current defined by (5) is in phase with voltage providing sinusoidal line voltage. That means purely resistive load for main. After compensating current of filter is given by:

$$i_F(t) = -I_{m1R} \sin\left(\omega t - \frac{\pi}{2}\right) + \sum_{i=2}^{n} I_{mi} \sin(i.\omega t - \varphi_i) \tag{6}$$

where I_{m1R} is the amplitude of reactive part of current fundamental component. This current representation has physical background. From the power representation, first component of (6) presents reactive power of fundamental component and second distortion power (considering sinusoidal line voltage).

3. PQ THEORY

This theory (Akagi, Kanazawa and Nabae in 1983-84) is suitable for APF control, specifically for reference current calculation. It is based on instantaneous voltage and current in three phase system (3 or 4 wire). Phase voltages and currents are transferred from abc reference frame to the orthogonal αβ reference frame. Using this transformation we obtain for a voltage system:

$$\begin{bmatrix} u_\alpha(t) \\ u_\beta(t) \\ u_0(t) \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a(t) \\ u_b(t) \\ u_c(t) \end{bmatrix} \tag{7}$$

And for three phase current system:

$$\begin{bmatrix} i_\alpha(t) \\ i_\beta(t) \\ i_0(t) \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} \tag{8}$$

Providing three phase three wire system (without neutral wire) where for currents is valid:

$$i_a(t) + i_b(t) + i_c(t) = 0 \tag{9}$$

We can eliminate zero sequence current from (8), this eliminates zero sequence of instantaneous power, which is for four wire system given by:

$$p_0(t) = u_0(t).i_0(t) \tag{10}$$

On the base of instantaneous αβ components Akagi et al defined "instantaneous active and reactive power" by following equations:

$$p(t) = u_\alpha(t).i_\alpha(t) + u_\beta(t).i_\beta(t) \tag{11}$$

$$q(t) = u_\beta(t).i_\alpha(t) - u_\alpha(t).i_\beta(t) \tag{12}$$

(note: in some literature we can meet with different signs in (12), it is about standards of inductive and capacitive character of reactive power).

Using the inverse transformation [6] αβ→abc can be obtained expression of "instantaneous active and reactive power" defined by instantaneous phase voltages and currents as:

$$p(t) = u_a(t).i_a(t) + u_b(t).i_b(t) + u_c(t).i_c(t) \tag{13}$$

$$q(t) = \left(\frac{u_c(t) - u_b(t)}{\sqrt{3}}\right).i_a(t) + \left(\frac{u_a(t) - u_c(t)}{\sqrt{3}}\right).i_b(t) + \left(\frac{u_b(t) - u_a(t)}{\sqrt{3}}\right).i_c(t) \tag{14}$$

Expressions in parentheses present system of voltages which are phase shifted by 90° compare to u_a, u_b, u_c that is:

$$q(t) = u_a'(t).i_a(t) + u_b'(t).i_b(t) + u_c'(t).i_c(t) \tag{15}$$

Where for voltages is valid:

$$u_a'(t) = u_a\left(t + \frac{T}{4}\right), \quad u_b'(t) = u_b\left(t + \frac{T}{4}\right), \quad u_c'(t) = u_c\left(t + \frac{T}{4}\right) \tag{16}$$

In vector representation they are voltage vectors perpendicular to the phase voltage vectors (as shown in fig.2).

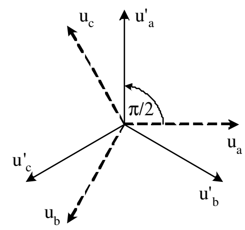

Fig. 2 Vector expression of u'_a, u'_b, u'_c

4. SEVERAL SHORTCOMINGS OF PQ THEORY

In many publications which deal with the control algorithm for shunt APF, we can meet with interpretation of pq theory as theory about three phase instantaneous power (for example [3]). Call this theory by this terminology is not quite correct even in some case it can be misleading. Objective of this part is not to contradict quality of pq theory only point of some misinterpretations. The circuit shown in fig.3 will be used like an example to explain some inadequacies of pq theory. There is three phase power supply which contains of fundamental and 5^{th} harmonic components (non-harmonic). This source supplies three phase non-linear load which draw non-harmonic current. Load current contains fundamental component and 5^{th} harmonic components too. Let us assume that others voltage and current harmonics are negligibly small.

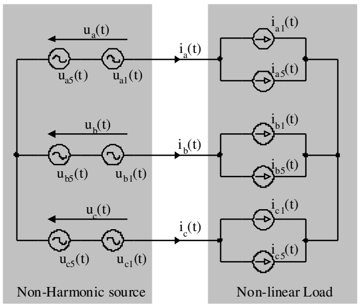

Fig.3 Three phase non-harmonic source supplies three phase non-linear load

In mathematical expression for voltages is valid following equations:

$$\begin{aligned} u_a(t) &= u_{a1}(t)+u_{a5}(t)=U_{m1}\sin(\omega t)+ \\ &+U_{m5}\sin(5\omega t)\,, \end{aligned} \tag{17}$$

$$\begin{aligned} u_b(t) &= u_{b1}(t)+u_{b5}(t)=U_{m1}\sin\left(\omega t-\frac{2\pi}{3}\right)+ \\ &+U_{m5}\sin\left(5\omega t+\frac{2\pi}{3}\right), \end{aligned} \tag{18}$$

$$\begin{aligned} u_c(t) &= u_{c1}(t)+u_{c5}(t)=U_{m1}\sin\left(\omega t+\frac{2\pi}{3}\right)+ \\ &+U_{m5}\sin\left(5\omega t-\frac{2\pi}{3}\right) \end{aligned} \tag{19}$$

And for currents:

$$\begin{aligned} i_a(t) &= i_{a1}(t)+i_{a5}(t)=I_{m1}\sin(\omega t-\varphi_1)+ \\ &+I_{m5}\sin(5\omega t-\varphi_5)\,, \end{aligned} \tag{20}$$

$$\begin{aligned} i_b(t) &= i_{b1}(t)+i_{b5}(t)=I_{m1}\sin\left(\omega t-\frac{2\pi}{3}-\varphi_1\right)+ \\ &+I_{m5}\sin\left(5\omega t+\frac{2\pi}{3}-\varphi_5\right), \end{aligned} \tag{21}$$

$$\begin{aligned} i_c(t) &= i_{c1}(t)+i_{c5}(t)=I_{m1}\sin\left(\omega t+\frac{2\pi}{3}-\varphi_1\right)+ \\ &+I_{m5}\sin\left(5\omega t-\frac{2\pi}{3}-\varphi_5\right) \end{aligned} \tag{22}$$

From (13) we can see that three phase instantaneous active power p(t) consists of sum of instantaneous powers from each phase. For the sake of brevity we will consider only phase a instantaneous power $p_a(t)$ which can be defined by the following equation:

$$\begin{aligned} p_a(t) &= u_a(t).i_a(t)=u_{a1}(t).i_{a1}(t)+u_{a5}(t).i_{a5}(t)+ \\ &+u_{a1}(t).i_{a5}(t)+u_{a5}(t).i_{a1}(t) \end{aligned} \tag{23}$$

(note: we should consider existence of others phase instantaneous powers $p_b(t)$, $p_c(t)$). For simplification, we will separate parts of (23) created by harmonics with the same order of voltage and current from parts created by harmonics with different order of voltage and current that is:

$$p_a(t)=x_a(t)+y_a(t) \tag{24}$$

$$x_a(t)=u_{a1}(t).i_{a1}(t)+u_{a5}(t).i_{a5}(t) \tag{25}$$

$$y_a(t)=u_{a1}(t).i_{a5}(t)+u_{a5}(t).i_{a1}(t) \tag{26}$$

From (17), (20) and (25) we may derive:

$$\begin{aligned} x_a(t) = &\left[\overbrace{\frac{U_{m1}.I_{m1}}{2}\left(\cos\varphi_1-\cos\varphi_1.\cos(2\omega t)\right)}^{\text{instantaneous active power from 1.harmonic}}+\right. \\ &\left.+\overbrace{\frac{U_{m5}.I_{m5}}{2}\left(\cos\varphi_5-\cos\varphi_5.\cos(10\omega t)\right)}^{\text{instantaneous active power from 5.harmonic}}\right]- \\ &-\left[\overbrace{\frac{U_{m1}.I_{m1}}{2}\sin\varphi_1.\sin(2\omega t)}^{\text{instantaneous reactive power from 1.harmonic}}+\right. \\ &\left.+\overbrace{\frac{U_{m5}.I_{m5}}{2}\sin\varphi_5.\sin(10\omega t)}^{\text{instantaneous reactive power from 5.harmonic}}\right] \end{aligned} \tag{27}$$

Part $x_a(t)$ of instantaneous power $p_a(t)$ contains of two terms. The first participate on production of active power P and the second participate on production reactive power Q for phase a. Parts in first square brackets represent instantaneous active power. Active power P of phase a can be defined as average value of this part over one period of fundamental component. Also can by defined as average value of total phase instantaneous power $p_a(t)$, because average values of instantaneous reactive and distortion powers over one period are zero. In general can be active power P expressed by:

$$P_{1ph}=AVG(p_{1ph}(t))=\frac{1}{T}\int_0^T p_{1ph}(t)dt \tag{28}$$

where $p_{1ph}(t)$ is one phase instantaneous power. Parts in second square brackets (27) represent instantaneous reactive power for phase a. Reactive power Q can be defined as a sum of maximal values of instantaneous reactive powers of each harmonic (with the same order of voltage and current).

$$Q_{1ph}=\sum_{i=1}^{n}MAX\left(\frac{U_{mi}.I_{mi}}{2}\sin\varphi_i.\sin(i.2\omega t)\right) \tag{29}$$

By defining $x_a(t)$ as a sum of instantaneous active and reactive power, we connect function $y_a(t)$ (26) with properties of distortion power (harmonics distortion). Definition of distortion power derives from interaction with different order harmonic components of voltage and current (so-called cross combination of voltage and current harmonics). That is consequential from function $y_a(t)$. From (17), (20) and (26) we may derive the following equation:

$$\begin{aligned} y_a(t) = &\left[\frac{U_{m1}.I_{m5}}{2}\left(\cos(4\omega t-\varphi_5)-\cos(6\omega t-\varphi_5)\right)+\right. \\ &\left.+\frac{U_{m5}.I_{m1}}{2}\left(\cos(4\omega t+\varphi_1)-\cos(6\omega t-\varphi_1)\right)\right] \end{aligned} \tag{30}$$

On the basis of the definition of apparent power S (2) and from P (28), Q (29) can be obtained value of distortion power D for phase a. Previous equations describe instantaneous power of phase a. We can obtain equivalent equations and waveforms for others phases ($x_b(t)$, $x_c(t)$ and $y_b(t)$, $y_c(t)$) with the respect of phase shift (see also fig.4, 5 and 6). Thus, from one phase instantaneous power we can define properties of active, reactive and distortion power.

If we will sum each phase instantaneous powers $p_a(t)$, $p_b(t)$ and $p_c(t)$ (equation (13)) then oscillating parts of $x_a(t)$, $x_b(t)$ a $x_c(t)$ and also parts of $y_a(t)$, $y_b(t)$ a $y_c(t)$ with 4ω frequency will cancel each others. This is given by following equation:

$$x(t) = x_a(t) + x_b(t) + x_c(t) = = 3.\frac{U_{m1}.I_{m1}}{2}\cos\varphi_1 + 3.\frac{U_{m5}.I_{m5}}{2}\cos\varphi_5 \quad (31)$$

$$y(t) = y_a(t) + y_b(t) + y_c(t) = = -3\left(\frac{U_{m1}.I_{m5}}{2}\cos(6\omega t - \varphi_5) + \frac{U_{m5}.I_{m1}}{2}\cos(6\omega t - \varphi_1)\right) \quad (32)$$

Fig.4, 5 and 6 show examples of this functions and three phase active power p(t), included theirs phase parts during one period of fundamental harmonic (valid for following parameters: U_{m1}=100V, U_{m5}=10V, I_{m1}=10A, I_{m5}=5A, $\varphi_1=\pi/4$ a $\varphi_5=\pi/4$).

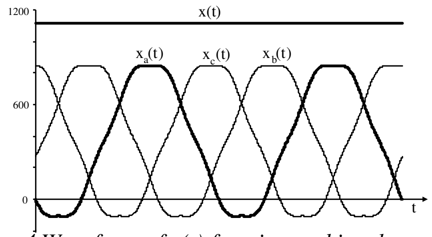

Fig. 4 Waveform of x(t) function and its phase parts

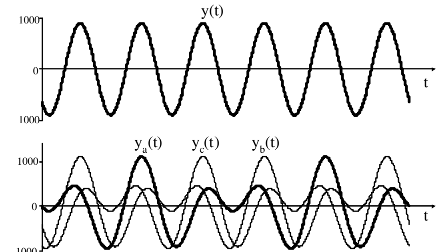

Fig. 5 Waveform of y(t) function and its phase parts

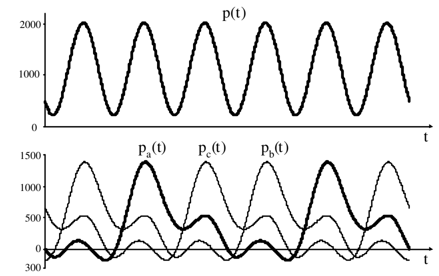

Fig. 6 Three phase instantaneous active power p(t) with its phase parts

As a final result, part x(t) represents DC component and y(t) represents AC component in three phase "instantaneous active power" p(t), that is:

$$p(t) = x(t) + y(t) = p_{DC} + p_{AC} \quad (33)$$

We can see that p_{DC} represents three phase active power P_{3ph}. It can be also defined as triple of one phase active power, defined by (28). AC component p_{AC} represents interaction between harmonics with different order of voltage and current (distortion power created by harmonics). From (31) it is clear that DC component p_{DC} of p(t) in this case of non-harmonic power supply is also created by 5.harmonic components of voltage and current. This fact eliminates the use of pq theory in reference current calculation of shunt APF in circuits with non-harmonic power supply (see also part of reference current calculation).

In paper [4] author intends if it is correct to use word "instantaneous" in pq theory. His reasoning was based on using the theory of the currents' physical components. There are some examples: "According to pq theory can occur instantaneous reactive currents even if a load has zero reactive power (purely resistive load), moreover this current can be non-sinusoidal in circuit with a sinusoidal supply voltage and no source of current distortion in load." To support this idea we can add some question with example. Can instantaneous active power during one period of fundamental harmonic contain two polarities? As an example can help fig.7, it is more theoretical than practical example, because in this case is amplitude of current 5.harmonic bigger than fundamental (consider circuit on fig.3 and valid parameters: U_{m1}=100V, U_{m5}=10V, I_{m1}=5A, I_{m5}=10A, $\varphi_1=\pi/4$ a $\varphi_5=\pi/4$)

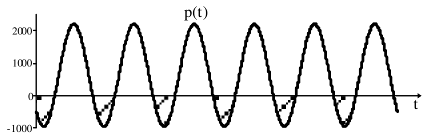

Fig. 7 Three phase instantaneous active power p(t) in case $I_{m5}>I_{m1}$

Fig.7 shows that in certain time load returns energy back to source. Behavior like this is usually connected with reactive or distortion (harmonic) power. In this case negative part of instantaneous active power is caused by harmonics interaction (amplitude of $p_{AC}(t)$) that is distortion power (note: we still consider balanced voltage and current system, i.e. power created by unbalanced is neglected). Total instantaneous active power for balanced three phase system should be constant and equal to triple of one phase active power, that is only DC component of "instantaneous active power" defined by pq theory.

Instantaneous reactive power defined by (12) has not any physical meaning, because is represented by non physical voltage system (16). Therefore authors of pq theory named this quantity as instantaneous imaginary power. In any case we would obtain similar results like before with "instantaneous active power" if we will use similar derivation. That means resultant instantaneous imaginary power would contain DC and AC components i.e.:

$$q(t) = q_{DC} + q_{AC} \quad (34)$$

Value of DC component would be equal to triple of reactive power Q_{1ph} defined by (29) for one phase system. Otherwise for definition instantaneous imaginary power by (12) is DC component q_{DC} equal to its average value during one period of fundamental harmonic. It is not correct definition of reactive power in physical meaning. The AC component q_{AC} similarly like in case of "instantaneous active power" would represent interaction between unequal harmonics of voltage (defined by (16)) and current.

5. CONTROL STRATEGY OF APF, REFERENCE CURRENT CALCULATION

In following part we will consider sinusoidal balanced system of line voltages. Reference is the most important part of APF control. In fig.8 is shown block diagram of APF reference current calculation. The calculation is based on pq theory. Inputs of the calculation are phase voltages (v_a, v_b, v_c) and phase load currents (i_{La}, i_{Lb}, i_{Lc}). After transformation (abc→αβ), the αβ components of voltage and load current are the inputs of the block of instantaneous active and reactive power calculation defined by pq theory, equations (11) and (12). As it has been explained before, both of instantaneous powers contain DC and AC components. Shunt APF should inject to the nonlinear load current which consists of every harmonics beyond active part of fundamental current component. In power expression it means all power beyond DC component of instantaneous active power. In this case would be necessary to applied high pass filter on p(t). But for AC component of p(t) it would be mean some time delay, which would cause a mistake for reference current calculation. Compensation of this time delay is quite complicated therefore it is easier to use different methods. The easier method to obtain reference current is based on calculation of active part of fundamental current component which will be after subtracted from load current (see equation 3, 5 and 6). To obtaining only DC part of instantaneous active power p(t) is desirable to use low pass filter. In this case the time delay will not occur because of DC component. We can use multiplication by zero for instantaneous imaginary power q(t) filtering. Back transformation for αβ current components is given by the following equation:

$$\begin{bmatrix} i_{\alpha 1.harm} \\ i_{\beta 1.harrm} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p_{DC} \\ 0 \end{bmatrix} \qquad (35)$$

After the inputs of back transformation will be only the DC part of instantaneous active power (active power of fundamental harmonic) and αβ components of voltage (see fig.8). By the back transformation (35) we will obtain αβ components of active part of current fundamental component. Definitive reference current components can be obtained by subtraction αβ current fundamental components from αβ load current components (shown in fig.8).

(Note: In a case of non-harmonic power supply DC component p_{DC} would contain not only active power of fundamental harmonic, but also some other parts (depend on harmonic spectrum of supply voltage and current, e.g.: in equation (30) with 5[th] harmonic component). That means bigger amplitude of current fundamental harmonic and then mistake in reference current calculation (see also simulation results).

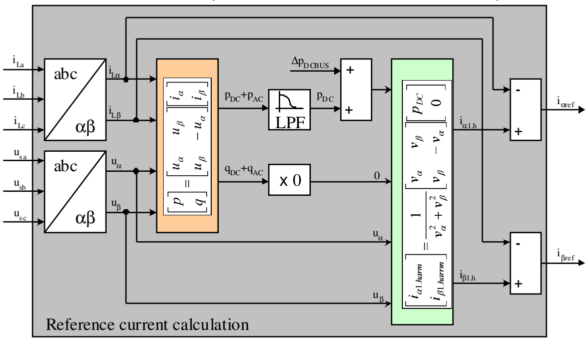

Fig. 8 Reference current calculation block diagram

For completeness' sake of reference current calculation is necessary to consider the DC bus voltage control (keeping constant voltage on capacitor). Charging and discharging of capacitor is ensured by active power flow, in this case represented by active part of current fundamental component. For DC bus control is used PI controller. Value from the output of PI controller Δp_{DCbus} (see fig.9) is added to value of DC component p_{DC} of instantaneous active power (see fig.8).

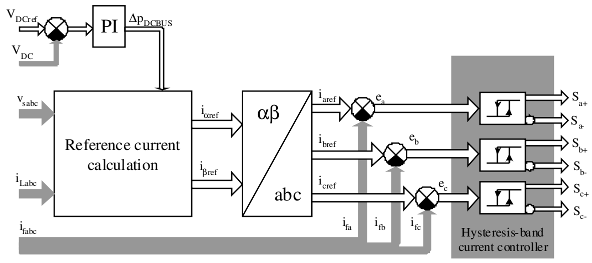

Fig. 9 Control strategy of shunt APF

Reference current in αβ coordinates is transferred by inverse transformation (αβ→abc) to abc reference frame. The hysteresis-band controller is used for the current control. The reference current wave is compared with the actual phase filter current wave. As the error exceeds a prescribed hysteresis band, the upper switch is turned off and the lower switch is turned on. As a results, the output voltage transitions from 0.5 to -0.5 V_{dc}, and the current starts decay. As the error crosses the lower band limit, the lower switch is turned off and the upper switch is turned on.

6. SIMULATION RESULTS

In this section, it is given the simulating results based on theory explained above. It was considered balanced voltage and current system and two possibilities of supply voltage, sinusoidal and non-sinusoidal. Three phase full bridge rectifier was used as a non-linear load. The following parameters were used: three phase balanced voltage system with

U_m=325V, f=50Hz, three phase full bridge rectifier with RL load R=56,3Ω, L=10mH, active filter with voltage on DC bus V_{dc}=700V, C_{dc}=370uF and filter inductance L_f=10mH.

In fig.10 are shown waveforms of line voltages, line currents, load currents and filter currents for a sinusoidal supply voltage. As it can be see line current are almost sinusoidal and in phase with line voltage. The total harmonic distortion of line current is THD_{is}=6% compare with load current THD_{iL}=30%.

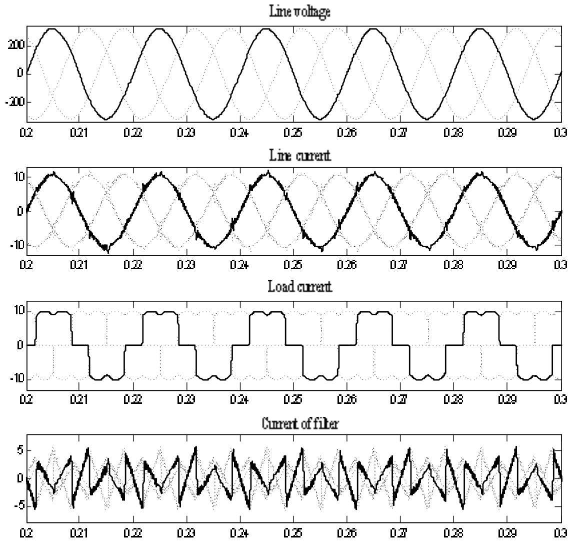

Fig. 10 Simulation results – sinusoidal supply

In fig.11 are shown similar waveforms like before, but the supply voltage is non-sinusoidal. This supply voltage contains fundamental component and 5^{th} harmonic component too (THD_{us}=10%). As it can be see the line current is more distorted (THD_{is}=13%) than before.

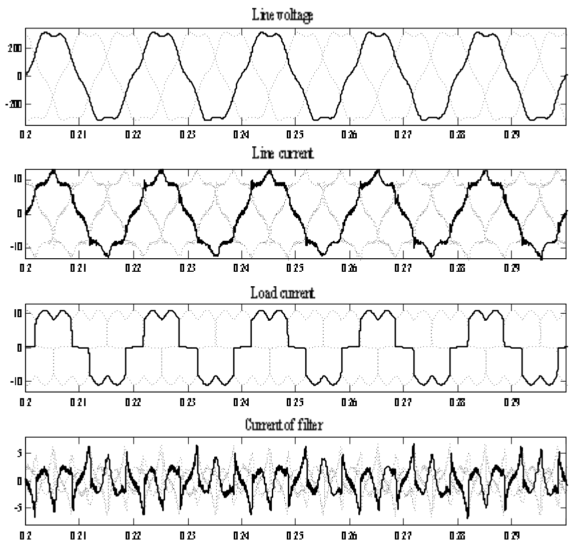

Fig. 11 Simulation results – non-sinusoidal supply

In this case distorted line current is caused by wrong calculation of reference. We can eliminate line voltage harmonics in control algorithm using for example: synchronous reference frame method [5]. However it will not provide an appropriate solution, because voltage in PCC will be still non-sinusoidal and line current could be still distorted.

7. CONCLUSION

Active power filters are an optimal solution to power quality improvement. Nevertheless some problem can occur if the control employed does not perform correctly. This paper analyzed some shortcomings of the pq theory used in the control of active power filters. These shortcomings are not related only to control issues. First it can be said that pq theory does not provide a proper description of power properties. Secondly a control algorithm based on this theory only achieves satisfactory results for sinusoidal balanced voltage system. However sinusoidal balanced voltage system is more a theoretical than a practical consideration. It is finally concluded that pq theory does not provide an appropriate solution when applied to active power filters connected to the Point of Common Coupling (PCC) with non-sinusoidal voltage waveforms.

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REFERENCES

[1] Rashid M. H.: Power electronics (handbook) - Morán L., Dixon J.: Active filters, 2001, pp. 829-851.

[2] Komatsu Y., Kawabata T.: Characteristic of Three Phase Active Power Filter Using Extension pq Theory, Industrial Electronics, 1997. ISIE 1997, Proceedings of the IEEE International Symposium on Jul 1997.

[3] Alfonso J., Couto C., Martins J.: Active Filters with Control Based on the p-q Theory, IEEE Industrial Electronics Society Newsletter vol. 47, n° 3, Sept. 2000, ISSN: 0746-1240, pp. 5-10.

[4] L. S. Czarnecky: On Some Misinterpretations of the Instantaneous Reactive Power p-q Theory, IEEE Trans. on Power Electronics, Volume 19, Issue 3, May 2004 Page(s):828 – 836.

[5] A. Emadi, A. Nasiri, S. B. Bekiarov: Uninterruptible Power Supplies and Active Filters (Power Electronics and Applications Series), CRC press LLC, 2005.

[6] Bose B. M.: Modern power electronics and AC drives, Prentice Hall PTR, 2002.