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THE REFERENCE CURRENT CALCULATION AND PERFORMANCES OF ACTIVE POWER FILTERS

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Abstract: - In last years, active power filters have been researched to suppress harmonics generated by static rectifiers. Notably, attention has been paid to the active power filters using insulated gate bipolar transistors – IGBT, which have made remarkable progress in switching performance. In our paper, two modalities for compensating reference currents calculation are analyzed: first, use low-pass Butterworth filter, and second using average value of instantaneous active power calculation.

Key-Words: - Parallel active filters, Active power theory, Harmonics mitigation

1 Introduction

The proliferation of nonlinear loads is resulting in degradation in the power quality of power distribution networks. The users achieve energy efficiency at the expense of generating current harmonics. The presence of current and voltage harmonics in power distribution systems increases losses in the lines, decreases the power factor, and can cause resonance with capacitors connected in parallel with the system. Also, precision instruments, communication equipment, and control systems may be affected by the EMI associated with high-frequency current harmonics [2]. Therefore, utility power quality has become an important issue for both utilities and their customers.

To alleviate harmonic-related problems, power distribution utilities are starting to impose more severe standards on their customers. These standards limit the amplitude of the current harmonic components that can be generated by the customers and also limit the maximum total harmonic distortion of the voltage waveform allowed to be supplied by the utility. The application of these standards has increased the need for more efficient and reliable approaches for harmonic filtering techniques.

Traditionally, passive filters have been used to absorb current harmonics generated by high-power nonlinear loads. However, it is well known that the compensation characteristics of passive filters are influenced by the power system equivalent impedance and, also, they can generate parallel or series resonance within the utility power supply. Active power conditioning equipment is becoming more important for electric utilities. Also, the control strategies, taking into account transient states as well as steady states have been developed, using instantaneous power theory [1].

2 Active filter configuration

The compensation objective of active power filters is eliminating the harmonics present in the load currents i_{sa}, i_{sb} and i_{sc}. Since the compensating currents of active filter, i_{Fa}, i_{Fb} and i_{Fc} are controlled so as the source currents i_a, i_b and i_c to became sinusoidal [7]. The three-phase active power filter shown in Figure 1 may be described as a PWM synchronous rectifier that is connected to a DC bus bar [3]. It consists of six power switches in a single three-phase full-bridge configuration, with anti-parallel diodes connected to each switch to provide a mechanism for bi-directional flow of compensation current to be either absorbed from or injected into the supply system.

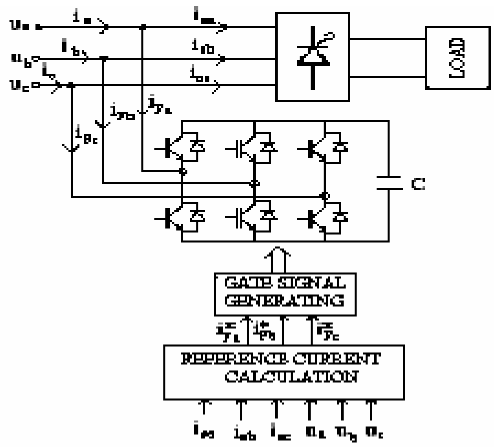

Fig. 1. Active filtering system

Normally a filter inductor is connected to enter of the filter to regulate the maximum allowable magnitude ripple current flow into the active filter. A proper design of the control has to be established in order to actively shape the supply current to a sinusoid wave shape.

3 Reference currents calculation

The current reference signals required the converter are obtained by using the instantaneous reactive power concept [8]. Depending on the reference signals used, active power filters can compensate for only the system displacement power factor, only current harmonics, or both at the same time [6]. This compensation characteristic is defined by the components of *p* and q used to calculate the inverter reference currents. If u_d, u_q and i_{sd}, i_{sq} are the components of the voltages and the load currents into the "d-q" orthogonal coordinates, the instantaneous complex load power has the expression [7]

$$\underline{s} = p + jq = \frac{3}{2}\underline{u}\bullet\underline{i}_s^* = \frac{3}{2}\left[u_d i_{sd} + u_q i_{sq} + j\left(-u_d i_{sq} + u_q i_{sd}\right)\right] \qquad (1)$$

The components into the "d-q" orthogonal coordinates to obtain by known relations [1]

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \dfrac{\sqrt{3}}{2} & -\dfrac{\sqrt{3}}{2} \end{bmatrix}\bullet\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \frac{2}{3}\bullet[A]\bullet\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}. \qquad (2)$$

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \frac{2}{3}\bullet[A]\bullet\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix}. \qquad (3)$$

From equation (1) can obtain the load current components

$$\underline{i}_s = i_{sd} + j i_{sq} = \frac{2}{3}\cdot\frac{1}{u_d^2 + u_q^2}\underline{u}\bullet\underline{s}^*. \qquad (4)$$

Similar, if $\underline{s}_F$ is the instantaneous complex filter power, the filter current components are given of the relation

$$\underline{i}_F = i_{Fd} + j i_{Fq} = \frac{2}{3}\cdot\frac{1}{u_d^2 + u_q^2}\underline{u}\bullet\underline{s}_F^*. \qquad (5)$$

The instantaneous active and reactive powers have dc and ac components, respectively

$$p = P + \tilde{p}; \quad q = Q + \tilde{q}. \qquad (6)$$

The active power P is required of the load but ac component and the instantaneous reactive power must be compensated by the active filter. Therefore, the instantaneous active and reactive filter powers must be

$$\underline{s}_F = p_F + jq_F = -\tilde{p} - jq. \qquad (7)$$

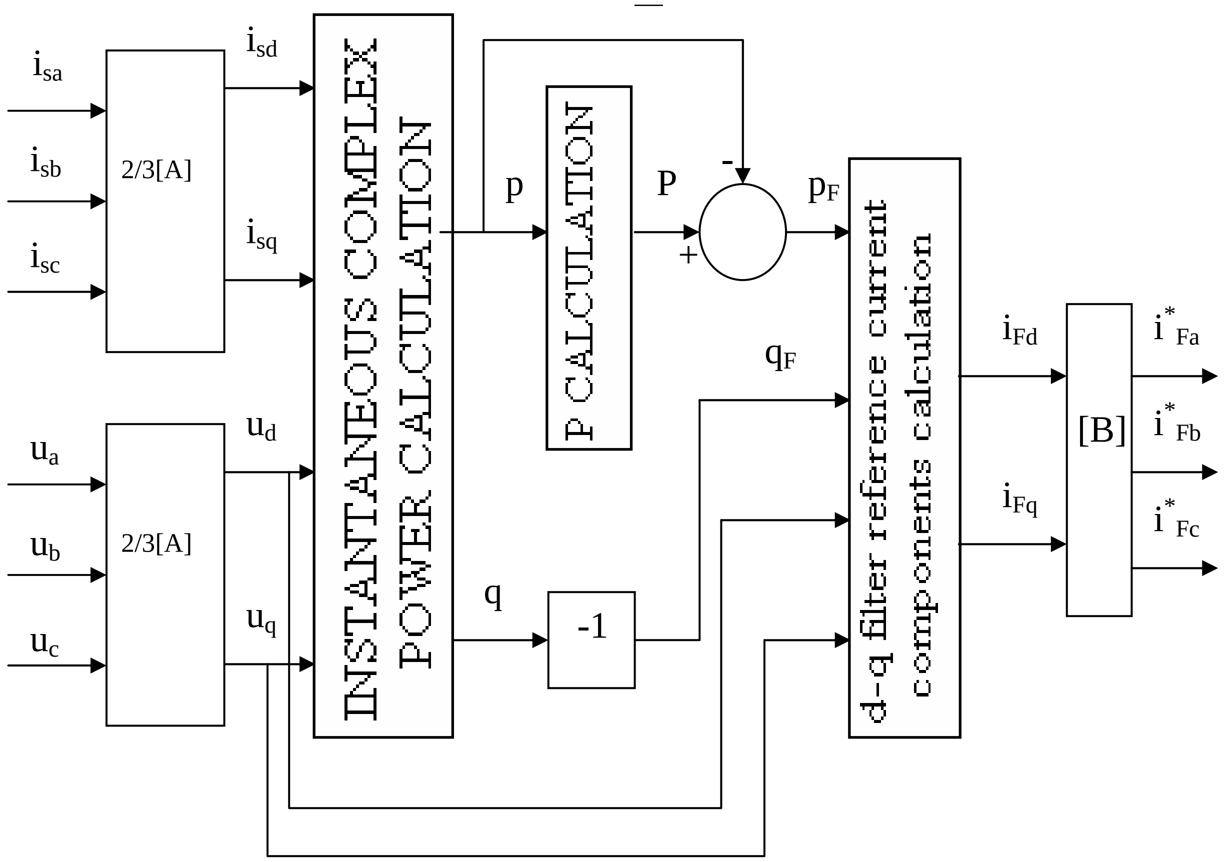

Fig. 2. The block diagram for the filter reference currents calculation

So, by equations (7) and (5), the components into the "d-q" orthogonal coordinates of the filter reference currents, can be calculated.

For the phase filter reference currents calculation, to use the inverse transformation

$$\begin{bmatrix} i_{Fa}^* \\ i_{Fb}^* \\ i_{Fc}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \bullet \begin{bmatrix} i_{Fd} \\ i_{Fq} \end{bmatrix} = [B] \bullet \begin{bmatrix} i_{Fd} \\ i_{Fq} \end{bmatrix} . \qquad (8)$$

The filter reference currents calculation can be placed in the block diagram form (Fig. 2).

3 Active Power Calculation

There are three important modalities for active power calculation by using instantaneous power theory.

1. A Butterworth low-pass filters utilization [1]. The design of the low-pass filter is the most important in the control circuit, because the compensation characteristics are depended of the cutoff frequency and order of the filter [1], [2]. The most important advantage consists in real time obtaining of the ac active power component. But this component is approximately, because the order of the Butterworth low-pass filter can't be high.
2. DC component calculation on the last period. It is clearly, in this case, the active power calculation is accurately, but the value is correctly after the first period only.
3. Utilization of active power estimation. There are many algorithms that use the active power on the last period and another information.

2.1 Butterworth low-pass filter characteristics

We used a second order Butterworth low-pass filter with 30 Hz pass frequency because, in this case, the necessary time for calculus isn't big and the filtering characteristics are good (Fig. 3).

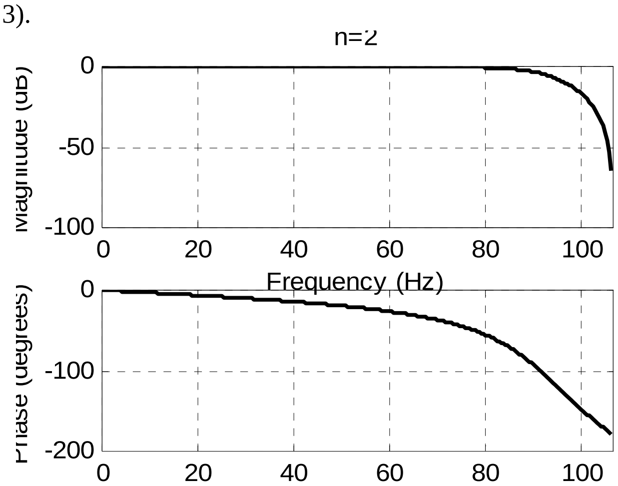

Fig. 3. The low-pass Butterworth filter characteristics

It is important that, if the pass frequency is lower, the response time of the filter is bigger. Anyhow, from the graphic form of the instantaneous active power (Fig. 4), can see that the first superior harmonic in the is six (Fig. 5).

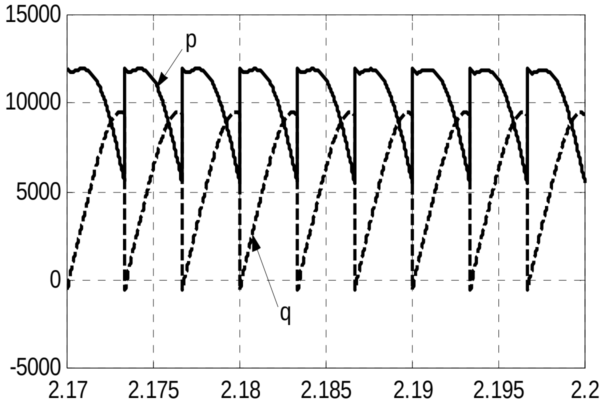

Fig. 4. The instantaneous powers wave shapes

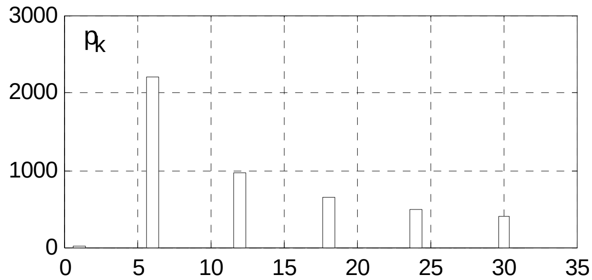

Fig. 5. The instantaneous active power spectra for six pulse rectifier and DC motor drive

4 Comparative analysis

We have considered three phase bridge rectifier which supplied a dc motor, load. The Simulink model of the filtering system is used, for obtain all the variables that characterize the filter working. First time was analyzed the steady state and the graphic shape results show of the

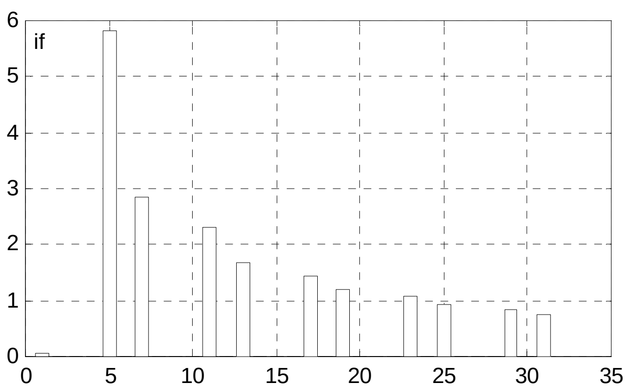

Fig. 6. The filter current spectra in the integrative calculation of the active power and without reactive power compensation

two calculus methods particularity. There is a little quantitative difference between the filter currents spectrum (Fig. 6 and 7). So, the current in the Butterworth filter utilization case, contain fundamental harmonic even the reactive power isn't compensated.

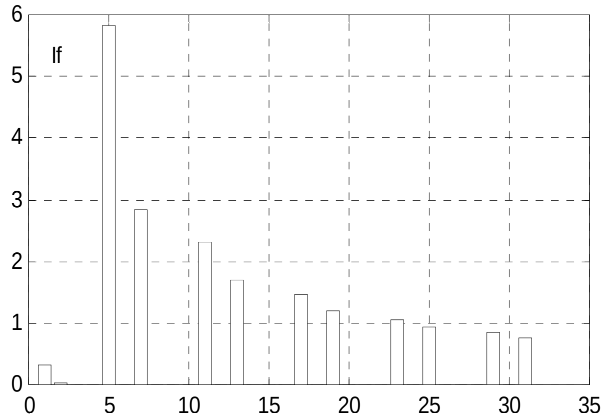

Fig. 7. The filter current spectra in the Butterworth filter utilisation and without reactive power compensation case

The explication of this difference consists in the Butterworth filter response (Fig. 8). So, the active power calculated by the Butterworth filter is bigger that the integrative calculated.

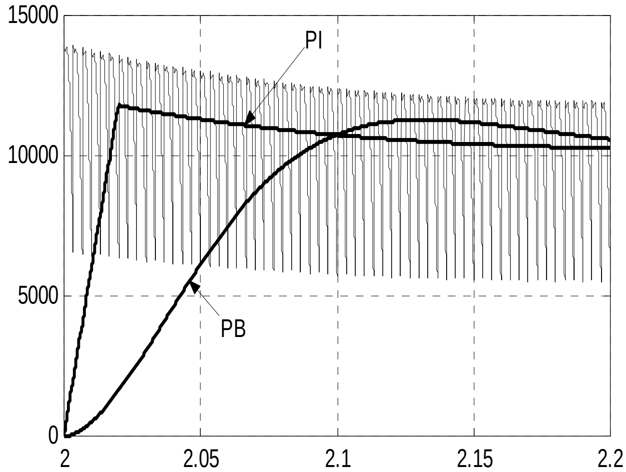

Fig. 8. The wave shapes of: the instantaneous active power – p; active power calculated by integration – PI; active power calculated by Butterworth filter – PB.

We ascertained that:

- it can compensate harmonic distortion and reactive power if the active filter currents are calculate by a.c. the instantaneous active power component and all the instantaneous reactive power (Fig. 9 and 10);
- it can compensates only harmonic distortion if the active filter currents are calculate only by a.c. instantaneous active power component and all the instantaneous reactive power (Fig. 9 and 10);

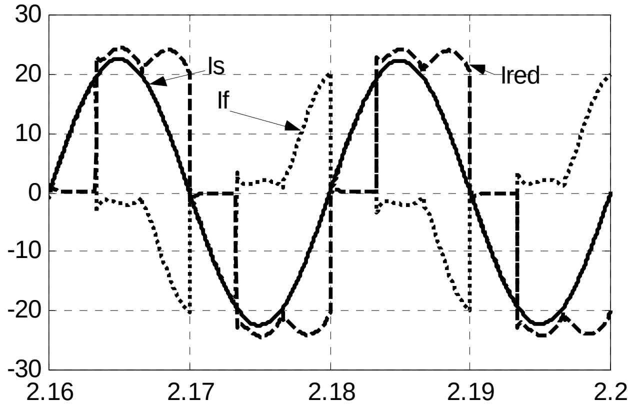

Fig. 9. The phase currents for distortion and reactive powers compensating: rectifier – ired; active filter – if; network – is.

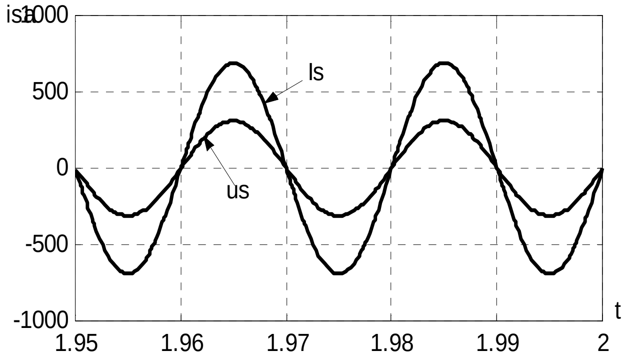

Fig. 10. Phase current and voltage with reactive power compensation

- it can compensates only harmonic distortion if the active filter currents are calculate only by a.c. instantaneous active and reactive powers components (Fig. 11 and 12).

The supply current, load current and compensated current of a phase are shown in Figure 9 and 11. The

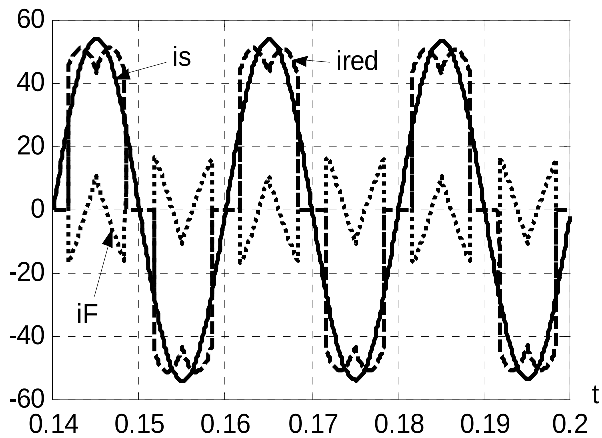

Fig. 11. The phase currents for distortion power compensating only: rectifier – ired; active filter – if; network – is.

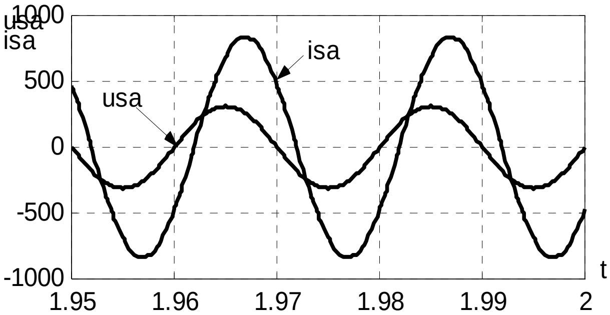

Fig. 12. Phase current and voltage without reactive power compensation

supply current proved that the calculus methods and the adopted control are capable compensate all the harmonics and reactive power too. The non-linear load is a three-phase full-bridge thyristor rectifier and dc motor. The first considered operating condition is characterized by a 30° thyristor bridge firing angle. In this case, the load phase current is late 30° too. If to compensate the reactive and distortion powers, the network phase current is in advance with 30° versus the load phase current (Fig. 8). The load current is distorted and contains the $6q \pm 1$ harmonics order (Fig. 13). In the steady-state, both methods for active power calculus establish a very good compensation and the network

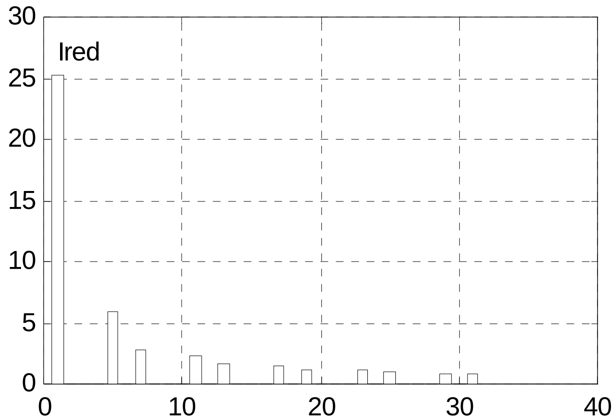

Fig. 13. The load current spectra

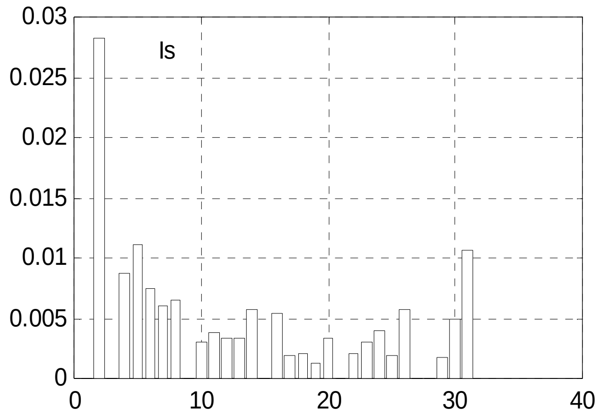

Fig. 14. The high network current spectra

current are practically sinusoidal (Fig. 14). The most important harmonic is 5 and it represents less 3%. The active filter is not designed to control transient currents flowing to the load. It is a steady state controller. However, it is important to understand the impacts of transient conditions on the active filter operating. The inverter controls include hard limits to prevent excessive compensating current generation during either steady state or transient conditions.

The main concern during transients is for the passive filter components in the interface module between the inverter and the power system. From this reason, simulations were performed to evaluate the effect of changing the thyristor bridge firing angle from 30° to 45°. It is also interesting to evaluate the effect of this transient on the powers and active filter currents. Fig. 15 shows the thyristor bridge currents, the active filter current and the line compensated currents and Fig. 16 shows the powers, in active and reactive powers by Butterworth filter calculation case. In the Figure 15, we

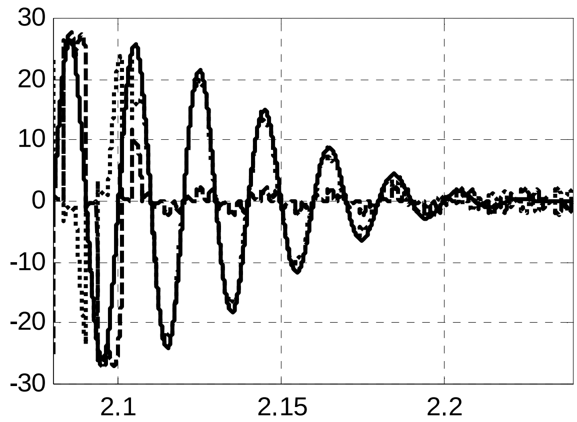

Fig. 15. The phase currents for firing angle changing (active and reactive powers calculate by Butterworth filter): rectifier – dashed line; active filter – doted line; network – continued line.

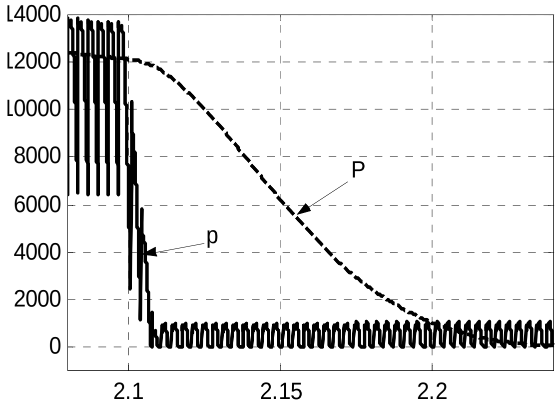

Fig. 16. The active powers for firing angle changing (active and reactive powers calculate by Butterworth filter): instantaneous – p; average – P.

can see that though the rectifier current is small, the active filter current continues to be big because the active power supplied by Butterworth filter is big too. Only after 30 instantaneous power periods, the active power values became near correct values. In fact, the transient regime of Butterworth filter is finished after 90 instantaneous power periods only (Fig. 16). We can say, in this case, the Butterworth filter response isn't adequate.

Fig. 17 shows the thyristor bridge currents, the active filter

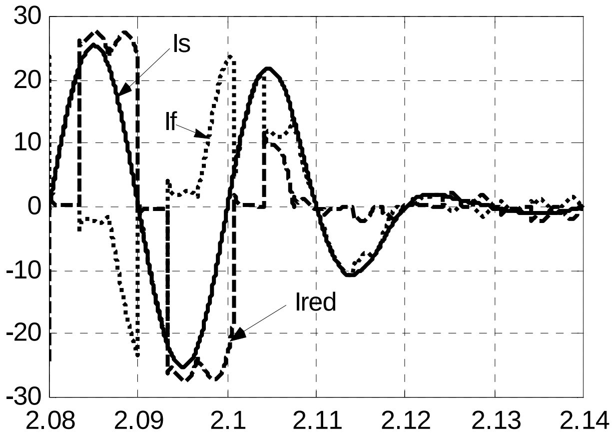

Fig. 17. The phase currents for firing angle changing (active and reactive powers calculate by average value): rectifier – dashed line; active filter – doted line; network – continued line.

current and the line compensated currents and Fig. 18 shows the powers, in active and reactive powers by average value calculation case. Now, because active filter decrease quickly, the network current decrease quickly too. So, after six instantaneous power periods only, the values of active filter current and network became near correct values. The cause of this evolution is the active power which follows better instantaneous active power values (Fig. 18).

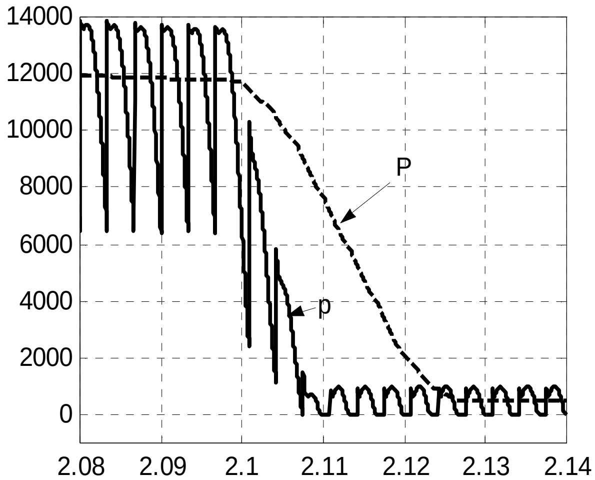

Fig. 18. The active powers for firing angle changing (active and reactive powers calculate by calculate by average value): instantaneous – p; average – P.

The transient regime is finished after 10 instantaneous power periods only (Fig. 18). It is a good response and it explains that the active filter current decrease quickly upon a time with load current.

5 Conclusion

This paper has discussed the difference in the dynamic performance of the two most used active power calculation techniques for active filter applications. The comparison is performed by simulating a typical, high-demanding active filter application where the distorting load to be compensated is a thyristor rectifier which supply a d.c. motor.

Two different values of the firing angle were considered to underline how the active filter current follows the load current. The changing of the firing angle to do in the step mode. Both calculus techniques, in steady state, determine obtaining good filtering performances.

References:

[1] X1. H. Akagi, A. Nabae, S. Atoh: Control strategy of Active Power Filters Using Multiple Voltage-Source PWM Converters, *IEEE Trans. Ind. Appl.*, IA-22, Vol. 3, pp. 460-465, 1986.

[2] X2. H. Akagi, New Trends in Active Filters for Power Conditioning, *IEEE Trans. Ind. Appl. 1996*, 32, (6), pp. 1312-1322.

[3] X3. S. Bhattacharya and D. Divan, Design and Implementation of a series active filter system, *Conf. Rec. PESC'95*, June 1995, pp. 189–195.

[4] X4. S. Buso, L. Malesani, P. Mattavelli: Comparison of Current Control Techniques for Active Filter Applications, *IEEE Transactions on Industrial Electronics*, vol. 45, no. 5, October 1998, pp. 722-729.

[5] X5. H., Fujita, H., Akagi: A Practical Approach to Harmonic Compensation in Power Systems Series Connection of Passive and Active Filters, *IEEE/IAS Ann. Meet. Conf. Rec.* pp. 1107-1112, 1990.

[6] X6. L. Malesani, L. Rossetto, and P. Tenti, "Active filter for reactive power and harmonics compensation," in *Proc. IEEE PESC'86*, 1986, pp. 321–330.

[7] X7. K. H. Yiauw and M. S. Khanniche: A Novel Three-Phase Active Power Filter, *Rev. Energ. Ren. : Power Engineering (2001)*, pp. 77-84.

[8] X8. V.,N., Nedelcu: *Teoria conversiei electromecanice*, Ed. Tehnica, Buc., 1978.