# Accentuating of the Resulting Effects after Connecting Power Active Filters on Supplying Line of the Electric Traction System

Ioan Baciu, Corina Daniela Cuntan, Raluca Rob, Caius Panoiu

**Abstract—**This paper analyzes the effects that are obtained after connecting an active filter in a traction substation. The active filter command is made in function of the active and reactive power obtained using Clarke transformation. The active filter simulated in PSCAD is connected at 110kV three phase system using power transformers. The authors present in this paper the currents and voltages variation waveforms for the mono phased an three phased circuits of a DC traction locomotive

***Keywords***— Active filter, active power, harmonic distortion factor. reactive power, voltage and current harmonics,

## I. INTRODUCTION

Active filters are power static converters that can accomplish various functions. Present filtering schemes permit the synthesizing of any current waveform that contains harmonic components of high orders at high power levels [1].

The electric energy consumer can choose in principle for one of the following solutions: abandons the equipments that absorb distorted current and invests in new equipments that contains circuits that makes the power system currents sinusoidal or invests in electric devices that keep the distortion level between imposed limits: active, passive or hybrid filters.

Term active power filter is applying to many categories of electric power circuits that contain power semiconductors and passive elements for energy stockage – inductivities or capacitors. The filters functions can be various, depending on the application [2].

There are two possible configurations: balanced and non balanced loads. For balanced loads there are used three phase filter for harmonic elimination. For non balanced loads, there are used three mono phased compensator, but there are four arms structures (three phases and null). The disadvantage consists in the following: null arm loading is harder the other three.

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## II. THEORETHICAL ISSUE

In order to solve the problems of the proliferation of the harmonic generation equipments, the electric energy dealers tries to stimulate the important industrials consumers to act in conformity with the present standards.

The tendency is strong enough to determine some equipment producers to include active filters in harmonics generation installations in order to improve power quality generation [3].

Parallel structure, presented in figure 1, of the filter connection has the largest distribution [4]. The active filter compensates the load harmonic currents that in other way would be injected in power system.

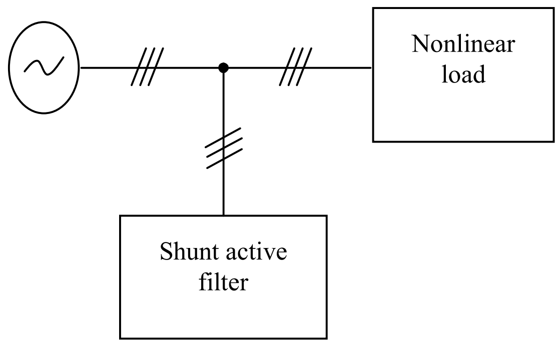


Figure 1. Active filter in parallel connection.

Depending on the structure and the command system, this topology has the possibility to compensate the reactive power and to equilibrate the power system. The filter conducts only the compensation current. This is an important advantage of parallel connection. In the same time there can be connected more filter unities in order to increase the system power. These types of filters are containing voltage inverters in current command.

In some modern actioning systems when the load variates between zero and nominal load, there are generated harmonics and real order harmonics which amplitudes and durations are variable in energy transmission lines. In order to ensure sinusoidal currents and in phase with the supplying voltage, it must be determined the avarage values for the current, and not to count the variations of the load current in fundamental frequency period [5][6].

These impose the necessity of elaboration of a new theory to lead to a instantaeous treatment of the situation. This is the p-q theory of the instantaneous real and imaginary powers that offers the possibility to determine the active and fictive components for each phase current of a three phase load. This leads to a real time control for the fictive power compensators.

In p-q theory domain, Akagy defines the instantaneous real power and also the instantaneous imaginary power [3]. The average period value of these lead to active and reactive powers. The expression of reactive power in non sinusoidal regime is different from the classical expression. More then this, each of instantaneous power contains an alternative power term. It is resulting that the distorted power appears as an expression of the electromagnetic energy oscillations between source and load, the both instantaneous powers containing parts of this.

Definition of the α, β, 0 components:

In order to define these powers the authors use Clarke transformation from $u_a, u_b, u_c$ components to $u_\alpha, u_\beta, u_o$ components.

$$\begin{cases} u_o = \sqrt{\dfrac{2}{3}}\left(\dfrac{1}{\sqrt{2}}u_a + \dfrac{1}{\sqrt{2}}u_b + \dfrac{1}{\sqrt{2}}u_c\right) \\ u_\alpha = \sqrt{\dfrac{2}{3}}\left(u_a - \dfrac{1}{2}u_b - \dfrac{1}{2}u_c\right) \\ u_\beta = \sqrt{\dfrac{2}{3}}\left(\dfrac{\sqrt{3}}{2}u_b - \dfrac{\sqrt{3}}{2}u_c\right) \end{cases} \tag{1}$$

or using matrix:

$$\begin{bmatrix} u_o \\ u_\alpha \\ u_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{2}$$

Using matrix inverting, there can be obtained voltages $u_a, u_b, u_c$

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_o \\ u_\alpha \\ u_\beta \end{bmatrix} \tag{3}$$

If $u_a(t), u_b(t), u_c(t)$ are phase voltages of a three phase load which transformated components are $u_\alpha(t), u_\beta(t), u_o(t)$ and these voltages supply the load with $i_a(t), i_b(t), i_c(t)$ currents which transformated components are $i_\alpha(t), i_\beta(t), i_o(t)$, then instantaneous real power is defined like in classical theory [7].

$$p(t) = u_a(t)i_a(t) + u_b(t)i_b(t) + u_c(t)i_c(t) = p_a(t) + p_b(t) + p_c(t) \tag{4}$$

This instantaneous power can be rewritten as the following:

$$p(t) = u_\alpha(t)i_\alpha(t) + u_\beta(t)i_\beta(t) + u_o(t)i_o(t) = p_\alpha(t) + p_\beta(t) + p_o(t) = p_r(t) + p_o(t) \tag{5}$$

where:

$$p_r(t) = p_\alpha(t) + p_\beta(t) \tag{6}$$

is instantaneous real power without homopolar components and:

$$p_o(t) = u_o(t)i_o(t) \tag{7}$$

is homopolar power.

As it can be observed from relations (6) and (7), one of the advantages of $\alpha$, β, 0 transformation is the separation of the instantaneous homopolar component from instantaneous real power expression.

Akagi suggested the defining of a new variable named instantaneous imaginary power q(t) (or $p_i(t)$) that will not be influenced by the homopolar sequence components:

$$q(t) = p_i(t) = u_\beta(t)i_\alpha(t) - u_\alpha(t)i_\beta(t) \tag{8}$$

The authors proposed a new measurement unit for its average value: imaginary volt-amper [VAI]. This new power can be expressed in function of line voltages and phase currents [2],[7]:

$$q(t) = \frac{1}{\sqrt{3}}\left[u_{ab}(t)i_c(t) + u_{bc}(t)i_a(t) + u_{ca}(t)i_b(t)\right] \tag{9}$$

In these conditions, $p_i(t)$ and q(t) can be expressed in matrix form:

$$\begin{bmatrix} p_r(t) \\ q(t) \end{bmatrix} = \begin{bmatrix} u_\alpha(t) & u_\beta(t) \\ u_\beta(t) & -u_\alpha(t) \end{bmatrix} \begin{bmatrix} i_\alpha(t) \\ i_\beta(t) \end{bmatrix} \tag{10}$$

Using notation:

$$\Delta = u_\alpha^2(t) + u_\beta^2(t) \tag{11}$$

from relation (11) can be written the values of the $\alpha$ and β currents components:

$$\begin{bmatrix} i_\alpha(t) \\ i_\beta(t) \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} -u_\alpha(t) & -u_\beta(t) \\ -u_\beta(t) & u_\alpha(t) \end{bmatrix}\begin{bmatrix} p_r(t) \\ q(t) \end{bmatrix} \quad (12)$$

The both of these instantaneous powers contain an average term and a variable term:

$$p(t) = \overline{p} + \widetilde{p}(t) \quad (13)$$

$$q(t) = \overline{q} + \widetilde{q}(t) \quad (14)$$

From relation (14) can be observed the difference from the classical theory in way that the reactive power is presented like an average value of instantaneous imaginary power. In classical theory reactive power expresses the maximum value of the oscillation from source and load that determines power loss in electric lines, being a part of this.

Practically, the alternative terms $\widetilde{p}(t)$ and $\widetilde{q}(t)$ determine power oscillations that appear between source and load. They contribute in appearing of a variable power which rms value is distorted power:

$$D = \sqrt{\widetilde{P}^2 + \widetilde{Q}^2} \quad (15)$$

where: $\widetilde{P}$ is rms value of $\widetilde{p}(t)$;

$\widetilde{Q}$ is rms value of $\widetilde{q}(t)$.

In other words, the distorted power is directly responsable for electromagnetic energy oscillations between source and load. Using this idea, reactive power exists practically in each phase, like reactive currrents [8].

Real and imaginary instantaneous powers at the load that functions in distorted regime. In the followings, the authors write the real and imaginary instantaneous powers in case when the both supplying voltages and the load currents are non sinusoidal, each of these systems admits Fourier decomposition.

-for voltages:

$$\begin{cases} u_a(t) = \sum\limits_{(k)} \sqrt{2} U_k \sin(k\omega t + \alpha_k) \\ u_b(t) = \sum\limits_{(k)} \sqrt{2} U_k \sin(k\omega t + \alpha_k - k2\pi/3) \\ u_c(t) = \sum\limits_{(k)} \sqrt{2} U_k \sin(k\omega t + \alpha_k + k2\pi/3) \end{cases} \quad (16)$$

- for currents:

$$\begin{cases} i_a(t) = \sum\limits_{(l)} \sqrt{2} I_l \sin(l\omega t + \beta_l) \\ i_b(t) = \sum\limits_{(l)} \sqrt{2} I_l \sin(l\omega t + \beta_l - l2\pi/3) \\ i_c(t) = \sum\limits_{(l)} \sqrt{2} I_l \sin(l\omega t + \beta_l + l2\pi/3) \end{cases} \quad (17)$$

Taking into consideration the relations (1), α,β,0 components of the supplying voltages and load currents are:

$$\begin{cases} u_\alpha(t) = \sum\limits_{(k)} \frac{2}{\sqrt{3}} U_k \sin(k\omega t + \alpha_k)[1 - \cos(k2\pi/3)] \\ u_\beta(t) = \sum\limits_{(k)} 2U_k \cos(k\omega t + \alpha_k)\sin(k2\pi/3) \\ u_o(t) = \sum\limits_{(k)} \sqrt{6} U_{3k} \sin(3k\omega t + \alpha_{3k}) \end{cases} \quad (18)$$

$$\begin{cases} i_\alpha(t) = \sum\limits_{(l)} \frac{2}{\sqrt{3}} I_l \sin(k\omega t + \beta_l)[1 - \cos(l2\pi/3)] \\ i_\beta(t) = \sum\limits_{(l)} 2I_l \cos(k\omega t + \beta_l)\sin(l2\pi/3) \\ i_o(t) = \sum\limits_{(l)} \sqrt{6} I_{3l} \sin(3l\omega t + \beta_{3l}) \end{cases} \quad (19)$$

The expression of real instantaneous power depends on the $\alpha$,β,0 components of the voltage and current. Taking into consideration relation (6), for calculating the real instantaneous power will be find:

$$p(t) = \overline{p} + \widetilde{p}(t) \quad (20)$$

where:

$$\overline{p} = 3\sum_{(k)} U_k I_k \cos\varphi_k,$$

$$\varphi_k = \alpha_k - \beta_k \quad (21)$$

represents the average value of the instantaneous real power, equal with active power in power system

Some observations can be made concerning the imaginary instantaneous power [2], [3], [12]:

The average value of this one, $\overline{q}$, does not contain the 3 multiple current harmonics. It is clear that $\overline{q}$ expression is different of classical reactive power.

2. The reactive power, as the average value of the imaginary instantaneous power is not the one that is responsible of the electromagnetic energy between source and load. Responsible elements are $\widetilde{p}(t)$ and $\widetilde{q}(t)$.

3. In the expression of reactive power appear with changed sign

$$\overline{q} = 3U_1I_1\sin\varphi_1 - 3U_2I_2\sin\varphi_2 + 3U_4I_4\sin\varphi_4$$
$$-3U_5I_5\sin\varphi_5 + 3U_7I_7\sin\varphi_7 \quad (22)$$

This may be an explanation for the reason that at the three phase loads that function in non sinusoidal regime, the load can be damaged in trying to compensate the powers on one superior harmonic. The average values of the real and imaginary instantaneous powers remain constant in stabile states (including the periodic ones) that lead to frequent alteration of the current, etc). [13], [14].

## III. Simulation results

Using PSCAD-EMTDC simulation tool, the authors studied the variation of the electrical parameters at the interface with the power distribution for two electric locomotives.

Simulating scheme contains the following elements (figure4):

- voltage source with nominal voltage Un=220kV and aparent power Sn=200MVA with three phase power transformer 220/110kV, 220MVA for the simulation of the electric transformation station Peştiş.
- two power transformers 110/27,5kV, 16MVA for simulation of the transformation station 110/27,5kV. Each locomotive has 6 dc motors with serial excitation. The locomotives are supplied through two feeders connected at 27,5kV voltage. Motors supplying (Un=0,77kV) is made using diode bridge rectifiers.

The continuous current motor model demands an input signal wm -the rotor rotation speed. Te is an output signal and represents the electric field generated by motor. For simulating the rotation movement of the motor, it is realised a model that generates the wm signals (figure 3).

In order to assign the harmonic distortion level that is introduced by this consumer in power distribution, using Fast Fourier Transformer and a harmonic distortion calculator, the authors calculate THD generated by Isa1, Isb1, Isc1 currents on 110kV level in 110/27,5kV electric station.

In order to reduce THD calculated in this way, a shunt active filter (SAF) installation is connected to 110kV level in 110/27,5kV electric station.

The installation contains two power transformers in serial connection: 110/27,5kV, 1MVA şi 27,5/1kV, 1MVA. The active filter with six GTO thyristors is supplying fom the secondary winding of the second transformer.

SAF installation contains three phase inverter and 110kV connection transformers, as in figure 2.

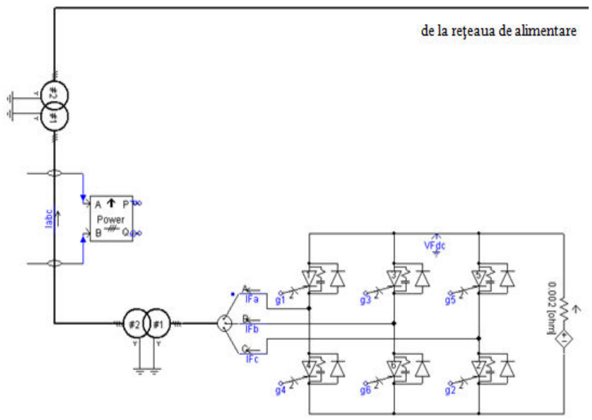


Figure 2. Shunt active filter realized with thyristors.

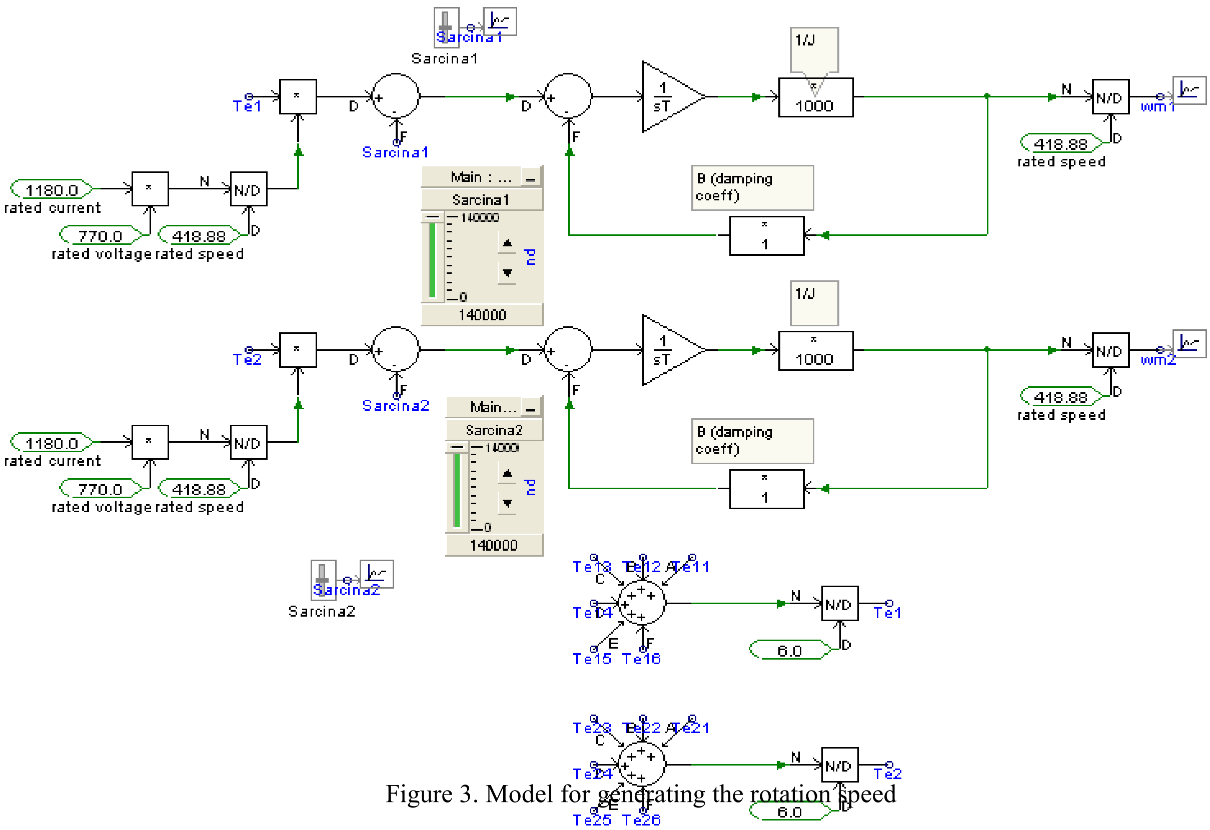


Figure 3. Model for generating the rotation speed

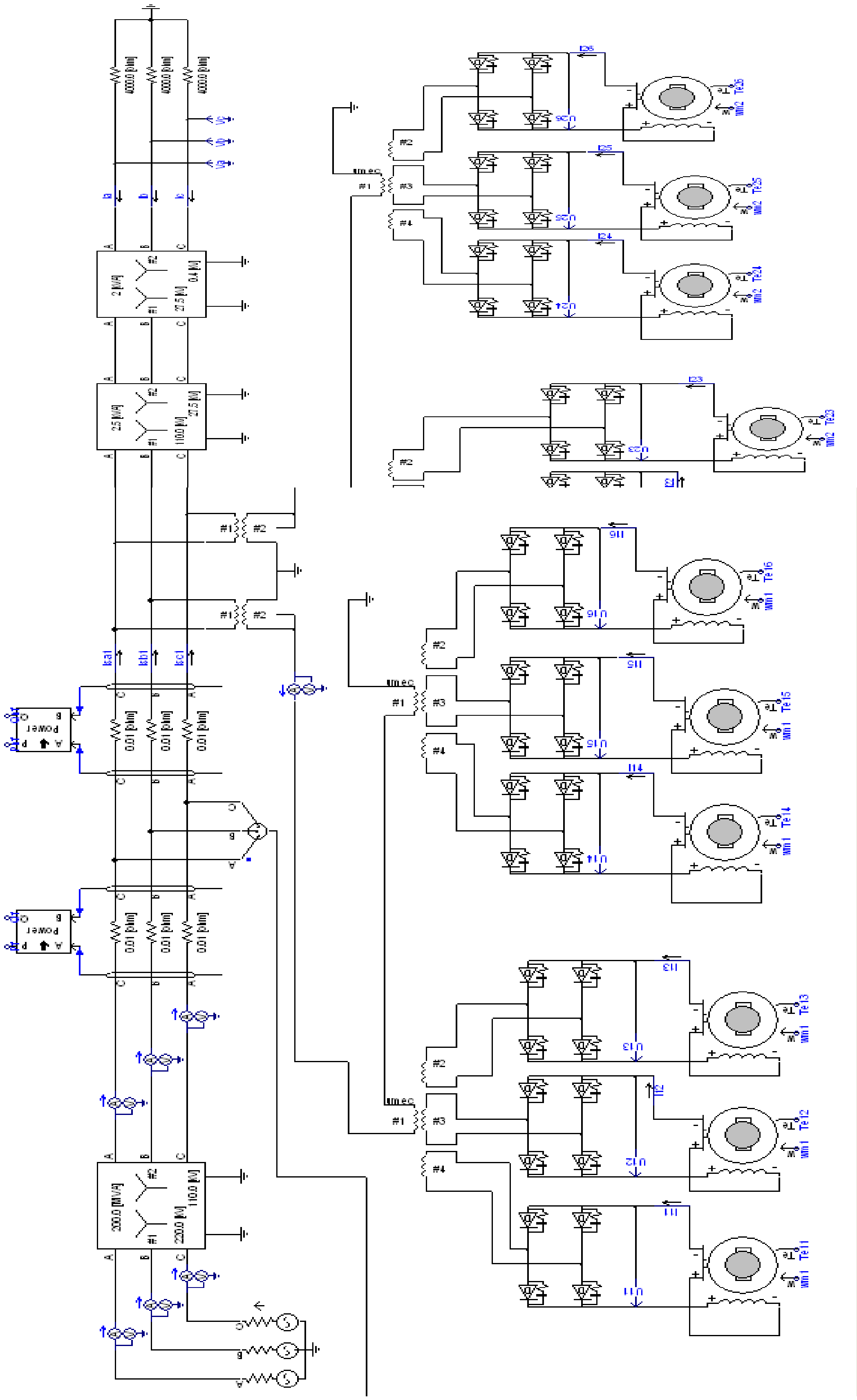

Figure 4. PSCAD simulation of the studied installation.

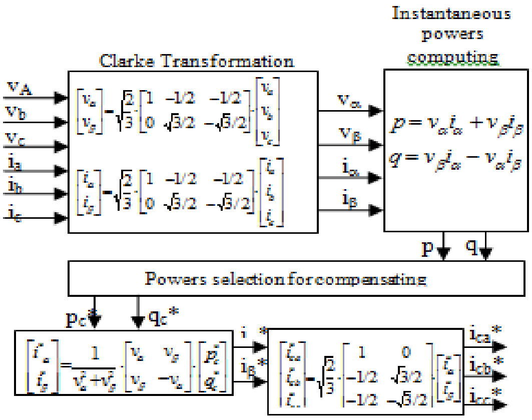


Figure 5. Control algorithm for current compensation based on p-q theory.

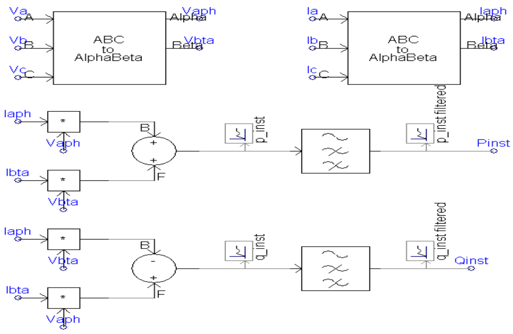


Figure 6. Model for active filter command using p-q theory.

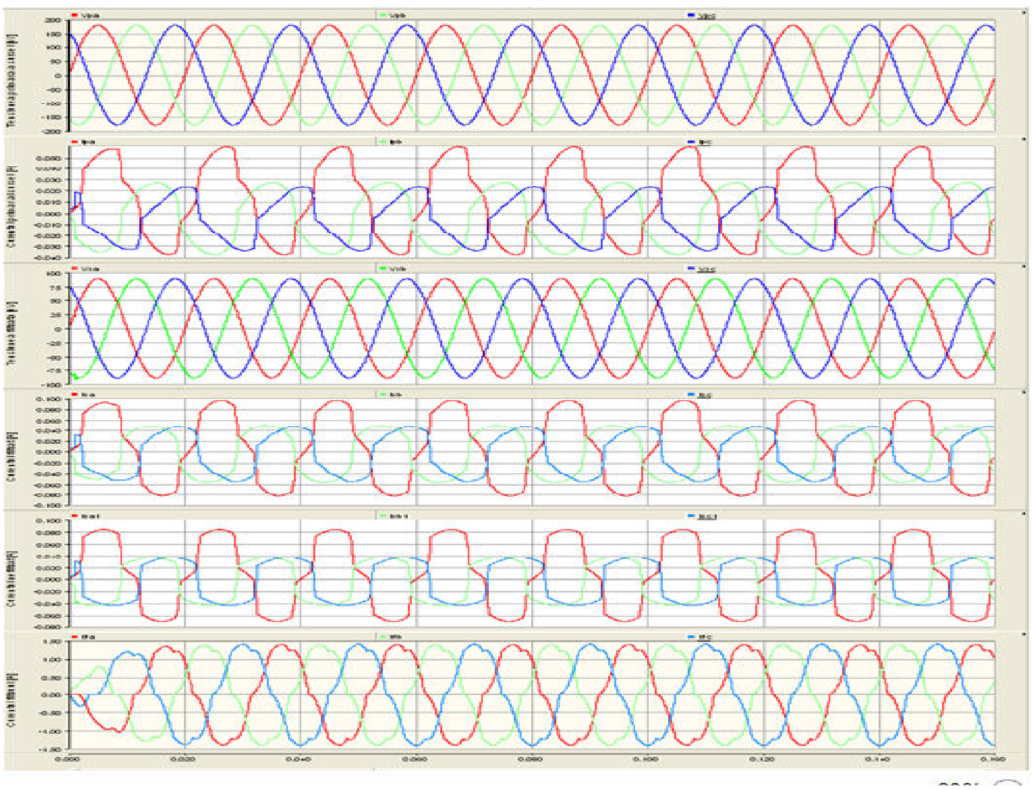

Figure 7. Three phase voltages and currents variations.

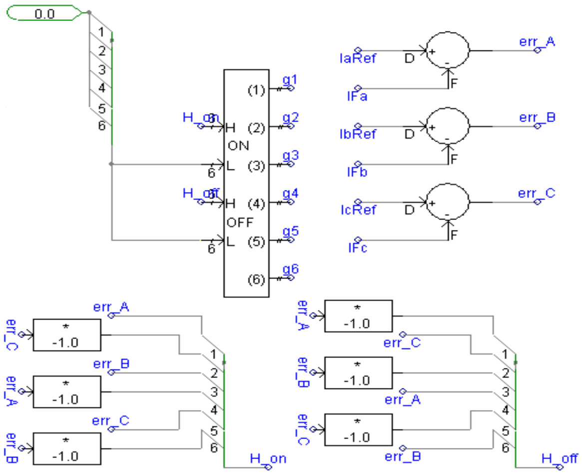


Figure 8. Model for GTO thyristor pulse command.

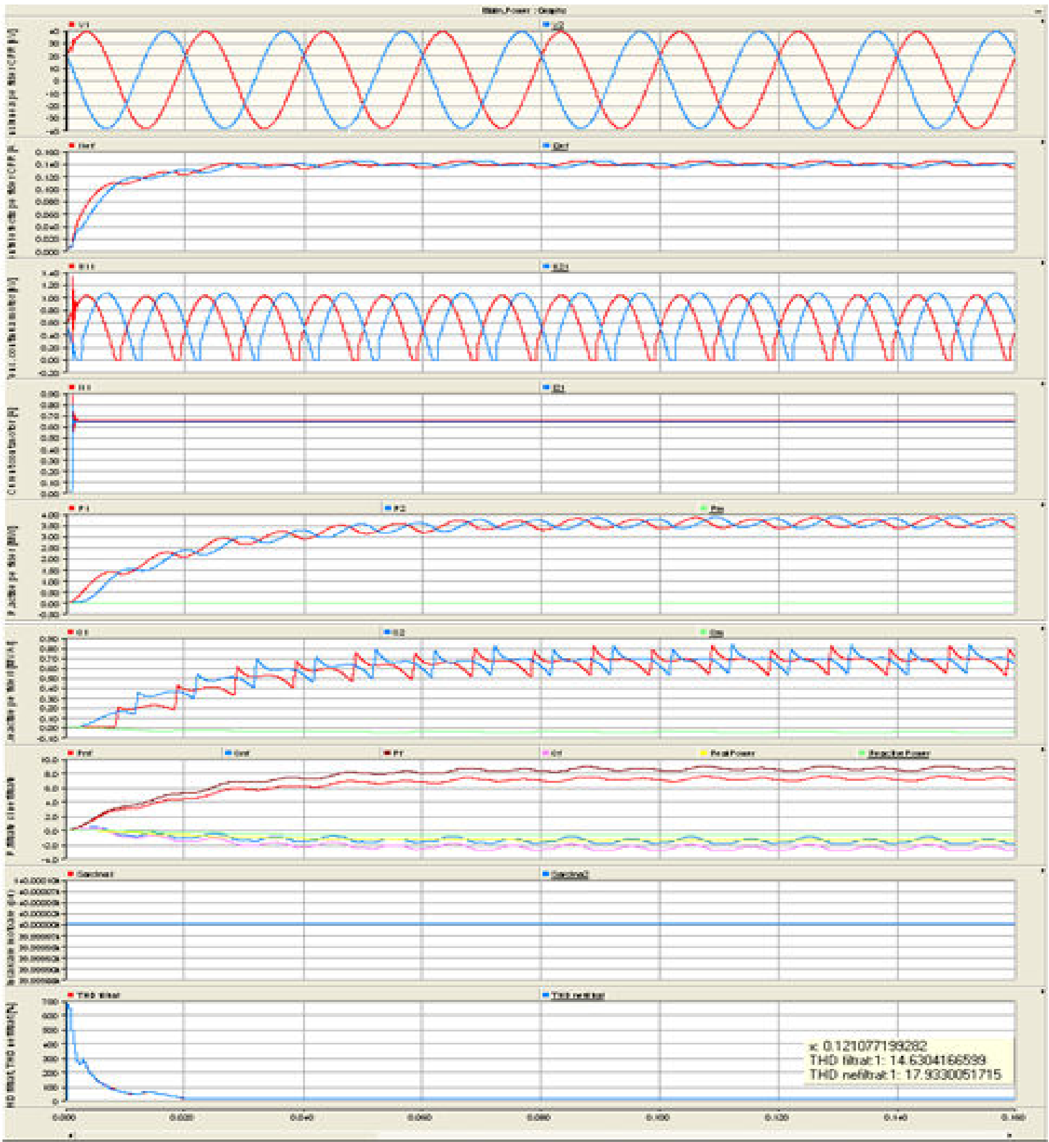


Figure 9. Mono phase voltages and currents, powers and THD variations.

SAF is modeled to inject a current equal in magnitude but in opposite phase to harmonic current to achieve a sinusoidal current wave in phase with the supply voltage [9],[10],[11].

Using instantaneous power theory introduced by prof. Hirofumi Akagi, it was created a model for calculating the reference currents for active filter, presented in figure 5 [7].

GTO thyristors are commanded by a firing control device that generates the firing pulses signals g1, g2, g3, g4, g5 and g6. The difference between filter currents and the reference currents generates the control signals of the firing control device.(figure 8)

PSCAD model for calculating the compensation currents permitts to determine instantaneous active and reactive powers (figure 6). Model of control signals of the firing control device for GTO uses reference signals that are determined in previous paragraph.

After running the simulating program at constant load of traction motors, there are obtained the line voltages and currents waveforms for three phase circuits, downstream and upstream to the SAF connection, as in figure 7. It can be observed that one phase current value is the double value of the currents on the other two phases. The explanation is that were connected two locomotive on two different phases.

For mono phase supplying, see figure 9, are presented the variations for the rectified voltage, dc motor current, active and reactive powers (before and after filtering) and THD.

## IV. Conclusion

Passive filters represent the simplest method of harmonic reducing, but in order to reduce the distortion regime introduced by electric traction equipments, there are necessary many passive devices, one for each harmonic.

This conclusion makes almost impossible the exclusive using of passive filters, so this method must be jointed with other power compensation devices.

Using active filters supposes THD reducing by connecting the filter at 110kV level with adaptation transformers. It can be observed the increasing of the consumed active power because of the adaptation transformer. Also can be observed the increasing of the reactive power with the same value (in modulus) because of the inductive character introduced by the adaptation transformer.

Using active filters connected at 110kV voltages demands high costs and important filtering powers. Reducing the installation power on the active filter imposes using passive filters for low harmonics (3, 5, 7 rank) and dimensioning the active filter for the rest of harmonics.

This method imposes an additional study regarding the location of the passive filter, because i tis difficult to realize the connection to the 110kV bars.

From analyzing the functioning of the shunt active filter, there can be observed an improvement of the non sinusoidal regime, but the installation are very expensive, so there must be made an analyzing of advantages and disadvantages.

## References

*[1] Bhattacharya S., Frank T., Divan D., Banerjee B., Parallel active filter system implementation and design issues for utility interface of adjustable speed drive systems, Proc. IEEE IAS Annu. Meeting Conf. Rec., pp. 1032 - 1039, 1996.*

*[2] Akagi H., Tsukamoto Y., Nabae A., "Analysis and design of an active power filter using quad-series voltage-source PWM converters", IEEE Trans. Ind. Appl. 26 (1), pp.93–98, 1990*

*[3]Akagi H., "Generalised Theory of the Instantaneous Reactive Power in Three-Phase Circuits ", International Conferences on Power Electronics, Tokyo, 1983.*

*[4]Adrian Buta, Adrian Pană, Symmetrization of the Electric Distribution Grids' Load, „University Horizons", Timişoara, 2000.*

*[5] Akagi H., "New trends in active filters for power conditioning", IEEE Trans. Ind. Appl. 32, pp.1312–1322, 1996.*

*[6] Steimel A., Electric Traction Motive-Power and Enrgy Supply. Basics and Practical Experience, Oldenbourg Industrie Gmbh, 2008.*

*[7] Akagi H., "Generalised Theory of the Instantaneous Reactive Power in Three-Phase Circuits ", International Conferences on Power Electronics, Tokyo, 1983*

*[8] Zhao J., Dai W., Wang K., Shunt Active Power Filter and Its Application, 2010 International Conference on Challenges in Environmental Science and Computer Engineering, vol. 2, 2010, pp. 373 – 376, China.*

*[9] Abaali H., Lamchich M.T., Raoufi M., Shunt Power Active Filter Control under Non Ideal Voltages Conditions, International Journal of Information Technology , pp.164-169, 2006.*

*[10] Popescu M., Bitoleanu Al., Dobriceanu M., „Case Study Survey of Harmonic Pollution Generated by Railway Systems and Filtering Solutions", 12 th WSEAS International Conference on Systems, Heraklion, Greece, July, 22-24, 2008, pp. 210 ÷ 215, ISBN 978-960-6766-83-1, ISSN 1970-2769.*

*[11] Popescu M., Bitoleanu A., Dobriceanu M., "Harmonic Current Reduction in Railway Systems", WSEAS Transactions on Systems, Issue 7, Vol. 7, iulie 2008, ISSN: 1109-2777, pp. 689-698.*

*[12] Nicolae P.M., Calitatea energiei electrice in sisteme electroenrgetice de putere limitata, Editura Tehnica, Bucuresti ,1998*