A NEW ADVANCED CONTROL STRATEGY FOR A SERIES ACTIVE POWER QUALITY CONDITIONER UNDER NETWORK DISTURBANCES.

B.Mazari*, M.C. Benhabib* , S.Fasla**
*University of Sciences and Technology of Oran-Mohamed Boudiaf-
Faculty of Electrical Engineering- Electrotechnic Department
B.P 1505 El Mnaouer USTO, 31000 Oran -Algeria
Tel & Fax: :00.213-41-42 55 09
**Enset 31000 Oran
E-Mail: mazari_dz@yahoo.fr

Abstract:

Harmonic current and/or voltage pollution of three phase supply electrical networks is becoming a very serious problem due to the wide use of non-linear loads such as arc furnace, industrial high power thyristor converters and adjustable speed drives. These non-linear loads draw current, with high harmonic content which produces a variety of undesirable phenomena on the power system such as power losses, decrease of power factor, over- voltages, voltage drop ... Theses disturbances affects can be minimised with the use of active power quality converters connected directly to the mains network. The authors in this paper propose a new advanced control strategy for a series active power quality conditioner connected to a three-phase electrical power network with sinusoidal or non-sinusoidal means voltages. A new definition of residual instantaneous active and reactive power based on the α,β transformation of instantaneous voltages and currents of the AC system are introduced to extract the voltage harmonic references to control the active power conditioner .The introduction of these components in the new control algorithm of the active power quality conditioner are investigated and compared under non-sinusoidal mains voltage conditions. The main advantage of this new advanced control method validated by simulations shows that the mains line currents constitute always a balanced sinusoidal system when operating under disturbances like flicker, sags, under-voltage ...Simulations have been performed to verify steady and dynamic compensation characteristics in case we have many disturbances in the electrical power system .The introduction of these new residual power components lead also to the definition of an advanced THD power factor that is compared to the classical one.

1 Introduction

In last decade, the proliferation of the non-linear load such as adjustable speed drive, power electronic like AC-DC converter, cycloconverter… in a three phase three wire becomes a very serious problem. These non-linear load draw current which have harmonics content, produces a variety of undesirable phenomena on the electrical power network such as power losses, decrease of power factor, over current do by resonance phenomena and voltage distorted.

For reduce and minimisation the harmonics current and compensate the power factor many control methods have been developed by many seekers. Among these we found, the instantaneous reference frame method [1], the adaptive method introduce by [2], the instantaneous direct and quadrature admittance components yd, yq method [3] pq theory [4],[5] and many others methods has been developer for perfect the unified power quality conditioner.

These types of control are performed when we hope extract harmonic current and compensate reactive power. However, the difficulties encountered for the treatment of many perturbation at the same time like harmonics current, over voltage, sags, over current, …etc, is becomes a very serious problem because:

- ✓ The use of a passive filter to extract harmonic components of all the non-linear load in all the control methods is not accurate. Moreover, it is very difficult to take out harmonic and sub harmonics that are near the fundamental sine wave.
- ✓ Every type of perturbations should be treated separately and every case requires an adequate control that leads to complex identification algorithms and treatment of the phenomena.

For eliminate these inconvenience, we propose a new control strategy which can correct and eliminate disturbances like voltage drop, sags, over-voltage … by use a series active power conditioner.

This new control strategy is a derived from a classical control introduce by [4] and [5], by used the instantaneous active and imaginary power with the αβ transformation of voltages and currents, but without use a passive filter in the control to extract the continuous components of the power.

The choice, for don't used a passive filter is very important, because instead of to extract completely the continuous components we preferred treat it like a harmonic. This is possible, if we research the common point of all the perturbations, we must unify the maximum disturbances at a same theory. The major advantage we can observe if we use this strategy, is that we can with only one control, to extract and treat many perturbation at the same time, then the supply voltage will works always at the nominal value and we obtain a minimum losses in lines, transformators …

2 Circuit configuration adopted and basic of the new control

In general for the treatment of perturbations like currents harmonics or reactive power we used parallel active power filter, however, if we hope treat other perturbation like sags, over voltage, voltage drop, … the most better is to use series active power filter. For this, we choose for the variation of current do by the variation of voltage a series active power filter.

2.1 Scheme Principe

Fig. 1. Give the principle scheme of the electrical system, which is composed of a three phase's source connected to a non-linear load, in this case we used a rectifier, and a series active power quality conditioner connected in series with the electrical network.

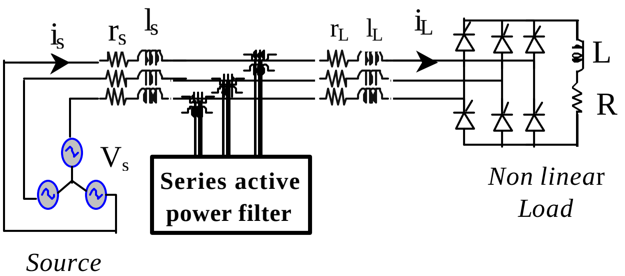


Fig. 1. Principle Scheme of electrical system with a series active power quality conditioner

2.2 Basic of the New Control

The principle idea of use the new control is based on the analysis of the instantaneous active and imaginary powers to compensate variations come from a supply voltage like over voltage, voltage drop and flicker in the case of a three phases balanced voltage system **Fig.2**.

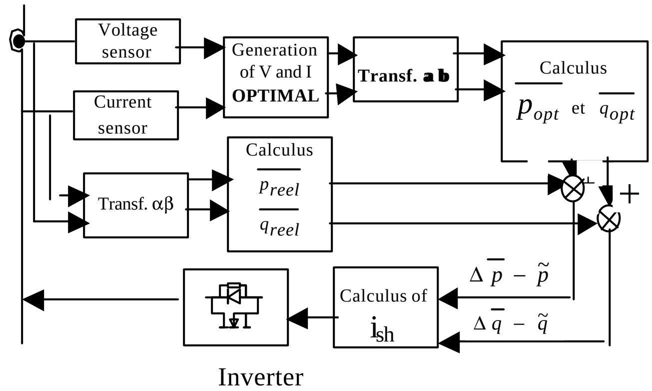


Fig. 2. Principle Scheme circuit of series active power conditioner control

We observe that, when the network is balanced and without any harmonics, the instantaneous active and imaginary power theory in αβ co-ordination are constant. Moreover when a variation of the sinusoidal voltage or line current occurs, we obtain a new but always a constant value of the instantaneous active and imaginary powers.
Then the basic of this new control method consist to investigate this change of the instantaneous active and reactive power when the network is subject to a non-linear load or other sources of perturbation.
The voltage and current of three phases are expressed by:

$$V_k=\sqrt{2}\,(V_{1source}-\delta V_{1source})\sin(\omega t-(k-1)\frac{2\pi}{3}) \qquad (1)$$

$$i_k=\sqrt{2}\,(i_{1source}-\delta i_{1.source})\sin(\omega t-(k-1)\frac{2\pi}{3}-\varphi_i) \qquad (2)$$

Avec k=1,2,3.

The instantaneous values of active and reactive power are given by the following equations:

$$\begin{bmatrix} q_{real} \\ p_{real} \end{bmatrix} = \begin{bmatrix} i_\beta & -i_\alpha \\ i_\alpha & i_\beta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \qquad (3)$$

With $v_\alpha, v_\beta, i_\alpha, i_\beta$ are obtained from the αβ transformation as follows:

$$\begin{bmatrix} v_a \\ v_b \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (4)$$

To put eq.1, eq.2 and eq.4 in eq.3 and with some development we obtain eq.5 and eq.6 :

$p = 3\,V_{1source}\, i_{1source} \cos\varphi_l + 3\,\delta V_{1source}\, \delta i_{1\ source} \cos\varphi_l - 3\,V_{1source}\, \delta i_{1\ source} \cos\varphi_l - 3\,\delta V_{1\ source}\, i_{1\ source} \cos\varphi_l$ (5)

$q = 3\,V_{1source}\, i_{1\ source} \sin\varphi_l + 3\,\delta V_{1source}\, \delta i_{1\ source} \sin\varphi_l - 3\,V_{1source}\, \delta i_{1\ source} \sin\varphi_l - 3\,\delta V_{1source}\, i_{1\ source} \sin\varphi_l$ (6)

The instantaneous active and imaginary powers of the eq.5 and eq.6 can be decomposed in two principle components, the first one is $\overline{p}_{real}$ and $\overline{q}_{real}$ representing respectively the continuous active and imaginary power and the second terms $\tilde{p}_{real}$ and $\tilde{q}_{real}$ represent respectively the harmonic components of active and imaginary power. So, the instantaneous active and reactive power can be rewrite as follows:

$$p = \overline{p} + \tilde{p} \qquad (7)$$

$$q = \overline{q} + \tilde{q} \qquad (8)$$

In the same time, the control must calculate the optimal values of the synthetic instantaneous active and imaginary powers named represented as p_{opt} and q_{opt} obtained from the optimal theoretical voltage V_{opt} and optimal theoretical fundamental currents of i_{opt} source take out from the real current circulating in the network.

We obtain:

$$p_{opt} = 3V_{opt}I_{opt} \cos\varphi_{opt} = \overline{p}_{opt} \qquad (9)$$

$$q_{opt} = 3V_{opt}I_{opt} \sin\varphi_{opt} = \overline{q}_{opt} \qquad (10)$$

with $\overline{p_{opt}}$ and $\overline{q_{opt}}$ represent respectively the active an imaginary continuous components of ideal theoretical network with no harmonics.

We calculate after, the difference of the two power equations (7) with (9) and (8) with (10). We get:

$$P = \overline{p}_{opt} - p_{real} \qquad (11)$$

$$Q = \overline{q}_{opt} - q_{real} \qquad (12)$$

Then we can write:

$$P = \overline{p}_{opt} - \tilde{p}_{real} - \overline{p}_{real} \qquad (13)$$

$$Q = \overline{q}_{opt} - \tilde{q}_{real} - \overline{q}_{real} \qquad (14)$$

While putting:

$$\overline{\delta p} = \overline{p}_{opt} - \overline{p}_{real} \qquad (15)$$

$$\overline{\delta q} = \overline{q}_{opt} - \overline{q}_{real} \qquad (16)$$

where $\overline{\delta p}$ and $\overline{\Delta q}$ represent respectively the active and reactive residual power of the continuous components.
We obtain:

$$P = \overline{\delta p} - \tilde{p}_{real} \qquad (17)$$

$$Q = \overline{\delta q} - \tilde{q}_{real} \qquad (18)$$

The advantage of this method is that the residues of the instantaneous active and imaginary continuous powers named respectively $\overline{\delta p}$ and $\overline{\delta q}$ are taken into account.

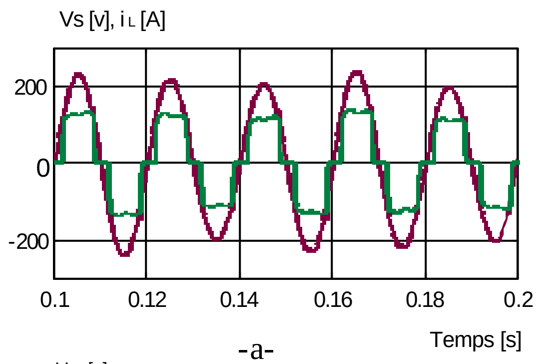
These components are very important because there are include in the treatment of all variation of the fundamental voltage, like sags, voltage drop, …

Then the new reference voltages of the series active power conditioner are calculated by the following expression:

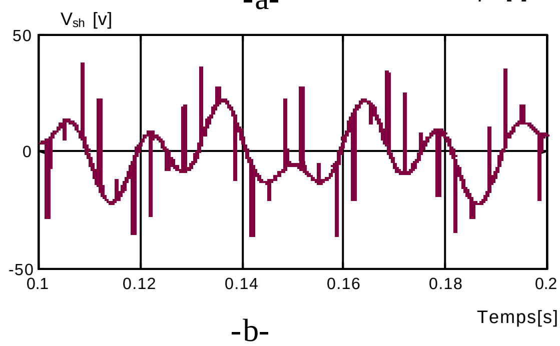
$$\begin{bmatrix} V_{sh1} \\ V_{sh2} \\ V_{sh3} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_\beta & -i_\alpha \\ i_\alpha & i_\beta \end{bmatrix}^{-1} \begin{bmatrix} \Delta\overline{q} - \tilde{q} \\ \Delta\overline{p} - \tilde{p} \end{bmatrix} \qquad (19)$$

3 Simulation and interpretation

For to validate this new control strategy for extracts the voltage reference, three simulations have been presented.

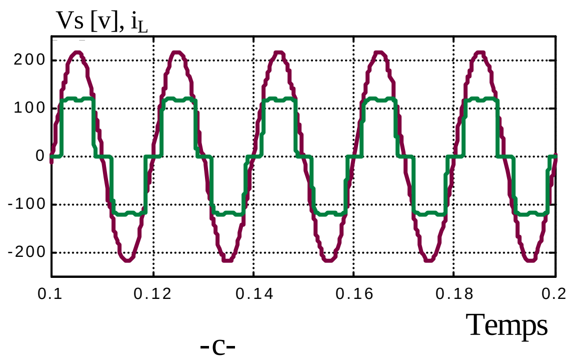


-a-



-b-

The first simulation concerns the magnitude variation of voltage source flicker presented by the Fig.3a

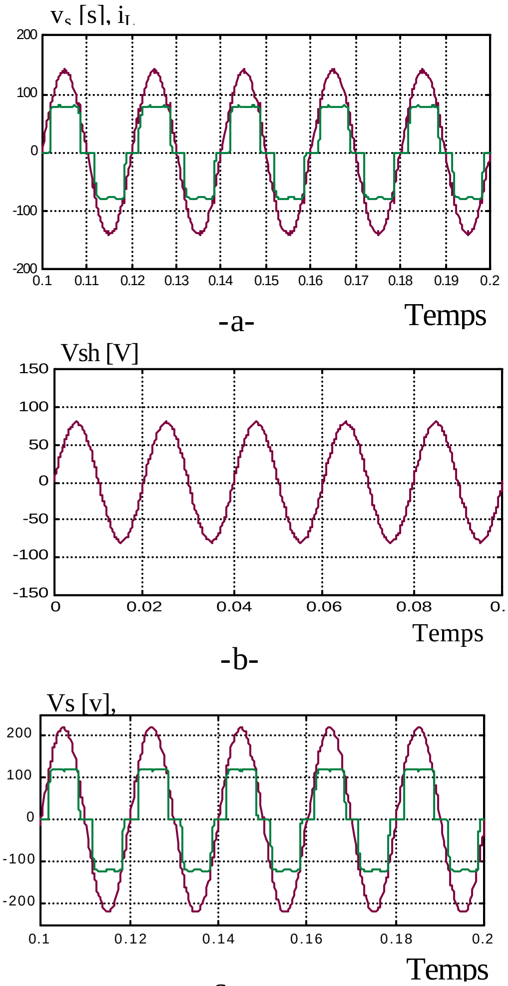


-c-

Figure 3: voltage and current source before and after compensation flicker

We remark that the series active power filter is injected the voltage figure 3b for compensate the variation of voltage. So, the source voltage will become constant and the non-linear load will be work with an optimal voltage Figure 3c.

The second simulation concerns the magnitude variation of voltage source when we have a voltage drop presented by the Fig.4a



-c-

Figure4 voltage and current source before and after compensation flicker

We remark that the series active power filter is injected the residual voltage figure 4b for compensate the voltage drop. So, the source voltage will become always constant and the non-linear load will also be work with an optimal voltage Figure 4c.

We observe from the simulations that the series active power filter is compensating all variation we can found in the network and so, their can stabilizer the voltage at the optimal value.

4. Classical and new indices

Many indices was proposed, among of them the THD ‘’Total Harmonic Distortion‘’ and PF ‘’Power Factor‘’, these indices was expressed as the following expressions:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_h^2}}{V}, \quad PF = \frac{P}{\sqrt{P^2 + Q^2 + H^2}} \qquad (20)$$

These two essential indices are generally used in the electrical power quality. However, it is not valid when we use this new control because the variation of the fundamental current is not taken into account in the classical control, then we propose two new other THD and PF definition named respectively ATHD for “Advanced Total Harmonic Distortion” and APF for “Advanced Power Factor”, that can be applied in the new control, there expression are described as follows:

$$\mathbf{ATHD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_h^2 + \delta V_{residual}}}{V_{1\,ref}} \qquad (21)$$

And

$$APF = \frac{P}{\sqrt{P^2 + Q^2 + H_a^2}} \qquad (22)$$

Where

$$\delta V_{residual} = \sum_{h=1}^{\infty} \delta V_h^2 \pm 2 \sum_{h=1}^{\infty} \delta V_h V_h \qquad (23)$$

$\delta V_{residual}$ represents the change of harmonics voltage in rms Values

$$\mathbf{H_a = i_s} \sqrt{\sum_{h=2}^{\infty} V_h^2 + \delta V_{residual}} \qquad (24)$$

We observe that, if there is no variation of the fundamental current source, then $\delta V_{residual} = 0$ and the formulas (21) and (22) will became the same of equation (20).

VI. CONCLUSION

New control strategy method of the series active power conditioner has been presented, giving better results then those using classical methods. Taking into account perturbation of variation voltage.

Moreover, any voltage fluctuation like flicker, voltage drop,… can be treat efficiently by the series active power filter, So, their guarantying stable state and a nominal load voltage , which was not possible with the classical one.

References:

[1] S. Bhattacharya, D. M. Divan, B. Banerjee: " Syncronous frame harmonic isolator using active series using active series filter " EPE Firenze 1991, pp 3.030-3.035.

[2] S. Luo, Z. Hou : " An adaptive detecting method for harmonic and reactive currents " IEEE Trans. On industrial electronics, vol. 42, N°1, 1995 pp. 85-89.

[3] P. Verdelho 'Analysis of control methods for active power filters and voltage type reversible rectifiers in unbalanced and non sinusoidal conditions' Electrimacs'99 ISBN 972-98257 pp II.95-II103

[4] H. Akagi et Y. Kanazawa, A. Nabae.: " Generalised Theory of the instantaneous reactive power in three-phase circuits" IPEC Tokyo'83 pp. 1375-1386.

[5] H. Akagi et Y. Kanazawa, A. Nabae. 'Instantaneous reactive power compensators comprising switching devices without energy storage components' IEEE Trans. Ind. Appl. Vol IA-22, N°3 1984 pp 625-630

[6] F. Z. Peng, H. Akagi, A Nabae: "Compensation characteristics of the combined system of shunt passive and series active filters" IEEE Transactions on Industry Applications, vol. 29, N°1, 1993, pp. 144-151.

[7] M. C. Benhabib, B. Mazari, C. Benachaiba: " New control strategy of an active power quality conditioner for harmonic compensation." UPEC'2000 – Ireland –

[8] M. C. Benhabib, B. Mazari: " Nouvelle technique de commade d'un conditionneur actif de puissance " ICEL. 2000 Algérie