HAL
open science

Direct Control for Active Power in three-phase application on perturbed network

Antoine F. Hanna Nohra, Maurice Fadel, Hadi Y. Kanaan

To cite this version:

Antoine F. Hanna Nohra, Maurice Fadel, Hadi Y. Kanaan. Direct Control for Active Power in three-phase application on perturbed network. Proc. Int. Conf. Theory and Application of Modeling and Simulation in Electrical Power Engineering, Jul 2017, Toulouse, France. hal-03545245

HAL Id: hal-03545245

https://ut3-toulouseinp.hal.science/hal-03545245

Submitted on 27 Jan 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Direct Control for Active Power in three-phase application on perturbed network

Antoine F. Hanna Nohra[1,2,3], Maurice Fadel[1,2] and Hadi Y. Kanaan[3]

[1] Université de Toulouse ; INPT, UPS ; ENSEEIHT, 2 rue Charles Camichel, BP 7122, Toulouse, France
[2]CNRS; LAPLACE; F-31071 Toulouse, France
[3] St-Joseph University, Faculty of Engineering – ESIB, Mar Roukoz, Mkalles, B.P. 11-0514, Beirut, Lebanon
antoine.hanna.nohra@laplace.univ-tlse.fr , maurice.fadel@laplace.univ-tlse.fr, hadi.kanaan@usj.edu.lb

Abstract -There are today many techniques for controlling active filters on three-phase networks in order to correct the power factor and limit the harmonics consumed at the source. Almost all of these methods are designed for a perfect sinusoidal source and don't perform sinusoidal current when voltages are perturbed. The work developed here concerns the active filtering on a perturbed network, that is to say the presence of voltage harmonics at the connection point in addition to an unbalanced voltages system. A proposed method is described and their results are compared to those obtained by the p-q theory, modified p-q theory and p-q-r method for an application on a three wire power distribution network under perturbed voltage and non-linear load. The assessment concerns the system of currents in the source side after filtering and a comparative evaluation for unbalance factor and THD_i for all methods.

Keywords – Active Filter, Distribution of electrical energy, power three-phase network, correction techniques, Instantaneous active power

1. INTRODUCTION

The increase of the non-linear loads connected on the distribution networks of the electric energy leads to an excessive injection of harmonics and the circulation of reactive power on the distribution lines. These periodic but non-sinusoidal currents circulate through the impedances of the networks and give rise to non-sinusoidal voltages which are added to the initial voltage [1]. We are faced with a degradation of the quality [2] of power which has detrimental consequences on the proper functioning of electrical appliances and which incurs an additional cost for the installations. This causes known damage that must be fought forcefully [3]. The ability of shunt active filters to remove these problems has given rise to a great deal of work in recent years and many solutions have emerged. Very often they are based on the concept of instantaneous reactive power and on the theory *p-q*. This approach is particularly effective but is based on the existence of a sinusoidal voltage source. If the source has harmonics of voltage the efficiency is reduced especially for the power factor. We propose here to develop a method based on the notion of instantaneous active power and based on the effective value of the fundamental of the voltage. This method explicitly takes into account voltage harmonics and is part of a general methodology applicable in multiphase systems particularly in three phase 3-wire, three-phase 4-wire and in single phase networks. The general approach has been the subject of a patent application [4].

This work is conducted as follow: In section 2, a presentation on the Active Power Filter APF and its control law is made. In section 3, control strategies are presented for the p-q theory, modified p-q theory, p-q-r method in addition to these of the proposed method called DCAP (Direct Control for Active Power). In section 4 the procedure that lead to a perturbed voltage (THD=25%) and the results for numerical experiment are discussed. This work finally ends with some conclusions.

2. SHUNT ACTIVE POWER FILTER SOLUTION

The parallel active filter (PAF) is the most common solution for the cancellation of harmonic currents. The conventional structure of the two-level inverter (fig 1) is very widespread for Low Voltage applications.

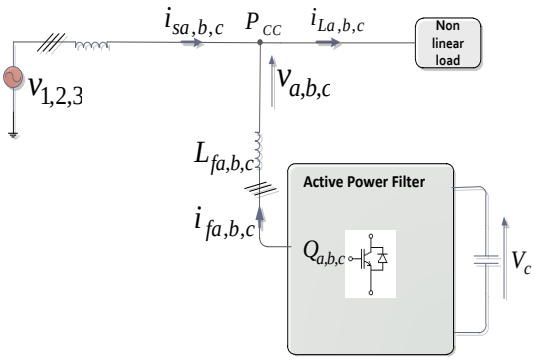


Fig.1. Three-wire Active Power Filter connected on the grid

Figure 2 shows the structure of the control law for a one phase only e.g. phase (a). It reveals 3 essential functions, first a block to extract the harmonics and reactive current $i_{r,h}$ to be compensated, a current loop and finally a voltage loop.

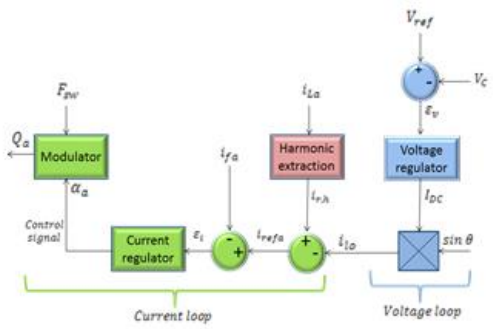


Fig. 2. Structure of control law

In this work we are particularly interested in the harmonic extraction block. This block in its simplest version uses only the current of the load but it is possible to use the power like as in the proposed method.

3. CONTROL STRATEGIES FOR APF

3.1. P-Q THEORY IN THREE PHASE

The p-q theory initially developed for the three-phase systems by Akagi and al., [5], is one of the theories more appropriate to generate references of current. The p-q theory translates into a high dynamic response and stable steady state. It is based on a transformation of currents and voltages vectors from the a, b, c to the α, β frame in (1) and (2) whose an instantaneous active power p(t) and an instantaneous reactive power q(t) are defined that are given by (4)

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \boldsymbol{C}_{23} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \boldsymbol{C}_{23} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (2)$$

With $\boldsymbol{C}_{23}$ is the Concordia matrix in (3):

$$\boldsymbol{C}_{23} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

The currents to be generated by the APF are given in (5) and obtained by the inversion of (4).

$$\begin{bmatrix} i_{r\alpha} \\ i_{r\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} p_C \\ q_C \end{bmatrix} \quad (5)$$

To perform compensation without using energy storage component it is good enough to eliminate the instantaneous reactive power without altering the active power like as (6).

$$\begin{cases} q_C = \bar{q} + \tilde{q} \\ p_C = 0 \end{cases} \quad (6)$$

To eliminate harmonics and reactive power, the undesirable powers to be compensated are expressed in (7).

$$\begin{cases} q_C = \bar{q} + \tilde{q} \\ p_C = \tilde{p} \end{cases} \quad (7)$$

And finally, the reference currents obtained in α, β frame, with taken into account the losses in the filter, then the power p_f to be absorbed by the source and needed to regulate the DC bus voltage, are formulated in (8).

$$\begin{bmatrix} i_{r\alpha} \\ i_{r\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} \tilde{p} - p_f \\ \bar{q} + \tilde{q} \end{bmatrix} \quad (8)$$

The bloc diagram in figure 3 shows the steps to extract the reference currents on the a, b, c frame.

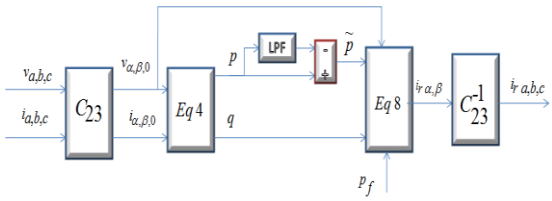


Fig. 3. Bloc diagram to extract the reference currents based on the p-q theory

3.2. MODIFED P-Q THEORY IN THREE PHASE

The modified p-q theory [6] is based on the definition of three reactive powers and an active power and it is dedicated in priority for 4 wire and formulated as (9).

$$\begin{bmatrix} p \\ q_0 \\ q_\alpha \\ q_\beta \end{bmatrix} = \begin{bmatrix} v_0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \\ v_\beta & 0 & -v_0 \\ -v_\alpha & v_0 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (9)$$

Its application in 3 wires is a particular case from (9) for $i_0 = 0$. In this paper the application aims the active filtering on a perturbed 3 wire network, then $v_0 \neq 0$ and $i_0 = 0$.

The reference currents are obtained by the inversion of (9) and are formulated in (10).

$$\begin{bmatrix} i_{r\alpha} \\ i_{r\beta} \end{bmatrix} = \frac{1}{v_{0\alpha\beta}^2} \cdot \begin{bmatrix} v_\alpha & -v_\beta & 0 & v_0 \\ v_\beta & v_\alpha & -v_0 & 0 \end{bmatrix} \cdot \begin{bmatrix} p_C \\ q_{0C} \\ q_{\alpha C} \\ q_{\beta C} \end{bmatrix} \quad (10)$$

With, $v_{0\alpha\beta} = \sqrt{v_0^2 + v_\alpha^2 + v_\beta^2}$ (10.a)

To compensate harmonics and reactive power, the reference compensation powers are in (11).

$$\begin{cases} p_C = \tilde{p} \\ q_{C0} = q_0 \\ q_{C\alpha} = q_\alpha \\ q_{C\beta} = q_\beta \end{cases} \quad (11)$$

Then, the system of reference currents obtained in α, β frame, is formulated in (12).

$$\begin{bmatrix} i_{r\alpha} \\ i_{r\beta} \end{bmatrix} = \frac{1}{v_{0\alpha\beta}^2} \begin{bmatrix} v_\alpha & -v_\beta & 0 & v_0 \\ v_\beta & v_\alpha & -v_0 & 0 \end{bmatrix} \begin{bmatrix} \tilde{p} - p_f \\ q_0 \\ q_\alpha \\ q_\beta \end{bmatrix} \quad (12)$$

The bloc diagram in figure 4 shows the extraction of reference currents on the a, b, c frame.

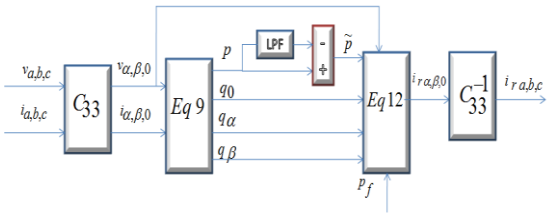


Fig. 4. Bloc diagram to extract the refrence currents based on the modified p-q theory

3.3. P-Q-R THEORY IN THREE PHASE

For this method [7,8], two transformations are required. Once currents calculated in the $\alpha, \beta, 0$ frame, an another transformation to the p, q, r frame is necessary (12). The pqr-coordinate is developed as well as space-vector transformation by using Euler angle rotation. By using the Euler angles methods of twice rotation the available mapping matrices model is resulted in (12):

$$\begin{bmatrix} i_p \\ i_q \\ i_r \end{bmatrix} = \boldsymbol{T}_{pqr} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (12)$$

With,

$$\boldsymbol{T}_{pqr} = \frac{1}{v_{0\alpha\beta}} \cdot \begin{bmatrix} v_0 & v_\alpha & v_\beta \\ 0 & -\frac{v_{0\alpha\beta} \cdot v_\beta}{v_{\alpha\beta}} & \frac{v_{0\alpha\beta} \cdot v_\alpha}{v_{\alpha\beta}} \\ v_{\alpha\beta} & -\frac{v_0 \cdot v_\alpha}{v_{\alpha\beta}} & -\frac{v_0 \cdot v_\beta}{v_{\alpha\beta}} \end{bmatrix} \quad (13)$$

And, $v_{\alpha\beta} = \sqrt{v_\alpha^2 + v_\beta^2}$ (13.a)

Note that, in the case of 3 wire the homopolaire component of current is nul $i_0 = 0$ but all equations remain valide and it is not necessary to reduce their expression. Automaticly, the components that depends on i_0 become nul.

This methode is based on the difinition of an active power and tow reactive powers in (14)

$$\begin{bmatrix} p \\ q_q \\ q_r \end{bmatrix} = \begin{bmatrix} v_p \cdot i_p \\ -v_p \cdot i_r \\ v_p \cdot i_q \end{bmatrix} = v_p \cdot \begin{bmatrix} i_p \\ -i_r \\ \cdot i_q \end{bmatrix} \quad (14)$$

In the pqr-coordinate transformation two consecutive transformations are made and the purpose of which is to cancel the voltage components on the q-axis and r-axis. So only one voltage is calculated in p-axis and that gives.

$$v_p = v_{0\alpha\beta} \quad (14.a)$$

They are two ways for the compensation in this method. The first is based on power compensation and these results are similar to those of the p-q and p-q modified methods. The second is based on the current compensation presented in following.

The reference currents of the p, q, r frame are then in (15) and recalculated in the $\alpha, \beta, 0$ frame in (16)

$$\begin{cases} i_{r\,p} = \tilde{i}_p \\ i_{rq} = i_q \\ i_{rr} = i_r + \frac{i_p \cdot v_0}{v_{\alpha\beta}} \end{cases} \quad (15)$$

$$\begin{bmatrix} i_{r\,0} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix} = \boldsymbol{T}_{pqr}^{-1} \begin{bmatrix} i_{rp} \\ i_{rq} \\ i_{rr} \end{bmatrix} \quad (16)$$

$\boldsymbol{T}_{pqr}^{-1}$ is the inverse of $\boldsymbol{T}_{pqr}$ expressed in (17).

$$\boldsymbol{T}_{pqr}^{-1} = \frac{1}{v_{0\alpha\beta}} \cdot \begin{bmatrix} v_0 & 0 & v_{\alpha\beta} \\ v_\alpha & -\frac{v_{0\alpha\beta} \cdot v_\beta}{v_{\alpha\beta}} & -\frac{v_0 \cdot v_\alpha}{v_{\alpha\beta}} \\ v_\beta & \frac{v_{0\alpha\beta} \cdot v_\alpha}{v_{\alpha\beta}} & -\frac{v_0 \cdot v_\beta}{v_{\alpha\beta}} \end{bmatrix} \cdot \begin{bmatrix} i_{rp} \\ i_{rq} \\ i_{rr} \end{bmatrix} \quad (17)$$

The bloc diagram in figure 5 shows the extraction of reference currents on the a, b, c frame.

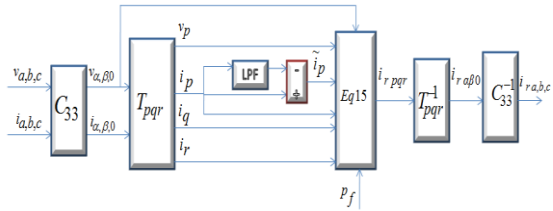


Fig.5. Bloc diagram to extract the reference currents based on the modified p-q-r theory

3.4. DCAP THEORY IN THREE PHASE

The proposed DCAP method is based on the repartion of sinusoidal and equilibrate currents in the source side and not on the repartition of equal powers in the lines of the source. It is developped for a polyphase system and it has been demonstrated that the fundamental conductance of eache phase, for a perturbed polyphase system, is then expressed in (17). In a futur work, more details are given for the DCAP method.

$$\begin{cases} G_{f1} = \frac{P_s}{V_{f1} \cdot \left(\sum_{j=1}^{k} V_{fj}\right)} \\ G_{f2} = \frac{P_s}{V_{f2} \cdot \left(\sum_{j=1}^{k} V_{fj}\right)} \\ \cdot \\ \cdot \\ \cdot \\ G_{fk} = \frac{P_s}{V_{fk} \cdot \left(\sum_{j=1}^{k} V_{fj}\right)} \end{cases} \quad (17)$$

The three phase system is a particular case of (17) for *k=3* and the desired currents in the soure side

$i_{sd\ a,b,c}$ for a 3 phase system are formulated like as (18)

$$\begin{cases} i_{sda} = \frac{P_s}{V_{fa}.(V_{fa}+V_{fb}+V_{fc})}.v_{fa} \\ i_{sdb} = \frac{P_s}{V_{fb}.(V_{fa}+V_{fb}+V_{fc})}.v_{fb} \\ i_{sdc} = \frac{P_s}{V_{fc}.(V_{fa}+V_{fb}+V_{fc})}.v_{fc} \end{cases} \quad (18)$$

P_s is the active power to be feeded by the source and deduced from (19)

$$P_s = P_L + P_f \quad (19)$$

P_L is the active power needed by the load and obtained at the output of a Low Pass Filter after the calculation of the instantaneous power in (20)

$$p_L(t) = v_a.i_{La} + v_b.i_{Lb} + v_c.i_{Lc} \quad (20)$$

P_f is the power to be absorbed by the filter and needed to the regulation of the DC bus voltage. The system of sinusoidal currents required for this action is in (21)

$$\begin{cases} i_{losse\ a} = \frac{P_f}{V_{fa}.(V_{fa}+V_{fb}+V_{fc})}.v_{fa} \\ i_{losse\ b} = \frac{P_f}{V_{fb}.(V_{fa}+V_{fb}+V_{fc})}.v_{fb} \\ i_{losse\ c} = \frac{P_f}{V_{fc}.(V_{fa}+V_{fb}+V_{fc})}.v_{fc} \end{cases} \quad (21)$$

The RMS value for equal currents is in (22)

$$I_{sda} = I_{sdb} = I_{sdc} = \frac{P_s}{(V_{fa}+V_{fb}+V_{fc})} \quad (22)$$

Once the sinusoidal actif currents desired in the source $i_{sd\ a,b,c}$ are calculated, the refrence currents are deduced by (23)

$$i_{r\ i} = i_{L\ i} - i_{sd\ i} \quad i = a, b, c. \quad (23)$$

4. SIMULATION AND RESULTS DISCUSSION

The schema of the power circuit is shown on fig. 6. v_1, v_2, and v_3 represent the voltages at the source. Three unequal impedances $Z_{a,b,c}$ are connected between the source and the P_{CC}, (R_a=44.4 Ω, R_b= 35 Ω et R_c=38.3 Ω) in series with (L_a= 45 µH, L_b = 20 µH et L_c = 21 µH). The load is constituted by a three phase diode bridge that feed a resistance R_{ch}=40.4Ω and an inductance L_{ch}=27.67mH. three identical impedances are connected at the input of the bridge L= 6,7 mH, R=0.5 Ω to simulate cables and connection impedance. The APF connected to the grid via three inductances (L_{fa}=12.81mH, L_{fb}=13.72 mH and L_{fc}=10.6mH) in series with their internal resistances (R_{fa}= 0.5Ω, R_{fb}=0.6Ω et R_{fc}=0.3Ω). The DC bus voltage is 650V. The maximum voltage for each capacitor is 400V, for it they are two capacitors in series. C_h=C_b=0.6mF. The switching frequency is equal to 10 kHz.

4.1. VOLTAGE PERTURBATION PROCEDURE

Harmonic model for voltages source v_1, v_2, and v_3 is given in (24). They are slightly perturbed and unbalanced on no load operation. When currents before filtering, in fig.7, pass through the impedances $Z_{a,b,c}$ having different values, it lead to

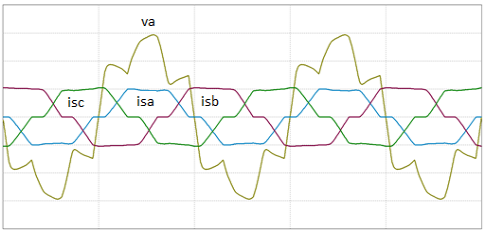


Fig. 7. Simulation of source currents and v_a voltage before filtering (50V-5A-5ms/div)

a large unequal voltages drop that induce unbalance on the voltages $v_{a,b,c}$ at the P_{CC} in fig.8. The RMS value of the fundamental of each voltage decreases then the THD increases and voltages become highly perturbed, e.g. $THD_{va} = 25\%$, fig.8

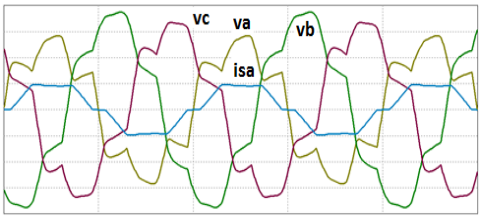


Fig.8. Perturbed voltages source and i_{sa} source current before filtering (50V-5A-5ms/div)

Fig 9 shows the simulation results using Psim tools for the four methods after filtering. For the DCAP, the currents system is sinusoidal and balanced fig.9.b despite the perturbation on voltages at the P_{cc} in fig.9.a. For the p-q and modified p-q methods, currents system, fig.9.d and fig.9.f, is not sinusoidal after filtering. For the p-q-r theory in fig.9.h, currents are better than those provided by the p-q and modified p-q. Visually, the currents given by p-q-r method and those given by the DCAP are similar but in reality their performance in terms of distortion and imbalance are not the same. In fact, in fig.10 a comparison of performances on terms of unbalance factor $UF\% = \frac{Xi}{Xd}$ based on the European standard EN50160 and THD is performed.

Xd and Xi are the direct and inverse components of voltages or currents. Note that these values are measured by Fluke 438B device after experimental work. It is shown that only the DCAP meet with standards recommendation with an $UF < 2\%$, and assumes the minimal THD_i.

5. CONCLUSION

In this work the proposed DCAP method, object of patent application, is presented and compared to three known methods. It is seen that under perturbed network only the DCAP can provides sunisoidal currents on the source side and an $UF < 2\%$. that meet with the standard recomandations. Its supperiority is evident.

ACKNOWLEDGEMENTS

This work has been supported by the PHC CEDRE 2016 project N°30108XK and the Lebanese National Council for Scientific Research (CNRS-L). The authors also gratefully thank the Research Council of Saint-Joseph University of Beirut, Lebanon, the laboratory LAPLACE, the Agence Universitaire de la Francophonie (AUF), the Institut Français of the French Embassy in Lebanon, and the Institut Supérieur des Sciences Appliquées et Economiques (ISSAE-CNAM Liban) for their financial contribution.

REFERENCES

[1] McBee, K.D.; Simoes, M.G., "Evaluating the long-term impact of a continuously increasing harmonic load demand on feeder level voltage distortion," Industry Applications Society Annual Meeting (IAS), 2012 IEEE , vol., no., pp.1,8, 7-11 Oct. 2012

[2] M. Masoum, P. S. Moses and A. S. Masoum, "Derating of Asymmetric Three-Phase Transformers Serving Unbalanced Nonlinear Loads", IEEE Trans. Power Delivery, vol.23, No. 4, Oct. 2008, pp. 2033-2041.

[3] IEEE Recommended Practice and Requirement for Harmonic Control in Electrical Power systems. IEEE Std.519-1992

[4] Antoine HANNA NOHRA, Maurice FADEL, Hadi KANAAN: Demande de dépôt de brevet intitulée «PROCÉDÉ DE COMMANDE D'UN FILTRE ACTIF PARALLÈLE POUR RÉSEAUX PERTURBÉS ET FILTRE ACTIF ASSOCIÉ» déposée le 11 octobre 2016 sous le N° FR1659825.

[5] Akagi, H.; Kanazawa, Yoshihira; Nabae, A., "Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components," Industry Applications, IEEE Transactions on, vol.IA-20, no.3, pp. 625-630, May 1984.

[6] Fang Zheng Peng; Ott, G.W., Jr.; Adams, D.J., "Harmonic and reactive power compensation based on the generalized instantaneous reactive power theory for three-phase four-wire systems," Power Electronics, IEEE Transactions on , vol.13, no.6, pp.1174,1181, Nov 1998.

[7] Hyosung Kim; Blaabjerg, F.; Bak-Jensen, B.; Jaeho Choi, "Instantaneous power compensation in three-phase systems by using p-q-r theory," Power Electronics, IEEE Transactions on , vol.17, no.5, pp.701,710, Sep 2002

[8] I. Yuniantoro, R. Gunawan and R. Setiabudy, "The pqr-coordinate in the mapping matrices model of Kim-Akagi on power transformation based on Euler angle rotation method," *2013 International Conference on QiR*, Yogyakarta, 2013, pp. 121-126

$$
\begin{aligned}
v_1 &= 335.4\sin(\omega t) + 1.27\sin(3\omega t + 43) + 7.77\sin(5\omega t - 171) + 3.39\sin(7\omega t + 24) \\
&\quad + 0.84\sin(9\omega t - 130) + 0.42\sin(11\omega t - 120) \\
v_2 &= 337.4\sin(\omega t - 120) + 1.27\sin(3\omega t + 2) + 7.9\sin(5\omega t - 53) + 2.54\sin(7\omega t - 104) \\
&\quad + 1.41\sin(9\omega t - 138) + 0.42\sin(11\omega t + 5) \\
v_3 &= 333.4\sin(\omega t - 240) + 0.3\sin(3\omega t - 278) + 8\sin(5\omega t - 291) + 2.82\sin(7\omega t + 216) \\
&\quad + 0.84\sin(9\omega t - 158) + 0.14\sin(11\omega t - 212)
\end{aligned}
\tag{24}
$$

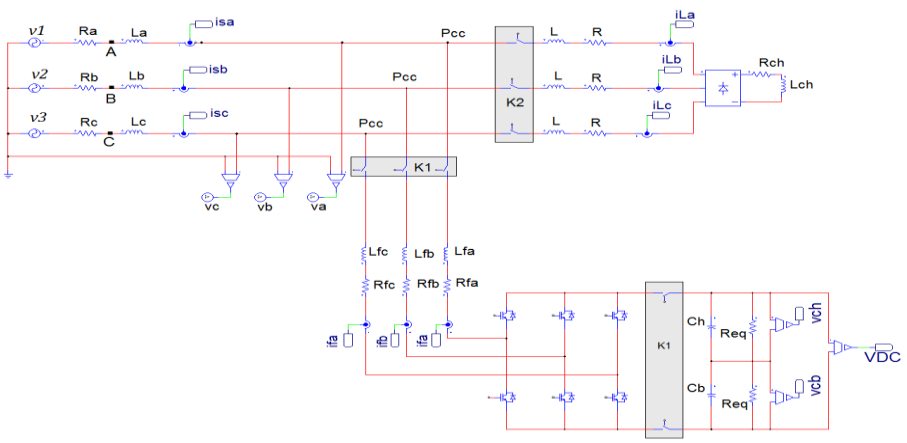


Fig. 6. Schema of the power circuit

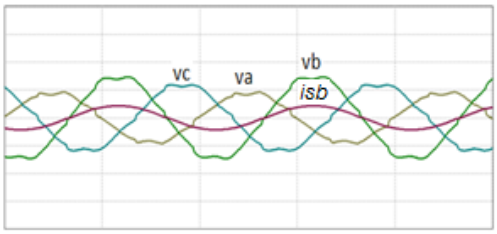
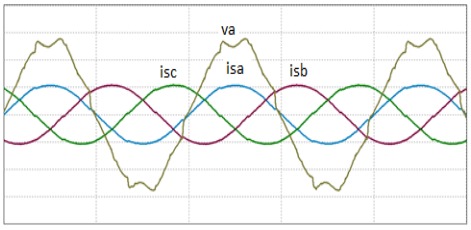
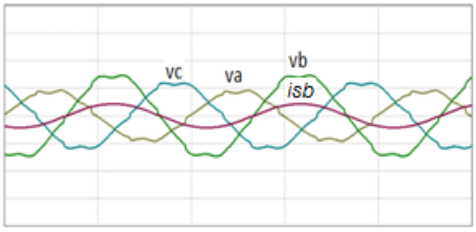
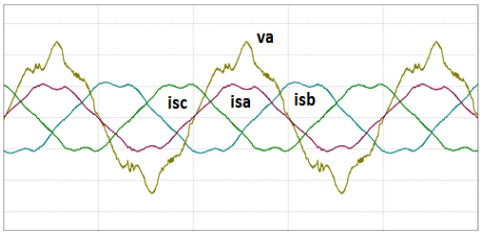
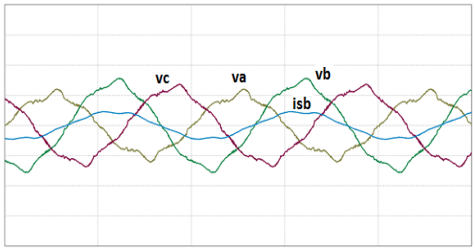
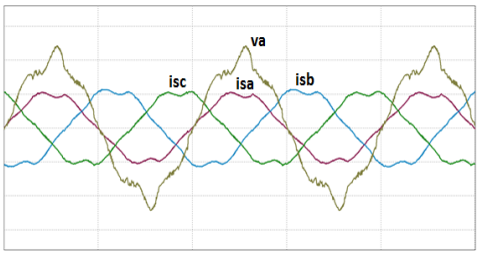
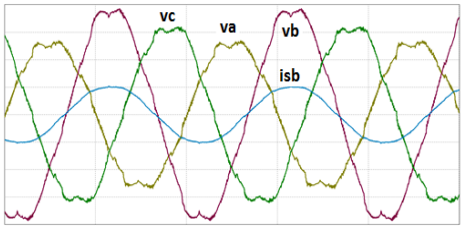
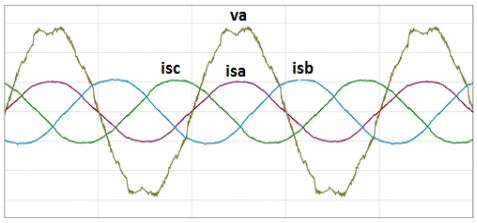
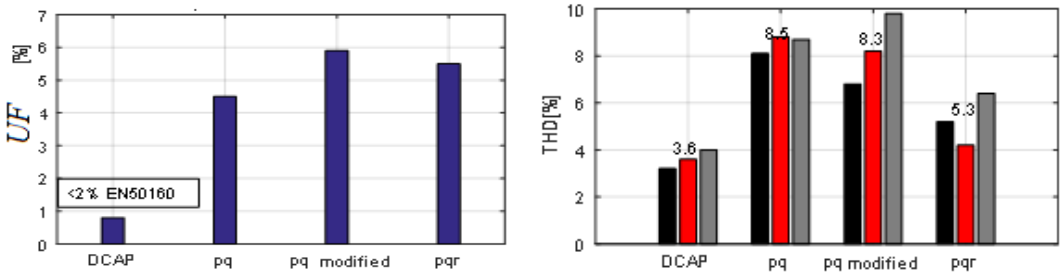
Results for DCAP after filtering	 100V-10A-5ms/div fig.9. a	 50V-5A-5ms/div fig.9. b
Results for modified p-q method after filtering	 100V-10A-5ms/div fig.9. c	 50V-5A-5ms/div fig.9. d
Results for modified p-q method after filtering	 100V-10A-5ms/div fig.9. e	 50V-5A-5ms/div fig.9. f
Results for p-q-r method after filtering	 50V-5A-5ms/div fig.9. g	 50V-5A-5ms/div fig.9. h
	voltages source after filtering	Source currents after filtering

Fig. 9. Wave forms for voltages and currents after filtering



a) Comparison on the Unbalance Factor b) Comparison on the THD

Fig.10. Comparison of performances