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A new approach to extract reference currents for multilevel shunt active filter in three phase systems

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ABSTRACT

In this article, we present a new study of technique to extract reference currents for three-level shunt active filter controlling by fuzzy logic. The APFs is realized using three phase voltage and the carrier-based PWM strategy. A new technique for identifying reference currents will be developed. It is based on concordia method using multi-variable filter, and makes the total or selective extraction harmonic currents of references, and by consequence making their compensations, total or selective. The results of digital simulation in the Matlab-Simulink environment of a system of power to thyristor outputs on an inductive load show well the effectiveness of this new technique of extraction of the harmonics of reference.

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1. INTRODUCTION

The use of the electrical appliance is increasingly intense since a certain number of years. However, the majority of the apparatuses absorb nonlinear currents which generate harmonic distortions in the whole of the electrical supply network. The presence of these harmonics is awkward insofar as they can deteriorate the performances of the apparatuses, and even to damage them. A solution then consists in compensating for the harmonic distortions while inserting filters in the electrical supply networks [1, 2].

These filters seek to identify the harmonic components in order to effectively reinjection them in the electrical supply network in opposition of phase. They are also able to compensate reactive power and to compensate for the possible imbalance of a three-phase system [3, 4]. Moreover, the shunt active filters can be inserted easily in the existing installations of electric distribution without requiring great modifications. Recognized for their simplicity of implementation, for their robustness and their reliability, they represent today the technique most largely employed to cleanse the electric systems.

A three-level shunt active filter based on the technique of extraction multi-variable filter can compensate, in real time, completely or partially any disturbance being able to occur on the electrical supply network [5, 6]. In this article, we present a new study of technique to extract reference currents for three-level shunt active filter controlling by fuzzy logic. The APFs is realized using three phase voltage and the carrier-based PWM strategy. A new technique for identifying reference currents will be developed. It is based on concordia method using multi-variable filter, and makes the total or selective extraction harmonic currents of references, and by consequence making their compensations, total or selective. The results of digital simulation in the Matlab-Simulink environment of a system of power to thyristor outputs on an inductive load show well the effectiveness of this new technique of extraction of the harmonics of reference.

2. CIRCUIT CONFIGURATION

The system configuration of the active power filter connected to the electrical network is shown in Figure 1. It gives the proposed system which is composed of a three-phase source, a rectifier as a non-linear load and shunt active power filter [7- 9].

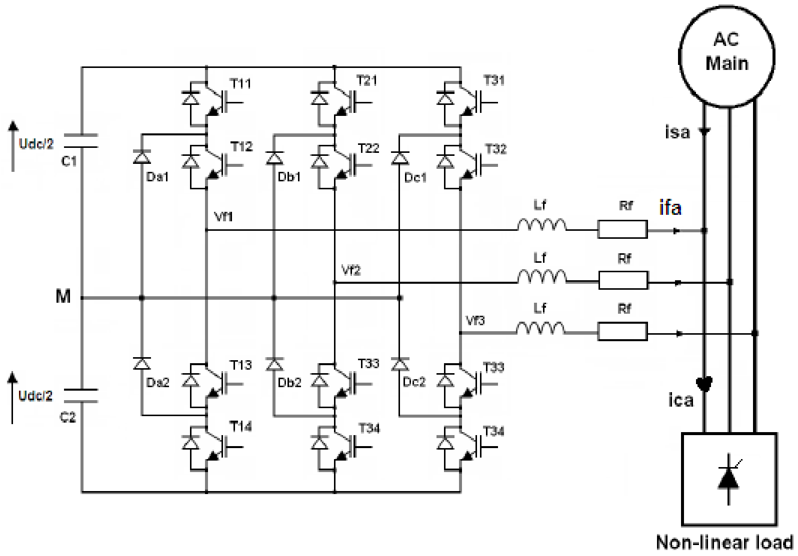

Figure 1. Overview of the system configuration of Three-level shunt active power filter

3. DEVELOPMENT OF THE IDENTIFICATION METHOD BY A MULTIVARIABLE FILTER

3.1. Principle of method multivariable filter (MVF)

A new type of extraction filter named here multivariable Filter (MVF) has been developed, Its basic principle is based on the work of Song Hong-Scok is based on the extraction of the fundamental component of the signals, directly according to the $(\alpha - \beta)$ axes. [5]

3.2. Mathematical model of the multivariable filter (MVF)

In his research, Hong Scok Song presented how he recovered the equivalent transfer function of the integration in the synchronous references frame expressed by (1) [5, 10].

$$\hat{i}_{\alpha\beta}(t) = e^{j\omega_c t} \int e^{-j\omega_c t} i_{\alpha\beta}(t).dt \tag{1}$$

He found in Laplace transformation the following equation “The demonstration is given in the annex of his thesis” [9]:

$$H(s) = \frac{\hat{i}_{\alpha\beta}(s)}{i_{\alpha\beta}(s)} = \frac{s + j\omega_c}{s^2 + \omega_c^2} \tag{2}$$

Now suppose that we add two new constants K_1 and K_2 in the transfers function of equation (2). Then we have the following expression:

$$H(s) = \frac{\hat{i}_{\alpha\beta}(s)}{i_{\alpha\beta}(s)} = K_2 . \frac{(s + K_1) + j\omega_c}{(s + K_1)^2 + \omega_c^2} \tag{3}$$

we set $K = 20$ and vary K_1. We can trace the Bode diagram in 3D (gain and phase as a function of f and K), as shown in Figure 2.

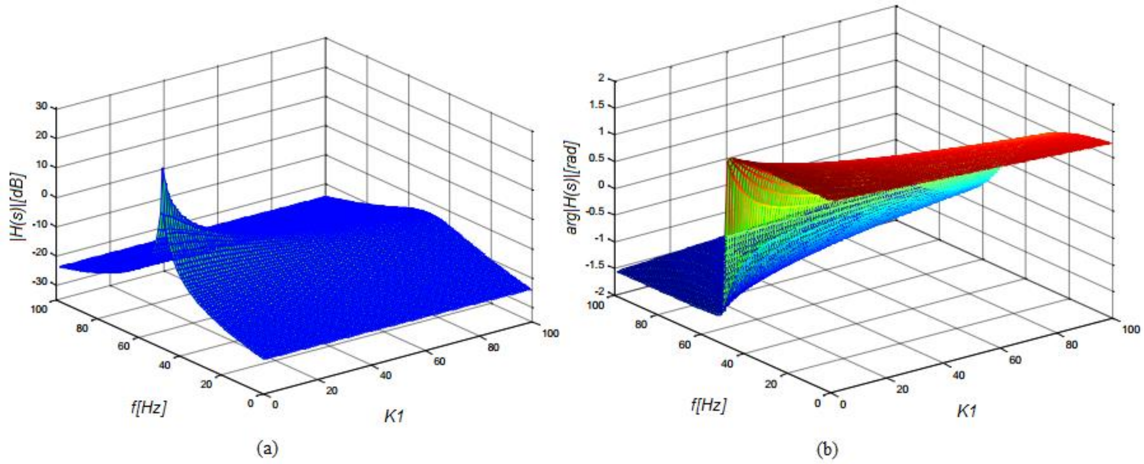

Figure 2. (a) Gain curve of $H(s)$ as a function of f and K_1 (b) phase curve of $H(s)$ as a function of f and K_1

Figure 2 show us that:

1. at $f = 50$ Hz, the phase angle of Bode diagram is null, this means that the two input and output signals are in phase either $K_1 = 20$.
2. to obtain $|H(s)| = 0\,dB$ is necessary to make $K_1 = K_2 = K = 20$

Equation (4) will become as a follow up:

$$H(s) = \frac{\hat{\imath}_{\alpha\beta}(s)}{i_{\alpha\beta}(s)} = K\frac{(s+K)+j\omega_c}{(s+K)^2+\omega_c^2} \tag{4}$$

The expressions linking the output components of the multi-variable filter to the input components are as follows:

$$\hat{i}_\alpha = \left(\frac{k}{s}\left[i_\alpha(s) - \hat{i}_\alpha(s)\right] - \frac{\omega_c}{s}.\hat{i}_\beta(s)\right) \tag{5}$$

$$\hat{i}_\beta = \left(\frac{k}{s}\left[i_\beta(s) - \hat{i}_\beta(s)\right] - \frac{\omega_c}{s}.\hat{i}_\alpha(s)\right) \tag{6}$$

Figure 3 gives the circuit diagram of the multivariable filter described by (5) and (6).

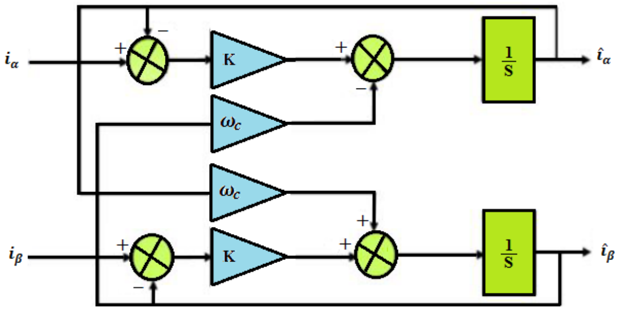

Figure 3. Circuit of the multivariable filter (MFV)

Thus, the selective identification of harmonic reference currents in a three-phase current system is done directly on the Concordia axis, it is sufficient to know their frequency and direction of direct or reverse propagation [3]. In our study, we have identified two harmonics, 5th and 7th simultaneously. Figure 4 shows Block diagram of simultaneous identification of the harmonic currents references 5th and 7th based multi-variable filter (MVF), the choice of the parameters K_5=18 and K_7=16 is done at base of the diagram of Bod in 3D [12].

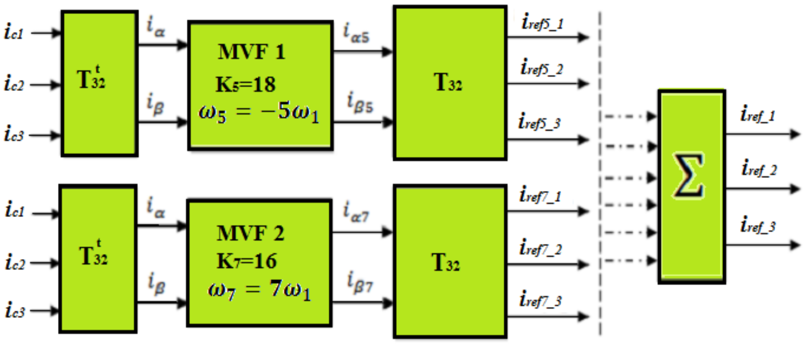

Figure 4. Block diagram of simultaneous identification of the harmonic currents references 5th and 7th based multi-variable filter (MVF)

3.3. Identification of overall harmonics based multi-variable filter

Two-phase axes (α - β) defined as the sum of a fundamental component and a harmonic component [11]:

$$\begin{cases} i_\alpha = i_{\alpha 1} + i_{\alpha h} \\ i_\beta = i_{\beta 1} + i_{\beta h} \end{cases} \tag{7}$$

Role of the multivariable filter is to extract the fundamental components of the pulsating charge current, directly along the axes$(\alpha - \beta)$. Then, the harmonic components of the current along the axes $(\alpha - \beta)$, $i_{\alpha h}$ and $i_{\beta h}$ are obtained by subtracting them on each axis, the output of multivariable from its input [13, 14].

The inverse Concordia transformation then allows us to obtain the three-phase references of the harmonic currents:

$$\begin{bmatrix} i_{c\_ref1} \\ i_{c\_ref2} \\ i_{c\_ref3} \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{\alpha h} \\ i_{\beta h} \end{bmatrix} \tag{8}$$

Figure 5 presents the diagram for the global identification of the reference currents based on the technique of the multivariable filter.

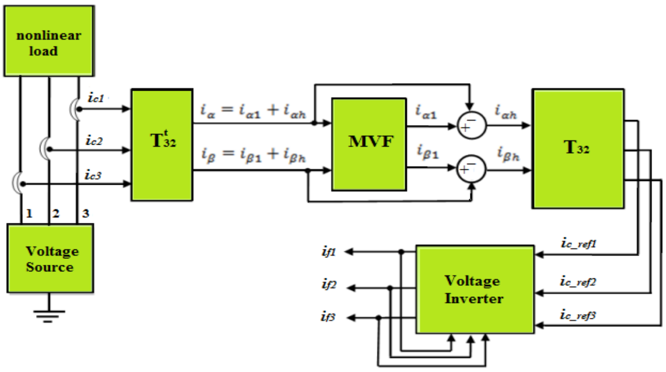

Figure 5. Determination of the reference currents of the active filter using the multivariable filter

4. FUZZY LOGIC CURRENT CONTROLLER

This modulation technique also consists in reducing the differences between the reference currents and the currents generated by the active filter and that at constant frequency. The variables in the equation can be easily implemented with fuzzy logic while improving the performance of the active filter [15-17].Figure 6 show fuzzy logic controller synoptic diagram, which possesses two inputs: the error (e), *(e = iref – if)* and its derivative *(de)*, and one output: the command *(cde)* [18-20].

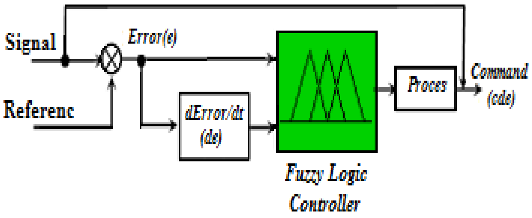

Figure 6. Fuzzy logic controller synoptic diagram

A fuzzy system is made up of four essential parts [15]:

1) The knowledge base consisting of a database and a rule base.
2) The inference system.
3) The fuzzification interface.
4) The defuzzification interface

The fuzzy logic current controller has two inputs, In this case. Change named of error ***de*** and error ***e*** one output named ***s***. Here the change of error ***de*** and error ***e*** is the input variable for the system. The fuzzy logic controller is characterized as follows:

1) There are three fuzzy sets for each of the two inputs *(e, de)* with Gaussian membership functions.
2) And there are five fuzzy sets for the output with triangular membership functions
3) Third implications using the ‘minimum’ operator, inference mechanism based on fuzzy implication containing five fuzzy rules.
4) At last defuzzyfication using the ‘centroïd’ method.

The linguistic rules for the fuzzy logic current controller are as follows:

1) If *(e)* is zero *(ZE)*, then *(cde)* is zero *(ZE).*
2) If *(e)* is positive *(P),* then *(cde)* is big positive *(BP).*
3) If *(e)* is negative *(N)*, then *(cde)* is big negative *(BN).*
4) If *(e)* is zero *(ZE)* and *(de)* is positive *(P)*, then *(cde)* is negative *(N).*
5) If *(e)* is zero *(ZE)* and *(de)* is negative *(N)*, then *(cde)* is positive *(P).*

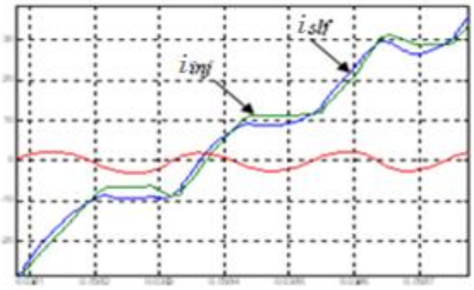

Figure 7. Fuzzy rules establishment

5. RESULTS OF THE SIMULATION

For clarity, and to an understanding we considered to present only the results we see interesting. The general structure of the studied system is described in Figure 8. It includes:

1. The three-phase power network.
2. Nonlinear load (Three-phase rectifier).
3. The parallel active filter with voltage structure (three-level inverter with NPC structure).

Models and simulations are implemented in the MATLAB / Simulink. The objective is to validate and show the effectiveness of the active compensation (total or selective) harmonics based MVF selective compensation is devoted to the first two harmonics 5th, 7th and both at the same time.

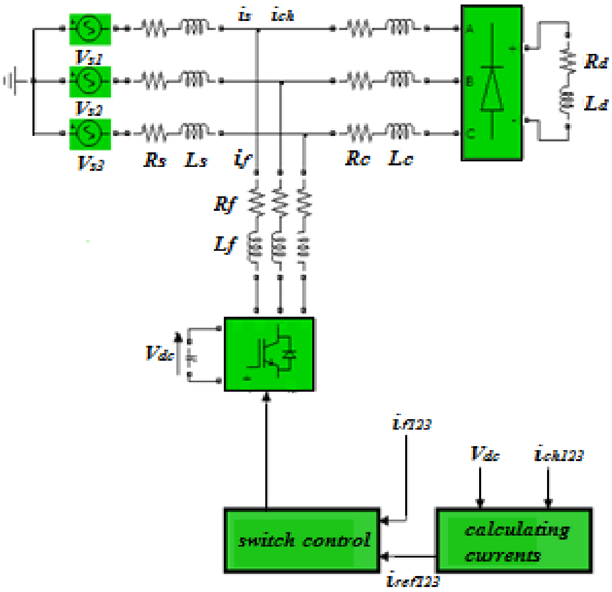

Figure 8. Simulated system

The Table 1.are summarized of the system parameters values

Table 1.System simulation parameters

Parameters	Numerical values
Source voltage & frequency	$220\ V\ (RMS), 50\ Hz$
Inductance L_s and resistance R_s of the line	$0.0115\ mH, 1\ m\Omega$
DC link's inductance L_{dc}, Resistance R_{dc}	$0.2\ H, 10\ \Omega$
Inductance Lc, Resistance Rc	$0.1mH, 1m\ \Omega$
Shunt active power filter : DC supply voltage	$800\ V$
Resistance R_f , Inductance L_f	$1\ m\Omega, 1\ mH$

5.1. Total compensation of current harmonics based on a multivariable filter (MVF)

The results of numerical simulation of the system Figure 8, are obtained by the PWM command of the inverter, and with the identification algorithm based on the multivariable filter to identify the reference harmonic currents.

The waveform of the load current before applying active filtering is shown in Figure 9. There is a symmetrical distortion of the current ich relative to the half-period point, which means that the multiple harmonics of 2 and 3 are nonexistent in the spectrum of $\boldsymbol{i_{ch}}$, and that only those of rank (6h ± 1) are present, this is confirmed by the spectrum of $\boldsymbol{i_{ch}}$ (Figure 10).

After applying the proposed active filter parallel, there is a marked improvement in the shape of $\boldsymbol{i_s}$ as shown in Figure 11.The fact that $\boldsymbol{i_s}$ has recovered its sinusoidal shape; this is confirmed by the spectrum of $\boldsymbol{i_s}$ (Figure 12).

Reassures us that the active filter has generated a current $\boldsymbol{i_f}$ which follows its reference $\boldsymbol{i_{ref}}$ well as shown in Figure 13.The distortion rate of the mains current is improved so that the THD goes from **30.84%** before filtering to **0.51%** after filtering.The harmonic spectra of the currents (Figure 12) justify the positive behavior of the active parallel filtering.

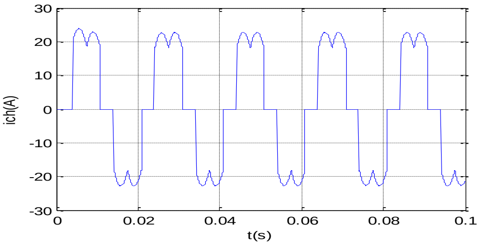

Figure 9. Load current before compensation i_{ch}

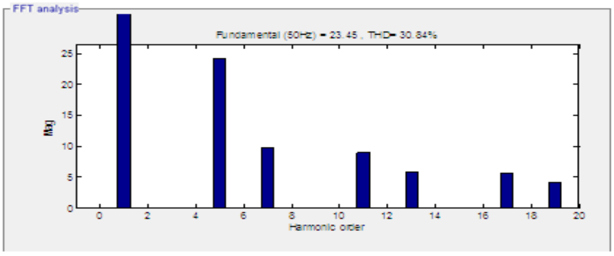

Figure 10. Harmonic Spectrum of load current i_{ch} before compensation

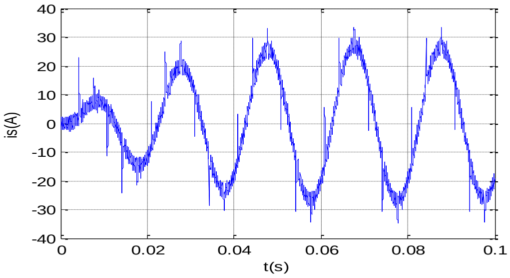

Figure 11. Supply current waveform i_s after compensation

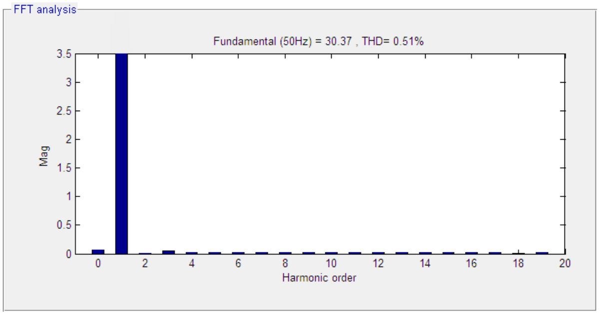

Figure 12. Harmonic spectrum of supply current i_s after compensation

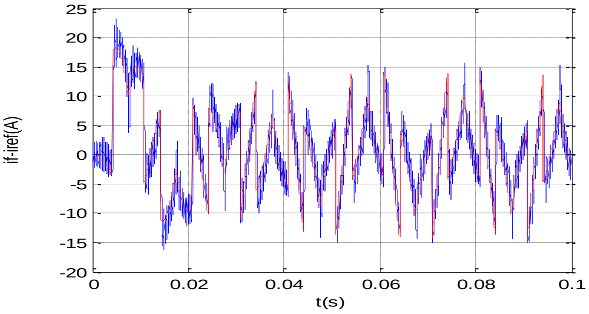

Figure 13. Current injected by APF and its reference with fuzzy logic controllers

5.2. Harmonic compensation 5th, 7th of the load current based on a multivariable filter (MVF)

The waveform of the load current before applying active filtering is shown in Figure 14. There is a symmetrical distortion of the current ich relative to the half-period point, which means that the multiple harmonics of 2 and 3 are nonexistent in the spectrum of i_{ch}, and that only those of rank $(6h \pm 1)$ are present, this is confirmed by the spectrum of i_{ch} (Figure 15).

The results of simulations obtained by the multi-variable filter method clearly show the efficiency of selective active parallel filtering, this appeared on the improvement of the waveform of the network current after the filtering of the desired harmonics (5, 7) see Figure 17. Table 2. Gives the distortion rate of i_s as a function of the harmonics eliminated

We have set up the principle of extracting the harmonic currents to be compensated by the multivariable filter method. The results of simulations obtained clearly assess the effectiveness of this technique. The ability of this technique compensate for the harmonics desired for the current load is demonstrated by rate of distortion after filtering of the source current, the major advantage this type of filtering is to minimize the energy supplied by the active parallel filter on the one hand and to compensate for the most harmful harmonics individually and simultaneously on the other hand

Table 2. The harmonic distortion rate of the source current i_s by the multivariable filter

The harmonics to compensate	0 (before filtering)	Total harmonic (after filtering)	Compensation of harmonics (5, 7)
Current distortion rate i_s (THD %)	30.84	0.51	15.75

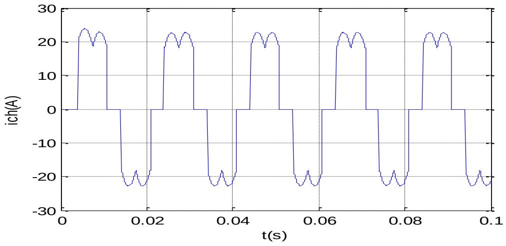

Figure 14. Load current before compensation i_{ch}

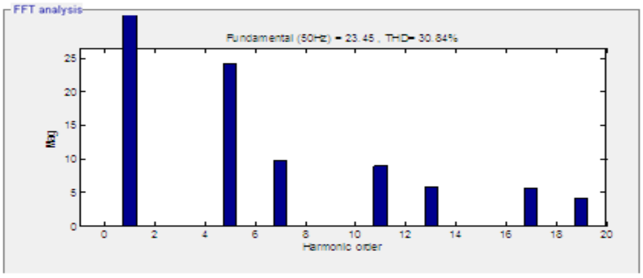

Figure 15. Harmonic Spectrum of load current ich before compensation

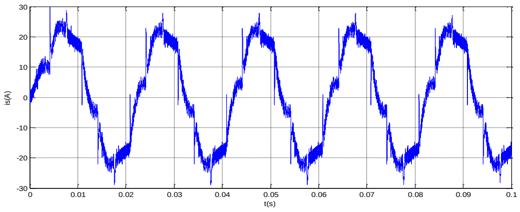

Figure 16. Supply current waveform is after elimination of 5th and 7th harmonic

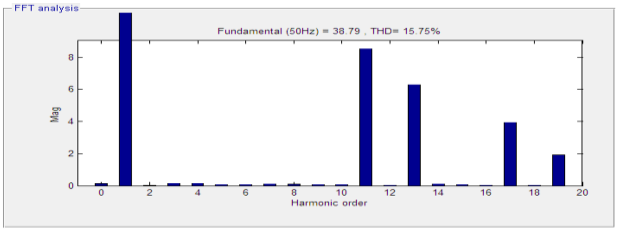

Figure 17. Harmonic spectrum of supply current is after compensation

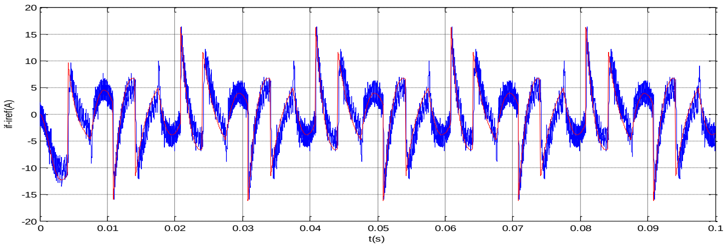

Figure 18. Current injected by APF and its reference with fuzzy logic controllers

6. CONCLUSION

We can conclude that; the parallel active filter can be compensated harmonics grid completely and individually. The MVF identification method is very effective to extract the harmonic references and easy implementation. The identification of harmonics does not require a contrary PLL circuit pq and dq .In a multivariable filter, we can reduce the number of extraction filters to obtain selective compensation, contrary to the extraction methods pq and dq. The MVF technique allows us to selectively or completely compensate harmonics in the network. The MVF technique allows us to compensate harmonics distorted and unbalanced network voltage regime.

REFERENCES

[1] D.Ould Abdeslam, P. Wira, D. Flieller, J. Mercklé, "Une nouvelle approche neuromimétique pour l'identification et la compensation des harmoniques dans les systèmes électriques", *International Conference on Electrical Engineering and its Applications*, Sidi Bel-Abbes, Algeria, 2006.

[2] Y P Obulesu, "Control Strategy for Three Phase Shunt Active Power Filter with Minimum Current Measurements", *International Journal of Electrical and Computer Engineering (IJECE)*, Vol 1, No 1, pages 31-42, 2011.

[3] N. Bruyant, "Etude et commande généralisées de filtres actifs parallèles, compensation global ou sélective des harmoniques, régime équilibré ou déséquilibré". *Doctoral thesis*, l'université de Nantes, France, 1999.

[4] Abdusalam, M., Poure, P. and Saadate, S. "Hardware implementation of a three-phase active filter system with harmonic isolation based on self-tuning filter*", 39th IEEE Power Electronics Specialists Conference*, Island of Rhodes, Greece,2008.

[5] Mesbahi, N., Ouari, A., Ould Abdeslam, D., Djamah, T. and Omeiri, A. "Direct power control of shunt active filter using high selectivity filter (HSF) under distorted or unbalanced conditions", *Electric Power Systems Research*, Vol. 108, pp.113–123,2014.

[6] N. Bruyant, "Etude et commande généralisées de filtres actifs parallèles, compensation global ou sélective des harmoniques, régime équilibré ou déséquilibré", *Doctoral thesis,* l'université de Nantes, France, 1999.

[7] M. C. Benhabib and S. Saadate, "A New Topology for a Modular Active Power Filter", *IEEE ISI*, 20-23, Dubrovnik, Croatia, 2005.

[8] S. Chennai , M-T .Benchouia ,A.Goléa, "Harmonic Current Compensation based on Three-phase Three-level Shunt Active Filter using Fuzzy Logic Current Controller" *Journal of Electrical Engineering & Technology*,Vol. 6, No. 5, pp. 595-604, 2011.

[9] Cheng-I Chen and Yeong-Chin Chen, "Comparative Study of Harmonic and Inter harmonic Estimation Methods for Stationery and Time-Varying Signals," *IEEE Transactions on Industrial Electronics*, Vol. 61, No. 1, pp. 397 – 404, 2014.

[10] S. Hong-Seok, P. Hyun-Gyu, N. Kwanghee, "An instantaneous phase angle detection algorithm under unbalanced line voltage condition", in*: IEEE 30th Annual Power Electronics Specialist Conference PESC'99*, vol. 1, Au, 1999.

[11] Scok, S.H., "Control Scheme for PWM Converter and Phase Angle Estimation Algorithm under Voltage Unbalanced and/or Sag Condition", *PhD in Electronic and Electrical Engineering*, University of Postecch, Republic of Korea, South, 2001.

[12] Lascu, C., Asiminoaei, L., Blaabjerg, F., Boldea, I., "High performance current controller for selective harmonic compensation in active power filters", *Proc. of OPTIM'06*, Vol. 1, pp. 205-212T, 2006.

[13] P. Thirumoorthi, Raheni T. D. "Adaptive Method for Power Quality Improvement through Minimization of Harmonics Using Artificial Intelligence", *International Journal of Power Electronics and Drive Systems (IJPEDS)*, Vol. 8, No. 1, pp. 470-482, 2017.

[14] K. Kubo, K. Sakai, "Feedforward voltage compensation for digital active filter using frequency domain decomposition", *EPE'97*, Trondheim, Vol.4, pp.786-791.1997.

[15] N. Gounden, S. Peter, H. Nallandula, and S. Krithiga, "Fuzzy logic controller with MPPT using line-commutated inverter for three- phase grid-connected photovoltaic systems", *Renewable Energy*, Vol. 34, pp. 909–915, 2009.

[16] M. Hameed, B. Das, and V. Pant, "A self-tuning fuzzy PI controller for TCSC to improve power system stability", *Electric Power Systems Research* ,78, pp.1726–1735, 2008.

[17] G. K. Singh, A. k. Singh and R. Mitra, "A simple fuzzy logic based robust active power filter for harmonics minimization under random load variation," *Electric Power Systems Research*, Vol. 77, pp. 1101–1111, 2007.

[18] Mridul Jha. S.P. Dubey, "NeuroFuzzy based Controller for a Three Phase FourWire Shunt Active Power Filter", *International Journal of Power Electronics and Drive Systems (IJPEDS),* Vol 1 No 2, pp. 148-155, 2011.

[19] B.-R. Lin, T.-Y. Yang, "Three-level voltage-source inverter for shunt active filter", *IEE, Electric Power Applications*, pp.744–751, Nov.2004.

[20] K. Selvakumar1, et al., "Hysteresis Control 3-Level SI-NPC Inverter with Wind Energy System," *International Journal of Power Electronics and Drive System (IJPEDS)*, Vol. 8, No. 4, pp. 1764-1770, 2017.