USING HYBRID POWER FILTER TO MITIGATE CURRENTS AND VOLTAGES HARMONICS IN THREE PHASE SYSTEM

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ABSTRACT

This paper describes different power quality problems in distribution systems and their solutions with power electronics based equipment. A hybrid power filter in combined system of shunt passive and series active power filter has been designed and simulate with Matlab/Simulink. This filter is a three level PWM voltage source inverter and we use a fuzzy logic controller algorithm to control the harmonic voltages. The viability of the proposed algorithm is validated in this work. This hybrid power filter is able to compensate the reactive power (showed that source voltage is sinusoidal and in phase with source current), and harmonics (voltage & current) for three phase of the non linear load current proposed with RL and RC load. The proposed solution has achieved an improvement of power quality in distribution system specifically the reduction of currents and voltages harmonics, we see that through the values of THD_I *and* THD_V *that are still below the IEC (61000) standard after filtering.*

Keywords: *Active Power Filter, Hybrid Filter, Passive Filter, Power quality, Harmonics; THD; fuzzy controller*

1. INTRODUCTION

The increased severity of harmonic pollution in power networks with the development of power semiconductors and power-electronics application techniques has attracted the attention to develop dynamic and adjustable solutions to the power quality problems. These power harmonics are called electrical pollution which will degrade the quality of the power supply. As a result, filtering process for these harmonics is needed in order to improve the quality of the power supply.

Therefore, these harmonics must be mitigating. In order to achieve this, series or parallel configurations or combinations of active and passive filters have been proposed depending on the application type [1], [2]. Traditionally, a passive *LC* power filter is used to eliminate current harmonics when it is connected in parallel with the load [3]. This compensation equipment has some drawbacks mainly related to the appearance of series or parallel resonances because of which the passive filter cannot provide a complete solution. Since the beginning of the 1980s, active power filters (APFs) have become one of the most habitual compensation methods [4]. A usual APF consists of a three-phase pulse width modulation (PWM) voltage source inverter. The APF can be connected either in parallel or in series with the load. The first one is especially appropriate for the mitigation of harmonics of the loads called harmonic current source. In contrast, the series configuration is suitable for the compensation of loads called harmonic voltage source. However, the costs of shunt active filters are relatively high for large-scale system and are difficult to use in high-voltage grids. In addition, their compensating performance is better in the harmonic current source load type than in the harmonic voltage source load type [7], [8].

2. POWER QUALITIES AND THEIR SOLUTION

Power Quality (PQ) related issues are of most concern nowadays. The widespread use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to a complete change of electric loads nature [8]. These loads are simultaneously the major causers and the major victims of power quality problems. Due to their non-linearity, all these loads cause disturbances in the voltage waveform Along with technology advance, the organization of the worldwide economy has evolved towards globalization and the profit margins of many activities tend to decrease. The increased sensitivity of the vast majority of processes (industrial, services and even residential) to PQ problems turns the availability of electric power with quality a crucial factor for competitiveness in every activity sector. There are two approaches to the mitigation of power quality problems. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. A flexible and versatile solution to voltage quality problems is offered by active power filters. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source [6], [9]. Both schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. Active power filters can perform one or more of the functions required to compensate power systems and improving power quality [7], [11].

3. SERIES APF TOPOLOGY DESCRIPTION AND MODELING

3.1 Description of the APF Topology

Fig.1 shows the topology of the combined SAPF and shunt passive filter (PF), acting as zero impedance for the fundamental frequency and as high resistor for the harmonics frequencies. The APF, which is supplied by a low power PWM inverter, is connected in series with the main supply and the non-linear load through the current transformer. The passive filter connected in parallel to the load is used to damp the 5th and the 7th harmonic of V_l because of their high amplitudes

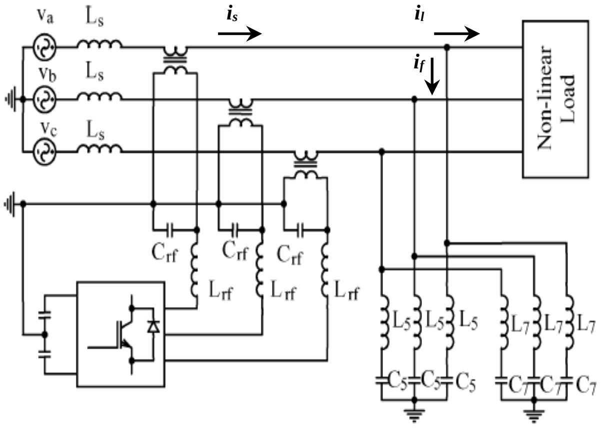

Fig. 1 General Configuration of a combined filter

The series APF acts as a voltage source and inject a compensating voltage in order to obtain a sinusoidal load voltage. The developments in digital electronics, communications and in process control system have made the loads very sensitive, requiring ideal sinusoidal supply voltage for their operation

3.2 Modeling

Fig.2. shows the per-phase equivalent scheme of the studied topology

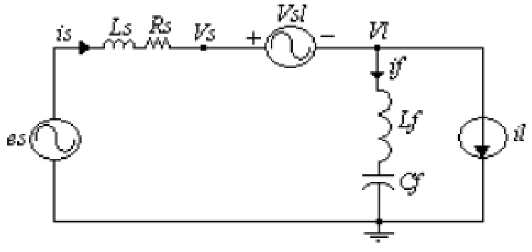

Fig. 2 Per-phase equivalent scheme.

Where:

e_s, i_s, L_s, R_s: Source voltage, source current, source inductance, and source resistance,

V_s: Line voltage,

V_l, i_l : Load voltage and load current,

V_{sl}: Controllable voltage source representing the series active power filter,

i_f, C_f, L_f: Shunt passive filter current, passive filter capacitance, and passive filter inductance.

This equivalent scheme is modeled by (1) and (2):

$$V_{sl} = V_s - V_l \tag{1}$$

$$i_s = i_f + i_l \tag{2}$$

Where,

$$V_s = e_s - (R_s \cdot i_s) - (L_s\, dt/di_s) \tag{3}$$

The voltage error is given by:

$$\Delta V_{sl} = V_{slref} - V_{sl} \tag{4}$$

V_{slref} : is expressed by:

$$V_{slref} = V_{sh} - V_{lh} \tag{5}$$

$$V_{sh} = k.\, i_{sh} \tag{6}$$

V_{sh}, V_{lh}, i_{sh}: represent, respectively, the harmonic components present in V_s, V_l, and i_s.

k: is a current sensor gain.

3.3 APF Voltage references determination

The harmonic component V_{slh} of V_{sl} is defined by:

$$V_{slh} = V_{sl} - V_{slf} \tag{7}$$

First, we extract the *p-q* components of V_{sl}:

$$\begin{bmatrix} V_{slp} \\ V_{slq} \end{bmatrix} = C_{pq} C_{32} \begin{bmatrix} V_{la} \\ V_{lb} \\ V_{lc} \end{bmatrix} \tag{8}$$

C_{pq}, C_{32} representing the Park matrix and Concordia matrix given respectively by:

$$\mathrm{C_{pq}} = \begin{bmatrix} \sin(\omega t) & -\cos(\omega t) \\ -\cos(\omega t) & -\sin(\omega t) \end{bmatrix} \tag{9}$$

$$\mathrm{C_{32}} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \tag{10}$$

Next, decomposition of $V_{slp}$and V_{slq}into continuous components $\overline{\mathrm{V}}_{\mathrm{slp}}$,$\overline{\mathrm{V}}_{\mathrm{slq}}$and alternative components$\widetilde{\mathrm{V}}_{\mathrm{slp}}$, $\widetilde{\mathrm{V}}_{\mathrm{slq}}$

$$V_{slp} = \overline{\mathrm{V}}_{\mathrm{slp}}+\widetilde{\mathrm{V}}_{\mathrm{slp}} \tag{11}$$

$$V_{slq} = \overline{\mathrm{V}}_{\mathrm{slq}}+\widetilde{\mathrm{V}}_{\mathrm{slq}} \tag{12}$$

$\overline{\mathrm{V}}_{\mathrm{slp}}$,$\overline{\mathrm{V}}_{\mathrm{slq}}$are obtained via a second order low-pass filter.

Then, the obtained three-phase fundamental components are presented below:

$$\begin{bmatrix} V_{slfa} \\ V_{slfb} \\ V_{slfc} \end{bmatrix} = C_{32} C_{pq}^{-1} = \begin{bmatrix} \overline{\mathrm{V}}_{\mathrm{slp}} \\ \overline{\mathrm{V}}_{\mathrm{slq}} \end{bmatrix} \tag{13}$$

Finally, this algorithm can be represented as shown in the block diagram of Fig.3.

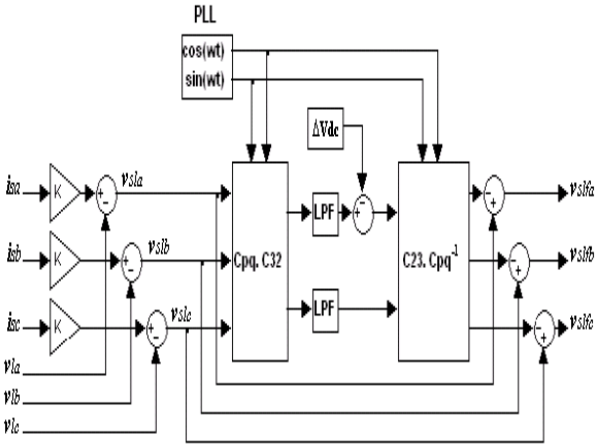

Fig. 3 Block diagram of voltages references determination

3.4 Inverter control using PWM

The control method is aimed to control PWM inverter to produce the desired compensation voltage**,** in the output of series APF. This method is achieved by implementing a fuzzy logic controller [5-10] which starts from the difference between the injected voltage (V_{inj}) and the calculated reference voltage (V_{slf}) that determines the reference voltage of the inverter (modulating wave). This reference voltage is compared with two carrying triangular identical waves shifted one from other by a half period of chopping producing the control signal to control the on-off of the IGBT. The general block diagram of voltage control is shown in Fig.4.

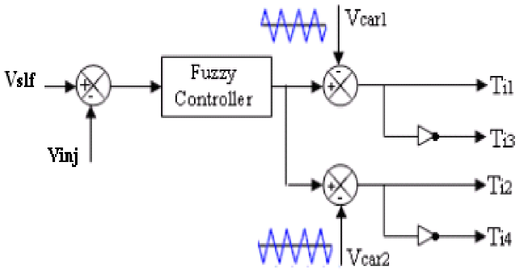

Fig. 4 PWM synoptic block diagram of voltage control

The control of inverter arm constituting the series active filter is summarized in the two following steps.

- Determination of the intermediate signals V_{i1} and V_{i2}.

Iferror ≥ carrying 1 => $V_{i1} = 1$

If error <carrying 1 => $V_{i1} = 0$

If error ≥ carrying 2 => $V_{i2} = 0$

If error <carrying 2 => $V_{i2} = -1$

Determination of control signals of the switches T_{ij} (j = 1, 2, 3, 4).

If (V_{i1}+ V_{i2}) = 1 => $T_{i1} = 1$, $T_{i2} = 1$, $T_{i3} = 0$, $T_{i4} = 0$

If (V_{i1}+ V_{i2}) = 0 => $T_{i1} = 0$, $T_{i2} = 1$, $T_{i3} = 1$, $T_{i4} = 0$

If (V_{i1}+ V_{i2}) = -1 => $T_{i1} = 0$, $T_{i2} = 0$, $T_{i3} = 1$, $T_{i4} = 1$

3.5 Fuzzy Control Application

Fuzzy logic serves to represent uncertain and imprecise knowledge of the system, whereas fuzzy control allows taking a decision even if we can't estimate inputs/outputs only from uncertain predicates. Fig. 5, shows the synoptic scheme of fuzzy controller, which possesses two inputs (the error (*e*),

($e = V_{slf} - V_{inj}$) and its derivative (*de*)) and one output (the command (c_{de})). [5]

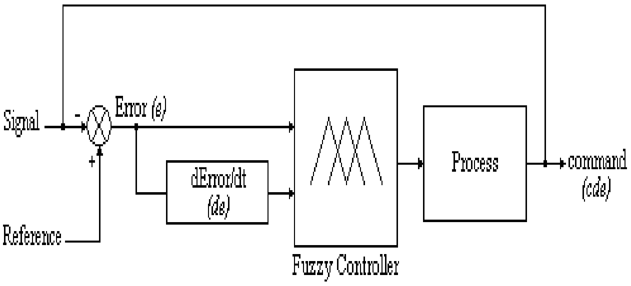

Fig. 5 Fuzzy controller synoptic diagram

5. SIMULATION RESULTS

The simulation is carried out using a program working in MATLAB/ Simulink environment. For non linear load we use a three phase diode rectifier with RL and RC load

Table 1 System Parameters

Source	e_s	230 V
	L_s	5,5 mH
	R_s	3,6 Ω
Load	R	25 Ω
	L	55 mH
	C	2200μF
Passive filter	L_{f5} ; C_{f5}	13,5 mH ;30 μF
	L_{f7} ; C_{f7}	6,75 mH ;50 μF
Ripple filter	L_{fr} ; C_{fr}	13,5 mH ;50 μF
Turns Ratio of Coupling Transformer		1:1
Switching Frequency		20 KHz

5.1 Simulation Results before Filtering

Simulation Results with RL Load

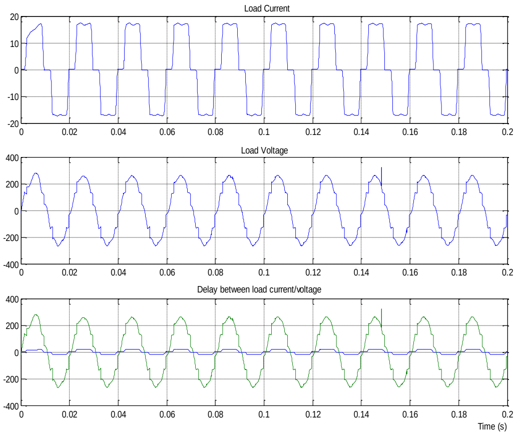

Fig. 6 Waveforms of load (current, voltage), and their delay for RL

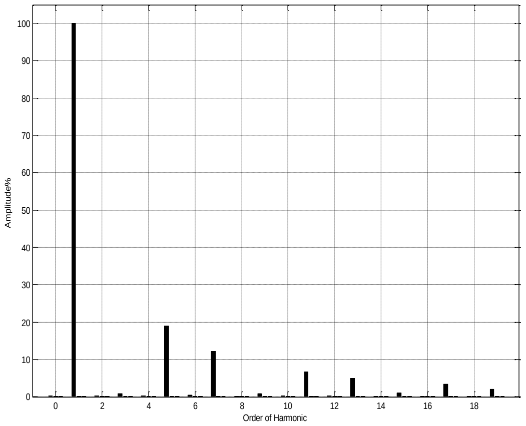

Fig. 7 Harmonic Spectrum of current

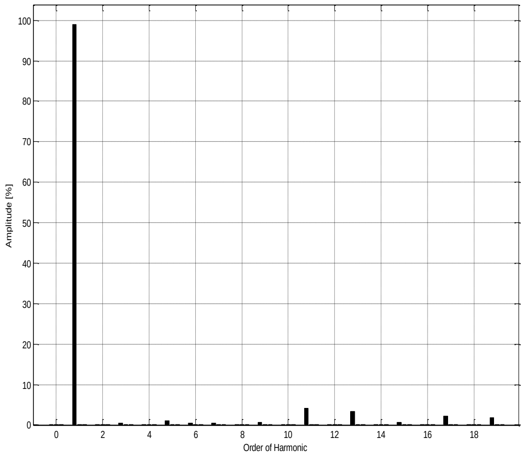

Fig. 8 Harmonic Spectrum of voltage

Simulation Results with RC Load

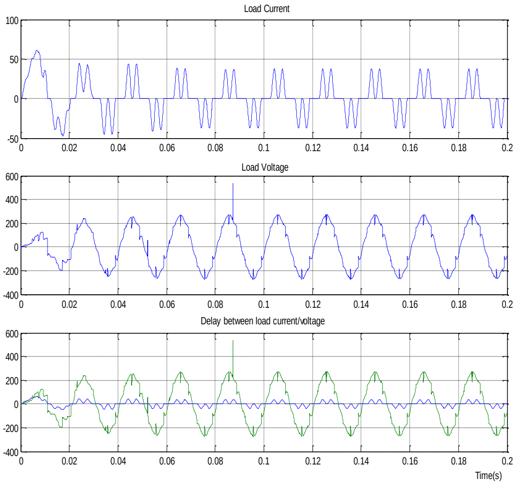

Fig. 9 Waveforms of load (current, voltage), and their delay for RC

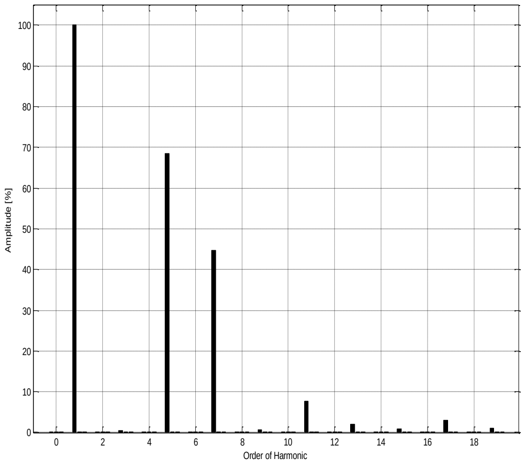

Fig. 10 Harmonic Spectrum of current

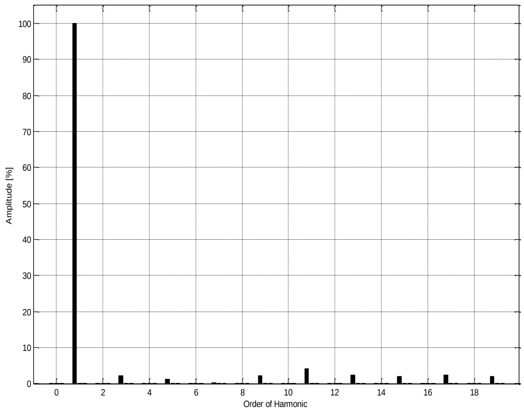

Fig. 11 Harmonic Spectrum of current voltage

5.2 Simulation Results after Filtering

Simulation Results with RL Load

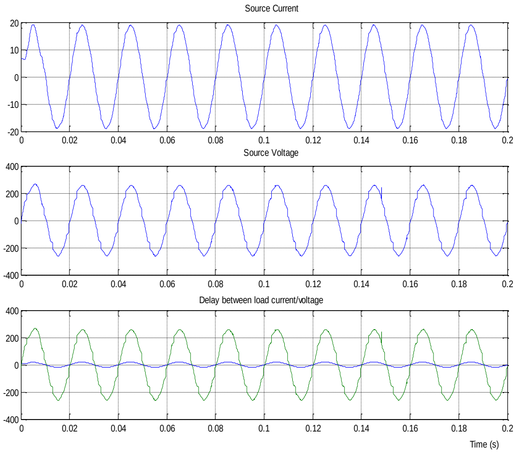

Fig. 12 Waveforms of sources (current, voltage), and their delay HP

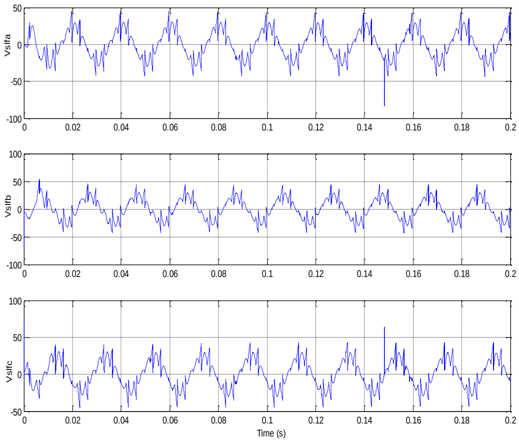

Fig. 13 Voltages references of HF for RL load

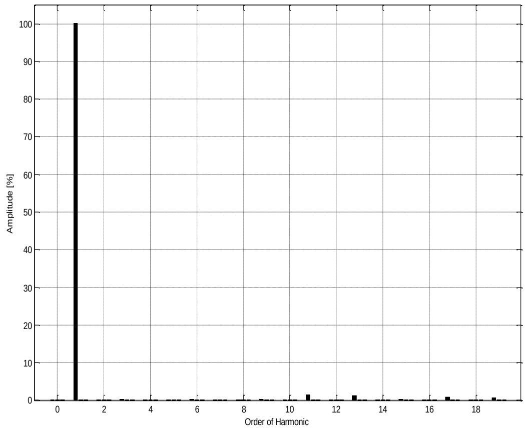

Fig. 14 Harmonic spectrum of current with HP

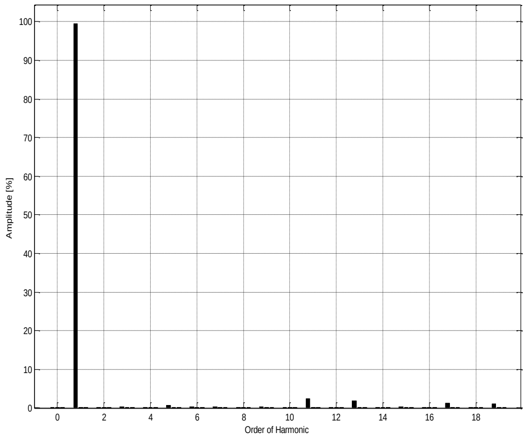

Fig. 15 Harmonic spectrum of voltage with HP

Simulation Results with RC Load

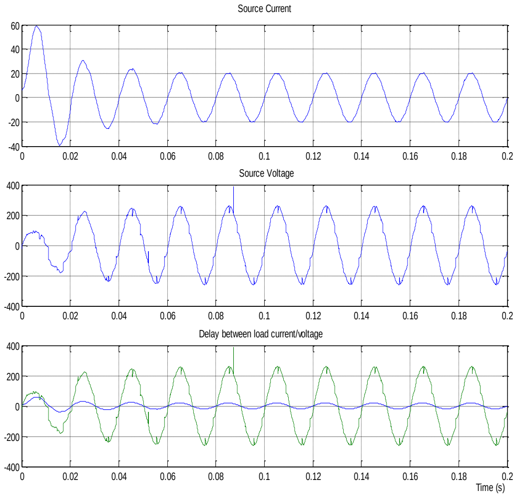

Fig. 16 Waveforms of sources (current, voltage), and their delay

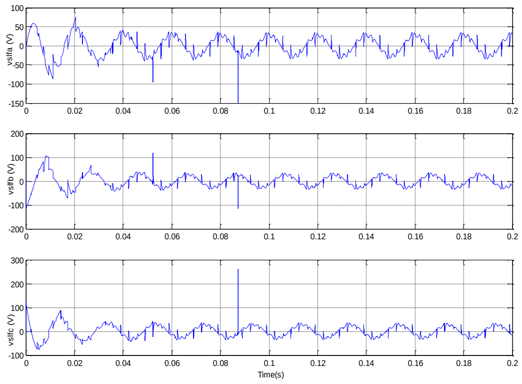

Fig. 17 Voltages references of HF for RC load

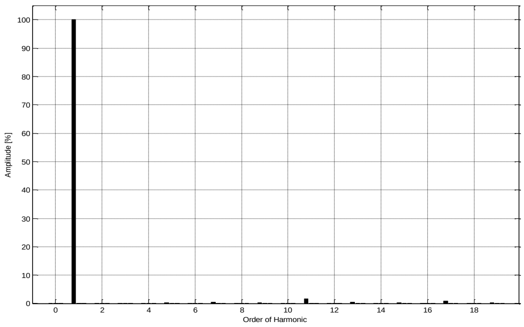

Fig. 18 Harmonic Spectrum of current

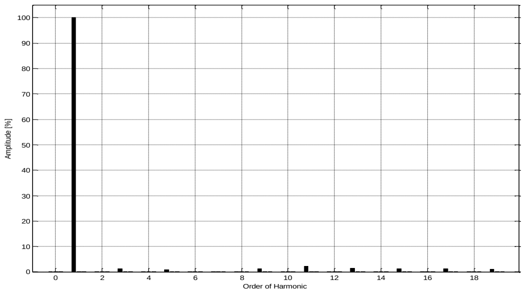

Fig19. Harmonic Spectrum of voltage

Table 2 Simulation Results of harmonics currents

Harmonic Currents	RL Load		RC Load	
	Before Filtering	After Filtering	Before Filtering	After Filtering
5	19,00 %	0,19 %	68,54 %	0,32 %
7	12,29 %	0,03 %	44,63 %	0,46 %
11	6,63 %	1,54 %	7,61 %	1,66 %
13	4,93 %	1,27 %	2,07 %	0,52 %
17	3,35 %	0,97 %	2,93 %	0,79 %
19	2,03 %	0,59 %	1,08 %	0,31 %
THDi	**24,46 %**	**2,19 %**	**81,76%**	**2,03 %**

Table 3 Simulation Results of harmonics voltages

Harmonic Voltages	RL Load		RC Load	
	Before Filtering	After Filtering	Before Filtering	After Filtering
5	1,14 %	0,67 %	1,35 %	0,81 %
7	0,48 %	0,28 %	0,37 %	0,16 %
11	4,08 %	2,42 %	4,19 %	2,33 %
13	3,34 %	1,94 %	2,38 %	1,39 %
17	2,12 %	1,29 %	2,44 %	1,31 %
19	1,88 %	1,07 %	2,00 %	1,17 %
THDv	**7,49 %**	**4,27 %**	**8,12 %**	**4,64 %**

6. CONCLUSION

In this article, we show the advantages of the hybrid power filter which consists of a combination of shunt passive filter and series active filter to improve the power quality especially harmonic mitigation (current and voltage) in three phase system with the use of fuzzy logic controllers.

The results obtained with the use of the hybrid filter (SAPF & PF) have clearly shown that mitigation are important of harmonic current of THD$_I$ from 24,46 % to 2,19% (Under the standard 5%) ; and even for harmonic voltages of THD$_V$ from 7,49 to 4,27 % (Under the standard .In figure 6 shows the delay between the voltage and current source is high but the figure 14 illustrates the reduction in the time between the current and the voltage of the source; ie correcting the power factor when the hybrid filter (SAPF & FP) is connected .

The fuzzy logic controller has improved the performance of the equilibrium state of the series active power filter. The effectiveness of the proposed system is proved by simulation.

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Received February 16, 2015, accepted March 3, 2016

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