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Hybrid unified power quality conditioner for power quality enhancement

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ABSTRACT

In a low-voltage electrical network, harmonics, reactive power, the current and voltage imbalance, and voltage dips have harmful effects on electrical equipments. To overcome these problems, the hybrid UPQC is proposed. This paper discusses the structure of passive filters, parallel active filters, serial and combines (UPQC) to study the compensation of all types of disturbances likely to appear in the grid. Furthermore, the aim of reducing the size, cost of UPQC is to improve the quality of electric power, making it in compliance with the new regulatory constraints, we proposed the hybrid UPQC which uses passive filters and a combination of active filters. To validate the proposed topology, several sags of source voltage have been applied, at the point of common coupling (PCC). The simulation results from MATLAB/Simulink are discussed to verify the proposed topology.

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1. INTRODUCTION

Power electronics-based systems are the most non-linear loads currently answered. These systems are increasingly causing power grid disturbances, such as harmonic distortions, imbalances, flicker, brief interruptions, voltage dips, and temporary and transient over voltages. In addition, these disturbances can generate nuisance or damage by the assignment of one or more parameters of the voltage of the electrical network, such as the frequency, the amplitude, the symmetry of the three-phase voltages and the shape of the wave. Several solutions for the decontamination of electricity networks have already been proposed in the literature. Those that best meet today's industrial constraints are the Active Shunt Compensator, Series and Active Shunt Combination Series (also known as UPQC). The active passive shunt filters are an indisputable solution only in high voltage transmission lines [1, 2]. However, in all other cases, including the supply of industrial loads and medium and low voltage distribution lines, passive filters encounter multiple difficulties that degrade their efficiency. Active filters have been designed to mitigate the problems of passive filters. However, these active filters used alone have certain drawbacks such as: the low efficiency, the limitation of the high-power bandwidth and the relatively high apparent power of the active filter. [3-5]

Although active filters used alone are useful in some applications, it is sometimes necessary to use hybrid topologies with passive filters and active filters. Hybrid filters treat and mitigate problems with passive and active filters. In addition, the hybrid active filters improve the compensation characteristics of the passive filters which can lead to a reduction of the power of the active filter. Therefore, the hybrid structure arose from the need for improved performance and reduced cost of active filters. Hybrid filters provide optimal solution for PQ mitigation with reduced cost, simple design and control with high reliability for PQ improvement [6].

The purpose of this paper is to contribute to improving the performance of current and voltage disturbance compensation from a parallel-series combined structure (UPQC). The active parallel-serial combination, also called "Unified Power Quality Conditioner" (UPQC), results from the combination of the two parallel and serial active filters. Taking advantage of the advantages of the two active filters, the UPQC provides a sinusoidal current and voltage of the electrical network from a disturbed current and voltage of it [7, 16-18].

The document is organized as follows: the general structure the hybrid UPQC in section 2. It also highlights the required units such the identification and regulation methods, hybrid UPQC and control algorithms. Then we will study the hybrid UPQC filter, by simulating the compensation of most current and voltage disturbances will be discussed in section 3. Finally, the document will be completed by the concluding remarks.

2. CONFIGURATION OF HYBRID UPQC

To reduce the size of the parallel active filter and its cost, the UPQC is associated with a passive filter whose role is to eliminate the specific frequencies enabling the sizing of the active filter to be reduced, which will compensate for the rest of the disturbances. The general structure of the UPQC Hybrid is composed of two parts: parallel-serial active filters (UPQC) and passive parallel filter as shown in Figure 1. In this configuration, the role of the passive filter is the compensation of the predominant low frequency harmonic currents (h5 and h7) emitted by the polluting load [8].

Passive filters are the simplest and most economical along with the demerits of large size and tuning issues. Hybrid filters provide optimal solution for PQ mitigation with reduced cost, simple design and control with high reliability for PQ improvement. [9]

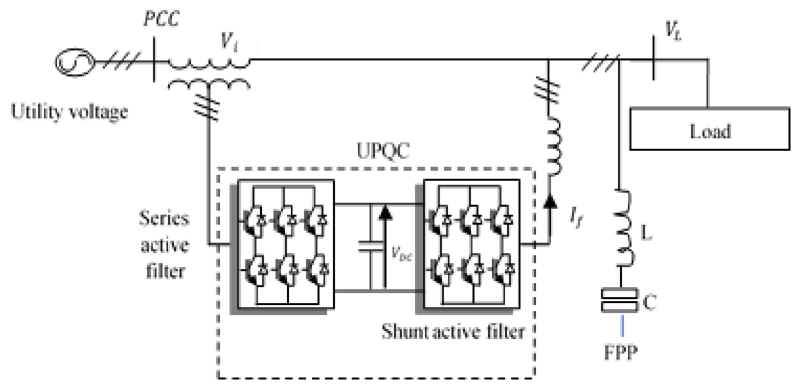

Figure 1. Structure of the hybrid UPQC

3. CONTROL STRATEGIES

The application of the Synchronous Reference Frame (SFR) based harmonic extraction, the three currents Ia, Ib and Ic are transformed from the three-phase reference form to the two-phase ds and qs to the reference currents I_d^s,I_q^s.

$$\begin{bmatrix} i_d^s \\ i_q^s \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

The currents $i_d^s$and i_q^s transformed to a synchronously rotating frame of reference of de andqe by the vector unit $\cos\omega_e$ and $\sin\omega_e$,as shown below:

$$\begin{bmatrix} i_q^e \\ i_d^e \end{bmatrix} = \begin{bmatrix} \cos\omega_e & -\sin\omega_e \\ \sin\omega_e & \cos\omega_e \end{bmatrix} \begin{bmatrix} i_q^s \\ i_d^s \end{bmatrix} \quad (2)$$

The frequency ω_e is derived from the harmonic order that must be isolated. It is important to note that the direction of the unit vector rotation must be in accordance with the order of the extracted harmonic. Figure 2 shows the transformation of the abc to the reference frame of d^e-q^e.

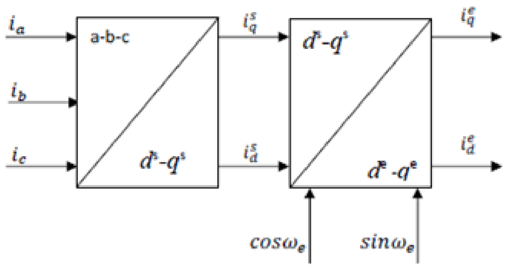

Figure 2. Transformation abc to d^e-q^e.

In the de-qereference frame the ωe components appear as quantities of C.C and all other harmonics are transformed to the amounts of C.A. Using a low pass filter, the amount of C.C can be accurately extracted. The current C.C component is now retransforming back to using stationary reference frame:

$$\begin{bmatrix} i_q^s \\ i_d^s \end{bmatrix} = \begin{bmatrix} \cos\omega_e \sin\omega_e \\ -\sin\omega_e \cos\omega_e \end{bmatrix} \begin{bmatrix} i_q^e \\ i_d^e \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} 1\ 0 \\ -\frac{1}{2}\frac{\sqrt{3}}{2} \\ -\frac{1}{2}\ -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_q^s \\ i_d^s \end{bmatrix} \tag{4}$$

Since a quantity of DC in the de-qe reference frame corresponds exactly to the harmonic frequency of interest, extracting the amount of DC using the low pass filter ensures the exact synthesis of the harmonic current in the reference frame of abc, Figure 3 shows the arrangement of the filtering.

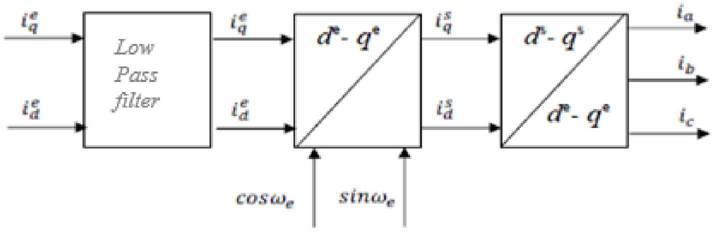

Figure 3. Transformation of de-qe to abc

3.1. Voltage control of DC bus

The average voltage across the capacitor must be maintained at a constant value. The causes of its variation are mainly the losses in the switches (in conduction and commutation), in the decoupling inductances Lf and the injection of the fundamental currents during the transient regimes [10-13]. In steady state, the source must provide active power equal to the power demanded by the load. When an active power imbalance occurs in the system, the energy storage capacity must provide the power difference between the network and the load [14-16]. This then results in a variation of the DC voltage across the capacitor supplying the active filter, where regulation is necessary in order to stabilize the voltage across the capacitor. The active power P_f needed to restore the capacitor voltage to a constant value is given by the expression:

$$P_f = P_L - P_S \tag{5}$$

With:
P_f: instantaneous power injected by the active filter.
P_L: active power consumed by the load.
P_s: active power delivered by the source.

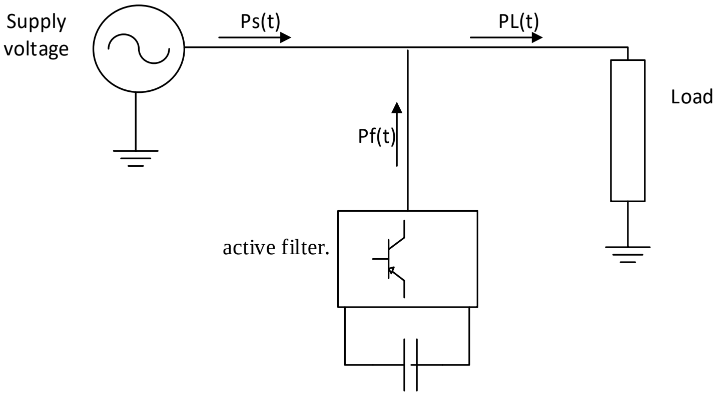

Figure 4. Exchange of power between the network, the load and the filter.

By neglecting the losses in the switches and inductors, the relationship between the active power absorbed by the capacitor and the voltage across it is given by:

$$P_c = \frac{d}{dc}\left(\frac{1}{2}C_{dc}V_c^2\right) \quad (6)$$

Note that the relation (6) is nonlinear. For small variations of the V_c voltage around its reference $V_{créf}$, it can be linearized through the following relationships.

$$P_c = C_{dc}V_{créf}\frac{d}{dt}(V_c) \quad (7)$$

Apply the Laplace transform:

$$\boldsymbol{V_c(s)} = \left(\frac{\boldsymbol{1}}{\boldsymbol{V_{dc-réf}C_{dc}s}}\right)\boldsymbol{P_s(s)} \quad (8)$$

From the relation (8), and taking into account the proportional controller K_c, the DC voltage control loop can be represented by the diagram in Figure 5. The choice of the K_c parameter will aim to obtain a minimum response time so as not to harm the dynamics of the active filter [17]. In order to obtain the signal $P_{réf}$ one has the choice between a proportional regulator and a proportional integral regulator.

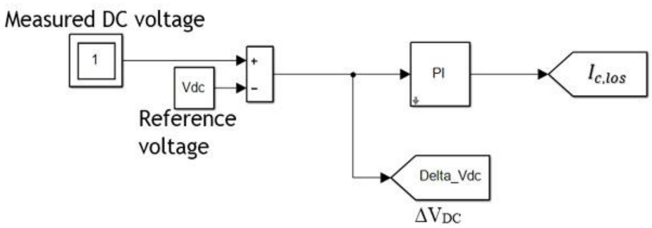

Figure 5. DC voltage regulation loop

We have the transfer function of the closed loop:

$$\frac{V_c^2}{V_{cr\acute{e}f}^2} = \frac{\frac{K_p}{C_{dc}}s + \frac{2K_i}{C_{dc}}}{s^2 + \frac{2K_p}{C_{dc}} + \frac{2K_i}{C_{dc}}} \tag{9}$$

By arranging them:

$$\frac{V_c^2}{V_{cr\acute{e}f}^2} = \frac{\omega^2 + 2\omega\varepsilon s}{s^2 + 2\omega\varepsilon s + \omega^2} \tag{10}$$

So:

$$\omega^2 = \frac{2K_i}{C_{dc}} and \varepsilon = K_p\sqrt{\frac{1}{2C_{dc}K_i}} \tag{11}$$

To have a good damping coefficient of the closed-loop system, we have chosen ε = 0.7

$$K_i = \frac{C_{dc}\omega^2}{2} \ and \ K_p = \varepsilon\sqrt{2C_{dc}K_i} \tag{12}$$

3.2. Series converter control

Since the series filter is considered to be a compensation voltage generator, the load current causes voltage drops in the output filter and therefore a larger difference between the set point and the output voltage.To compensate for the error produced by the LRC filter, the voltage loop can be closed and based on the filter model, develop voltage correctors [18,19]. So, the contribution I_L will be eliminated during the designation of the PI controller of the voltage control loop, and therefore the model of the output filter will be modified to have a structure of two nested loops, one internal current and the other external voltage as shown in Figure 6 [20-22].

3.3. Shunt converter control

The regulator design is typically connected to the speed specification required response of the closed loop or, also, the maximum error to follow respecting the reference signal. These specifications can be specifications of the bandwidth and phase margin of the closed loop. So, it is necessary to determine the parameters Kp and Ki to guarantee these necessities. To quickly have an estimation on the sought values, we suppose that we can approximate the transfer function to the cutoff frequency ωCL = 2πfCL to the following expression [23-25]. Shunt filter control loop is shown in Figure 7.

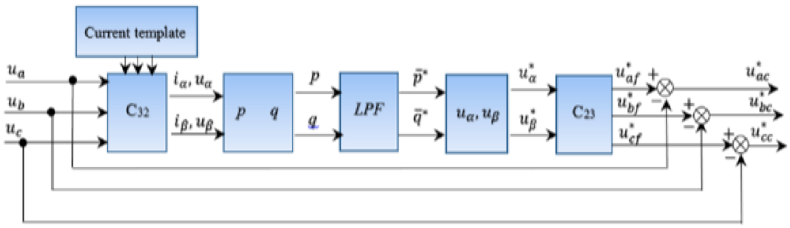

Figure 6. Two-loop control scheme (internal current and external voltage)

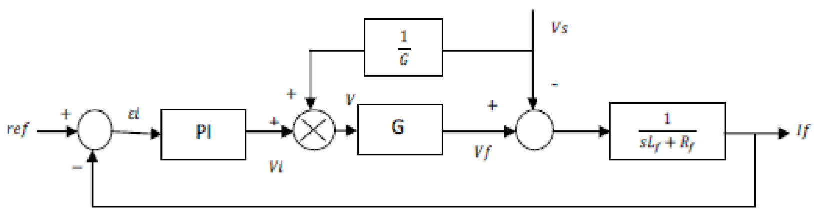

Figure 7. Shunt filter control loop

4. RESULTS AND DISCUSSION

The overall modeling of the structure, allowed studying the hybrid UPQC for the harmonic compensation and the reduction of the parallel active filter sizing through simulations on MATLAB/Simulink.Two resonant passive filters tuned at the frequency 250 Hz (h5) and 350Hz (h7) respectively are connected in parallel with the UPQC load side. The proposed hybrid UPQC model is simulated by MATLAB/Simulink Figure 8. The system parameters considered for this study are given in Table 1.

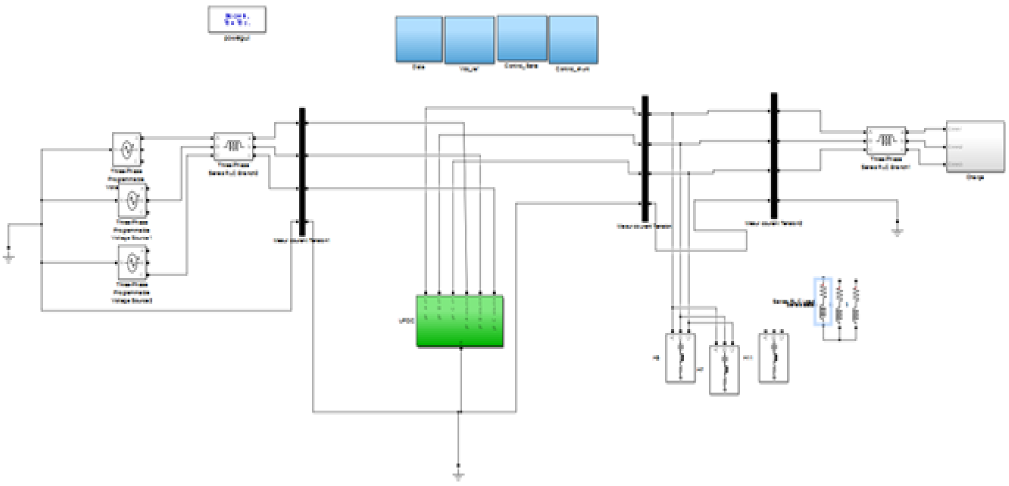

Figure 8. MATLAB/Simulink modelled system.

Table 1. System parameters

System parameters	value
Power system	
Grid voltage	$300V$
Frequency	$50Hz$
Line impedance	$0{,}01 + j10e^{-6}\Omega$
Nonlinear load	R_a=40_ ; La=0.01mH ;
	R_b=10_ ; Lb=0.01mH ;
	R_c=13_ ; Lc=0.01mH ;
UPQC	$735.6V$
DC link voltage	$0.0087\ F$
DC link capacitor	$12\ KHz$
PWM switching	$R = 0.02\Omega$, $L = 2.2mH$
Connection filter of shunt filter	
KP-shunt=0.6183; KI-shunt = 757.4515/sec	$R = 0{,}002\ \Omega$, $L = 0.148mH$, $C = 52.675\mu F$
Connection filter of series filter (RLC)	
KI-current=0.0427/sec;KP-curnt= 52.4701	
KI-voltage= 1.9950 103 /sec ; KP- voltage = 0.5690	

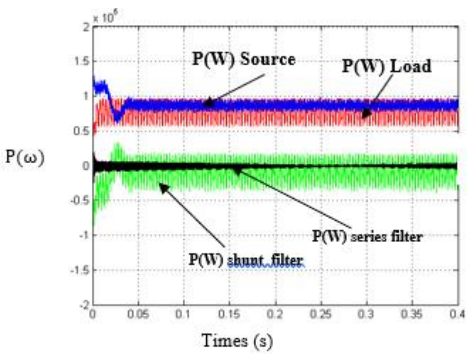

Figure 9. Active power without passive filter

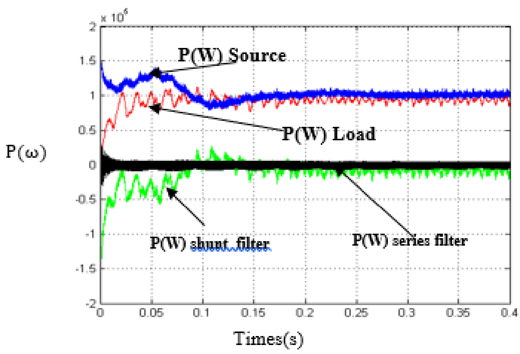

Figure 10. Active power with passive filter

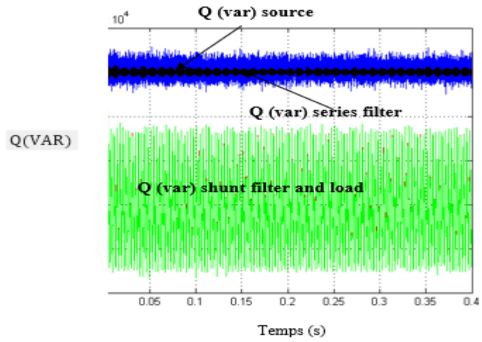

Figure 11. Reactive power without passive filter

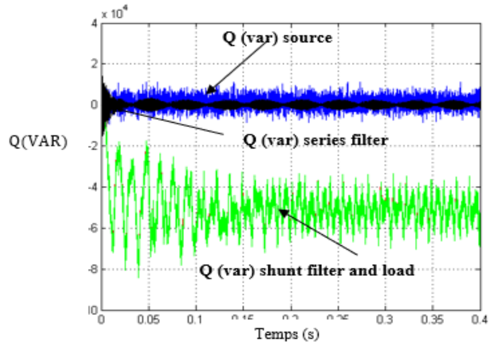

Figure 12. Reactive power with passive filter

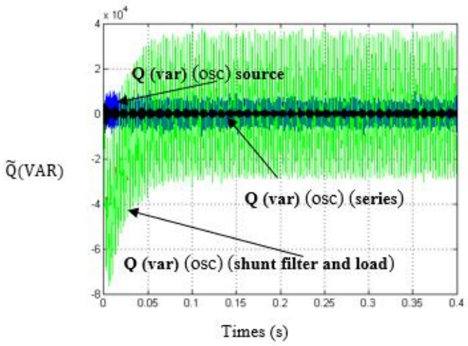

Figure 13. Reactive power (osc) without passive filter

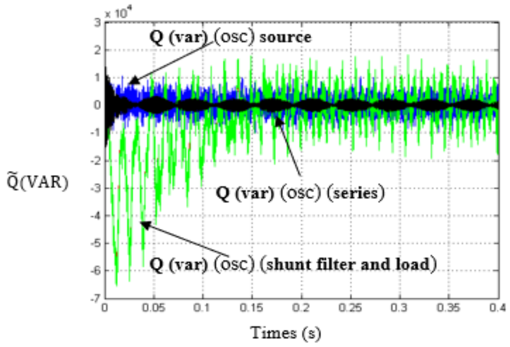

Figure 14. Reactive power (osc) with passive filter

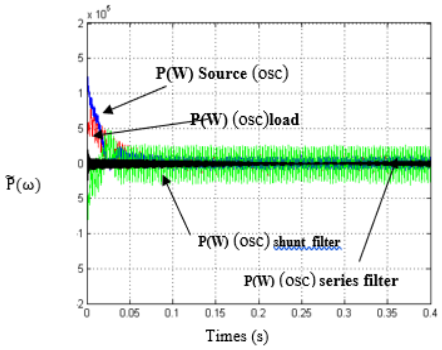

Figure 15. Active power(osc) without passive filter

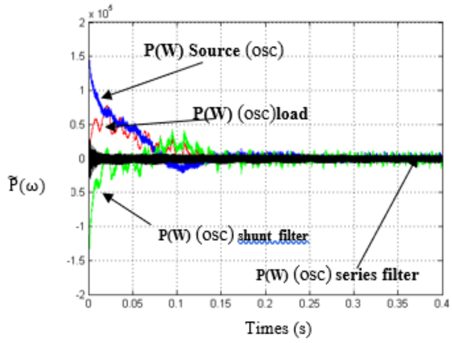

Figure 16. Active power(osc) with passive filter

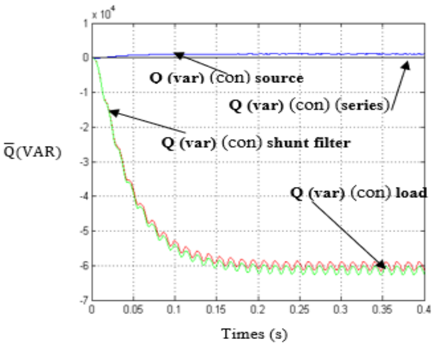

Figure 17. Reactive power (con) without passive filter

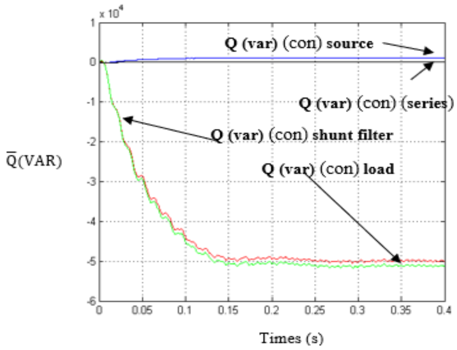

Figure 18. Reactive power (con) with passive filter

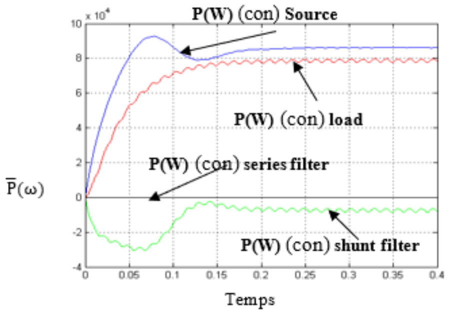

Figure 19. Active power (con) without passive filter

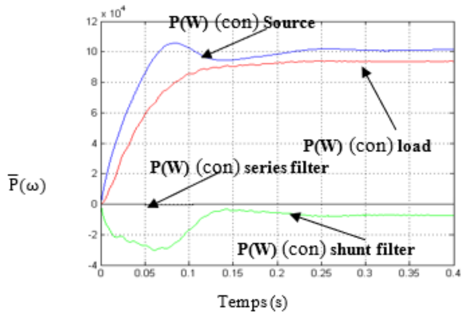

Figure 20. Active power(con) with passive filter

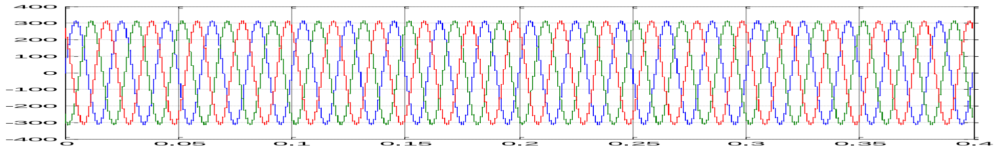

Figure 21. load voltage

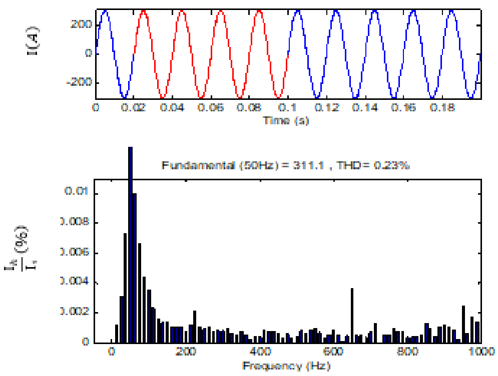

Figure 22. Source current with filter passif

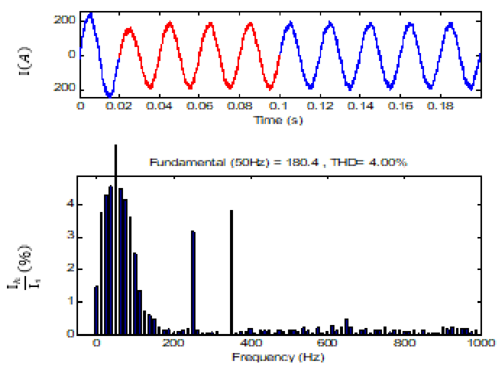

Figure 23. Source current without passive filter

5. CONCLUSION

In this article After validating the parallel and serial active filters, an active parallel-serial combination and a passive filter (UPQC hybrid) were studied in order to validate the simultaneous operation of these three filters. This combination could benefit from the common operation of some elements of these three parts (the voltage source and the capacitor recharge). The structure chosen for the UPQC hybrid, offering the possibility, via the parallel active filter, to recharge the energy storage capacitors online. A reduction in the size of these capacitors has been achieved by the passive filter. Thus, it can be said that the resonant passive filter (h5 + h7) further improved the operation of the parallel active filter of the UPQC and further decreased its apparent power. It has become very reasonable. The UPQC Hybrid performs better than the conventional UPQC as it has less apparent power than the UPQC Classic. The only drawback of the parallel hybrid filter is the risk of resonance with the impedance of the network but the use of a low value inductance between the resonant passive filter and the UPQC reduces this risk. The UPQC hybrid provides sinusoidal current and voltage from the power grid from a disturbed current and voltage thereof. Sizing has decreased and the cost is reduced.

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