Simulation of Shunt Active Power Filter Controlled by SVPWM Connected to a Photovoltaic Generator

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Abstract—**In this paper we study the shunt active power filter. This filter contains a voltage three-level inverter controlled by the SVPWM strategy supplied by a the DC bus powered by a solar array to improve the quality of electric energy and eliminate harmonics currents generated by non-linear loads, the latter identified by the method of multivariable filter. The objective of this study is to obtain an unpolluted source into the power grid where all the simulation results are obtained by using MATLAB Environment.**

Keywords—shunt active power filter; harmonic currents; MVF; SVPWM; three level inverter; GPV

I. INTRODUCTION

The Sources of Energy are divided into two categories. The Renewable sources and the Petrol and Gas energies. The Renewable are divided into many types such as: Solar, Wind and Hydraulic energies. These energies were used from the foundation of humans which means its usage was from long ages throughout history until the out-break of the industrial Revolution.

In this period of time, Petrol's prices were very sheep as a consequence, renewable sources were excluded. In contrary, during recent years and due to the increase of fuel's prices and the environmental problems caused by the use of conventional fuels we come back to use renewable sources of energy.

Renewable sources are inexhaustible, clean. These sources can be used in a decentralized way that makes it so easy to work with. It also had the additional advantage of being complimentary wherein the integration between them is favorable.

The two-level voltage source inverter has been very popular in drives for many years due to its ease of implementation and control. However, two-level inverters can be limited by the voltage ratings of the semiconductor devices, particularly in high power applications [1]. Multilevel inverters were developed to help address this concern as well as other limitations of two-level inverters. In particular, three-level inverters have been popular due to their improvement in output waveforms without overly complicating the design and control of the inverter[2].

The Multi- variable filter is proposed to extract harmonic currents instead of classical harmonics extraction based on High Pass Filters, the Three Phase Currents/Voltages are detected by using current/voltage sensors. The inverter currents had been controlled by using SVPWM. This paper is presented in order to analyze the simulation of a PV interactive Shunt Active Power Filter topology that simultaneously achieves Harmonic Current damping. To reference the Shunt Active Filter Current Computation we should use the "Multi-variable filter" method and apply the carrier-based SVPWM to get a signal generation.

II. THE STUDIED CONFIGURATION

The proposed configuration consists of a PV solar generator connected to a DC bus to a three –phase voltage inverter, coupled in parallel to a network through an inductor. This electrical system supplies a non-linear receiver consisting of a rectifier having as a load resistor in series with an inductor. The block diagram in Figure 1 illustrate this configuration. The photovoltaic installation connected to the network with an active filter to improve the quality of energy on the network connection point. It is therefore the voltage inverter control algorithm which is adopted to simultaneously ensure at the electrical network compensation harmonic pollution.
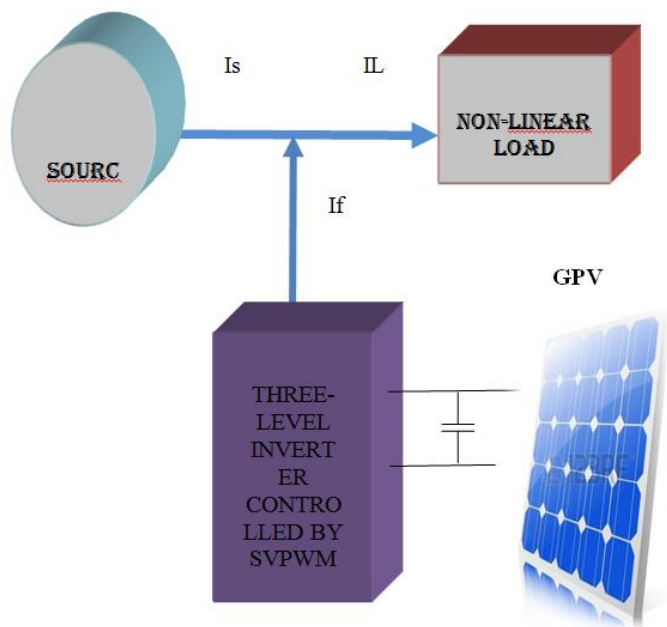
Fig. 1.   Configurations of photovoltaic interactive Shunt Active Filter system

III.   PV MODEL

The Photovoltaic cell is mainly a p-n junction made in a slender plate semiconductor, a solar energy sent an electromagnetic radiation, and this radiation is converted into electricity by the photovoltaic panel when it is exposed to the Sun rays, the Photons, which have an energy higher than the Band-Gap Energy of the semiconductor, create some pairs Electron-Hole proportional to the incident rays, if we want to build a model of the PV generator, we have to start by the identification of the equivalent electrical circuit to the source. Several Mathematical models have been designed to represent their highly non-linear characteristics given by semiconductor junctions that are the most important components in PV modules. Most models of photovoltaic generators that have some numbers of concerned parameters in the compute of output voltage and current, the model of single diodes in this paper is shown on (Fig.2). [3]
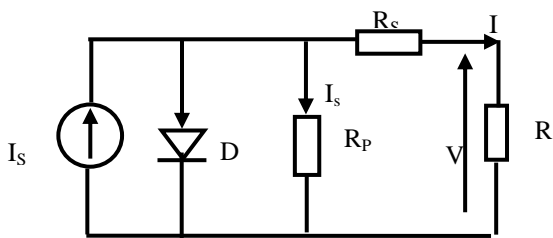

Fig. 2.   Equivalent circuit model

The above model can be extended to represent PV array with Np cells in parallel and Ns cell in series so we have here and.

$$I(1+\frac{R_{sT}}{R_{shT}}) = n_p I_{SC} - n_p I_S (\exp[\frac{q(\frac{V}{n_s}+IR_{ST})}{AkT_c}]-1)$$

$$-\frac{V/n_s}{R_{shT}}$$

here $R_{shT} = \frac{n_p}{n_s} \times R_P$ and $R_{sT} = \frac{n_s}{n_p} \times R_s$.

The above model shows that an array of PV cells is nonlinear device having its characteristics depending on the solar irradiance and ambient temperature. The temperature. The following figure (Fig.3) represents the evolution of a DC bus voltage.
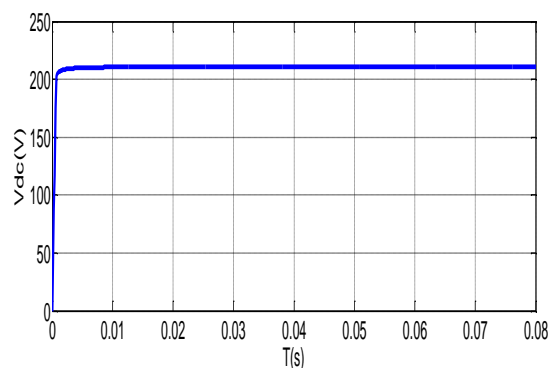

Fig. 3.   Evolution of a Dc bus voltage

IV.   THREE LEVEL INVERTER (NPC)

Currently, Multilevel inverters are being investigated. Moreover, these are being used in various industrial applications. A three level inverter is one of the most popular converters employed in medium and high power applications. Their advantages include the capability to reduce the harmonic content and decrease the voltage or current ratings of the semiconductors. As shown in Figure 1. The studied system is constituted of a DC supply, and a three level inverter bridge, we start by defining the Fij connection function of switch. It is "1" if the switch closed and "0" otherwise.

In controllable mode, the connection functions are related to the relation (1).

F_{ij} in the following manner:

$$F_{ij} = \begin{cases} 1 \; if \; S_{ij} \; is \; closed \\ 0 \; if \; S_{ij} \; is \; open \end{cases} \tag{2}$$

The switches of each leg are complementary pairs:
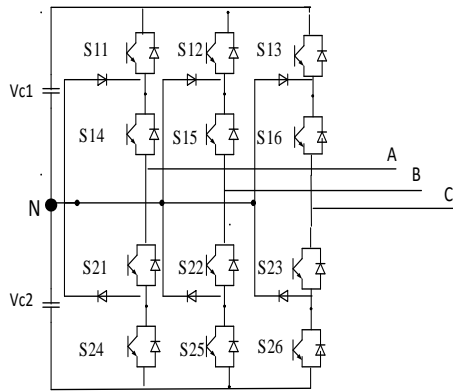
$$F_{ij}=1-F_{(i-2)j};i=3;j=1,2,3$$

Fig. 4.   Three level inverter

1) Space Vector PWM for a Three Level Inverter

There are altogether 27 switching states (table 1) that correspond to 19 voltage vectors whose positions are fixed. These space voltage vectors can be classified into four groups, where the first group corresponds 3 zero vectors or null vectors (V0, V7, V14), the second group consists of large voltage vectors (V15-V20), the third group consists of medium voltage vectors (V8-V13), and finally the fourth group consists of small voltage vectors (V1-V6). The last three groups can be distinguished by three hexagons illustrated in Figure 5.

TABLE I.   THE SWITCHING STATES OF A THREE-LEVEL INVERTER

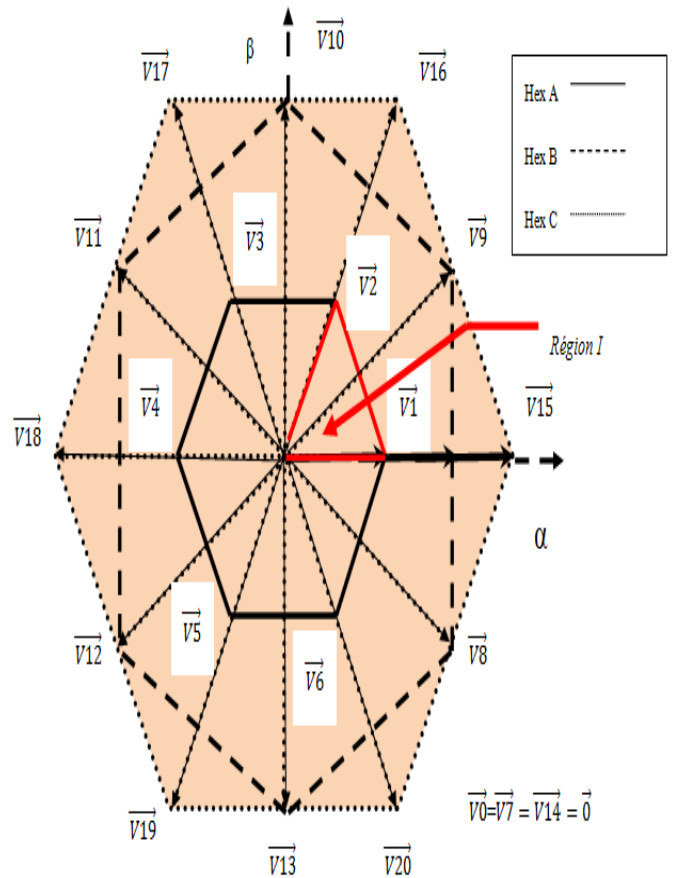| Switching States	S11	S12	S13	Vector
1	0	0	0	V0
2	1	1	1	V7
3	2	2	2	V14
4	1	0	0	V1
5	1	1	0	V2
6	0	1	0	V3
7	0	1	1	V4
8	0	0	1	V5
9	1	0	1	V6
10	2	1	1	V1
11	2	2	1	V2
12	1	2	1	V3
13	1	2	2	V4
14	1	1	2	V5
15	2	1	2	V6
16	2	1	0	V8
17	1	2	0	V9
18	0	2	1	V10
19	0	1	2	V11
20	1	0	2	V12
21	2	0	1	V13
22	2	0	0	V15
23	2	2	0	V16
24	0	2	0	V17
25	0	2	2	V18
26	0	0	2	V19
27	2	0	2	V20

The figure 5.shows the different switching state

Fig. 5.   A Three-level voltage inverter vectors in the (α-β) frame

2) Hexagon Identification

The small hexagon, we now called Hex A, bounded by the vectors, identical amplitude equal to 0.408.Vdc, The average hexagon, be called Hex. B, defined by the vectors, identical amplitude equal to 0.612.Vdc, The large hexagon, be called Hex. C, delimited by the vectors,identical amplitude equal to 0.816.Vdc.[5]

Each hexagon contains six sectors.

3) Sectors Identification

$$sector = \begin{cases} 1 & \text{if } 0 \le \theta < \pi/3 \\ 2 & \text{if } \pi/3 \le \theta < 2.\pi/3 \\ 3 & \text{if } 2.\pi/3 \le \theta < \pi \\ 4 & \text{if } \pi \le \theta < 4.\pi/3 \\ 5 & \text{if } 4.\pi/3 \le \theta < 5.\pi/3 \\ 6 & \text{if } 5.\pi/3 \le \theta < 2.\pi \end{cases} \tag{3}$$

4) Calculating the period of Application of the control Vector

As mentioned before, we separate between 03 hexagons Figure 5. When each one is founded by 06 areas. Therefore, we have 18 areas; the computing of their switching time is carried out, respectively. To make this ask easy, and for goal

of the resemblance between the 06 areas of a hexagon on one side, and the similitude between hexagons "a" and "c" on the other side, and similitude between hexagons 'a' and 'c' on the other side (the biggest magnitude in hexagon 'a' (E/ $\sqrt{6}$) is the half of the biggest magnitude in hexagon 'c' (E. $\sqrt{2}/\sqrt{3}$)), due to all these causes , the procedure for the switching times calculation, is by taking only two areas of the hexagon 'a' and hexagon 'b', corresponds to the positive component of Vref will take into account. Then the other switching times will be counted from the others four areas. Do not forget that the limiting vectors (V1 to V20) magnitudes will take the values below [5]

   - Region I switching times calculation:

$$T_s = T_k + T_{k+1} + nT \tag{4}$$

Region I for k=0

$$\begin{cases} T_1 = T_s . \dfrac{\sqrt{6}V_\alpha^* - \sqrt{2}V_\beta^*}{Vdc} \\[2mm] T_2 = T_s . 2\sqrt{2}\dfrac{V_\beta^*}{Vdc} \\[2mm] T_0 = (T_s - T_1 - T_2)/6 \end{cases} \tag{5}$$

The strategy of vector PWM consists of five steps diagrammed by the flowchart Figure 6.

| Step 1 | Calculated the reference vector Vref |

| Step 2 | Hexagon identification |

| Step 3 | Sectors identification |

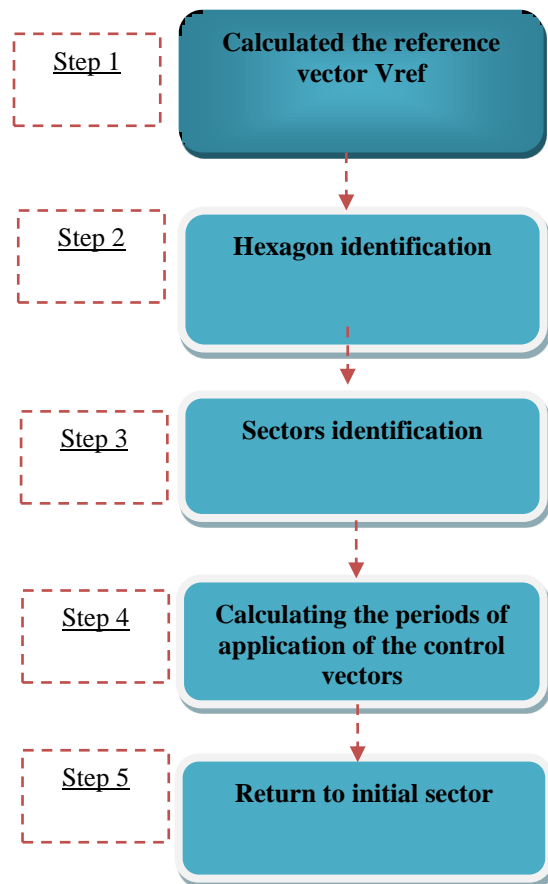| Step 4 | Calculating the periods of application of the control vectors |

| Step 5 | Return to initial sector |

Fig. 6.   Steps in SVPWM

VI. IDENTIFYING HARMONIC CURRENT

1) Identifying Harmonic Current by the Method of MVF

MVF is a filter has been produced by M.Benhabibe [6]. Its operating principle is based on the work of the Song Hong-Scok basing on the extraction of the fundamental signals from the axes. However, is practically used to isolate the direct particular order of harmonics even for the inverse [7].

The equivalent transfer function of integration in the synchronous reference "SRF" is given by:

$$i_{\alpha\beta}(s) = e^{j\omega_c t} \int e^{-j\omega_c t} i_{\alpha\beta}(t)\, dt \qquad (6)$$

Once we apply the Laplace transformation, we get:

$$H(s) = \frac{\hat{i}_{\alpha\beta}(s)}{i_{\alpha\beta}(s)} = \frac{s + jw_c}{s^2 + w_c^2} \qquad (7)$$

When developing this equation, we get the expressions:

$$\hat{i}_\alpha = \frac{k}{s}\left[i_\alpha(s) - \hat{i}_\alpha(s)\right] - \frac{\omega_c}{s}\hat{i}_\beta(s)) \qquad (8)$$

$$\hat{i}_\beta = \frac{k}{s}\left[i_\beta(s) - \hat{i}_\beta(s)\right] - \frac{\omega_c}{s}.\hat{i}_\alpha(s)) \qquad (9)$$

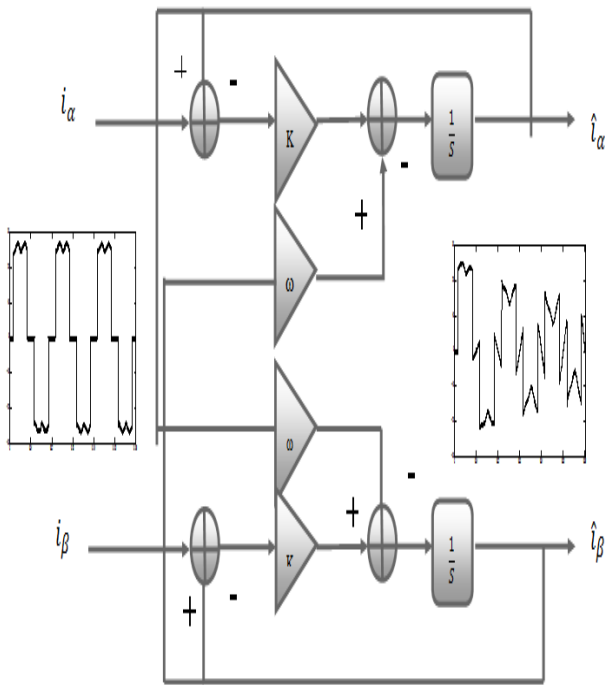Figure 7 illustrates the multi variable filter's scheme.

Fig. 7. Multi-Variable Filter

VII. SHUNT ACTIVE FILTER

In power distribution network, active power filters are widely used to reduce harmonics caused by nonlinear loads. This paper describes a shunt active power filter with a control system based on the multi-level inverter (PWM). The wide spread of power electronics equipment in modern electrical systems and power convertor units causes the increase of the harmonics disturbance in the AC mains currents which became a major concern due to the adverse effects on all equipment and distribution network [4].

The circuit configuration of the studied active filter is shown in Figure 8. The configuration is designed to cancel current harmonics on the AC side and make the source current in phase with the voltage source. The source current, after compensation, becomes sinusoidal and in phase with the voltage source.
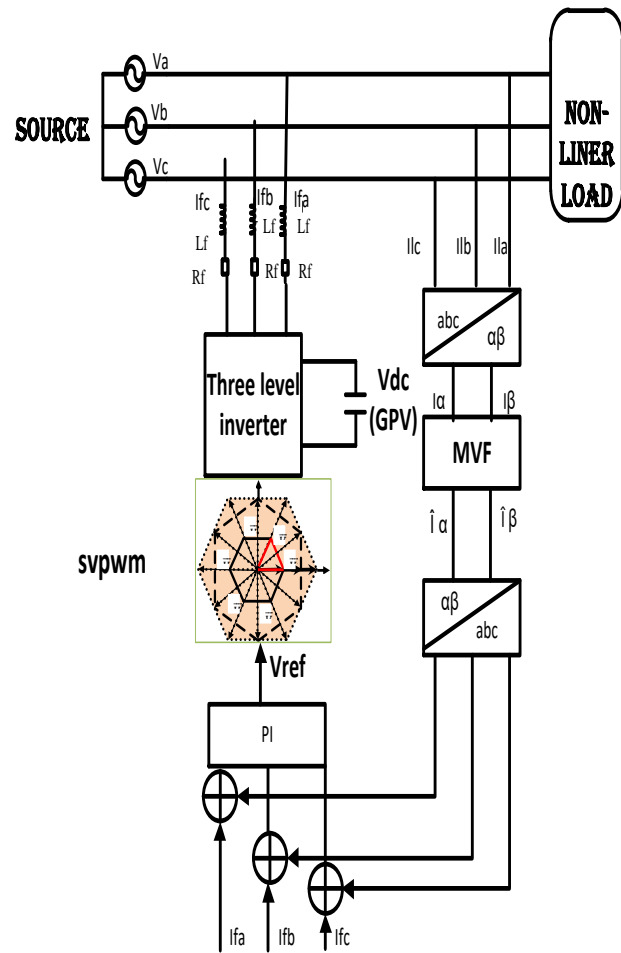
A. Control Scheme

Fig. 8. the block diagram of a Shunt Active Power Filter control scheme

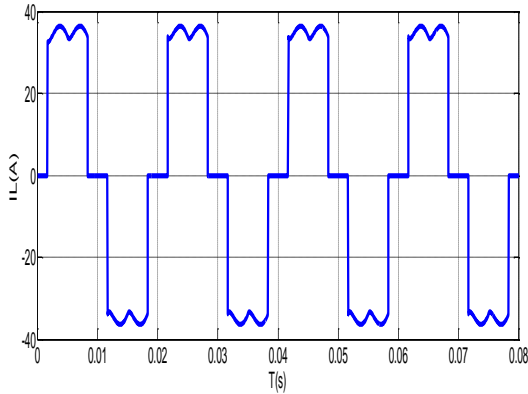VIII.   SIMULATION RESULT

Fig. 9.   The current to be terminal of non-linear load
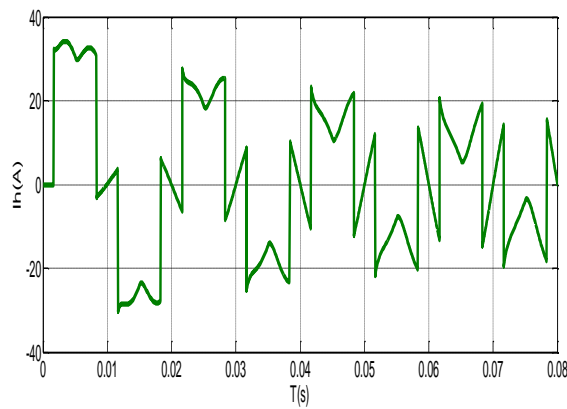

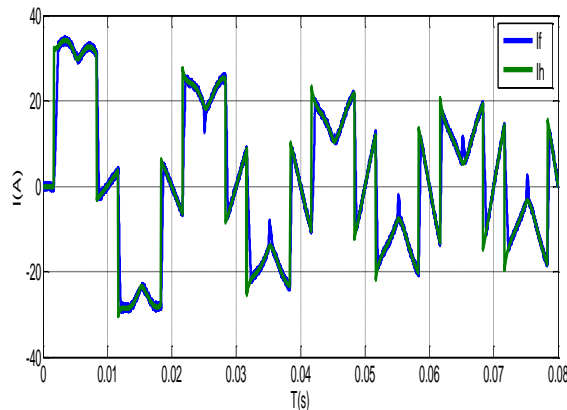Fig. 10. harmonic current identifying by MVF

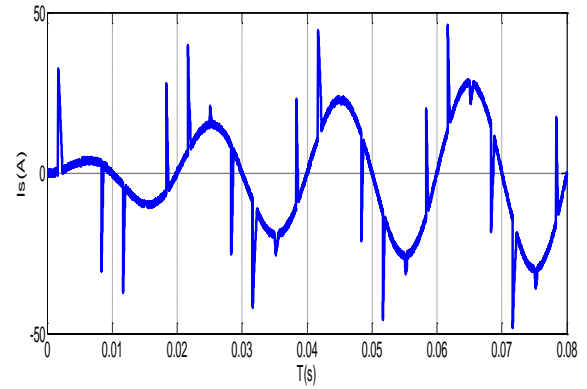Fig. 11. The output current of the inverter and the harmonic current
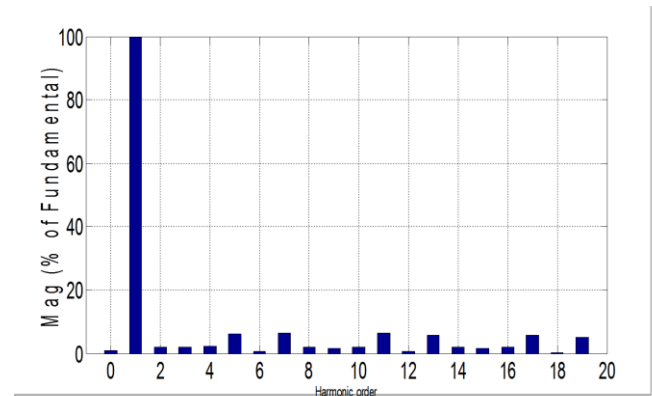

Fig. 12. The filter current

Fig. 13. harmonic current spectrum filtered

IX.   CONCLUSION

The purpose of this article is focused on improving the power quality of the network based on the compensation of harmonic currents using a shunt active power filter.

The control of SVPWM take an essential part in improving the performance of APF and Produces good filtering quality, which has been obtained by the used of Matlab simulation environment, Show us that some self-charging current source stay close to a sinusoidal wave. Note that other techniques can also be used to enhance the system response.

The work that will be continued in this context is the development of the experimental applications of these proposed strategies, to confirm the effectiveness of the achieved Results.

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