Implementation of Active Power Filter for Harmonic Elimination and Reactive Power Compensation with Different Control Algorithms

T.M.Thamizh Thentral\textsuperscript{1}, R. Jegatheesan\textsuperscript{2} and K.Vijayakumar\textsuperscript{3}

\textsuperscript{1,2,3} Dept. EEE, SRM Institute of Science and Technology, Kattankulathur , Chennai , India.

Abstract: Low tension power distribution systems have severe power quality issues as a result of the non-linear existence in the loads such as diode rectifiers, cyclo-converters, fully controlled solid state device based dc to ac converter, drive systems with variable speed and switched mode power supply etc. The main power quality issue is the harmonics leading to overheating the transformers in the distribution systems. By employing passive filters, active filters and custom power devices the harmonic component in the source current can be reduced. In this paper an attempt is made to effectively lessening the polluted element exist in the input current using the stipulated element injected from the three-phase three-wire active inverter act as a filter connected in shunt with the input and load. This filter has been investigated through three methods namely Synchronous Reference Frame (SRF) theory, P-Q Theory and Indirect Reference Current Theory (IRCT). The hardware implemented reveals that SRF technique has better control proneness in terms of Total Harmonic Distortion (THD), when compared to other control methods. Further power factor improvement and greater reactive power quittance is achieved with the implementation of hardware.

Keywords: Harmonic Compensation, SRF Theory, P-Q Theory, Indirect Reference Current Theory, Shunt Active Power Filter.

I Introduction

Power Quality (PQ) is referred in different ways by different people. In theoretical definition it involves traditional utility planning subjects such as voltage, current, regulation in frequency and reliability. To the concern of utility suppliers, Power Quality, known as the quality of service delivered is measured by the ability of a consumer to utilise the delivered energy in a specific desired manner. The idea of power quality as per the user revolves around their ability to utilise the energy delivered to them in a specific desired manner. But the major topics of concern are more specific and they involve magnitude and duration of different events and wave shape concerns. At the end a good working definition of power quality is not given any importance since most end users use own definition to meet their end goals\cite{1}.

The occurrence of deviations in the current, voltage and frequency leads to power quality problems in the distribution system resulting in the breakdown of electrical equipment. An ideal distribution system provides continuous and real power at the constant voltage without any power loss. This is not practically possible due to the factors such as outages, voltage drop, power drop, transients and non-linear steady state load conditions.
Harmonics are considered as a major power quality issue after the installation of non-linear devices. Both the current and voltage harmonics are characterized by their order, magnitude, which is expressed as percentage of magnitude at fundamental frequency, phase angle and sequence [2-3]. Total Harmonic Distortion (THD) is the term used to measure the harmonics in percentage, present in the fundamental component [4]. The THD percentage in voltage and current are defined as,

\[
\% \text{THD (Voltage)} = \left( \frac{\sum_{n=2}^{\infty} V_{n}^{2}}{V_{1}^{2}} \right) \times 100
\]

\[
\% \text{THD (Current)} = \left( \frac{\sum_{n=2}^{\infty} I_{n}^{2}}{I_{1}^{2}} \right) \times 100
\]

IEC1000-3-2, IEEE 519 (USA), AS 2279, D.A.CH.CZ, EN61000-3-2/EN61000-3-12 and ER GS/4 (UK) are the standards and recommended values designed by the engineering team were introduced to suppress the level of the distortions at the Common Coupling point [5-6]. To maintain the power quality issues within these harmonic standards, various compensation techniques are introduced in the distortion system. For an uncontrolled or half controlled rectifier load, a DC side choke can be included to reduce the harmonics. The main disadvantage of using DC choke is that it will degrade the ride-through capability by causing DC bus voltage drop [7]. Passive Power Filters (PPF) can be added in shunt or series to the load on AC side of the system to reduce the harmonic pollution. Passive power filter will provide only fixed compensation and also will introduce additional resonances. To overcome the drawbacks created by passive filters, active filters can be included in the AC side of the system either in series or parallel. There are several active power filter topologies according to their power circuit configurations as illustrated in below Figure 1 [8-10].

**Figure 1 Active Power Filter Topologies**

Based on this, the active power filters are classified as series, shunt and hybrid active power filters [11]. Active Power Filters (APF) is designed as an inverter with active elements such as IGBT, MOSFET or SCR supplied by either a voltage or current. In series type of filtering device, compensation is provided by connecting the filter in series with the load, which mainly compensates the voltage and provides voltage balance in three-phase system, it can also be used for current compensation [12].

448
As given in Figure 2 the inverter along with the DC link capacitor, connected in shunt between the source and the load, provides current compensation and power factor correction. Hybrid power filter have a combination of either passive and dynamic filters or series and parallel active power filters. By connecting hybrid filter the rating of the inverter can be reduced [13-14].

In this paper three-phase three-wire shunt active power filter is being investigated to reduce the percentage of THD for a non-linear load taken as three-phase bridge rectifier. The inverter of the shunt active power filter is controlled by Hysteresis Current Controller (HCC). The reference current to the HCC is extracted from the load side of the non-linear load with the help of different control strategies. Here the work is mainly concentrated on the performance of shunt active power filter based on the three control strategies namely d-q Theory, P-Q theory also known as Instantaneous Reactive Power Theory and Indirect Reference Current Theory (IRCT). The system with filter is analysed with these three control techniques in matlab / simulink platform and the hardware results for SRF technique is implemented and compared with the simulation results.

![Figure 2 Topology of parallel connected filter](image)

II Design procedure

The filter can be supplied from either voltage or current supply. With respect to input applied to the system, filters can be categorized into two basic structures [15-16], Voltage Source Active Filter (VSAF) which consists of voltage fed inverter and Current Source Active Filter (CSAF) made of current fed inverter. Figure 3 demonstrates the filter provided with voltage source inverter due to its well known topology and easy installation procedure. Compensation in supply current is achieved by the injection of equal but opposite harmonic compensating currents from the filter. The cancellation of harmonic content present in the load current helps the supply side component remains sinusoidal and in-phase with the line voltage.
This paper deals with the simulation and comparison, based on the performance, of a system with a three-phase three-wire pulse width modulation control voltage source shunt APF employing three control techniques namely SRF, P-Q and IRCT. The results obtained are compared with IEEE 519 regulations for compliance.

A three-phase three-wire SAPF is considered, for designing the parameters. While designing the filter parameters, the six switches of the inverter are considered as ideal switches. The filter inductors are taken as pure inductances. Load currents are assumed to be balanced. The sampling time and switching frequency are already chosen. For the required values of three-phase supply voltages, three-phase supply currents and three-phase load currents, the DC link capacitor voltages, filter Inductance value and SAPF ratings are calculated from the formulae given in equations 3-9.

The rms value of the rectifier is calculated from the equation,

\[ I_{rms} = 0.816I_o, \]  
where \( I_o \) is the rectifier output current \hspace{1cm} (3)

Fundamental components of rectifier input current is represented as \( I_1 = 0.779I_o \) \hspace{1cm} (4)

The harmonic current \( I_h \) is found by \( I_h = \sqrt{I_{rms}^2 - I_1^2} \) \hspace{1cm} (5)

The rating (S) of the shunt active power filter is calculated as \( S = 3I_h \) phase voltage \hspace{1cm} (6)

DC link capacitor voltage is mention as \( V_{DC\text{ Voltage}} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3m}}, \) \hspace{1cm} (7)

Modulation index (m) value is assumed as 1 and the output line voltage of the SAPF is referred as \( V_{LL} \)

DC link capacitor, \( C_{DC} = \frac{I_{sapf}}{2\omega V_{DC\text{ Ripple}}}, \) \hspace{1cm} (8)

where, \( I_{sapf} \) is the supply current of filter, \( V_{DC\text{ ripple}} \) is the maximum Dc link ripple voltage (1 to 3 % of \( V_{DC\text{ Voltage}} \)), \( \omega = 2\pi f. \)
Filter inductor, \( L_C = \frac{\sqrt{3} V_{\text{DCvoltage}}}{12a f_{\text{sw}} I_{\text{ripple}}} \), where, ‘a’ is the overload factor. \( (9) \)

III Control algorithm

The reference current to control the shunt module is extracted from the load side current by using three different techniques [17-23]. In SRF theory the feedback signals are the load currents, PCC voltages and DC bus voltage. The block diagram for SRF technique is given in Figure 4. Using Park’s transformation, the load currents are transformed into a d-q-o frame. The currents \( i_{dL}, i_{qL} \) and \( i_{oL} \) are processed using the matrix equation 10.

\[
\begin{bmatrix}
  i_{dL} \\
  i_{qL} \\
  i_{oL}
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
  \cos \theta & -\sin \theta & \frac{1}{2} \\
  \cos \left( \theta - \frac{2\pi}{3} \right) & -\sin \left( \theta - \frac{2\pi}{3} \right) & \frac{1}{2} \\
  \cos \left( \theta + \frac{2\pi}{3} \right) & \sin \left( \theta + \frac{2\pi}{3} \right) & \frac{1}{2}
\end{bmatrix} \begin{bmatrix}
  i_{La} \\
  i_{Lb} \\
  i_{Lc}
\end{bmatrix}
\]
\( (10) \)

Equations 11 and 12 represent the AC and DC components present in the d-q currents. The current signals are synchronized with the PCC voltages by connecting three-phased Phase Locked Loop (PLL). To extract the DC components of \( i_{dL} \) and \( i_{qL} \) the d-q current components are passed through a first order Butter worth low Pass Filter (BPF).

\[
i_{dL} = i_{dDC} + i_{dAC} \quad \text{(11)}, \quad i_{qL} = i_{qDC} + i_{qAC} \quad \text{(12)}
\]

The DC quantities extracted by the Low Pass Filter (LPF) are considered as fundamental quantities, they are separated from the harmonic signals. For the compensation of harmonics the D axis components are mainly...
taken into consideration. The error signal to the PI controller is the difference between the reference voltage and the voltage across the capacitor, which is given to the PI controller to maintain the DC capacitor voltage of the inverter. The required reference current is derived from $i_d - i_q$ rotating frame using inverse transformation. Then, the extracted reference signal is given to the hysteresis current controller to make the gate pulses.

Figure 5 demonstrates the instantaneous reactive power theory control algorithm of SAPF.

In the second step, the real and reactive power is calculated from the relations given in the equation 15.

$$
\begin{align*}
\begin{pmatrix}
  v_\alpha \\
  v_\beta
\end{pmatrix} &= \frac{2}{\sqrt{3}} \begin{pmatrix}
  1 & \frac{-1}{2} & \frac{-1}{\sqrt{3}} \\
  0 & \frac{2}{\sqrt{3}} & \frac{-2}{2}
\end{pmatrix} \begin{pmatrix}
  v_{\alpha} \\
  v_{\beta} \\
  v_{\gamma}
\end{pmatrix} \\
\text{and} \quad \begin{pmatrix}
  i_\alpha \\
  i_\beta
\end{pmatrix} &= \frac{2}{\sqrt{3}} \begin{pmatrix}
  1 & \frac{-1}{2} & \frac{-1}{\sqrt{3}} \\
  0 & \frac{2}{\sqrt{3}} & \frac{-2}{2}
\end{pmatrix} \begin{pmatrix}
  i_{\alpha} \\
  i_{\beta} \\
  i_{\gamma}
\end{pmatrix}
\end{align*}
$$

In the second step, the real and reactive power is calculated from the relations given in the equation 15.
In the third step, the AC component of active (P*) and reactive (q*) power are separated from the DC component by considering the LPF as shown in Figure 6. Here, the fundamental components of the load power are considered as DC components (\(\overline{P}_L\) and \(\overline{Q}_L\)) and harmonic components are considered as AC components (\(\tilde{P}_L\) and \(\tilde{Q}_L\)) which are expressed in the equations 16 and 17.

\[
p_L = \overline{P}_L + \tilde{P}_L \quad \text{and} \quad q_L = \overline{Q}_L + \tilde{Q}_L
\]

In the step four, the reference currents are calculated using inverse Clark’s transformation. The reference currents (\(i_{sa}^*\), \(i_{sb}^*\) and \(i_{sc}^*\)) are obtained by the equation 18.

\[
\begin{pmatrix}
    i_{sa}^* \\
    i_{sb}^* \\
    i_{sc}^*
\end{pmatrix} = \frac{1}{\sqrt{3}} \begin{pmatrix}
    1 & 1 & 0 \\
    \frac{1}{2} & \frac{-1}{2} & \frac{-1}{2} \\
    0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2}
\end{pmatrix} \begin{pmatrix}
    v_\alpha \\
    v_\beta \\
    -v_\alpha
\end{pmatrix}^{-1} \begin{pmatrix}
    p^* \\
    q^*
\end{pmatrix}
\]

The third control strategy is the unit template based control algorithm in which an indirect current control method is introduced to get the reference current. A PCC voltage is sensed to estimate the amplitude of the supply current supplied by three-phase. Figure 6 gives the block diagram representation for SAPF with indirect current control algorithm. In this method the amplitude of the voltage is obtained using the formula in equation 19.

\[
\text{Estimated voltage} = \left(\frac{2}{3}(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)\right)^{1/2}
\]

\(U_{pa}\), \(U_{pb}\) and \(U_{pc}\) are the in-phase unit vectors that are derived by equation 20,

\[
U_{pa} = v_{sa}/\text{Estimated voltage}, \quad U_{pb} = v_{sb}/\text{Estimated voltage} \quad \text{and} \quad U_{pc} = v_{sc}/\text{Estimated voltage}
\]

The three-phased supply current is obtained by multiplying the in-phase unit current vectors and the amplitude of the reference supply current derived from the PI controller.
IV Simulation results and discussion

The non-linear system with filter is simulated for three different control strategies in Matlab/Simulink model. Three-phase uncontrolled full bridge converter is taken as a non-sinusoidal producing source in this system. FFT analysis is conducted for the system without considering SAPF to check THD percentage for the considered non-linear load. The source current waveform of the non-linear system before filter compensation is shown in figure 7. Figure 8 shows the THD percentage as 42.34 %, without the addition of filter.
FFT analysis for the indirect reference current control technique is shown in Figure 9. The system with filter is simulated for 0.5 seconds and the FFT is taken for 5 cycles from 0.1 seconds. After adding the filter the THD percentage is reduced to 11.25%.

![Figure 9 THD % after filter](image)

Figures 10a to 10g show the source voltage, source current waveform before and after the filter is connected and voltage across the DC link capacitor. When the filter is inserted, as seen in waveform 10a and 10b after 0.1 second the source current is changed to pure sinusoidal. In the simulation model the filter is connected to the system through the switch to inject the opposite harmonic current after 0 second. After 0.05 second the voltage across the dc link capacitor maintains constant value till further change in the supply side or load side occurs.

![Waveform](image)
Figure 10 a-h input and output waveforms of bridge rectifier

a) Voltage and current in input side, b) Per phase source voltage and source current, c) load current waveform at PCC, d) Filter current, e) Dc link voltage, f) DC output voltage of bridge rectifier, g) DC output current waveform of bridge rectifier.

The FFT analysis of the P-Q theory based shunt active filter is depicted in Figure 11. Here, the current is compensated at 0.1 second. The percentage of contaminated component present of the fundamental current is 4.35 %. Figures 12a to 12g give the voltage and current waveform of the system in input and output side. Compare to the indirect current control method, the THD percentage in P-Q method is reduced to the IEEE 519 recommendations.
Figure 12a-g input and output waveforms for PQ theory based control Algorithm

a) Source Current, b) Input Voltage waveform, c) Point of common coupling load current, d) Injected current, e) Voltage across the filter capacitor, f) Output Voltage, g) Output current.

The FFT analysis for SRF method is represented in Figure 13. Total harmonic distortion percentage in this method is 1.47%. It shows that by using SRF technique reduced level of THD percentage can be obtained. The various input and output waveforms of the SRF technique are shown in Figures 14a to 14h.
Figure 14 a-f different voltage and current waveform of SRF technique

a) Supply side voltage and current, b) Voltage and current at the PCC, c) Compensation current, d) voltage across the dc link capacitor, e) rectified voltage, f) Rectifier load Current.
Table 1 THD % of three techniques before and after compensation

<table>
<thead>
<tr>
<th>THD % before compensation</th>
<th>THD % in IRCT Method</th>
<th>THD % P-Q Theory</th>
<th>THD % in SRF Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.34 %</td>
<td>11.25 %</td>
<td>4.35 %</td>
<td>1.47 %</td>
</tr>
</tbody>
</table>

Table 1 gives the results obtained from three different techniques. It reveals that generating the negative element by sensing the load side current gives the less THD%.

V Hardware implementation

The hardware implementation for the proposed system with SRF control algorithm is carried out. The hardware setup mainly consists of an auto transformer to provide three-phase source voltage, source side impedance to limit the supply current, voltage and current sensor board to sense feedback signal and the input and output voltages, coupling impedance between the filter and the line to limit the filter current, voltage source intelligent power module with DC link capacitor and non-linear load block. The feedback signal such as three-phased PCC voltages, load current and DC link voltage are sensed through the sensor board and it is processed through SPARTAN 6 FPGA processor to produce the switching pulse to the filter, so that the opposite harmonic current can be injected to the line to reduce the harmonics present in the source current. The THD percentage of the source current is observed from fluke analyser. The hardware layout of the shunt active power filter is revealed in Figure 15. To verify the results the system is simulated for 110 V. The uncompensated and compensated supply current is publicized in Figure 16a-16d.

Figure 15 Hardware implementation of system with filter

Figure 16a Source current waveform for 110 V
Initially the hardware setup operates without considering the compensating device and the supply current is observed through Digital Storage Oscilloscope (DSO). Figure 17a depicts the waveform of the source voltage and source current. The source current in Figure 17a contains the harmonic component along with fundamental current. Then, negative current injecting equipment is connected to the system in cascade through the coupling inductor. It injects the opposite harmonic current to the line to remove the harmonic content present in the system. The harmonic free input current is measured through DSO along with the source voltage and the filter current. They are shown in Figure 17b. It is observed from Figure 17f that after the introduction of filter, the main supply voltage and current are in phase. With the filters connected to the system, it is tested with different voltage level as shown in Figures 17c. Corresponding three-phase source voltage, source current and the filter current are shown in Figures 17d, 17e and 17g. Figure 17h denotes the switching pulses given to the inverter switches.
Figure 17a Uncompensated voltage and current

Figure 17b Compensated voltage and current

Figure 17c Voltage and current for various load

Figure 17d Source voltage

Figure 17e Source current

Figure 17f Supply voltage and current

Figure 17g Filter current

Figure 17h Switching pulse of SAPF
Total harmonic distortion with and without filter is measured with the help of power quality analyser for the hardware setup. Figures 18a to 18j depict the voltage and current waveforms with and without the filter. The percentage total harmonic distortions without filter are taken for two different voltages. Before connecting the filter the distortion was in the range of 23.9 % and 24.7 %. After introducing the filter THD % is reduced to 3.2% and 2.3 %.

The magnitude of source current is observed as 3.017A for the applied voltage of 109.1V before adding the filter into the non-linear system, which is mention in Figure 18a. The non-sinusoidal nature of the fundamental current waveform reveals that there is a harmonic content present in the source current. The percentage of THD is noticed as 23.9%, which is shown in Figure 18b.

For the same applied voltage of 109.1V, the source voltage maintains sinusoidal waveform both before and after the filter is added to the system. The THD% of source voltage is 1.8% which is depicted in Figures 18c. Figure 18d.
Figures 18e and f represent the compensated source current waveform and THD%. It is observed that total harmonic distortion is reduced from 23.9% to 3.2%.

The source voltage and source current waveform and the THD% of source voltage for 182V are shown in Figure 18g and h.

Figure 18a to 18j fluke analyser voltage and current waveform with and without SAPF
a) Source current (3.017 A) without filter, b) current FFT Window with THD % = 23.9 % without filter, C) Source Voltage (109 V) with filter, d) Source voltage FFT Window with THD % = 1.8 % with filter, e) Source current(3.201 A) with filter, f) Source current FFT Window with THD % = 3.2 % with filter, g) source voltage (182 V), and source current(4.021 A), h) Source voltage FFT Window with THD % = 2.0 % with filter, i) Source current THD % = 24.7 % without filter  and j) Source current FFT Window with THD % = 2.3 % with filter.

Figures 18i and j represents the percentage of total harmonic distortion for input current before and after the injection of filter. It can be seen that the THD% before and after compensation are 24.7% and 2.3% respectively.

The system is tested with different levels of voltages and the corresponding THD % with and without filter is recorded by the fluke analyser and the reports are tabulated in Table 2. The DC voltage for the various voltage levels are also measured by the multi-meter.

Table 2 voltage and current with and without filter

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Source Voltage (V)</th>
<th>Source Current (A)</th>
<th>Source Voltage THD%</th>
<th>Source Current THD%</th>
<th>DC link voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>102.8</td>
<td>2.748</td>
<td>2.68</td>
<td>23.75</td>
<td>2.993</td>
</tr>
<tr>
<td>2</td>
<td>103.2</td>
<td>2.756</td>
<td>2.72</td>
<td>23.84</td>
<td>2.606</td>
</tr>
<tr>
<td>3</td>
<td>109.1</td>
<td>3.017</td>
<td>2.43</td>
<td>23.93</td>
<td>3.201</td>
</tr>
<tr>
<td>4</td>
<td>111.75</td>
<td>2.559</td>
<td>2.17</td>
<td>24.26</td>
<td>3.213</td>
</tr>
<tr>
<td>5</td>
<td>163.9</td>
<td>4.47</td>
<td>2.28</td>
<td>24.46</td>
<td>4.392</td>
</tr>
<tr>
<td>6</td>
<td>182</td>
<td>4.561</td>
<td>2.19</td>
<td>24.7</td>
<td>4.511</td>
</tr>
<tr>
<td>7</td>
<td>191.7</td>
<td>4.456</td>
<td>1.97</td>
<td>24.92</td>
<td>4.479</td>
</tr>
<tr>
<td>9</td>
<td>196.6</td>
<td>4.459</td>
<td>2.25</td>
<td>24.98</td>
<td>4.559</td>
</tr>
<tr>
<td>10</td>
<td>212.8</td>
<td>4.768</td>
<td>2.8</td>
<td>25</td>
<td>5.18</td>
</tr>
</tbody>
</table>

Table 3 Real and reactive power with and without SAPF

<table>
<thead>
<tr>
<th>System parameters</th>
<th>Without SAPF</th>
<th>With SAPF</th>
<th>Without SAPF</th>
<th>With SAPF</th>
<th>Enhancement in system parameters (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root mean square voltage (Volts)</td>
<td>109.1</td>
<td>212.8</td>
<td>109.1</td>
<td>212.8</td>
<td></td>
</tr>
<tr>
<td>Root mean square current (A)</td>
<td>3.017</td>
<td>3.201</td>
<td>4.874</td>
<td>5.18</td>
<td>6.09</td>
</tr>
<tr>
<td>Real Power (W)</td>
<td>311.4</td>
<td>350.9</td>
<td>983.15</td>
<td>1109</td>
<td>12.60</td>
</tr>
<tr>
<td>Apparent Power (VA)</td>
<td>329.8</td>
<td>351.4</td>
<td>1040.59</td>
<td>1110</td>
<td>6.54</td>
</tr>
<tr>
<td>Reactive Power (var)</td>
<td>71.9</td>
<td>8.4</td>
<td>340.94</td>
<td>4.5</td>
<td>88.3</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.94</td>
<td>1.00</td>
<td>0.95</td>
<td>1</td>
<td>6.38</td>
</tr>
</tbody>
</table>
The system is tested for different levels of voltage with and without the implementation of filter. The real and reactive power for two set of voltage is noticed and the hardware readings recorded in the fluke analyser is listed in Table 3. It is observed that, once the filter is added the real power and the apparent power for voltages 109.1V and 212.8V are improved by 12.60%, 12.80% and 6.54%, 6.67% respectively. The reactive power is compensated by 88.3% and 87.4% respectively. Similarly the power factor also improved by 6.38% and 6.51% respectively for the two set of voltages.

VI Conclusion

The proposed system considered here to retrieve the supply side current as pure sinusoidal is simulated for three different control techniques and the results obtained from each technique are compared. From the comparison it is evident that the synchronous reference frame theory method provides least THD % of 1.47 % using MATLAB simulation and 2.3 % from the hardware. Apart from minimizing the THD, the power factor is improved to 6.38 % and the reactive power compensation is increased by 87.4 %.

References

15. Fabio Ronchi, Andrea Tilli, Design Methodology for Shunt Active Filters.