CHAPTER 7

ADAPTIVE LMS ALGORITHM BASED CURRENT HARMONIC SUPPRESSION IN AC-DC-AC DRIVE

7.1 INTRODUCTION

Irrespective of the application, the switch-mode DC-AC power inverters are controlled towards the objective of producing a sinusoidal ac output with controllable magnitude and frequency. In ac motor drives, PWM inverters make it possible to control both frequency and magnitude of the voltage and current applied to a motor. Although the basic circuit for an inverter may seem simple, accurately switching these devices provides a number of challenges for the power electronic engineer. Recent years have seen the development of numerous PWM pattern generation techniques for improving the performance of the VSI. Majority of the PWM works with a common philosophy that switching the power switches at higher frequency than the desired output frequency and thereby displacing the harmonics away from the fundamental component. Through this idea, the filtering becomes easy at the cost of increased switching losses.

A higher quality spectrum even at low switching frequency can be obtained through eliminating specific LOH. The SHE aims at complete elimination of some LOH from a PWM waveform, while maintaining the amplitude of the fundamental components at a pre-specific value. The elimination of specific low-order voltage harmonics from a given voltage/current waveform generated by a VSI/CSI using what is widely
known as optimal, “programmed” or SHE-PWM techniques, has been dealt with in numerous papers and for various converter topologies, systems and applications. Harmonic elimination has been a research topic since the early 1960’s.

7.2 PROBLEM DEFINITION

SHE is a widely accepted practice in industrial drives and evolved as an alternative to high switching loss causing traditional PWM techniques. The load behaviour of the voltage source converter based applications depends directly on current harmonics rather than voltage harmonics. This time varying nature of current harmonic profile mandates the on-line SCHE than the off-line voltage harmonic elimination. Such a SCHE in an AC-DC-AC drive can be done at two ways. One is for the motor line currents and the other is at source current (rectifier input current). The former improves the motor performance while the later helps in preventing power system pollution.

This chapter presents an adaptive filtering algorithm for the SCHE at the supply side of the AC-DC-AC drive system. This LMS based method can be employed in the drive to perform SCHE in the load current by just feeding only the order of harmonics to be eliminated. The algorithm is simulated using MATLAB/Simulink tool for the elimination of the fifth and seventh harmonics. The performance is analyzed based on THD, magnitude of eliminated harmonics and load current waveform. The corroboration is done in the designed VSI feeding induction motor using DSP TMS320LF2407. The developed algorithm is transferred to DSP using VisSim software.
7.3 LEAST MEAN SQUARE ALGORITHM

The LMS algorithm was introduced by Widrow and Hoff in the year 1959. It is a simple and robust algorithm, which does not require correlation function calculation and matrix inversions. It is an adaptive algorithm, which uses a gradient-based method of steepest decent. It uses the estimates of the gradient vector from the available data. It incorporates an iterative procedure that makes successive corrections to the weight vector in the direction of the negative of the gradient vector, which eventually leads to the minimum mean square error.

The pot like structure shown in Figure 7.1 can help in understanding the LMS algorithm. Initially the weights are assigned at the point indicated by the arrow mark. As already stated the LMS algorithm tries to reach the steepest gradient, the final weights and the corresponding error will reach the bottom point of the pot.

![Figure 7.1 Structure of LMS algorithm](image)

The ASHE filter, shown in the Figure 7.2 consists of a combiner, the LMS algorithm, and a summing point. It operates as follows.
(i) The reference signal with two orthogonal components cosine and sine ($X_1$ and $X_2$) has the selected frequency ($\omega_o=2\pi f_o$), which is to be eliminated from the line current $D_k$. $T$ is a sampling period and $K$ is a discrete time index.

(ii) The reference input ($X_1$ and $X_2$) is multiplied with corresponding weights ($W_1$ and $W_2$). The weighted sine and cosine components of reference signal are combined/added together to match amplitude and phase angle of interfering sinusoid in the line current $D_k$. Adaptation process adjusts weights to exactly match amplitude and phase of the interference.

(iii) The signal $Y_k$ created by a combiner, which is subtracted from the line current $D_k$ (signal to be filtered) and eliminated from the output of the filter $\varepsilon_k$.

Figure 7.2 Structure of single frequency ASHE filter
The LMS algorithm can be formulated as follows. The error estimation is given by

\[ \varepsilon_k = D_k - Y_k = D_k - X_k^T W_k \]  

(7.1)

The reference and weight vectors are defined by

\[ X_k^T = [X_1 \ X_2] \]  

(7.2)

\[ W_k^T = [W_1 \ W_2] \]  

(7.3)

The gradient \( \nabla_k \) is estimated as the following

\[ \nabla_k = \begin{bmatrix} \frac{\partial \varepsilon_k^2}{\partial \omega^e} \\ \frac{\partial \varepsilon_k^2}{\partial \omega^s} \end{bmatrix} 2 \varepsilon_k \begin{bmatrix} \frac{\partial \varepsilon_k}{\partial \omega^e} \\ \frac{\partial \varepsilon_k}{\partial \omega^s} \end{bmatrix} - 2 \varepsilon_k X_k \]  

(7.4)

The weight updating formula is given by

\[ W_{k+1} = W_k - \mu \nabla_k = W_k + 2\mu \varepsilon_k X_k \]  

(7.5)

Where, \( \mu \) is the adaptation gain constant. The gradient estimate contains substantial amount of noise. It is attenuated by the adaptive process.

7.4 LMS ALGORITHM FOR SHE PROBLEM

Extension of the structure shown in Figure 7.2 can lead to selective elimination of multiple harmonics. That is more harmonic components can be set to be eliminated by including corresponding blocks. Selective elimination
of multiple harmonics is illustrated in the Figure 7.3. The fifth and seventh harmonics are eliminated from the output variable of the inverter. The expansion to eliminate the other harmonic components can be done by adding blocks like fifth and seventh. Additional blocks will have the same error input ε, frequency of the reference signal will be equal to the input harmonic component to be eliminated and the output will be added to the outputs of the previous blocks (5 and 7).

Figure 7.3 Selective elimination of multiple harmonics

Using the block 1, which contains ASHE from Figure 7.2, the fundamental component is taken out of the primary input. The output of the block 1, which is still having fifth and seventh harmonic components, is introduced to the error inputs of the blocks 5 and 7. The reference signal of the fundamental, fifth and seventh are represented as (X₁ and X₂), (X₃ and X₄), and (X₅ and X₆) in the Figure 7.3. The primary input \( D_k = U_c + U_{\text{dis}} \) where,
$U_c$ is the control input and $U_{dis}$ is the undesirable harmonic component of the inverter output.

The complete system of ASHE for eliminating harmonics in three phase front end uncontrolled rectifier is shown in Figure 7.4.

![Figure 7.4 LMS algorithm based ASHE for front end diode rectifier](image)

As shown in the figure the system uses two PI regulators in the synchronous reference frame for current control (for $I_{q1}$ and $I_{d1}$). Reference
angle for generation of sine and cosine functions, frequency of fundamental component, fifth harmonics, seventh and eleventh harmonics are created by a phase look loop block. Sine and cosine components with fundamental frequency are phase locked with utility voltage and are used for stationary to synchronous (and vice versa) reference frames transformations. Sine and cosine components with five, seven and eleven times higher frequencies are used for selective harmonic elimination. The sample line currents \( I_a, I_b, I_c \) are transformed from the stationary \((a,b,c)\) reference frame to two phase \(q,d\) stationary reference frame (block 3/2) and then into synchronous frame \(I_q, I_d\) (block s/e).

The conventional part of control works as follows: voltage regulator \( U_{\text{reg}} \) depending on dc bus voltage error creates an active current reference PI current regulators maintain an average value of feedback currents \( I_{q}^e \) and \( I_{d}^e \) equal to the average values of corresponding references. Outputs of current regulators are transformed first from synchronous to stationary reference frame (block e/s) and then from two-phase \((q,d)\) to three phase \((a,b,c)\) system and written into PWM control the inverter. The components contributed to PWM from ASHE blocks will create voltage at the output of the inverter with amplitudes and phase angles as needed to cancel harmonic components from the load currents.

### 7.5 SIMULATION STUDY

The proposed ASHE algorithm is simulated MATLAB/Simulink software. The three phase PWM-VSI with a front end uncontrolled rectifier is simulated without and with ASHE algorithms. The carrier frequency is 10 KHz. Figures 7.5-7.8 show the relevant transformations. The images may not give ready interpretations to the system performance. But the functionality of
the inner modules of the proposed system can be validated with the help of Park’s and Clark’s transformations. Figure 7.9 indicates the output of Multiple Frequency ASHE (MF-ASHE) block.

**Figure 7.5 abc to dq- stationary transformation**

**Figure 7.6 dq- stationary to dq- rotationary transformation**
Figure 7.7 dq- rotational to dq- stationary transformation

Fig 7.8 dq - stationary to abc transformation
The performance of the system without ASHE algorithm is shown in Figure 7.10. Figure 7.11 shows the triumph of the ASHE based on LMS algorithm in shaping the current, which is the improved wave forms of line currents. The corresponding harmonic spectrum after application of ASHE is shown in Figure 7.12.
Figure 7.11 Filtering action of ASHE on source current

Figure 7.12 Current and harmonic spectrum with ASHE
Table 7.1 compares the various lower order current harmonics and THD. It is evident that almost all the harmonic components including THD are less in ASHE filtering. The targeted harmonics are reduced below 5%. There is about 30% reduction in THD also. The variations of weights are shown in Figure 7.13, Figure 7.14 and Figure 7.15 for fundamental, fifth harmonic and seventh harmonics respectively. The effect of adaptation constant on the performance of the algorithm in presented in Figure 7.16. Adaptation constant influences the harmonic values and the THD faithfully.

Table 7.1 Comparison of current harmonics without ASHE and with ASHE

<table>
<thead>
<tr>
<th>Method</th>
<th>$I_1$</th>
<th>$I_5$</th>
<th>$I_7$</th>
<th>$I_{11}$</th>
<th>$I_{17}$</th>
<th>THD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without ASHE</td>
<td>100</td>
<td>39.59</td>
<td>15.23</td>
<td>7.97</td>
<td>1.75</td>
<td>87.75</td>
</tr>
<tr>
<td>With ASHE</td>
<td>100</td>
<td>3.81</td>
<td>4.43</td>
<td>2.28</td>
<td>0.62</td>
<td>57.84</td>
</tr>
</tbody>
</table>

Figure 7.13 Weights for fundamental Component
Figure 7.14 Weights for fifth harmonics

Figure 7.15 Weights for seventh harmonics
7.6 EXPERIMENTAL INVESTIGATIONS

The layout of the proposed experimental system is shown in Figure 7.17. It mainly consists of an uncontrolled rectifier, DC link filter, Application Specific Intelligent Power Module (ASIPM) and Texas TMS320LF2407 DSP Processor. Gating pulses for the inverter switches are generated by DSP controller and 0.75KW, 415V, 50Hz three phase induction motor is used as load. The LMS based adaptive algorithm is schematized in VisSim and then downloaded to personal computer. The developed schematic is diagrammed in Figure 7.18. The representative weight update is presented in Figure 7.19 while the error is indicated in Figure 7.20.
Figure 7.17 Layout of the experimental setup

Figure 7.18 LMS algorithm in VisSim window
Figure 7.19 Weight update in LMS algorithm

Figure 7.20 Error convergences in developed LMS algorithm
Figure 7.21 details about the R-Phase line current while LMS algorithm is in process. Figure 7.22 shows R-Phase line current when LMS algorithm reached optimum point and corresponding harmonic spectrum is illustrated in Figure 7.23. Table 7.2 shortens the results of both simulation and hardware for comparison.
Table 7.2 Comparison of simulation and hardware results

<table>
<thead>
<tr>
<th>Method</th>
<th>Simulation</th>
<th>Hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I₅</td>
<td>I₇</td>
</tr>
<tr>
<td></td>
<td>% of I₁</td>
<td>%</td>
</tr>
<tr>
<td>Without ASHE</td>
<td>39.59</td>
<td>15.23</td>
</tr>
<tr>
<td>With ASHE</td>
<td>3.81</td>
<td>4.43</td>
</tr>
</tbody>
</table>

7.7 SUMMARY

This chapter has presented an adaptive digital signal processing filtering algorithm for SCHE in front end rectifier. The algorithm features unconstrained SHE and has no load and circuit dependency. For any selected frequency, the approach uses an iterative/adaptive weighted combination of sine and cosine components to equal the amplitude and phase angle of
harmonics present in the line current, the sum is subtracted from the line current and eliminated from the final output. The effectiveness of the simulation has been investigated by eliminating the LOH in the source currents of the AC-DC-AC drive. The proposed ASHE algorithm amends the weights and conjures up a notch filter action for the selected frequencies. Thus the harmonic profile of the input current of AC-DC-AC system can be improved by using LMS algorithm based SCHE.