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A Normalized Least Mean Squares Algorithm Based On-Line Adaptive Selective Current Harmonic Elimination Technique For Three Phase AC Voltage Controllers

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Abstract:

Selective harmonic elimination (SHE) is a widely accepted practice in industrial drives and evolved as an alternative to high switching loss causing traditional pulse width modulation (PWM) techniques. The load behaviour of the voltage source converters based applications depends directly on current harmonics rather than voltage harmonics. This time varying nature of current harmonic profile mandates the on-line selected current harmonic elimination (SCHE) than the off-line voltage harmonic elimination. This paper presents an adaptive filtering algorithm for the SCHE in a three phase ac voltage controller based system. Among the adaptive algorithms, the least mean square (LMS) algorithm is the most popular one. However, the LMS algorithm suffers from slow and data dependent convergence behaviour and its variant, the normalized LMS (NLMS) algorithm exhibits a better balance between simplicity and performance. This method can be employed in ac voltage controller based systems 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 total harmonic distortion (THD), magnitude of eliminated harmonics and load current waveform. The key results of NLMS algorithm is compared with the LMS algorithm.

Keywords: Normalized LMS (NLMS) algorithm, selected current harmonic elimination (SCHE), on-line adaptive current harmonic elimination.

I. Introduction

The demand of higher power rating equipment has increasingly grown in the recent years. It has become very essential to control the ac voltage. The ac voltage is controlled to obtain the desired performance of electrical systems.For AC-AC power conversion, the most populartopologies are indirect AC/AC converters with a DC link and direct pulse width modulation (PWM) AC/AC converters. An indirect AC/AC converter can provideoutput voltage with a variable frequency. However, forapplications where only voltage regulation is needed, the direct PWM AC/AC converters have merits such asproviding a good power factor, high efficiency, low harmonic current in line, single-stage conversion, a simpletopology, ease of control, small size and low cost.The power flow can be controlled by varying the rms value of ac voltage applied. The major employment of AC voltage controller is to control fixed AC voltage to variable AC voltage.These controllers have numerous applications, such as electrical heating, electrical welding, speed control of induction motors, output voltage stabilizers etc.Conventional line frequency ac voltage regulators have inherent drawbacks, such as poor factor and large low frequency harmonics of input line current[1]-[4]. Also, the output voltage contains harmonics at multiples of supply frequency and harmonic currents flowing through the load cause heating and contributes to pulsating torque on motor loads.

Commonly used voltage control methods are phase angle control (PAC), Symmetrical Angle Control (SAC), integral cycle control, and Pulse Width Modulation (PWM) control. Although large amounts of ac power can be controlled economically by these regulators employing conventional controlmethods like PAC, they result in poor Power Factor (PF) on the input side even for a resistive load and a discontinuous power flow to the load [5]-[8]. Also, the output voltage contains harmonics at multiples of supply frequency and harmonic currents flowing through the load cause heating and contributes to pulsating torque on motor loads. The power factor of the phase controlled ac voltage regulators employing line commutation depends on the delay angle α, and is in general low, especially at decreased output voltages [9]. Research in the recent past and literature review make known that ac voltage regulators employing forced commutation can achieve a marginal improvement in the input power factor and reduce the harmonics levels to some extent [10]-[13]. Very few contributions are found with harmonic elimination in ac choppers. The microprocessor based selective harmonic elimination (SHE) has been initially attempted [14]. The effective utilization of genetic algorithm based switching angle elimination has been demonstrated for ac chopper [15]. An adaptive filtering algorithm for the SCHE in a three phase voltage source inverter has been developed [16]. The effective implementation of the filtering algorithm could suppress the fifth and the seventh harmonics of the line currents to about 1%. Similar effort has been attempted for multi-level inverter (MLI) structure also.

This paper presents the adaptation of an adaptive filtering algorithm for the SCHE in a three phase ac voltage controller. Even though the current harmonic proposed Normalized Least Mean Squares (NLMS) algorithm based scheme eliminates the selected dominant elimination is a direct method to improve the quality of any power conversion system, it demands a self-adaptive algorithm to manage with the time varying nature of load (current). The harmonics elimination in the load current is done with only the information of the frequencies to be eliminated. The algorithm is simulated using MATLAB/SIMULINK tool for a three-phase VSI to eliminate the fifth and seventh harmonics. The system performance is analysed based on the simulation results considering total harmonic distortion (THD), magnitude of eliminated harmonics and frequency spectrum.

II. Current Harmonic Elimination in Drives

In common discussion about harmonics, the difference between current and voltage harmonics is rarely addressed. While current and voltage harmonics are related. The effects are different. Current harmonics are caused by non-linear loads such as thyristor drives, induction furnaces etc. The effect of these loads is the distortion of the fundamental sinusoidal current waveform alternating at 50 Hz. Current harmonics affect the system by loading the distribution system as the waveforms of the other frequencies use up capacity without contributing any power to the load. They also contribute the Copper losses I^2Z losses in the system. Besides, Harmonic currents load the power sources such as transformers and alternators.

Of these non-linear loads, the major source of harmonic currents is the switch mode power supply found in most desktop computers, terminals, data processors and other office equipment.The amount of harmonics produced by a given load is represented by the term “K” factor. The larger the “K” factor, the more harmonics are present. The chart below provides a guide of typical “K” factors of different loads. This chart is only a guide and the “K” factor of equipment will vary from one manufacturer to another. The best way to determine “K” factor is by spectrum analysis and should be left to a professional with the proper power quality analysis equipment. The typical values are tabulated in Table 1.

Table 1. K factor by type of load

K-1	Resistance Heating Incandescent Lighting Electric Motors Control Transformers Distribution Transformers	K-13	Telecommunications Equipment Branch Circuits in Classrooms Health Care Facilities
K-4	Welders Induction Heaters HID Lighting Fluorescent Lighting Solid State Controls	K-20	Main Frame Computers AC Variable Speed Drives Circuits with DP Equipment Personal Computers Computer Terminals

III. Proposed on-line Current harmonic Elimination Algorithm

As shown in the above Fig.1 the inverter had PI controller U_reg for dc bus voltage control and two PI regulators Iq_1 and Id_1 implemented in synchronous reference frame for current control. Reference angle for generation of sine and cosine functions with frequency of fundamental component and frequencies of fifth and seventh harmonics is created by a phase locked loop (PLL) 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 and seven times higher frequencies are used for selective harmonic elimination. Sample currents Ia, I_b, I_c from the stationary (a,b,c) reference were transformed into 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_reg depending on dc bus voltage error creates an active current reference Iq*. For unity power factor reactive current reference I_d* is kept zero. 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. The complete procedure is detailed in Fig.2.

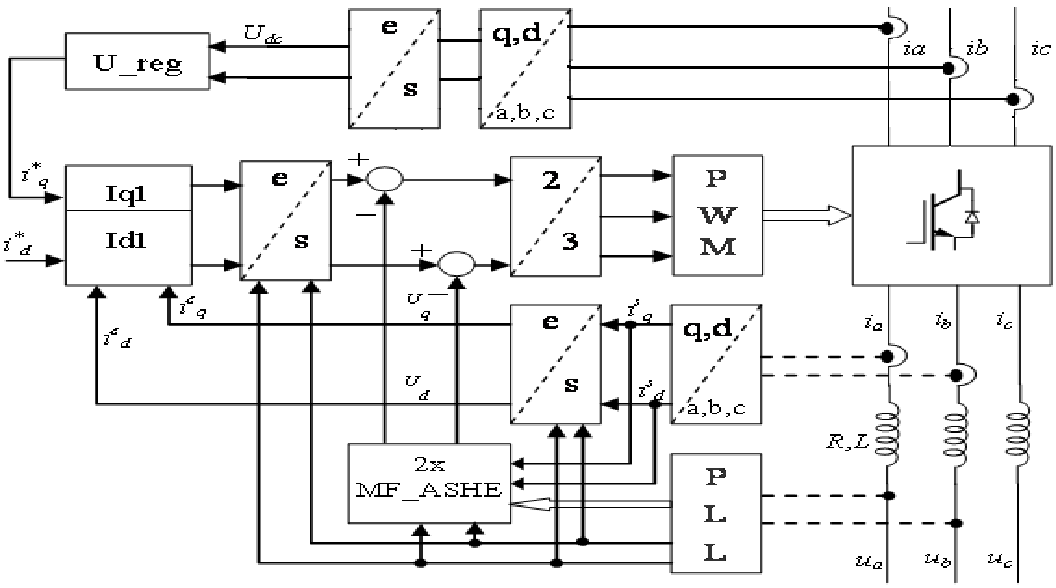

Fig.1. The proposed on-line filtering algorithm

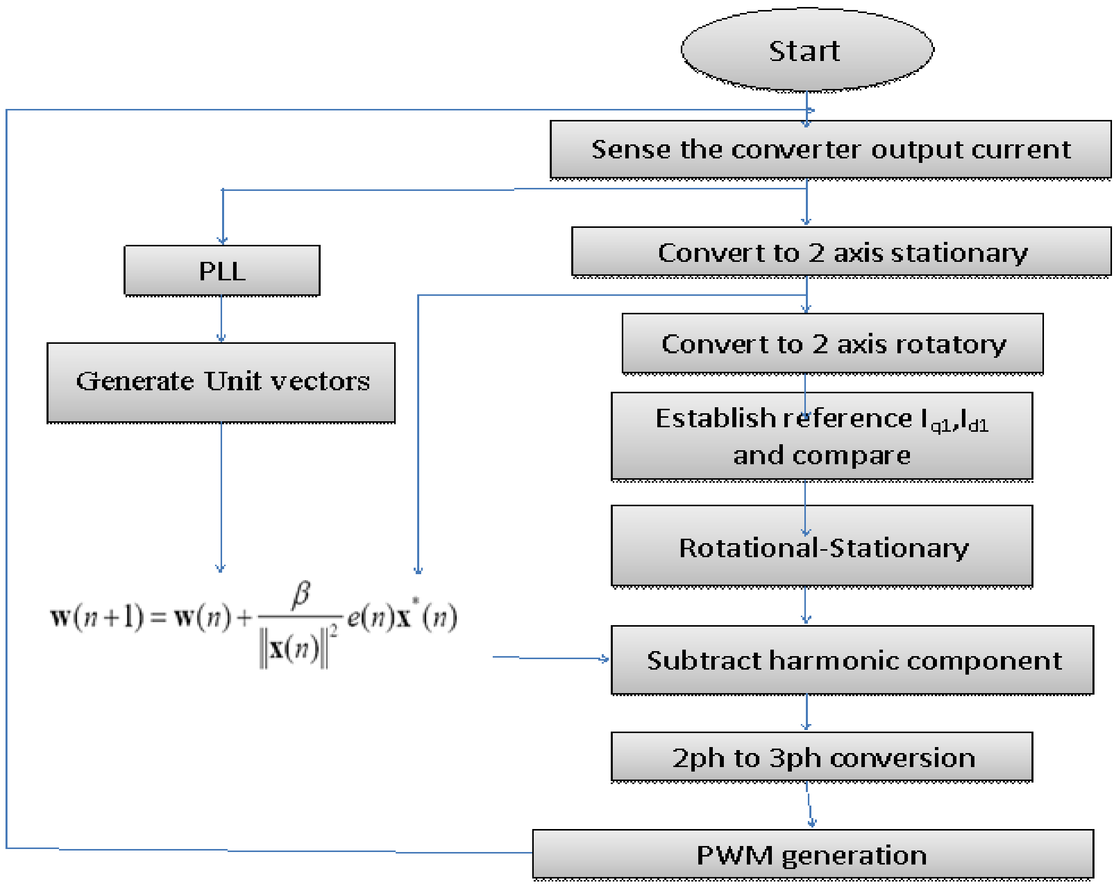

Fig.2. The steps involved in the propoased SHE-PWM

IV. Implementation of NLMS Algorithm

The suggested SCHE method is implemented in MATLAB/Simulink platform. Three phase ac voltage controller is simulated without and with the algorithms. The NLMS based SCHE algorithm is designed to eliminate 5^{th} and 7^{th} harmonic components of load current.The specifications are carrier frequency-10 kHz, Load R=100 Ω. The waveforms at various stages are illustrated form Fig.3 to Fig.8.

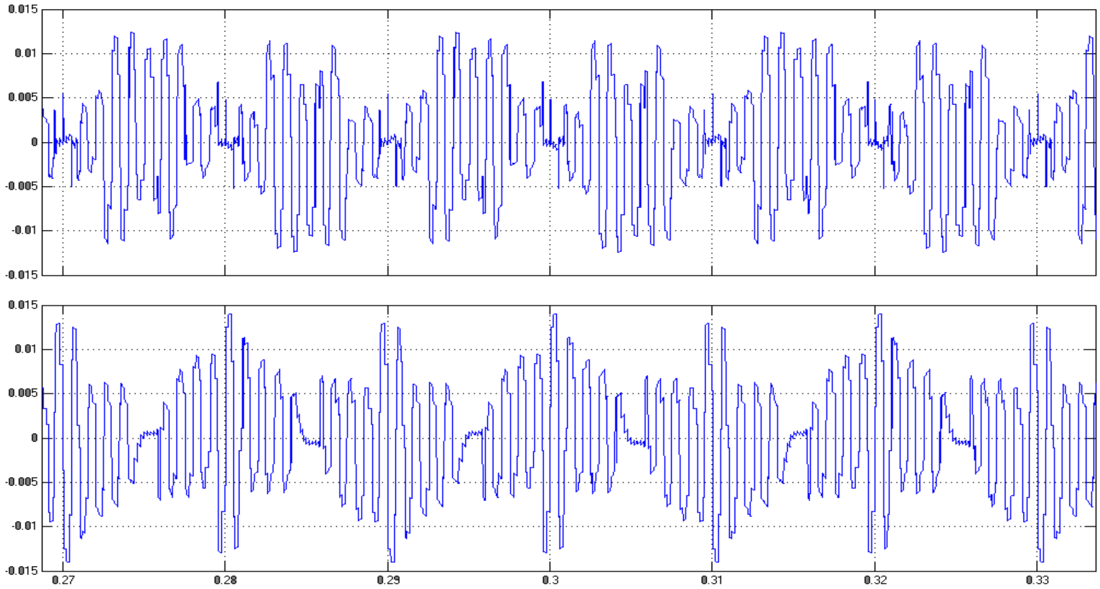

Fig.3. Output of Output of MF SHE block

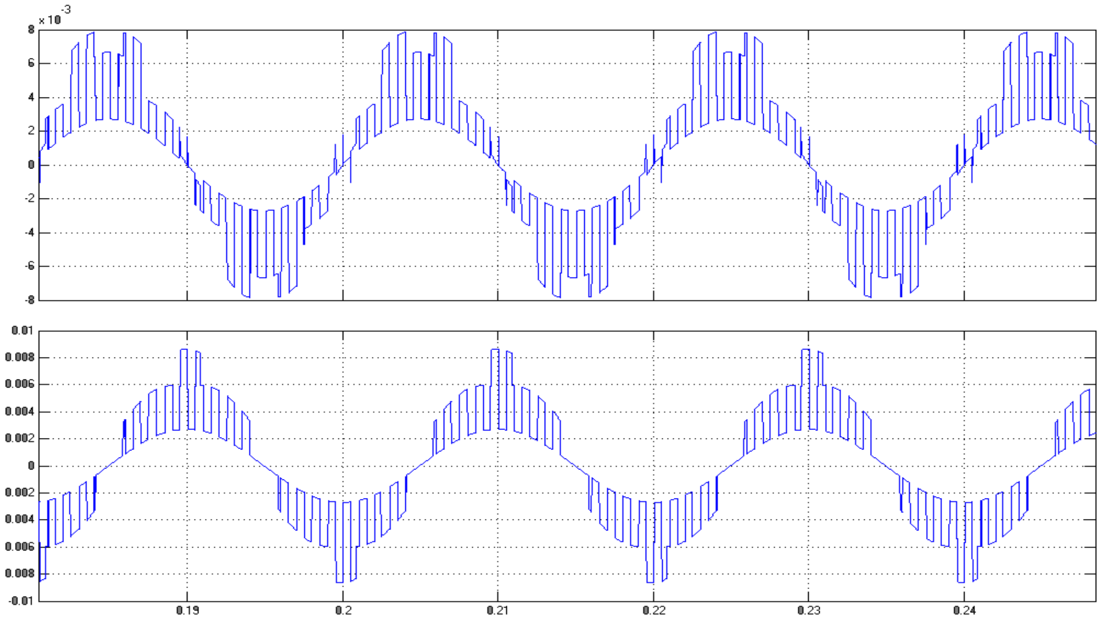

Fig.4 abc to dq-stationary transformation

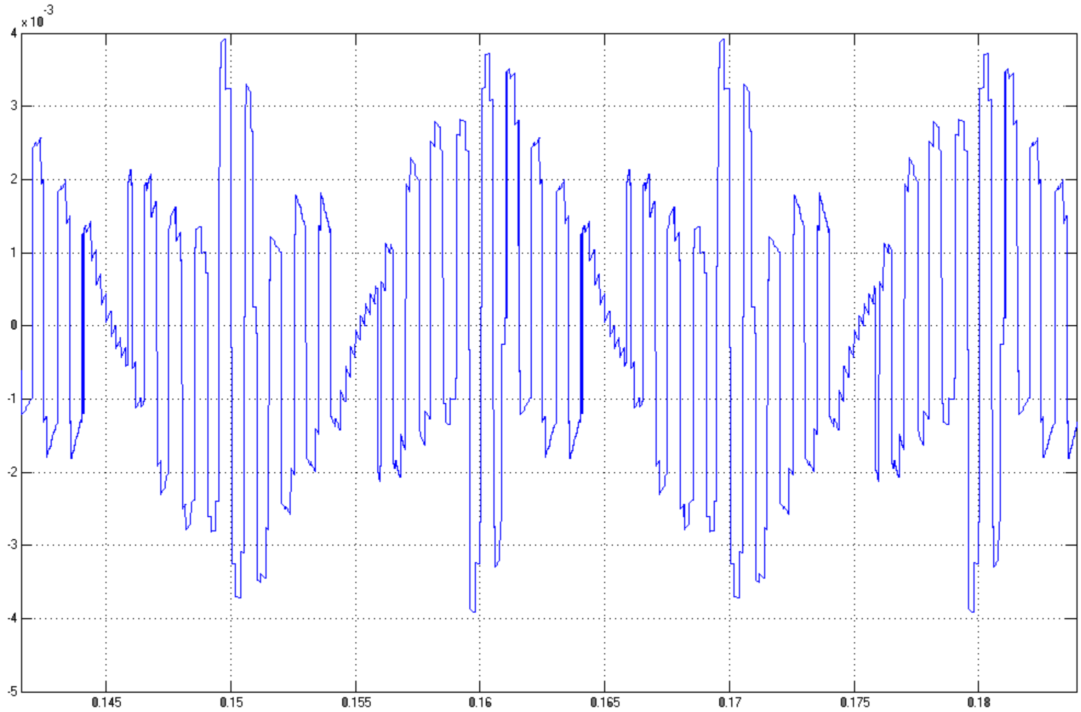

Fig.5. Weights appraisal for fundamental component

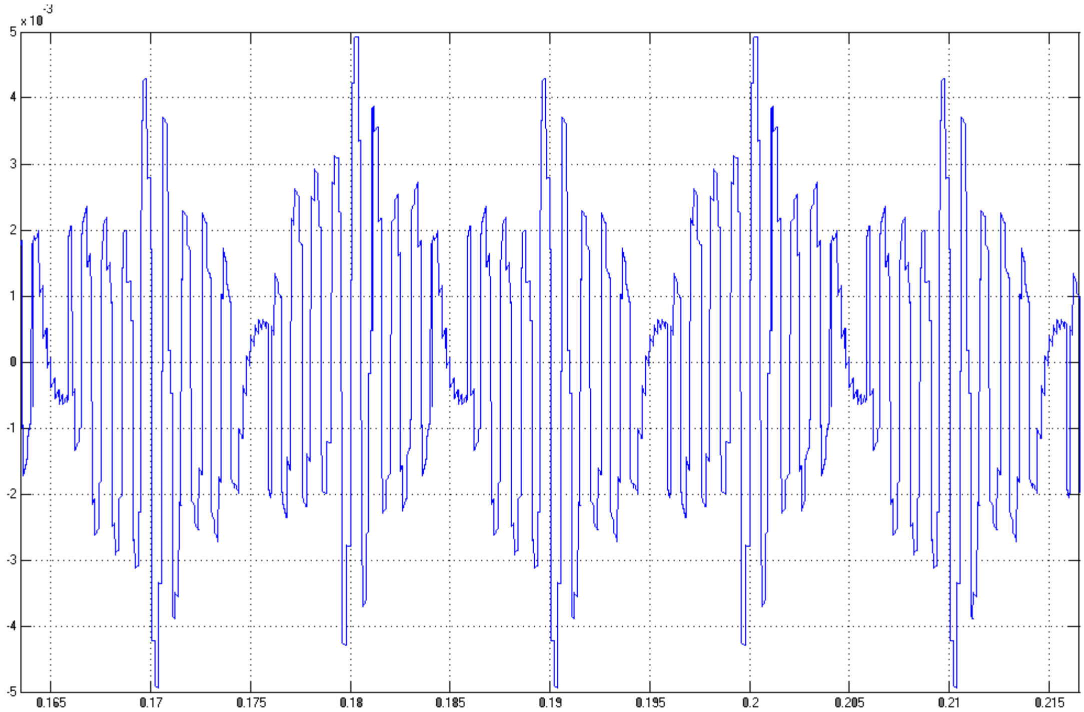

Fig.6. Weights appraisal for fifth Harmonics

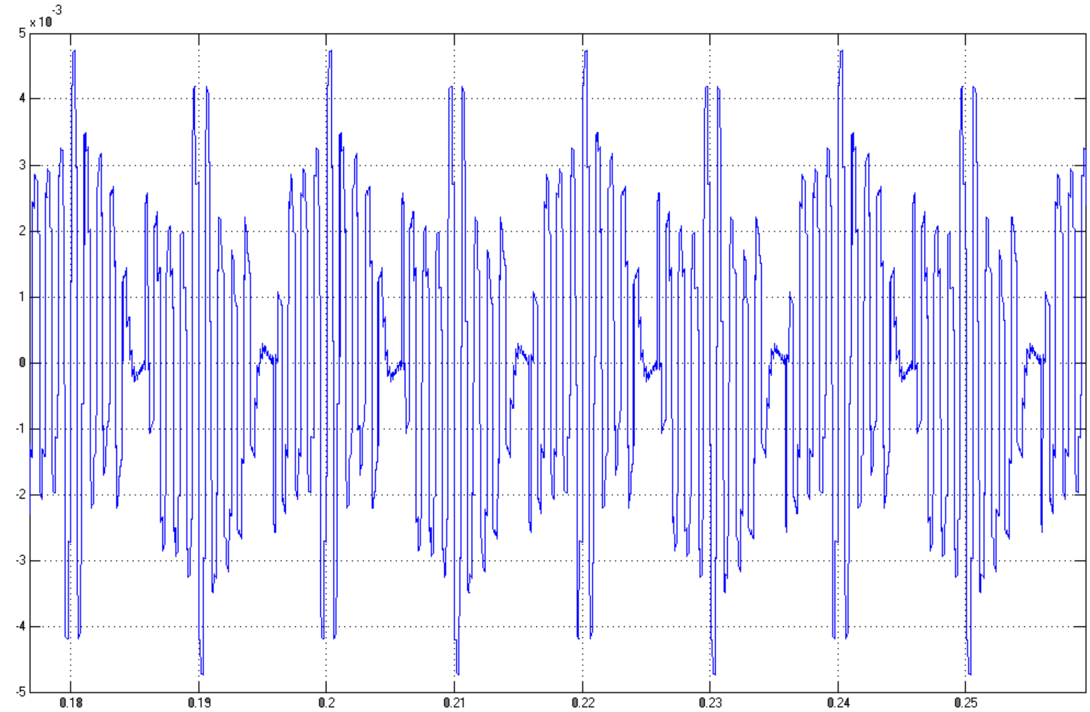

Fig.7. Weights appraisal for seventh Harmonics

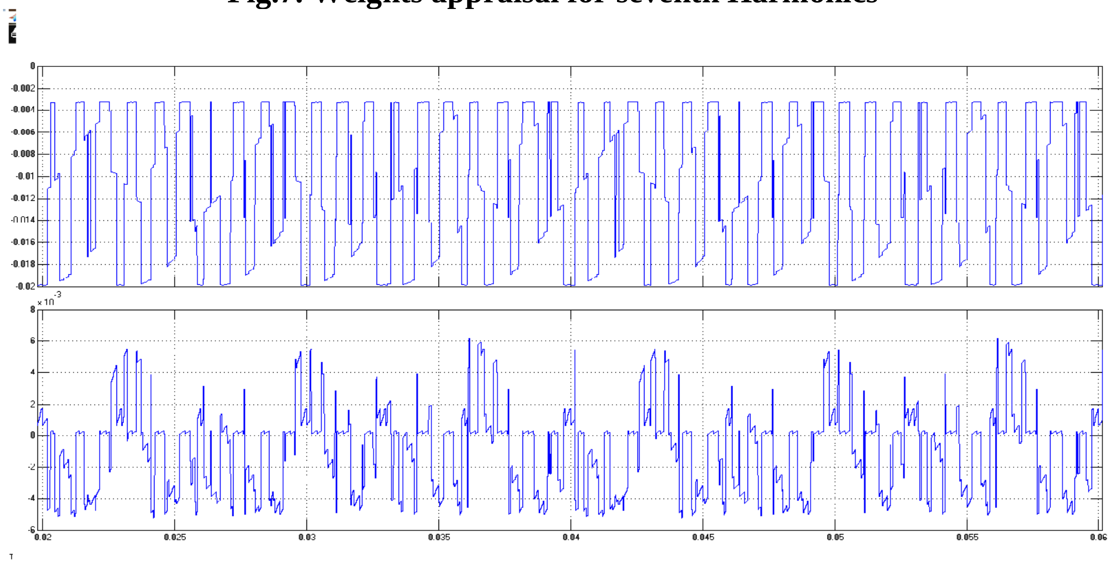

Fig.8. dq-stationary to dq- rotationary transformation

V. Results and Discussion

The current harmonic elimination with the proposed NLMS based algorithm is possible only by active current shaping. The uncompensated open loop line currents are shown in Fig.9. The harmonic spectrum of representative line current is given in Fig.10. The line current with objectionable magnitudes are noticed in addition to the poor THD value.

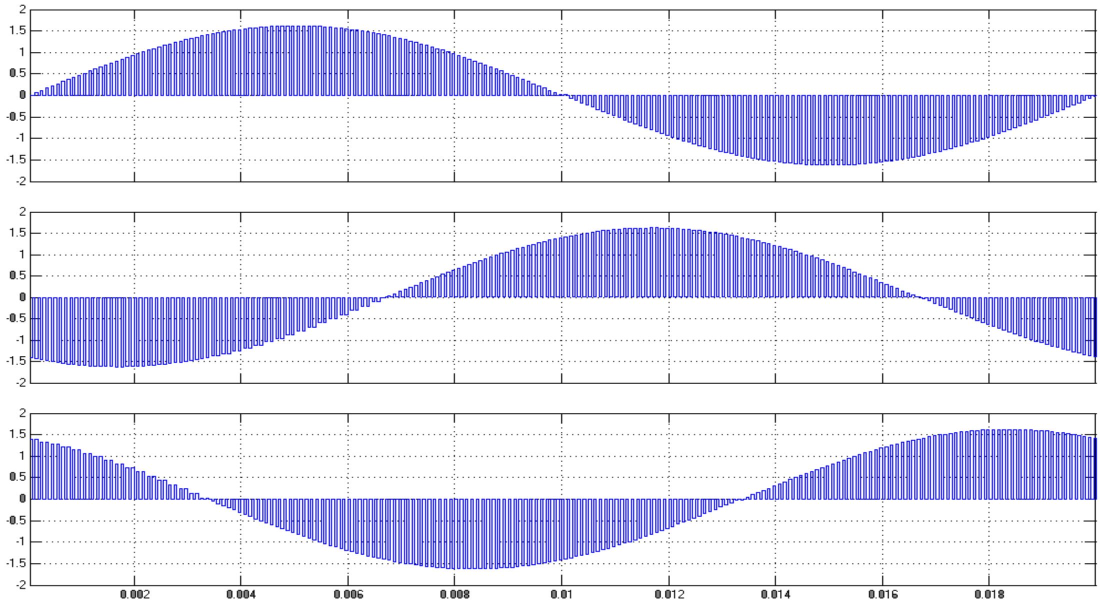

Fig.9. Output Line currents – Open loop

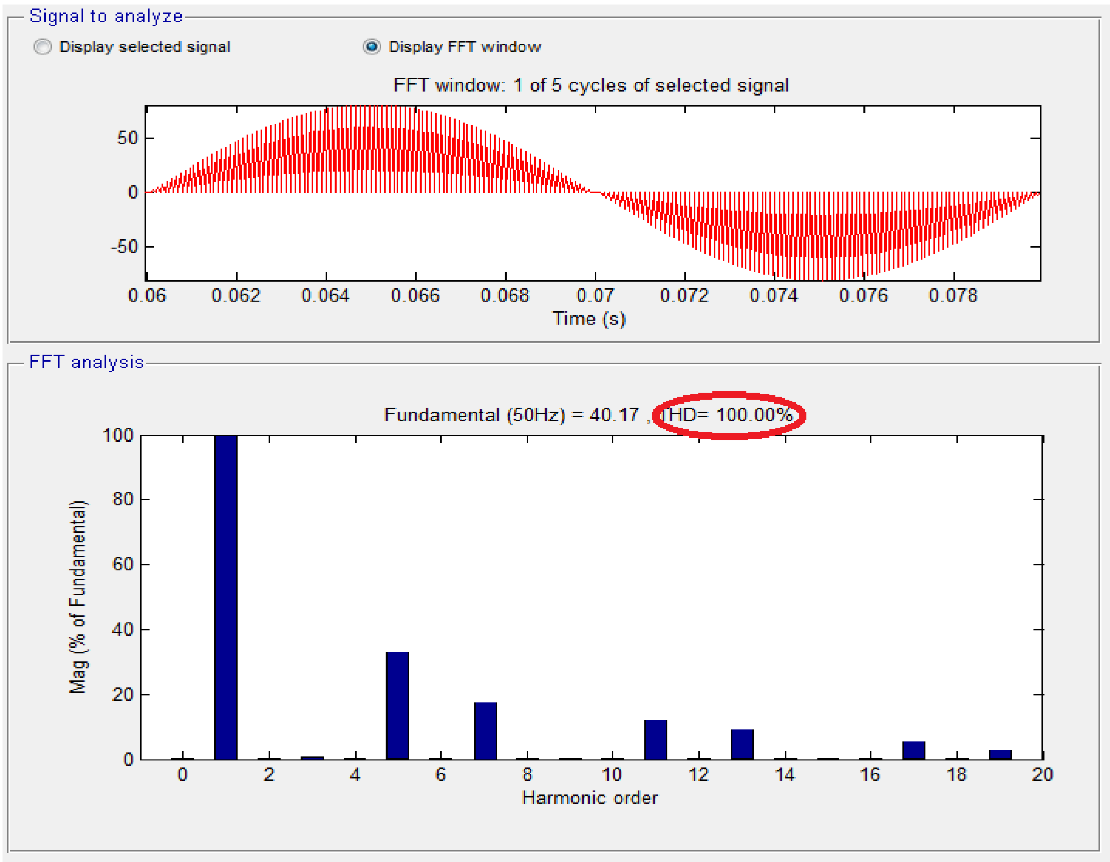

Fig.10. Output Line1 currents and harmonic spectrum– Open loop

The active current shaping ability of the NLMS based filtering algorithm is evidenced from Fig.11. The THD value and the selected harmonics are improved noticeably. The table 2 compare the performance of the proposed algorithm with the LMS based algorithm. Fifth harmonics is reduced 85% further from the LMS while the seventh harmonics is about 88%. There is a marginal improvement in the THD also obtained.

Table 2. Performance comparison of different SCHE filter algorithms

Harmonic Order	NLMS	LMS	Without SCHE
	(% of V_1)		
Fundamental (V_1)	100	100	100
5^{th} harmonics	2.67	18.76	38.87
7^{th} harmonics	1.36	11.98	18.17
THD (%)	61.57	69.26	72.94

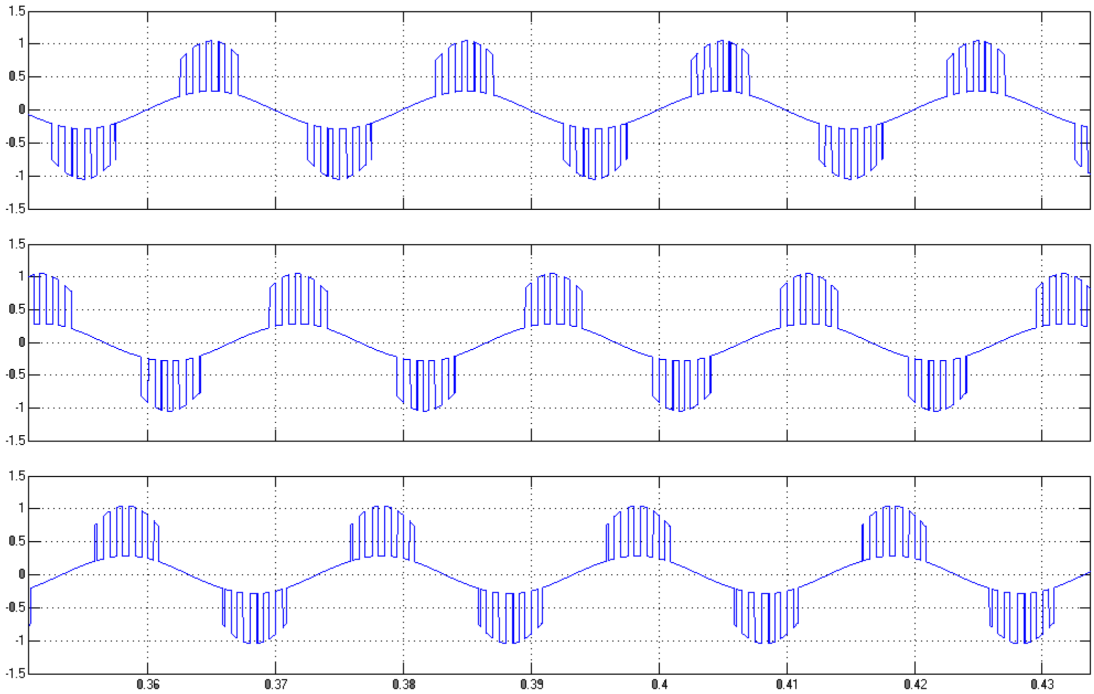

Fig.11. Three phase Line current waveforms with NLMS-SCHE filter

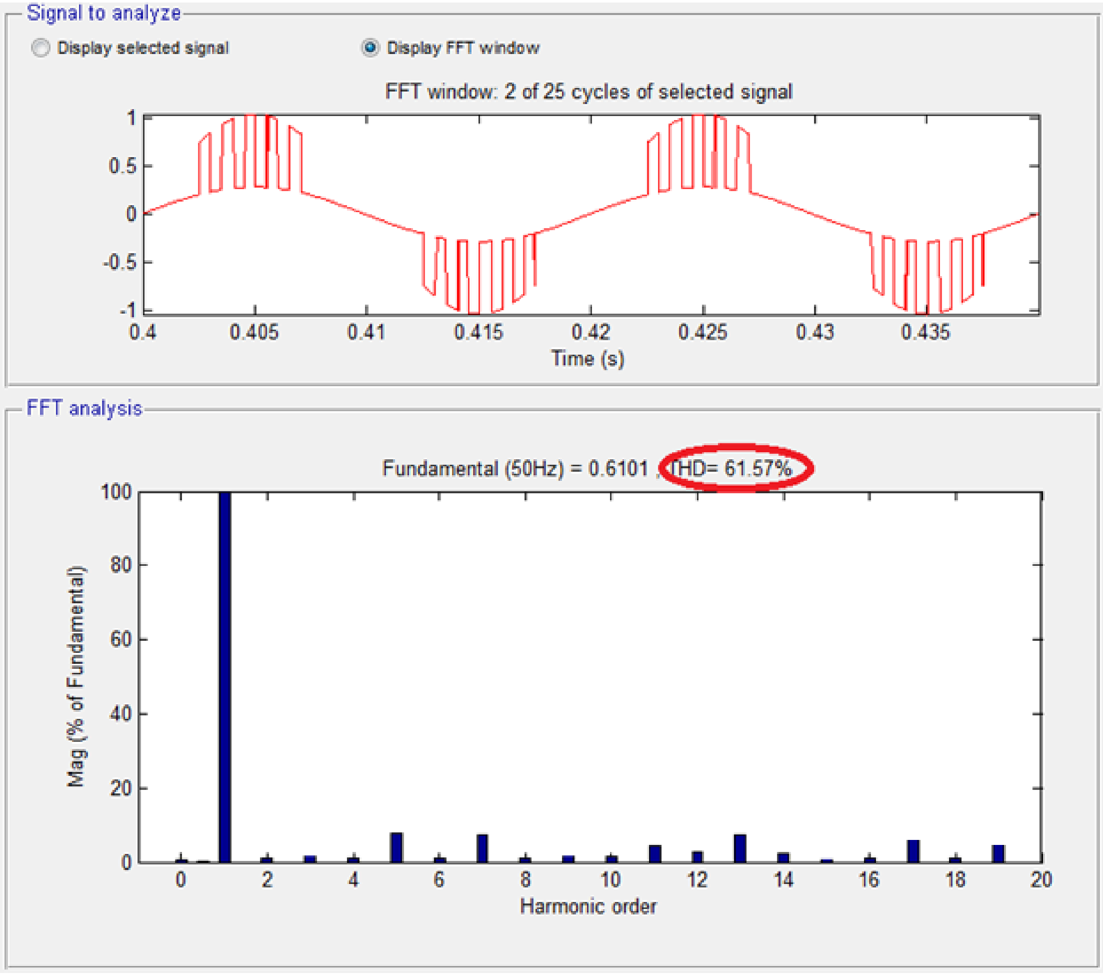

Fig.12. Line current and harmonic spectrum with NLMS-SCHE filter

VI. Conclusion

The presence and influence of line current harmonics in the direct ac voltage conversion is highlighted in this paper. Elimination of objectionable orders of current harmonics can improve the system. The algorithm for adaptive cancelling of selected harmonic components in three phase ac voltage controller is successfully implemented. As the NLMS algorithms function is to eliminate undesirable dominant harmonic components from selected variable it requires only knowledge of the frequency of the component to be eliminated. The methodology can be applied for a wide range of equipment like uninterrupted power systems, regenerative converters, active power filters, etc. The algorithm performances issimulated using MATLAB toolbox.Fifth harmonics is reduced 85% further from the LMS while the seventh harmonics is about 88%. There is a marginal improvement in the THD also obtained.

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