Recursive Least Square Algorithm based Selective Current Harmonic Elimination in PMBLDC Motor Drive

V. M.Varatharaju
Research Scholar,
Department of Electrical and Electronics Engineering,Anna University, Chennai, INDIA, 600 025

B L Mathur
Department of Electrical and Electronics Engineering,
SSN College of Engineering, Kalavakkam, INDIA 603 110

K.Udhayakumar
Assistant Professor,
Department of Electrical and Electronics Engineering,Anna University, Chennai, INDIA, 600 025

ABSTRACT
This paper describes the concept of adaptive current harmonic elimination for the permanent magnet brushless dc (PMBLDC) motor drive. Selective harmonic elimination pulse-width modulation (SHE-PWM) techniques offer a tight control of the harmonic spectrum of a given voltage/current waveform generated by a power electronic converter. In the proposed recursive mean square (RMS) adaptive filtering algorithm, the reference input is adaptively selected and subtracted from the line current. The reference is containing harmonics to be eliminated and correlated in some unknown way with the distorted line current. The weights of adaptive filter are adjusted to totally eliminate the component with undesired frequency. An important feature of RLS algorithm is that it utilizes the information contained in the input data. The simulation results demonstrate the good performance of the proposed algorithm in eliminating selected harmonics in the drive line current.

Keywords: Adaptive Selective Current Harmonic Elimination (ASCHE), Current harmonics, Recursive Least Squares algorithm, BLDC Drive.

1. INTRODUCTION
It is generally accepted that the performance of a voltage source inverter (VSI) with any switching strategy can be related to the harmonic content of its output voltage [1]. While in VSI fed drives application, the anticipation of current harmonics magnitude and their order is less possible. Motor driving variable shaft load will behave like variable impedance and hence the current magnitude and shape (distortion) are dictated by the shaft load. Selective harmonic elimination (SHE) is being used as a prominent solution in a wide range of power electronics applications. Permanent Magnet Brushless Direct Current (PMBLDC) motors are one of the motor types rapidly gaining popularity [2]-[3]. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. These PMBLDC's offer many attractive features in certain aspects, such as high reliability, long life cycle, variable speed control, and high efficiency [4]-[5].

Selective harmonic elimination pulse-width modulation (SHE-PWM) methods remain of great interest for the control of high-power converters [6]. These converters are the key technology behind advanced power electronics applications associated with modern drives and power systems. There have been many approaches to this problem reported in the technical literature including: sequential homotopy-based computation [7], resultants theory [8], optimization search [9], Walsh functions [10], [11] and other optimal methods [12] including genetic algorithms (GAs) [13], [14].

Adaptive-selective harmonic elimination is being used as a prominent solution in a wide range of power electronics applications. The systems like adaptive filtering, multilayer neural networks etc depend largely on training/learning algorithms for their system weight updates. A quasi-Newton based learning rule has been proposed by Beigi and Li [15] in 1993 to reduce the training time. However, time-consuming processing in estimating the inverse Hessian matrix and complex line searching process are the drawbacks. Conjugate gradient type [16],[17] learning algorithms were suggested to conquer the local minimum problem.

This paper presents an adaptive scheme based on recursive least square (RLS) algorithm to eliminate unwanted lower order dominant current harmonic components present in the PMBLDC motor drive. The RLS algorithm has established itself as the "ultimate" adaptive filtering algorithm in the sense that it is the adaptive filter exhibiting the best convergence behavior. Based on in-depth study of adaptive filter, the recursive least squares are applied to harmonic elimination problems by employing the steepest descent method for weight updating. The proposed Adaptive Selective Current Harmonic Cancellation (ASCHC) algorithm for the BLDC motor drive is tested in MATLAB/SIMULINK simulation.

2. BACKGROUNDS ON RECURSIVE MEAN SQUARE ALGORITHM
Adaptive filter has "self-regulation" and "tracking" capacities. From the standpoint of performance, it is widely known [18] that the RLS algorithm offers fast convergence and good error performance. RLS algorithms have wide-spread applications in many areas, such as real-time signal processing, control and communications. Least-squares algorithms aim at the minimization of the sum of the squares of the difference between the desired signal and the model filter output [19]. When new samples of the incoming signals are received at every iteration, the solution for the least-squares problem can be computed in recursive form resulting in the recursive least-squares algorithms. The RLS algorithm is known to pursue fast convergence even when the Eigen value spread of the input signal correlation matrix is large. This algorithm has excellent

performance when working in time- varying environment. All these advantages come with cost of an increased computational complexity and some stability problems [20].

The task of eliminating an undesirable harmonic component from a signal in digital signal processing can be done by the adaptive elimination algorithm or filter. The filter, shown in the following Fig.1 consists of a combiner, a RLS algorithm, and a summing point. The step by step procedure for RLS algorithm is as follows:

Step 1: Start
Step2: Get input reference signal and output reference
Step 3: Calculate error
Step 4: Calculate gradient of the error
Step 5: If gradient is zero then go to step 7 else go to next step.
Step 6: update the weights and go to step 4

Step 7: Stop

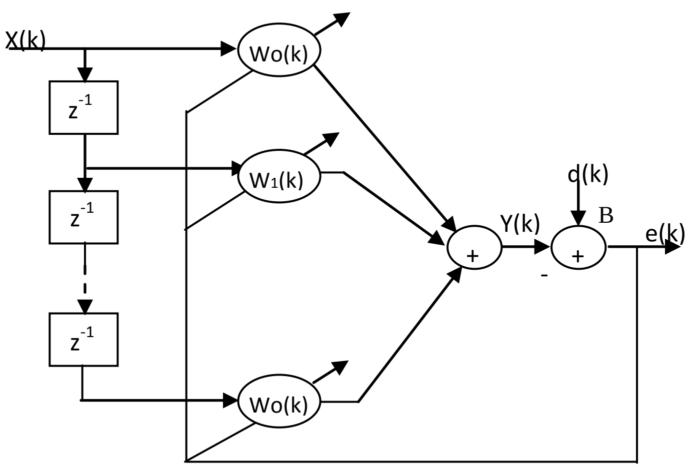

Figure1. Structure of single frequency canceling adaptive filter

The key concept of this algorithm is updating of weights. Gradient-based methods are one of the most widely used error minimization methods used to train back propagation networks. The steepest descent or Gradient decent method is the most widely used class of algorithm for supervised learning of neural networks and has suitability to work with any training algorithm. It is the first order method that minimizes the error function by updating the weights using the steepest descent method.

$$w(t+1) = w(t) - \eta \Delta E(w(t)) \text{ w (t+1)} \qquad (1)$$

'E' is the batch error measure; 'ΔE' is the gradient vector '. The parameter η is the heuristic called convergence rate. The optimal value of η depends on the shape of the error function. The gradient descent algorithm can train any system as long as its weight, net input, and transfer functions have derivative functions. Minimum of a function is found by following the slope of the function as shown in Fig.2.

(i) Start with a point (guess)

(ii) Repeat

(iii) Determine a descent direction

(iv) Choose a step

(v) Update

(vi) Until stopping criterion is satisfied

The RLS algorithm can be incorporated with regular plant control as shown in the Fig.3. The output from the RLS block is given to the inverse transfer function of the inverter (plant), which is given to the combiner to compare with regular plant controller output. The combiner output is given to the plant transfer function, which will be given to the load. It is a closed loop, so the iterations of RLS algorithm will stop only if the estimation of the mean square error is minimum.

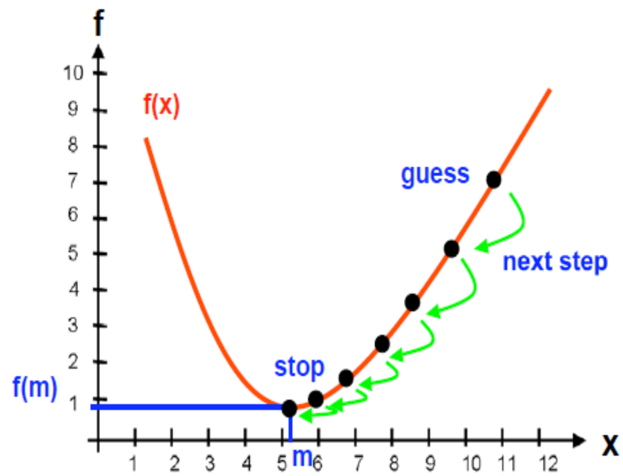

Figure2. Gradient descent algorithm

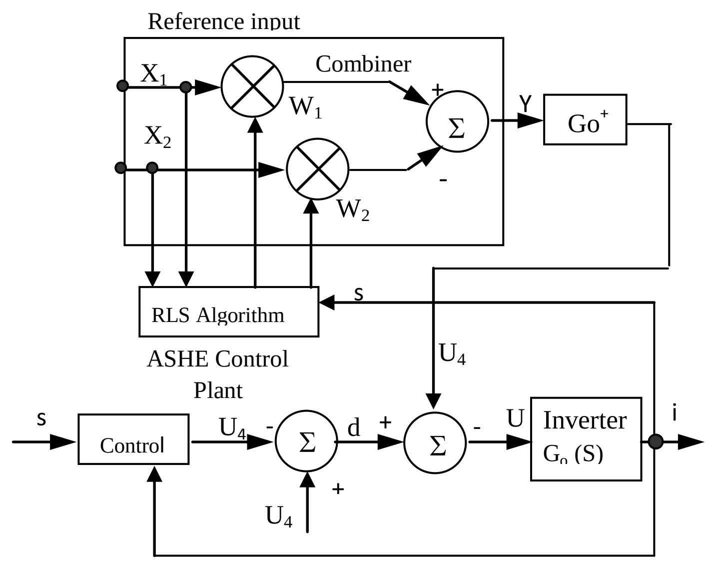

Figure 3 Implementation of RLS algorithm

3. RLS ALGORITHM FOR SHE PROBLEM

Selective elimination of multiple harmonics is illustrated in the below Fig.4.The fifth and seventh harmonics are eliminated from the output variable of the plant current i. 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).

Using the block 1, the first harmonic (fundamental component) is taken out of the primary input although not necessary, considerably reduces noise in gradient estimation in blocks 5 and 7 (for elimination of fifth and seventh harmonics) and makes adaptation process faster. The output of the block 1, with filtered out the fundamental and with fifth and seventh harmonic components still present is introduced to the error inputs of the blocks 5 and 7. The primary input $D_k=U_c+U_{dis}$, where, U_c is the control input and U_{dis} is the undesirable harmonic component of the plant output as shown in Fig.4. Block diagram for Elimination of fifth and seventh harmonics from controlled plant output by multiple frequencies-adaptive selective harmonic elimination block (MF-ASHE).

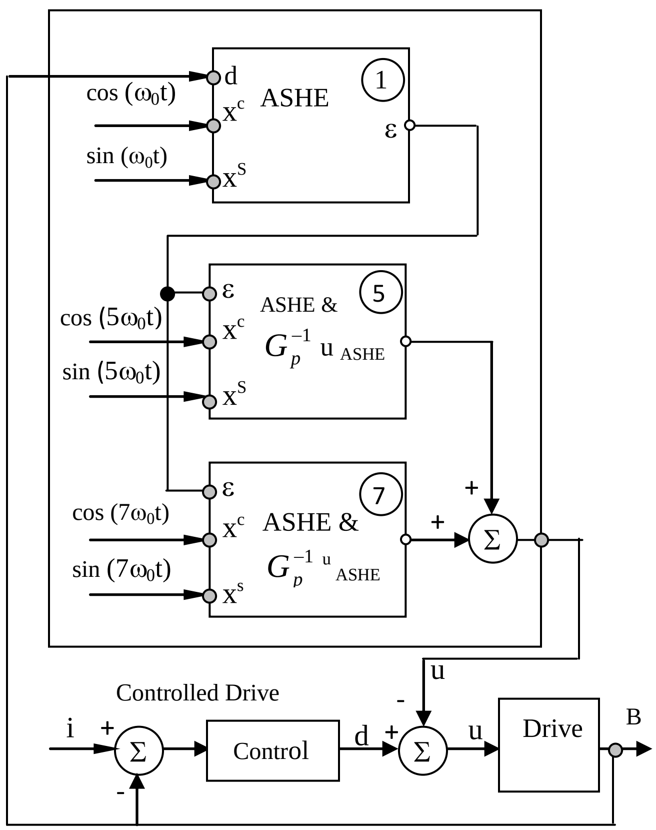

Figure4. Selective elimination of multiple harmonics

The complete system of ASHE for eliminating the current harmonics in PMBLDC drive is shown in Fig.5. As shown in the figure the system uses proportional-integral (PI) controller for voltage control and two PI regulators in synchronous reference frame for current control (Iq1 and Id1). Reference angle for generation of sine and cosine functions, frequency of fundamental component, fifth harmonics and seventh harmonics are done by a phase look 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. The 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 q.d/a,b,c) and then into synchronous frame Iq, Id (block s/e).

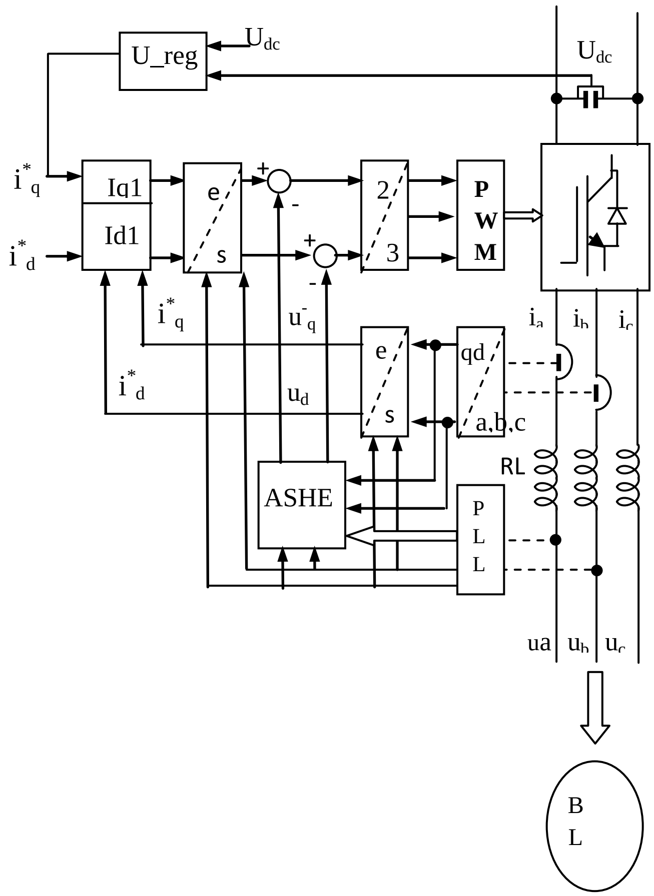

Figure5. RMS algorithm based ASHE for PMBLDC motor drive

The conventional part of control works as follows: voltage regulator U_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 fed into pulse width modulation (PWM) control the inverter. The components contributed to PWM from ASHE blocks will create voltage at the output of the inverter (drive) with a pattern as needed to cancel harmonic components from the drive line currents.

4. RESULT AND DISCUSSIONS

The proposed Gradient decent weight updated RLS algorithm based adaptive selective current harmonic elimination (ASCHE) is simulated MATLAB/SIMULINK software. The conventional PMBLDC drive, the voltage source inverter with six switches is simulated without and with ASCHE algorithm. The carrier frequency is 10 KHz and the sampling rate is 5KHz. Figures 5-8 show the relevant transformations. Fig.5 illustrates the three-phase line currents into two phase q,d stationary reference frame while Fig.6 presents respective equivalent in two phase synchronously rotating reference frame. Fig.7 shows the current converted into two phase q,d stationary reference frame after the regular (PI) control action while Fig.8 shows its corresponding three phase (a,b,c) system. Fig.9 indicates the output of ASCHE block.

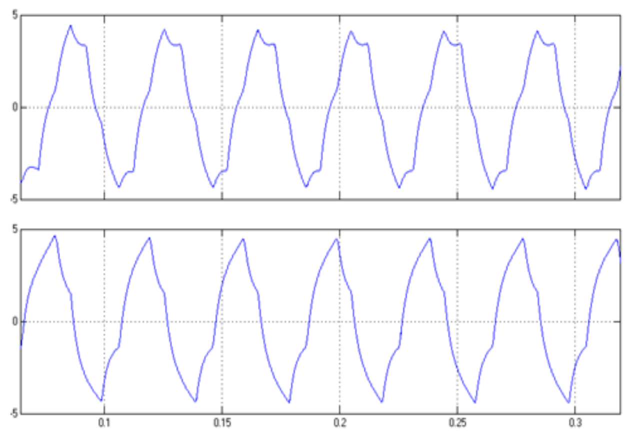

Figure6. abc to dq- stationary transformation

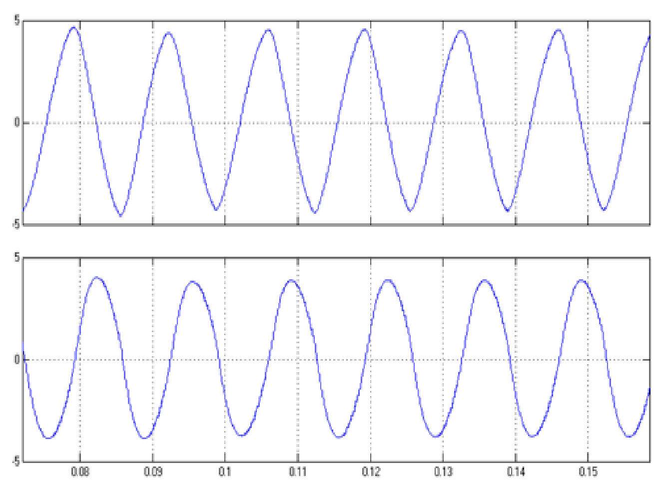

Figure7. dq- stationary to dq- rotationary transformation

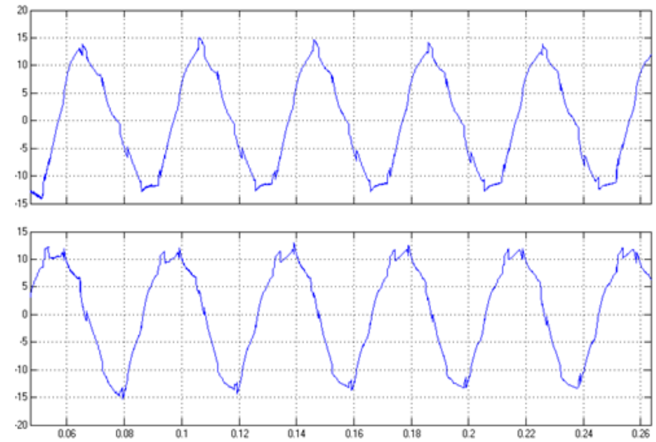

Figure8. dq- rotationary to dq- stationary transformation

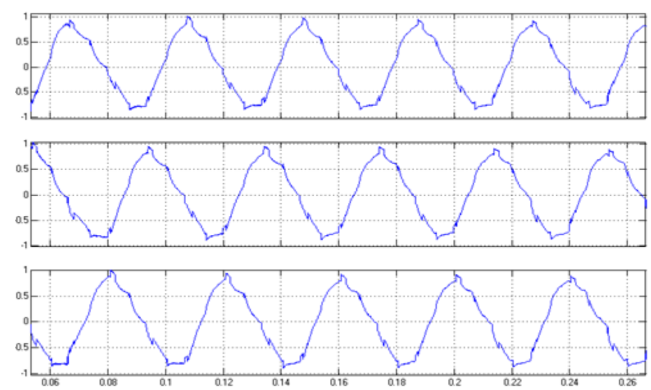

Figure9. dq Stationary to abc transformation

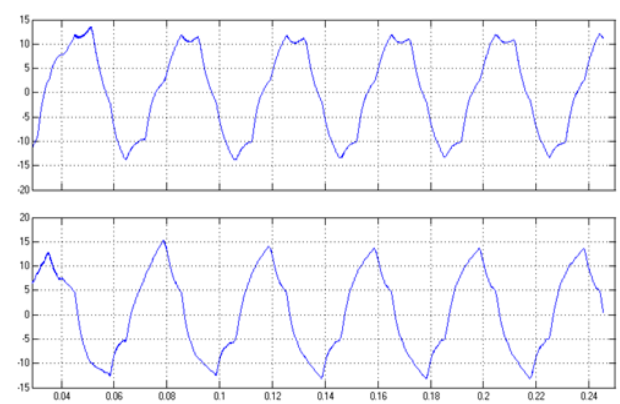

Figure10. Output of ASCHC block

The performance of the system without ASCHE algorithm is shown in Fig.10. Fig.11 shows the triumph of the ASCHE based on RMS algorithm in shaping the current. The improved wave forms of line currents and harmonic spectrum after application of ASCHE are evidenced from the figure. Table 1 compares the lower order current harmonics and total harmonic distortion (THD). It is evident that almost all the harmonic components and the THD are less in ASCHE filtering. The variations of weights are shown in Fig.12, Fig.13 and Fig.14 for fundamental, fifth harmonic and seventh harmonics respectively.

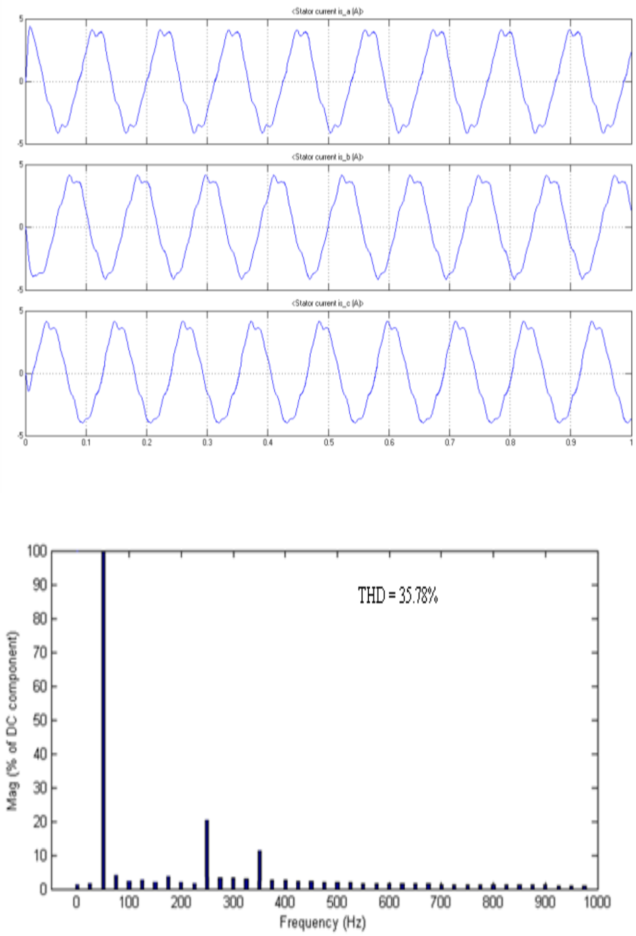

Figure11. Current and harmonic spectrum without ASCHE

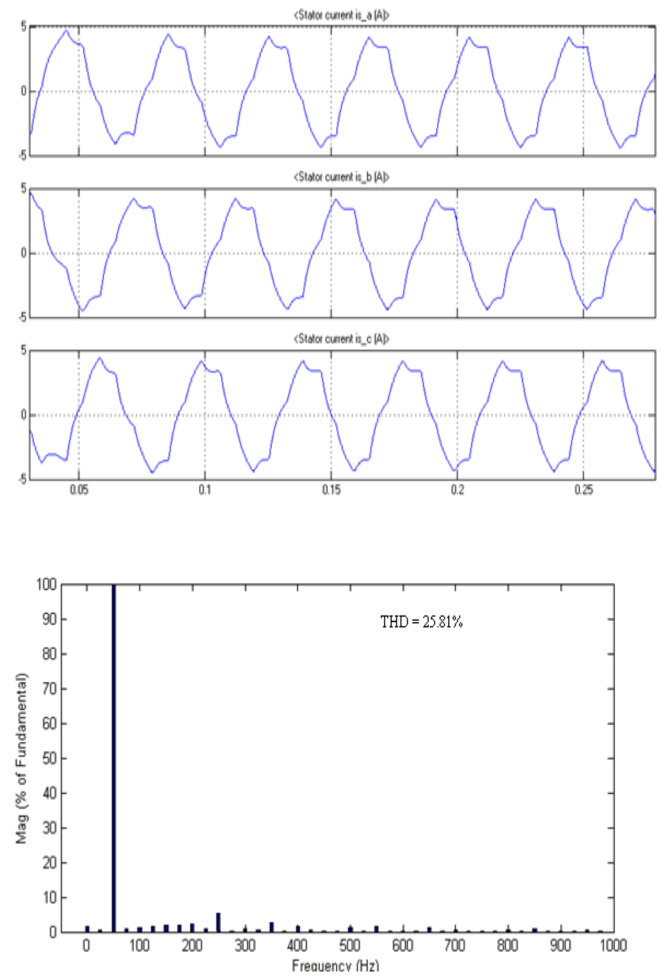

Figure12. Current and harmonic spectrum with ASCHC

TABLE I

COMPARISON OF HARMONICS WITHOUT ASCHE AND WITH ASCHE

Method	I_1 (% of I_1)	I_5 (% of I_1)	I_7 (% of I_1)	THD (%)
Without ASCHE	100	22.10	14.50	35.78
With ASCHE	100	5.20	2.60	25.81

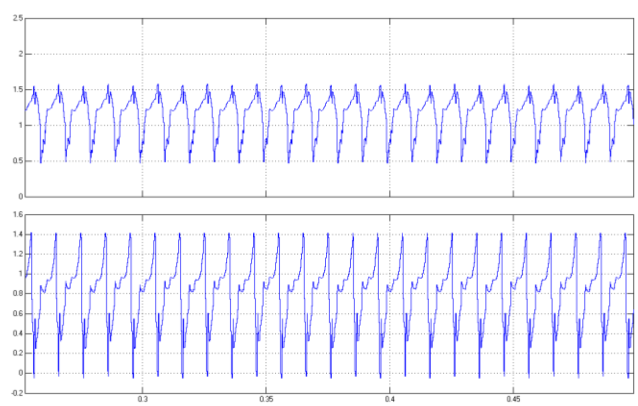

Figure13. Weights for fundamental Component

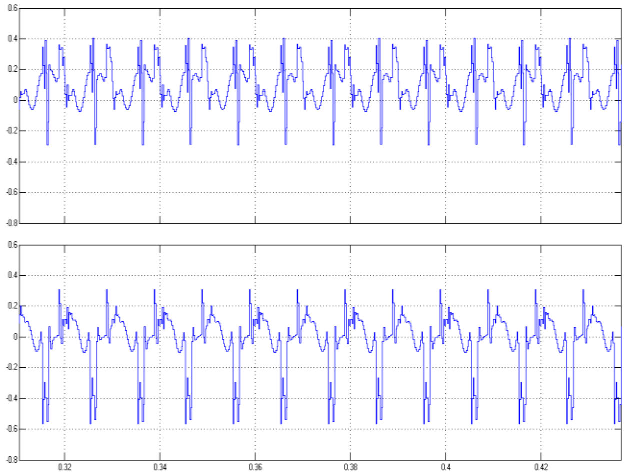

Figure14. Weights for fifth harmonics

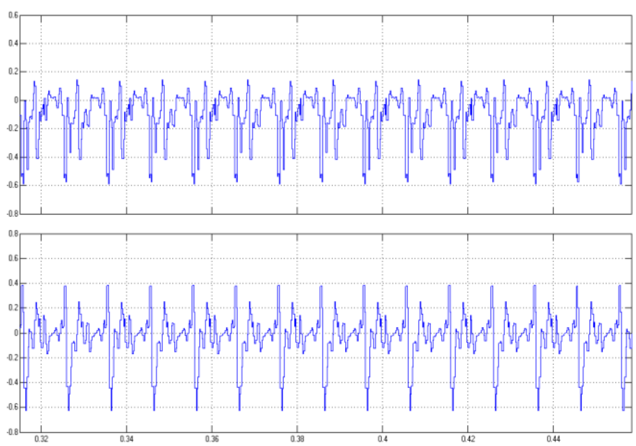

Figure15. Weights for seventh harmonics

5. CONCLUSION

Due to switched mode operation and fluctuating shaft loads, the line current of BLDC motor contains harmonics component and this causes torque ripple and high electromagnetic interference problems. An adaptive current harmonic elimination technique for BLDC motor drive is presented in this paper. The proposed adaptive digital signal processing filtering algorithm for selective current harmonic elimination features unconstrained harmonic elimination 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. Adaptive noise cancelling is a method of adaptive filtering that can be applied whenever a suitable 'reference input is available. The principal advantages of the method are its adaptive capability, its low output noise, and its low signal distortion. The adaptive capability allows the processing of inputs whose properties are unknown.

6. REFERENCES

[1] Johan Hamman and Frederik S. Van Der Merwe, "Voltage Harmonics Generated by Voltage-Fed Inverters Using PWM Natural Sampling", *IEEE Transactions on Power Electronics*, vol.3, no.1, pp. 297-302, July 1988.

[2] T.J.E.Miller, Brushless Permanent Magnet and Reluctance Motor Drives (Oxford Science Publication, UK, 1989).

[3] P. Pillay and P. Freere, Literature survey of permanent magnet ac motors and drives", *Proc. IEEE IAS Rec.*, 1989, pp. 74–84.

[4] Bhim Singh and Sanjeev Singh, State of the Art on Permanent Magnet Brushless DC Motor Drives", *Journal of Power Electronics*, vol. 9, no.1, January 2009, pp.1-17.

[5] R.Krishnan and A.J. Beutler, "Performance and design of an axial field permanent magnet synchronous motor servo drive", *Proceedings of IEEE IAS Annual Meeting*, 1985, pp.634-640.

[6] L. Xu and V.G. Agelidis, "VSC transmission system using flying capacitor multilevel converters and hybrid PWM control," *IEEE Trans. on Power Delivery*, Vol. 22, No. 1, pp. 693-702, Jan. 2007.

[7] T. Kato, "Sequential homotopy-based computation of multiple solutions for selected harmonic elimination in PWM inverters," *IEEE Trans. Circuits Systems I*, vol. 46, no. 5, pp. 586–593, May 1999.

[8] J. Chiasson, L. M. Tolbert, K. McKenzie, and Z. Du, "A complete solution to the harmonic elimination problem," *IEEE Trans. Power Electron.*, vol. 19, no. 2, pp. 491–499, Mar. 2004.

[9] V. G. Agelidis, A. Balouktsis, and I. Balouktsis, "On applying a minimization technique to the harmonic elimination PWM control: The bipolarwaveform," *IEEE Power Electron. Lett.*, vol. 2, no. 2, pp. 41–44, Jun. 2004.

[10] F. Swift and A. Kamberis, "A new Walsh domain technique of harmonic elimination and voltage control in pulse-width modulated inverters," *IEEE Trans. Power Electron.*, vol. 8, no. 2, pp. 170–185, Apr. 1993.

[11] T. J. Liang, R. M.O'Connell, and R. G. Hoft, "Inverter harmonic reduction usingWalsh function harmonic elimination method," *IEEE Trans. Power Electron.*, vol. 12, no. 6, pp. 971–982, Nov. 1997.

[12] J. R. Wells, B. M. Nee, P. L. Chapman, and P. T. Krein, "Optimal harmonic elimination control," *Proc. IEEE Power Electron. Spec. Conf.*, 2004, pp. 4214–4219.

[13] B. Ozpineci, L. M. Tolbert, and J. N. Chiasson, "Harmonic optimization of multilevel converters using genetic algorithms," *IEEE Power Electron. Lett.*, vol. 3, pp. 92–95, Sep. 2005.

[14] M. S. A. Dahidah and V. G. Agelidis, "A hybrid genetic algorithm for selective harmonic elimination control of a multilevel inverter with non-equal dc sources," *Proc. 6th IEEE Power Electron. Drives Syst. Conf.*, Kuala Lumpur, Malaysia, Nov. 2005, pp. 1205–1210.

[15] Beigei, H.S.M., and Li, C.J.,"Learning Algorithms for Neural Networks Based on Quasi-Newton Method with Self-Scaling," *ASME Transactions on Journal of Dynamic System, Measurement, and Control*, Vol. 115, pp. 38-43, 1993.

[16] Moller, M. S.,"A scaled conjugate gradient algorithm for fast supervised learning" *IEEE Transactions on Neural Networks*, Vol. 6, No. 4, pp.524-534, 1993.

[17] Van der Smgt P. P., "Minimization methods for training feed forward neural network", *IEEE Transactions on Neural Networks*, Vol. 7, No. 1, pp. 1-11, 1994.

[18] S. Haykin, Adaptive Filter Theory, 4th ed. Pearson Education, 2002.

[19] S.Sangeetha, CH.Venkatesh, S.Jeevananthan, "Selective Current Harmonic Elimination in a Current Controlled DC-AC Inverter Drive System using LMS Algorithm**"**, *Proceedings of International conference on Computer Application in Electrical Engineering Recent Advances (CERA-2009)*, paper no.:333, Indian Institute of Technology, ROORKEE, 19^{th} to 21^{st} Feb. 2010.

[20] A.A.Girgis, W.B.Chang and E.B.Makram, A digital recursive measurement scheme for online tracking of harmonics, *IEEE Trans. Power Delivery* ***6*** (July(3)) (1991), pp. 153-1160.