Adaline Based Frequency and Harmonic Estimation

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***Abstract*—This paper combines the LMS algorithm and Adaline network in the estimation of fundamental frequency, harmonic frequency and the amplitude of the harmonic frequency at a faster convergence rate. Power electronic circuits are the main source of harmonics. The estimation of harmonics and their amplitudes in these circuits is very essential for reduction of harmonics. Using SIMULINK an AC-DC Converter and a AC Voltage Controller circuit are designed. The voltage and current signals of these circuits are used for applying the proposed technique. Fixed step size, optimal variable step size and recurrent variable step size algorithms combined with Adaline network are the techniques to be applied for the power electronic circuitry introducing harmonics. The distorted signals are then analyzed for the calculation of the magnitudes of the harmonics amplitude and the fundamental frequency traction by the above three algorithms. For the sake of comparison the magnitudes are estimated by the Fast Fourier Transform technique also. Then the results of the three algorithms with the Adaline network and the results of FFT technique are compared and tabulated.**

***Index Terms*— Adaline network, harmonics, LMS algorithm, power quality.**

I. Introduction

THE power quality has become a major concern in the deregulated environment. With the enormous usage of power electronic equipment and the personal computers the Quality of the power supply has deteriorated. The increasing use of power electronic converters and AC voltage controllers has polluted the power supply to a large extent. The system is getting polluted with the increased use of power electronic devices [1]. There are a variety of techniques to monitor the quality of the power supply. But there is a difficulty in tracking the signals if the signals are distorted. Harmonics monitoring is still, not well developed [2]. Discrete Fourier Transform (DFT) has been a well known method for frequency spectra evaluation [3]. Then Fast Fourier Transform (FFT) techniques are used in frequency spectra evaluation as the FFT algorithms are associated with less computational time. There are some limitations in the DFT approach due to the windowing of the data while processing blocks of data with FFT. Spectral leakage occurs when the time record data used by the FFT algorithm is not an integral number of power frequency cycles [4]. The accuracy is deteriorated with high level of harmonic distortion and noise contamination. The methods of linear least square and Kalman filtering were developed in estimation of the fundamental component. In the paper [5] and [6] neural network is implemented in the estimation of harmonics. With the development of artificial intelligence technique, artificial neural network is used to analyze the power quality [7]. In section II the ADALINE network and its frequency tracking method is analyzed. In this paper in section III, the LMS algorithm is discussed in detail. The three different methods of varying the step size are discussed. In section IV the combination of the three algorithms with the ADALINE network is imposed on the power electronic circuitry namely an AC-DC Voltage converter, AC voltage regulator. The estimation of harmonics and the comparison of the three techniques with the FFT algorithm are discussed in detail. Section V concludes with the comparison results.

II. Adaline Architecture

Adaline was first proposed by Widrow and Hoff [8, 9] from Stanford University. Adaline is an architecture that gets trained with the changing inputs and it has a simple structure.

The input vector to the network is $X_k = [x_{1k}, x_{2k,...,} x_{nk}]$.

The weight vector to the network is $W_k = [w_{1k,} w_{2k,...,} w_{nk}]$.

The output of the network is $y_k = \sum_{i=1}^{n} w_{ik} x_i = W_k X_k^T$ .The error output is given by $e_k = \hat{y}_k - y_k$, where $\hat{y}_k$ is the target output. With reference to the inputs applied the weights of the network get modified. The error between the target output and the real output y_k can be minimized. The output error function of the linear network is defined as

$$E = \frac{1}{2}\sum_{k}[y_k \hat{-} y_k]^2 .$$

The weights and the target output are the deciding factors in minimizing E. The architecture is as in figure 1.

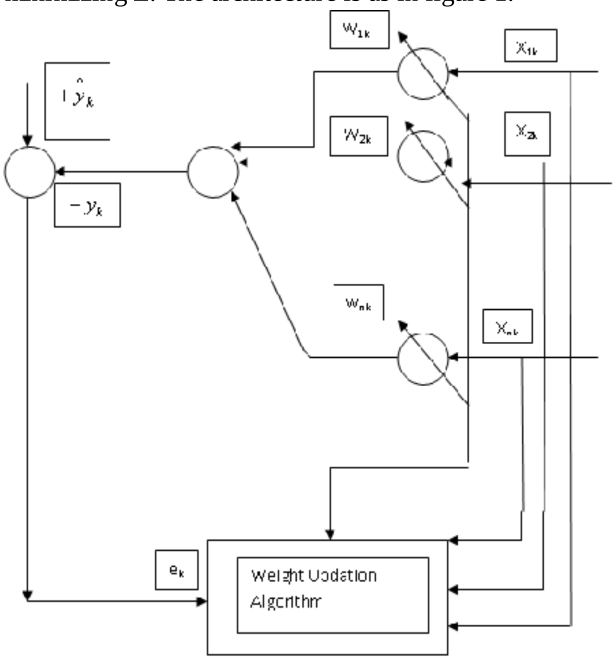

Fig.1. ADALINE Architecture

III. LMS ALGORITHM

In this paper the least squares approach is used in the harmonic estimation. The least square approach method fits the sampled waveform into a harmonic equation. In general the voltage or current waveform with harmonics can be expressed as

$$f(t) = \sum_{k=0}^{n} a_k \sin(2\pi kft) + b_k \cos(2\pi kft)$$

Our aim is to estimate the values of a and b in the range of k varying from 0 to n. The error E is given by

$$E = \sum_{i=0}^{m-1}(f_i - \sum_{k=0}^{n} a_k \sin(2\pi kft) + b_k \cos(2\pi kft))^2$$

m is the measuring samples. The error E could be minimized by optimizing on all variables. For optimizing the error function three elements of ∇E are derived as follows:

$$\frac{\partial E}{\partial a_k} = 2\mu_{a_k}\sum_{i=0}^{m-1}(f_i - \sum_{k=0}^{n} a_k \sin(2\pi kft) + b_k \cos(2\pi kft))\sin(2\pi kft_i)$$

$$\frac{\partial E}{\partial b_k} = 2\mu_{b_k}\sum_{i=0}^{m-1}(f_i - \sum_{k=0}^{n} a_k \sin(2\pi kft) + b_k \cos(2\pi kft))\cos(2\pi kft_i)$$

$$\frac{\partial E}{\partial f} = 4\pi\mu_f \sum_{i=0}^{m-1}(f_i - \sum_{k=0}^{n} a_k \sin(2\pi kft) + b_k \cos(2\pi kft))DF$$

$$DF = t_i \sum_{k=0}^{n} k[-b_k \sin 2\pi kft_i + a_k \cos 2\pi kft_i]$$

The step size parameters are $\mu_{a_k,}\mu_{b_k}, and \mu_f$. These step size parameters are varied by three different algorithms. In the first algorithm the step size parameters are kept a constant. In the algorithm 2, the step size parameters are varied.

In the variable step size algorithm the value of μ is computed using the equation given below.

$$\mu(i) = \alpha\mu(i-1) + \gamma e^2(i)$$

In case of Recursive Variable Step Size LMS algorithm μ is varied by applying the equation given below.

$$\mu(i) = \alpha\mu(i-1) + \gamma p^2(i)$$

$$p(i) = \beta p(i-1) + (1-\beta)e(i)e(i-1)$$

The assumptions made in this paper are with the values of γ and β.

IV. COMPARISON OF THE ALGORITHMS FOR HARMONIC ESTIMATION

The single phase fully controlled AC-DC Converter circuit is simulated using MATLAB. The circuit is shown in figure 2.

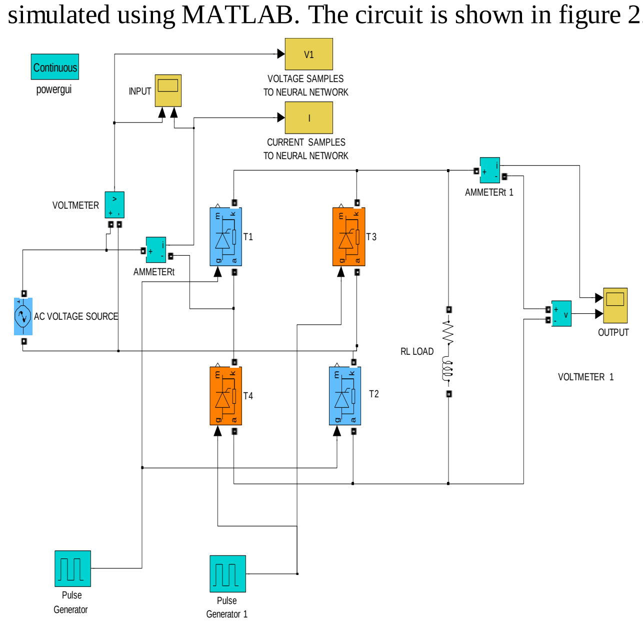

Fig.2. Single phase fully controlled AC-DC Converter

The specifications of the circuit are the input voltage is 220 V, with a load resistance of 50 ohms and inductance 1 mH. The input frequency used in this circuitry is 49 Hz to check the traction of the proposed technique. The input voltage and current is sampled at regular interval and it is given to the Neural network. The neural network estimate the harmonics present in the sampled signal with the help of Least Mean Square algorithm.

The estimated fundamental frequency of the AC-DC converter using various algorithms is as follows. The frequency is 48.9923 Hz using Fixed Step Size algorithm, the frequency is 49.0043 Hz using Variable Step Size algorithm (optimal) and the frequency is 49.0030 Hz using Variable Step Size algorithm (normalized).This frequency variation by the three methods is plotted in figure 3.

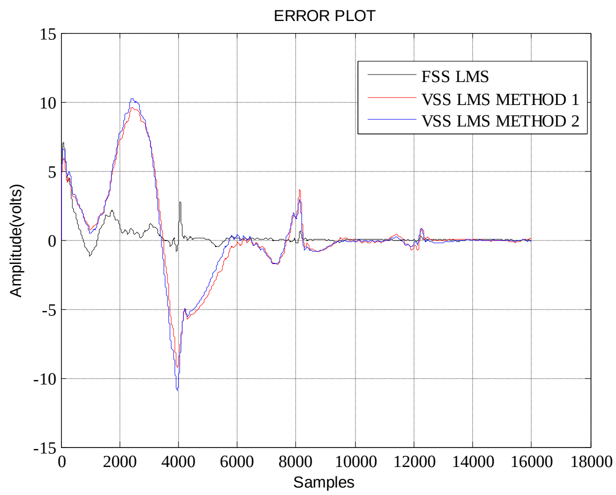

Fig.3. Error in Fundamental frequency tracking using the three algorithms based on ADALINE.

The estimated frequency by the three algorithms is as in figure 4. Since by simulation the input frequency is taken as 49 Hz. the convergence of the three algorithms towards 49 Hz could be seen.

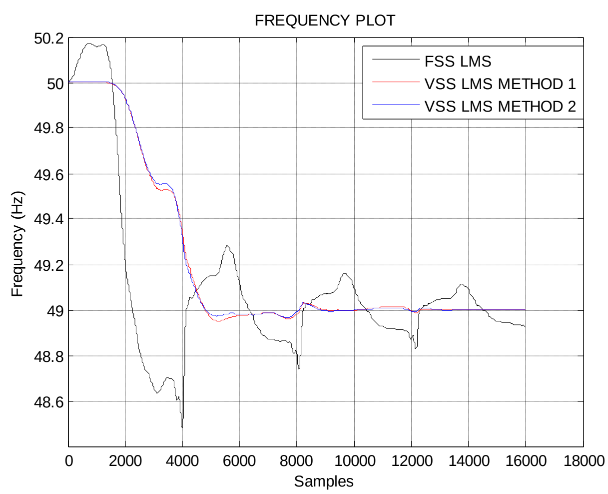

Fig. 4. Frequency tracking of the ADALINE based algorithms.

The amplitude of the voltage harmonics is estimated. The amplitudes of the odd and even harmonics are estimated. Here the various order harmonics and their magnitudes are shown in figure 5 and 6. The other harmonics amplitudes can be estimated in a similar manner. The amplitudes of the fundamental, second, third and fourth harmonic plots are given in figure 5. The amplitudes of the fifth, sixth, seventh and eighth harmonic plots are given in figure 6.

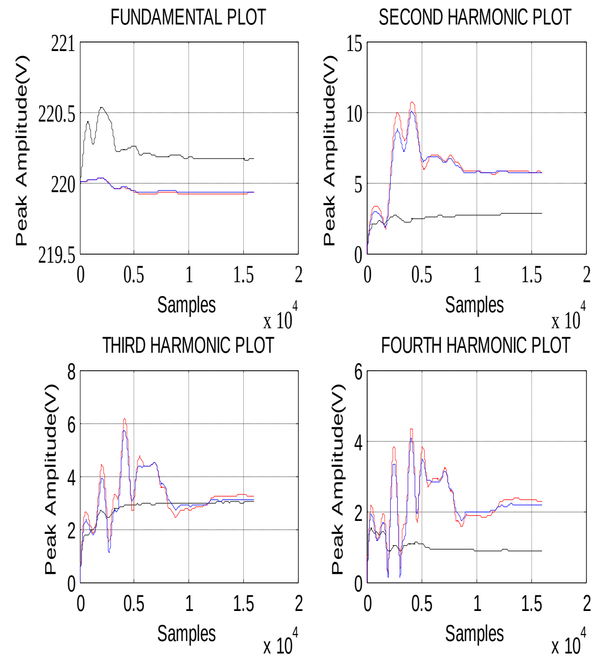

Fig.5. Comparison of Amplitude Traction of the fundamental and harmonics 2-4 by ADALINE based LMS algorithms.

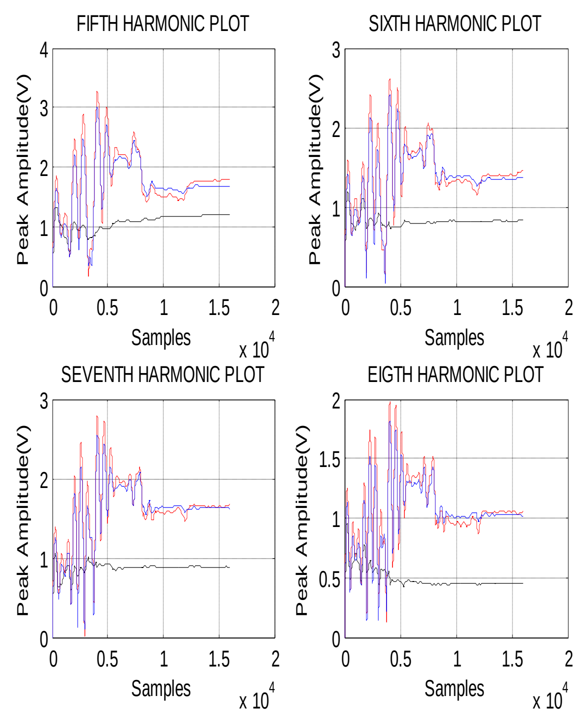

Fig.6. Amplitude plot of the harmonics 5-8 by ADALINE based LMS algorithms.

By the FFT technique the amplitudes of the various components are estimated for comparison with these Adaline based algorithms. The results are tabulated in table I. The harmonic order, the amplitudes of the voltage by FFT technique, the amplitudes of the voltage by Fixed Step Size algorithm and the amplitudes by the variable step size algorithm is given in table I.

Table II gives the application of the three algorithms with reference to the current signal of the AC-DC Converter. The higher order harmonics are given in figures 7-10.

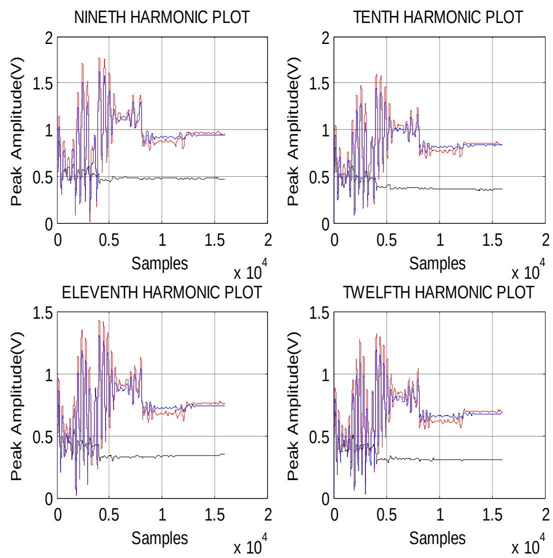

Fig.7. Amplitude plot of the harmonics 9-12 by ADALINE based LMS Techniques.

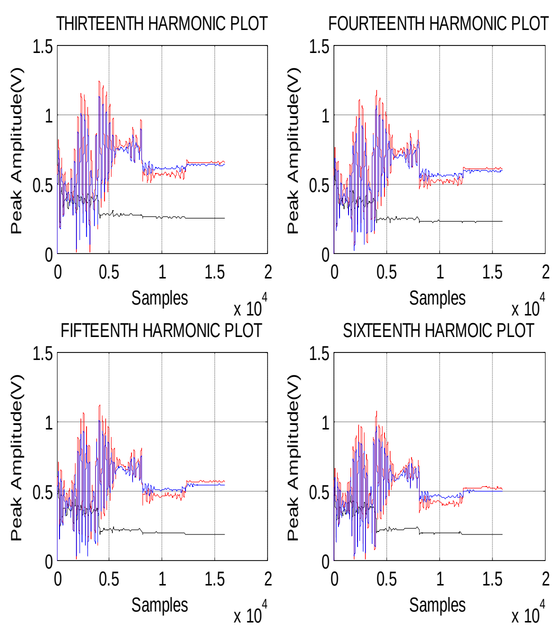

Fig.8. Amplitude plot of the harmonics 12-16 by ADALINE based LMS algorithms.

The harmonics of higher orders could be estimated. For comparison the harmonics till 24th order is calculated. The resultant amplitudes of the voltages at different sampling instants are used for calculation of the peak voltage.

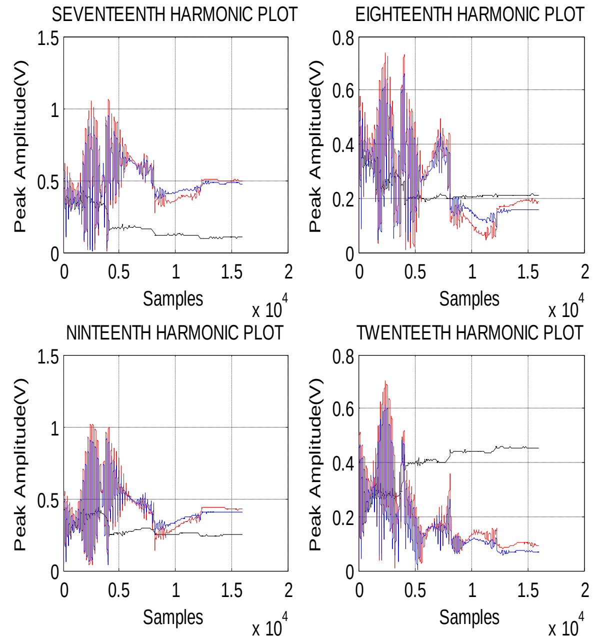

Fig.9. Amplitude plot of the harmonics 17-20 by ADALINE based LMS algorithms.

The harmonics of order from 21-24 are plotted in figure 9. The harmonics of higher orders could be estimated. For comparison the harmonics till 24th order is calculated. The

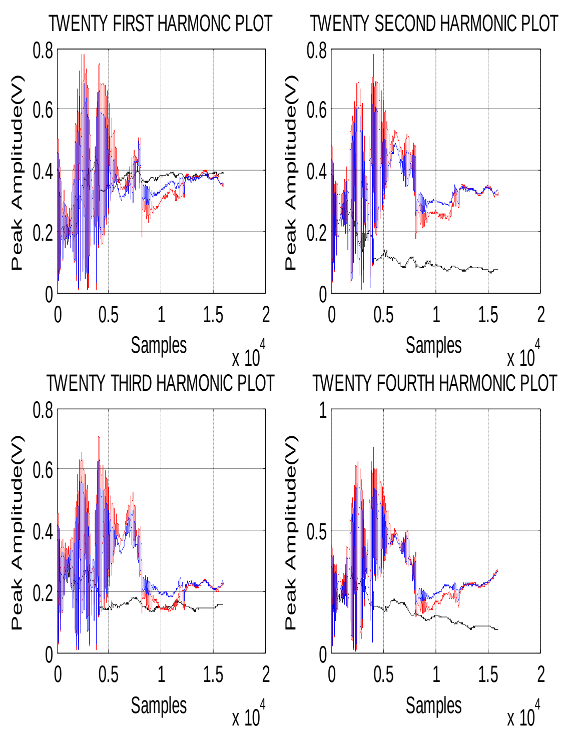

Fig.10. Amplitude plot of the harmonics 21-24 by ADALINE based LMS algorithms.

TABLE I
COMPARISON OF THE THREE ADALINE BASED ALGORITHMS FOR THE VOLTAGE SIGNAL

HARMONIC ORDER	FFT Peak voltage(V)	FSSLMS Peak voltage(V)	VSSLMS METHOD 1 Peak voltage(V)	VSSLMS METHOD 2 Peak voltage(V)
1	222	220.1590	219.9254	219.9351
2	5.72	2.7818	5.7424	5.7445
3	3.234	3.0081	3.2060	3.1046
4	2.31	0.8832	2.2688	2.1679
5	1.804	1.2163	1.7857	1.6734
6	1.469	0.8177	1.4445	1.3558
7	1.676	0.8861	1.6673	1.6117
8	1.100	0.4562	1.0484	1.0122
9	0.999	0.4875	0.9450	0.9273
10	0.880	0.3685	0.8378	0.8278
11	0.792	0.3558	0.7514	0.7435
12	0.726	0.3165	0.6898	0.6827
13	0.682	0.2727	0.6490	0.6397
14	0.638	0.2482	0.6052	0.5936
15	0.594	0.2038	0.5617	0.5455
16	0.550	0.188	0.5112	0.4935
17	0.528	0.0731	0.4933	0.4748
18	0.484	0.1379	0.1810	0.1496
19	0.462	0.1608	0.4198	0.4070
20	0.440	0.2726	0.1219	0.0854
21	0.418	0.365	0.3612	0.3567
22	0.296	0.1517	0.3306	0.3349
23	0.296	0.1345	0.2521	0.2502
24	0.374	0.3509	0.3378	0.3318

TABLE II
COMPARISON OF THE THREE ADALINE BASED ALGORITHMS FOR THE CURRENT SIGNAL

HARMONIC ORDER	FFTPeak current(A)	FSSLMSPeak current(A)	VSS LMS METHOD1 Peak current (A)	VSSLMS METHOD 2 Peak current (A)
1	4.171	4.1875	4.0574	4.0574
2	0	0.0075	0.1134	0.1134
3	0.4909	0.2709	0.4254	0.4257
4	0	0.0028	0.0451	0.0452
5	0.40625	0.2232	0.3734	0.3742
6	0	0	0.0300	0.0300
7	0.3010	0.1655	0.3000	0.3005
8	0	0.0014	0.0225	0.0225
9	0.2022	0.1106	0.2346	0.2182
10	0	0.0022	0.0170	0.0170
11	0.1343	0.0735	0.1444	0.1444
12	0	0.0023	0.0134	0.0134
13	0.1139	0.0619	0.1030	0.1030
14	0	0.0017	0.0124	0.0124
15	0.1143	0.0614	0.1003	0.1004
16	0	0.0013	0.0124	0.0124
17	0.1068	0.0570	0.1044	0.1044
18	0	0.0016	0.0115	0.0115
19	0.0892	0.0476	0.0947	0.0947
20	0	0.0020	0.0096	0.0096
21	0.0730	0.0387	0.0726	0.0727
22	0	0.0018	0.0086	0.0086
23	0.0670	0.0348	0.0508	0.0507
24	0	0.0013	0.0105	0.0105

For the comparison of the algorithm the next circuit used is single phase full wave AC Voltage Controller. The SIMULINK circuit used for the generation of voltage and current signal is as shown in figure 7.

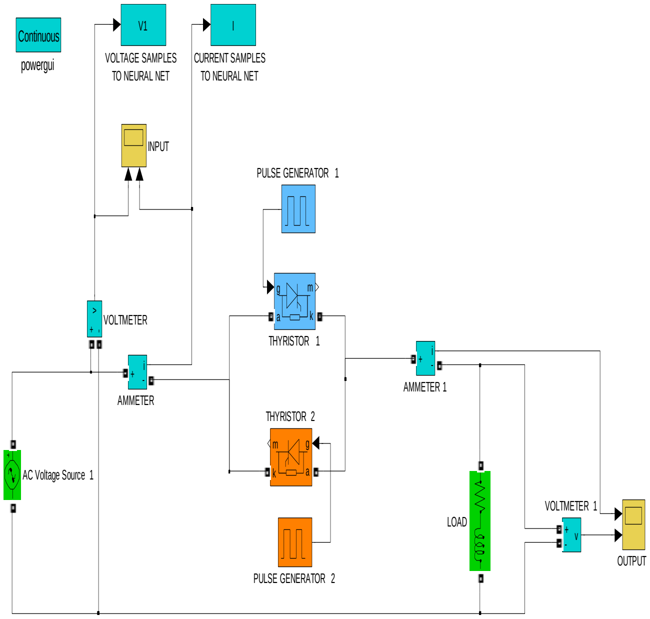

Fig. 11. Single Phase AC Voltage Controller.

The harmonics in voltage is not seen much. The distortions in current signal are used for the comparison of the algorithm. The estimated current waveform is as shown in figure 8. This current signal is used in the ADALINE based algorithm for comparison and the results are tabulated in table III.

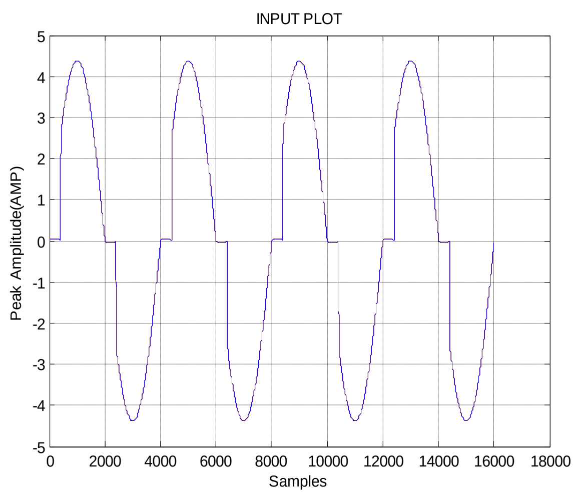

Fig.12. Current Signal of AC Voltage Controller.

TABLE III
COMPARISON OF THE THREE ADALINE BASED ALGORITHMS FOR THE CURRENT SIGNAL

HARMONIC ORDER	FFT Peak Current(A)	FSSLMS Peak Current(A)	VSS LMS METHOD1 1Peakcurrent (A)	VSSLMS METHOD 2 Peak current(A)
1	4.193	4.2035	4.0725	4.0725
2	0	0.0074	0.1137	0.1138
3	0.400	0.2644	0.4136	0.4137
4	0	0.0028	0.0454	0.0453
5	0.3001	0.2192	0.3668	0.3667
6	0	0	0.0301	0.0302
7	0.20	0.1641	0.2980	0.2981
8	0	0.0013	0.0226	0.0226
9	0.135	0.1113	0.2193	0.2193
10	0	0.0021	0.0171	0.0172
11	0.1124	0.0743	0.1465	0.1465
12	0	0.0023	0.0134	0.0134
13	0.1065	0.0612	0.1025	0.1025
14	0	0.0018	0.0124	0.0125
15	0.0909	0.0601	0.0976	0.0977
16	0	0.0013	0.0124	0.0123
17	0.0742	0.0565	0.1029	0.1029
18	0	0.0016	0.0116	0.0117
19	0.0666	0.0481	0.0955	0.0955
20	0	0.0019	0.0097	0.0097
21	4.193	0.0396	0.0747	0.0748
22	0	0.0018	0.0087	0.0087
23	0.400	0.0351	0.0520	0.0519
24	0	0.0013	0.0106	0.0105

V. CONCLUSION

The peak values are estimated using the FFT algorithm, Fixed Step Size algorithm, Variable step size algorithm with two different techniques. From the results it could be concluded that the accuracy of the FFT algorithm is poor. The estimation of harmonics by Adaline based LMS algorithm is good. The accuracy is the best in case Recursive Variable step size algorithm

REFERENCES

[1] T.H. Ortmeyer, K.R. Chakravarthi and A.A. Mahoud, "The effects of power system harmonics on power system equipment and loads," *IEEE Trans. on Power Apparatus and Systems*, Vol. PAS-104,No.9,September 1985, pp.2555-2563.

[2] J.Arillaga,D.A.Bradley and P.S.Bodger, Power System Harmonics, New York: John Wiley & Sons, 1985.

[3] J.T. Broch , Principles of experimental frequency analysis, England: Elsevier Science Publishers Ltd., 1990, ch 4.

[4] A.A. Girgis and F.M.Ham, " A qualitative study of pitfalls in FFT" *IEEE Trans. on Aerospace and Electronic Systems*, Vol. AES 16, No 4, July 1980, pp.434-439.

[5] R.K. Hartana and G.H. Richards, " Harmonic source monitoring and identification using neural networks", IEEE Trans. on Power Systems, Vol. 5, No.4, November, 1990, pp. 1098-1104.M.

[6] S. Osowski, "Neural network for estimation of harmonic components in a power system", IEEE Proceedings, Pt. C, Vol. 139, No. 2, March 1992, pp. 129- 135.

[7] T.K. Abdel-Galil, E.F.El-Saadany, M.M.A. Salama, Power quality event detection using adaline, J.Electr. Power Syst. Res. 64 (2) (2003) 137-144.J.

[8] B.Widrow, M.E. Hoff, Adaptive switching circuits, WESTCON Convention, Record Part IV, 1960, pp. 96-104.

[9] B.Widrow, M.A. Lehr, 30 years of adaptive neural networks: perceptrons, adaline and backpropogation, IEEE Proc. 78 (9) (1990) 1415-1442.