A VLLMS based Harmonic Estimation of Distorted Power System Signals and Hybrid Active Power Filter Design

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***Abstract*—This paper presents a Variable Leaky Least Mean Square (VLLMS) based algorithm for harmonics estimation in distorted power system signals. Further, for mitigation of these harmonics a Hybrid Active Power Filter (HAPF) with modified Pulse Width Modulation (PWM) control technique has been designed. Both simulation and experimental studies are carried out for evaluating the estimation and filtering performances. VLLMS provides improved performance in estimation compared to LMS and Variable Step Size LMS (VSSLMS). Further, HAPF exhibits improved harmonics filtering performance compared to both active and passive power filters.**

I. INTRODUCTION

In recent years with the development of power semiconductor technology, power electronics based devices such as static var compensators, adjustable speed drives and uninterruptible power supplies are widely employed in various applications. Because of their nonlinear V-I characteristics, these devices draw current with harmonic content and reactive power from AC mains. Some work employ passive filters for harmonics elimination. But the passive methods suffer from large size and fixed compensation. Recently some Active Power Filters (APFs) [1-3] have been widely investigated for compensation of harmonics in electric power system. Shunt active power filter operates on the principle of injecting harmonic current into the power system with the same magnitude as the harmonics current generated by a nonlinear load but having 180^0 phase shift [4]. They are capable of controlling the voltage variations and distortions as well as suppression of harmonics. This paper exploits VLLMS approach to estimation of harmonics content of the distorted power system signal due to its superior performance in frequency estimation in [5]. Frequent dynamical changes in a power system motivate one to implement such an algorithm for efficiently estimating power system harmonics. Performances of VLLMS have been compared with only LMS and VSSLMS algorithms. After estimation of harmonics with the proposed algorithm, a modified PWM control technique is applied to HAPF [6] for harmonics compensation in a distorted power signals. The simulated results of this hybrid power filter using modified PWM technique are compared with the active and passive filter. The performance of HAPF is also verified from the experiments conducted on a laboratory prototype setup.

II. VLLMS APPROACH TO HARMONICS ESTIMATION

A distorted power system signal may be represented as

$$y(t)=\sum_{n=1}^{N}A_n\sin(\omega_n t+\phi_n)+A_{dc}\exp(-\alpha_{dc}t)+\varepsilon(t) \quad (1)$$

where N: number of harmonics; $\omega_n = n2\pi f_0$; f_0:fundamental frequency; $\varepsilon(t)$:additive noise; $A_{dc}\exp(-\alpha_{dc}t)$: dc offset decaying term. Dscretizing (1) gives

$$y(k)=\sum_{n=1}^{N}A_n\sin(\omega_n kT+\phi_n)+A_{dc}\exp(-\alpha_{dc}kT)+\varepsilon(k) \quad (2)$$

T denotes sampling time. Invoking Taylor series expansion of the dc decaying term, $A_{dc}\exp(-\alpha_{dc}t)$ and retaining only first two terms of the series yields $y(k)$ as

$$y(k)=\sum_{n=1}^{N}A_n\sin(\omega_n kT+\phi_n)+A_{dc}-A_{dc}\alpha_{dc}kT+\varepsilon(k) \quad (3)$$

For estimation amplitudes and phases (3) can be rewritten as

$$y(k)=\sum_{n=1}^{N}[A_n\sin(\omega_n kT)\cos\varphi_n+A_n\cos(\omega_n kT)\sin\varphi_n] +A_{dc}-A_{dc}\alpha_{dc}kT+\varepsilon(k) \quad (4)$$

Eq. (4) can be rewritten in parametric form as $y(k) = H(k)X$

$$H(k) = \begin{bmatrix} \sin(\omega_1 kT) & \cos(\omega_1 kT) & \dots & \sin(\omega_N kT) \\ & \cos(\omega_N kT) & 1 & -kT \end{bmatrix}^T \quad (5)$$

The vector of unknown parameters

$$X = \begin{bmatrix} A_1\cos(\varphi_1) & A_1\sin(\varphi_1) & \dots & A_n\cos(\varphi_n) \\ & A_n\sin(\varphi_n) & A_{dc} & A_{dc}\alpha_{dc} \end{bmatrix}^T \quad (6)$$

The VLLMS algorithm [5] is applied to estimate X. The proposed VLLMS harmonics estimation algorithm minimizes the square of the error recursively by altering the unknown parameter X_k at each sampling instant using (7) as

$$X_{k+1} = (1 - 2\mu_k \gamma_k) X_k + 2\mu_k e_k \hat{y}_k \quad (7)$$

$$e_k = y_k - \hat{y}_k$$

(Step size μ_k is varied for better convergence of the VLLMS algorithm in the presence of noise.

$$\mu_{k+1} = \lambda\mu_k + \gamma R_k^2 \quad (8)$$

where R_k represents the autocorrelation of e_k and e_{k-1}. It is computed as

$$R_k = \rho R_{k-1} + (1-\rho) e_k e_{k-1} \quad (9)$$

where ρ :an exponential weighting parameter ; $0 < \rho < 1$, $\lambda (0 < \lambda < 1)$; $\gamma > 0$ control the convergence time. The variable leakage factor γ_k [6] can be adjusted as

$$\gamma_{k+1} = \gamma_k - 2\mu_k \rho e_k \hat{y}_k X_{k-1} \quad (10)$$

After the updating X using VLLMS algorithm, amplitudes, phases of the fundamental and n[th] harmonic parameters can be derived as

$$A_n = \sqrt{\left(X_{2N}^2 + X_{2N-1}^2\right)}$$

$$\phi_n = \tan^{-1}\left(\frac{X_{2N}}{X_{2N-1}}\right)$$

III. PROPOSED HAPF FOR HARMONICS ELIMINATION

After estimation of the different harmonic component of the signal using VLLMS algorithm, next aim of the paper is to eliminate the harmonic content of the signal. The current of a non-linear load is given by

$$i_L(\theta_s) = \sum_{k=1}^{\infty} I_{Lk}\sin(k\theta_s - \varphi_k) = I_{L1}\sin(\theta_s - \varphi_1) + \sum_{k=2}^{\infty} I_{Lk}\sin(k\theta_s - \varphi_k) \quad (11)$$

The fundamental current $i_{Lf} = I_{L1}\sin(\theta_s - \phi_1)$ is divided into two currents: fundamental active current, $i_{Lfa} = I_{L1}\cos\phi_1 \sin\theta_s$ and fundamental reactive current, $i_{Lfr} = I_{L1}\sin\phi_1\cos\theta_s$. The objective of the work is to eliminate harmonics

$$i_{Lk} = \sum_{k=2}^{\infty} I_{Lk}\sin(k\theta_s - \phi_k).$$

Therefore, the reference current of the active filter i_s^* is equal to fundamental active current i_{Lfa} i.e.

$$i_s^* = i_{Lfa} = i_L - (i_{Lk} + i_{Lfr})$$

For simplifying the filtering of the load current, i_{Lk}, fundamental component is transformed into DC component by multiplying both sides of (11) by $\sin\theta_s$.

Above expression shows the presence of DC component and the AC components. So a low pass filter with a low cut-off frequency is used to prevent the high frequency component entering the output. The filtered output current is given by $(i_L \sin\theta_s)_{filtered} = \frac{I_{L1}}{2}\cos\varphi_1$.

The error between the reference value V_{dc}^* and the sensed feedback value V_{dc} is passed through a PI controller giving a signal which is added to $2i_{Lf}$, that gives peak value of the reference current. For reconstituting the fundamental active current, peak value is multiplied by $\sin\theta_s$. The current reference i_s^*, obtained from the control algorithm is compared with the sensed signal i_s. The error obtained is fed to a current controller with limiter at its output. The signal obtained from the controller and its opposite is compared with a high frequency triangular wave, generating the gating signal . Accordingly, the corresponding IGBT's will be made on or off number of times over the cycle. Hence the output current of the PWM inverter can be controlled by means of proposed control strategies which will be useful for elimination of source harmonics present due to the non-linear load. The block diagram of proposed indirect current control algorithm and principle of generation of gating signal of APF is discussed in Fig.1.

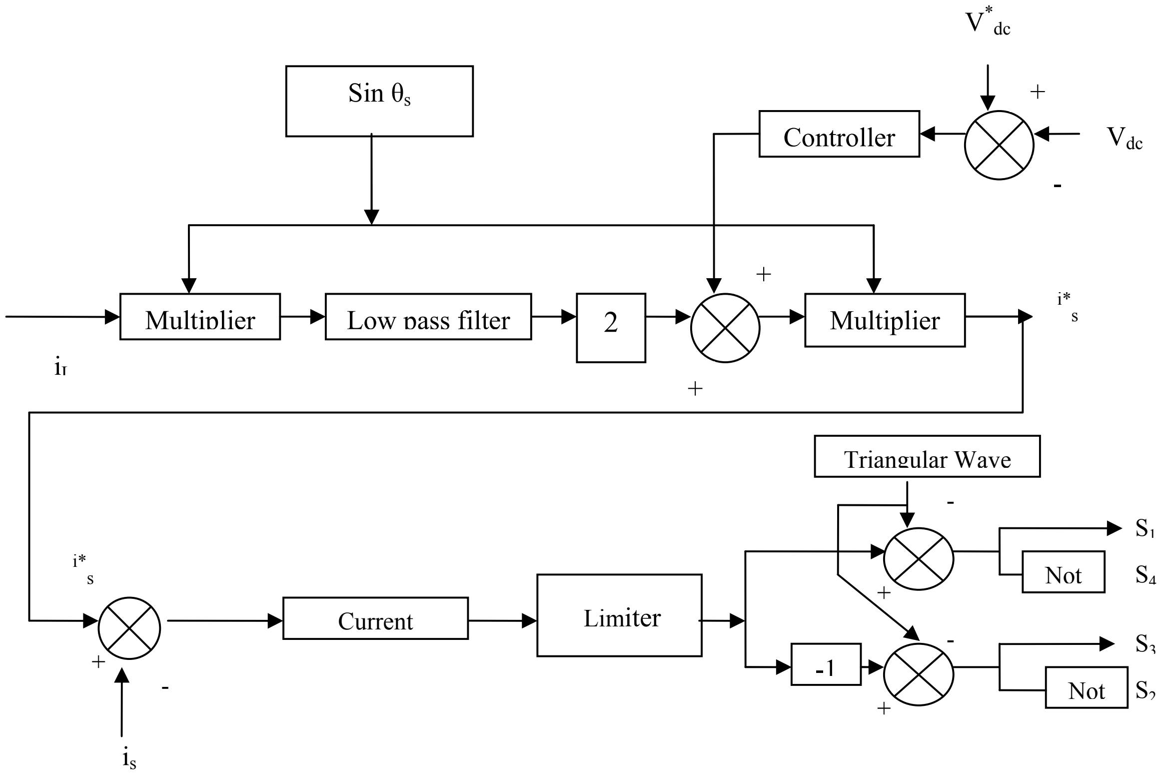

Fig. 1 Proposed indirect current control algorithm and principle of generation of gating signal of active power filter system

IV. Simulation Results

In order to validate the accuracy of the Shunt Hybrid Power Filter with the proposed control algorithm, the system described [6] has been modeled and simulated using MATLAB/SIMULINK. Comparison of performances of estimation for HAPF using LMS, VSSLMS and VLLMS methods are shown in Fig.2 from where it is found that VLLMS provides improved results compared to LMS and VSSLMS for harmonic estimation. The important feature of VLLMS algorithm is that not allowing the weight parameters to drift beyond limit is the reason of its superior performance. The load current i_L, shunt passive filter current i_c, supply current i_s and supply voltage v_s are shown in Fig. 3. The harmonic spectrum of the source current without using filter and with using different types of filters is shown in Fig.4. The THD from 19.46% before compensation is reduced to 8.75% in case of Passive filter, 4.67% in case of Active filter and 1.82% in case of HAPF after compensation. So HAPF provides a good quality of compensation as compared to other two filters such as Passive and Active filters.

This proposed technique in HAPF easily extracts the source current reference from distorted waveform of load current. This method eliminates switching spikes in the main current and easily determines the proportional gain K_p, which is the possible reason of achieving improved performance of HAPF using this control technique compared to other filters.

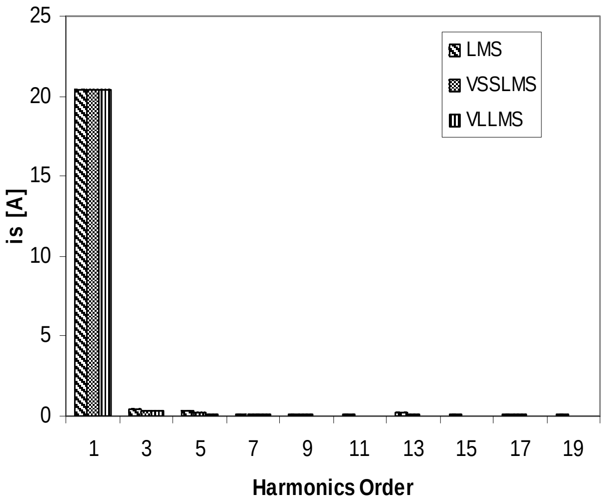

Fig.2 Comparison of source current spectrum of HAPF using different methods

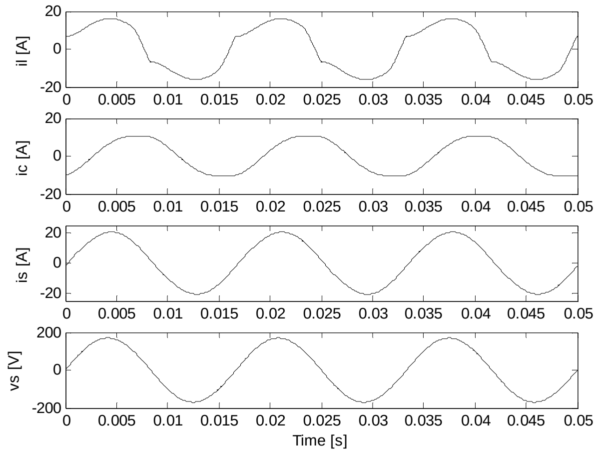

Fig. 3 Simulated waveforms with HAPF

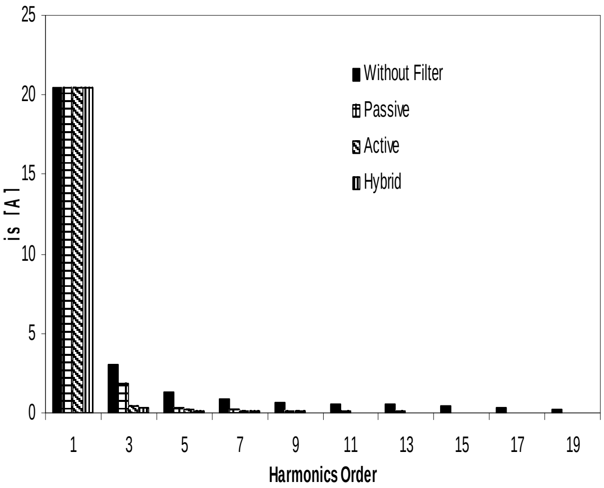

Fig. 4 Comparison of Source Current Spectrum without and with different filters

V. VALIDATION ON EXPERIMENTAL SET-UP

In order to validate the results obtained by simulation, a laboratory prototype [6] has been built. The experimental setup parameters are: 0.5 kVA diode rectifier is taken as the non-linear load, the input supply voltage is 70 V, 50 Hz. The APF is made of 4 IGBT modules. The DC voltage is set at 150 V, filter inductor of 0.5 mH and DC bus capacitor of 1000µF. The switching frequency of the IGBT devices is 5 kHz. . The source current waveform is stored in a Digital Storage Oscilloscope and then through Oscilloscope software, data is acquired to the personal computer. The sampling time in this case is fixed at 0.05ms. The Total Harmonics Distortion (THD) of this current is reduced from 34.8 % to 3.4 % using VLLMS. The results show the capability of the HAPF using modified PWM technique to compensate better the low frequency harmonics.

VI. CONCLUSIONS

The paper presents a comparative analysis of passive, active and hybrid power filters for power system harmonics mitigation in distorted environment. Initially, harmonics components of signal are estimated using VLLMS algorithm and mitigation is achieved using Hybrid Active Power Filter (HAPF). Estimation performance of VLLMS is also compared with LMS and VSSLMS algorithms. THD of the shunt hybrid power filter using proposed control algorithm is reduced to 1.82 %, which is minimum among the three cases of filtering. The results on simulation and experimental set-up establish the performance of proposed VLLMS for harmonics estimations and HAPF for mitigation.

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