International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 10, October- 2014

Identification and Mitigation of Power Quality Disturbances by Shunt Active Power Filter using Particle Swarm Optimized - Wavelet Transform Technique

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Abstract— **The impact of Power Quality (PQ) Disturbances on present day power utilities are increasing day by day with wide spread use of non – linear loads. "Harmonic content in utility system is one such disturbance which will decay the power phenomenon in the power system". These disturbances are identified, detected and then compensated in a better means by using Shunt Active Power Filters (SAPF). The identification and reference current generation is carried out by using Wavelet Transform (WT) Theory. Wavelet Transform Theory at present is one of the most powerful Digital Signal Processing (DSP) tool for time – frequency analysis of power quality disturbances. The gate pulses for Voltage Source Inverter (VSI) of Shunt Active Power Filter are generated by using Hysteresis Regulator (HBCC). Hence disturbance can be mitigated by controlling action of Shunt Active Power Filter. Further the parameters of PI controller are optimized by using Particle Swarm Optimization (PSO). The effective simulations of Identification and Mitigation of Power Quality Disturbances by Shunt Active Power Filter Using Particle Swarm Optimized – Wavelet Transform Techniques are carried out in MATLAB/SIMULINK.**

Keywords— Power Quality (PQ), Active Power Filter (APF), Wavelet Transform (WT), Digital Signal Processing (DSP), Hysteresis Band Current Controller (HBCC), Total Harmonic Distortion (THD), Particle Swarm Optimization (PSO).

I. INTRODUCTION

In recent years, the quality of electric power is a major concern since poor electric power quality can result in malfunction, instabilities and shorter lifetime of the load. The poor quality of electric power can be attributed to power line disturbances such as wave shape faults, over voltages, capacitor switching transients, harmonic distortion, and impulse transients. To improve the electric power quality, sources of disturbances must be known and controlled. In order to keep power quality under limits proposed by standards, different compensating techniques using series and shunt active filters have been proposed [1-3]. In this paper shunt active power filter (SAPF) is used for mitigating the harmonic distortion on source side for maintaining stability and improving power quality of the system. The effectiveness of shunt active power filter depends on accurate extraction of fundamental component of current waveform and fastness of control strategy. For operation of SAPF the instantaneous power theory or PQ theory is implemented in the majority of today's harmonic filters. It's easy implementation and relatively small computing power are the driving forces for this. Furthermore, it can respond rapidly in transient conditions mainly depending on the high- or band-pass filter. The disadvantage of this method is that the source of the harmonics, the voltage source or the load current, cannot be determined and that in the case of voltage and current harmonics not all harmonics are detected. In fact this method tries to modulate a resistive load, which could be the preferred control strategy. To overcome this disadvantage Wavelet Transform based technique is investigated in this paper to extract fundamental frequency component from non sinusoidal current [4]. Further the parameters of PI controller are optimized by using Particle Swarm Optimization (PSO) [8]. This paper lay out in six parts. Starting with an introduction, the subsequent sections cover literature survey, operating principle of active power filters, wavelet transform based controller, particle swarm optimization and simulation results.

II. ACTIVE POWER FILTERS

To reduce the harmonics conventionally passive L–C filters were used and also capacitors were employed to improve the power factor of the ac loads .But the passive filters have several drawbacks like fixed compensation, large size and resonance problem. To mitigate the harmonics problem, many research work development are developed on the active power (APF) filters or active power line conditioners. Active filters appear to be a viable solution for power quality conditioning.

The APF technology is now mature for providing compensation for harmonics, reactive power, and/or neutral current in ac networks. It has evolved in the past quarter century of development with varying configurations, control strategies, and solid-state devices. APF's are also used to eliminate voltage harmonics, to regulate terminal voltage, to suppress voltage flicker, and to improve voltage balance in three-phase systems [1-3].

This wide range of objectives is achieved either individually or in combination, depending upon the requirements, control strategy and configuration which have to be selected appropriately. In this we are using active power filter in shunt to suppress the current harmonics and extracts the fundamental component from the distorted wave form by using wavelet transform technique in the supply current. The effectiveness of active power filter depends on accurate extraction of fundamental component of current waveform and fastness of control strategy.

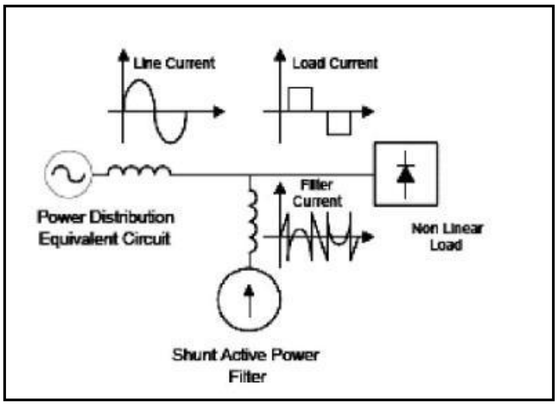

Fig. 1. Block Diagram of Shunt Active Power Filter.

III. WT BASED CONTROLLER

Wavelet is a mathematical tool leading to representations of the type for a large class of functions, f. Jean Morlet in 1982, introduced the idea of the wavelet transform and provided a new mathematical tool for seismic wave analysis. Morlet first considered wavelets as a family of functions constructed from approximations and dilations of a single function called "mother wavelet" ψ(t) [5].

$$\square ab(t) = \frac{1}{\sqrt{a}} \square \left(\frac{t-b}{a}\right), a, b \in R, a \neq 0 \quad (1)$$

The function $\Psi ab(t)$ is the base function or the mother wavelet a and b, are the approximation and details parameters, respectively and R is a real number. The wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other functions. The fundamental idea behind wavelets is to analyze according to scale. The wavelet transform procedure is to adopt a wavelet prototype function, called an analyzing wavelet or mother wavelet.

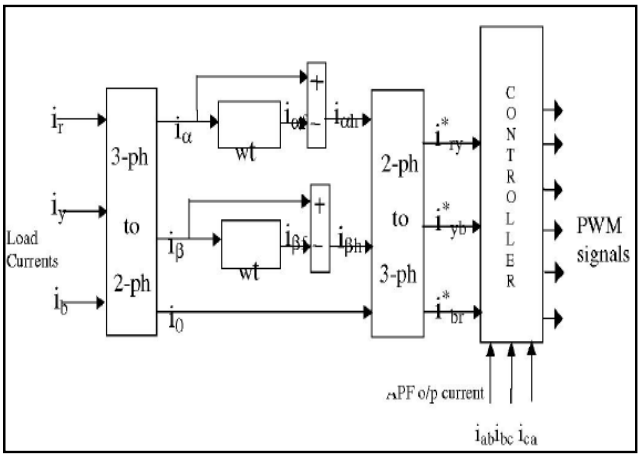

Fig. 2. Block diagram of WT based controller

The block diagram of proposed WT based controller of APF is shown in Fig. 2 [4]. The three phase load currents i_R, i_Y, and i_B are first transformed from three phase system to two phase system currents i_α, i_β and i_o using d-q model. The alpha and beta axis currents do not contain zero sequence current. Hence, the fundamental components of i_α and i_β are extracted by proposed technique. The two phase harmonic currents $i_{\alpha h}$ and $i_{\beta h}$ are then obtained by subtracting the extracted fundamental currents $i_{\alpha f}$ and $i_{\beta f}$ from the two phase source currents i_α and i_β, respectively. Finally, these two-phase harmonic components and zero sequence current are transformed into three phase system using d-q model. These three phase currents obtained after transformation are then used as reference signals in hysteresis current controller for the generation of switching signals for IGBT's used in VSI.

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & \frac{-1}{3} & \frac{-1}{3} \\ 0 & \frac{1}{\sqrt{3}} & \frac{-1}{\sqrt{3}} \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_o \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & \frac{-1}{3} & \frac{-1}{3} \\ 0 & \frac{1}{\sqrt{3}} & \frac{-1}{\sqrt{3}} \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} & 1 \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} \quad (4)$$

Transformation of three phase (a, b, c) currents and voltages to two-phase (α, β) using the direct conversion is shown in (2) & (3) respectively. The reference currents are generated by converting two-phase (□, □) to three phase (a, b, c) is shown in (4).

The wavelet transform is often compared with the Fourier transform. Fourier transform is a powerful tool for analyzing the components of a stationary signal. Wavelet transforms allow the components of a non-stationary signal to be analyzed. Wavelets also allow filters to be constructed for stationary and non-stationary signals. The main difference is that wavelets are well localized in both time and frequency domain whereas the standard Fourier transform is only localized in frequency domain. The Short-time Fourier transform (STFT) is also time and frequency localized but there are issues with the frequency time resolution and wavelets often give a better signal representation using Multiresolution analysis (MRA) [4-7].

The Wavelet Transforms are classified into two types they are:

A. Continuous Wavelet Transform

The continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function is shown in (5).

$$\mathrm{C(scale, position)} = \int_{-\infty}^{+\infty} f(t)\psi(scale, position, t)dt \qquad (5)$$

Where $\psi(t)$ is a continuous function in both the time domain and the frequency domain called the mother wavelet and the over line represents operation of complex conjugate. The main purpose of the mother wavelet is to provide a source function to generate the daughter wavelets which are simply the translated and scaled versions of the mother wavelet. To recover the original signal $f(t)$, the first inverse continuous wavelet transform can be exploited.

B. Discrete Wavelet Transform

If we choose scales and positions based on powers of two — so-called *dyadic scales and positions — then our analysis will* be much more efficient and just as accurate. This is called discrete wavelet transform. Therefore, instead of continuous dilation and translation, the mother wavelet may be dilated and translated discretely by selecting $a = a_o^m$ and $b = nb_o a_o^m$, where a_o and b_o are fixed constants with $a_o > 1$ and $b_o > 0$ and m, n are scale and shift parameters respectively, both which are integers [5]. The resulting expression is given with

$$\mathrm{DWT[m,n]} = \frac{1}{\sqrt{a_o^m}} \sum_{k=-\infty}^{\infty} f[k]\, \Psi\left[\frac{k-nb_o a_o^m}{a_o^m}\right] \qquad (6)$$

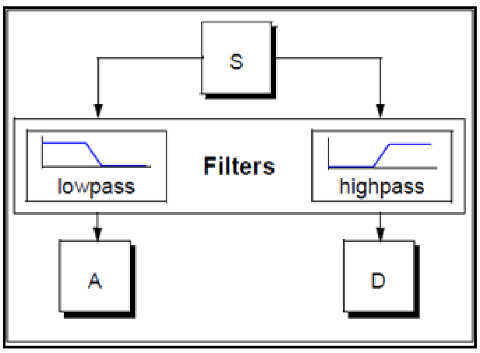

Fig. 3. Single Level Decomposition.

The Fig. 3 shows the single level decomposition of proposed WT technique. In this single level decomposition the signal is decomposed into Approximations (A) and Detail (D).

The wavelet families are classified into several types, they are *Haar, Daubechies, Biorthogonal, Coiflets, Symlets, Morlet, Mexican Hat, Meyer etc,.* In this we are using Daubechies wavelets for extraction of fundamental frequency from distorted wave form.

C. Daubechies Wavelets: dbN

The Daubechies wavelets, based on the work of ingrid daubechies, are a family of orthogonal wavelets defining a discrete wavelet transform and characterized by a maximal number of vanishing moments for some given support. With each wavelet type of this class, there is a scaling function (called the father wavelet) which generates an orthogonal multiresolution analysis. The dbN wavelets are the daubechies' external phase wavelets. N refers to the number of vanishing moments. These filters are also referred to in the literature by the number of filter taps, which is 2N. By typing waveinfo ('db), at the MATLAB command prompt, you can obtain a survey of the main properties of this family. These wavelets have no explicit expression except for db1, which is the Haar wavelet. However, the square modulus of the transfer function of h is explicit and fairly simple [4-7].

IV. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling. The moments of the birds are reflected as and we call it as moments of "particle". All particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles [8-10]. This paper employs the objective function as minimization of Total Harmonic Distortion (THD). The fitness function is defined as follow:

$$F = f_{THD} \qquad (7)$$

The optimization parameters are proportional gain (K_P) and integral gain (K_i), the transfer function of PI controller is defined by:

$$G_C(s) = K_p + \frac{K_i}{s} \qquad (8)$$

The gains K_p and K_i of PI controller are generated by the PSO algorithm for a given plant is shown in fig.4

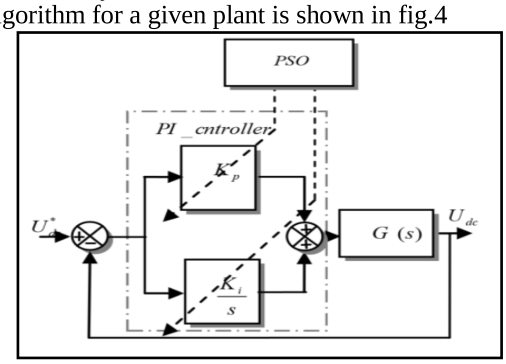

Fig. 4. PI -PSO Control System.

The output of the PI controller u(t) is given by:

$$u(t) = K_p e(t) + K_I \int_0^t e(t)dt \qquad (9)$$

The position of particle move rule is shown as follows:

$$V_s(t+1) = wV_S(t) + c_1 r_1 \big(p_{best} - x_s(t)\big) + c_2 r_2 \big(G_{best} - x_s(t)\big) \qquad (10)$$

$$x_s(t+1) = x_s(t) + V_s(t+1) \qquad (11)$$

Where $V_s(t)$ represents the velocity vector of particle s in t time; $x_s(t)$ represents the position vector of particle s in t time; p_{best} is the personal best position of particle s, G_{best} is the best position of the particle found at present; w represents inertia weight; c_1, c_2 are two acceleration constants, called cognitive and social parameters respectively; and r_1 and r_2 are two random functions in the range [0, 1]. The flow chart of general PSO is shown in Fig. 5.

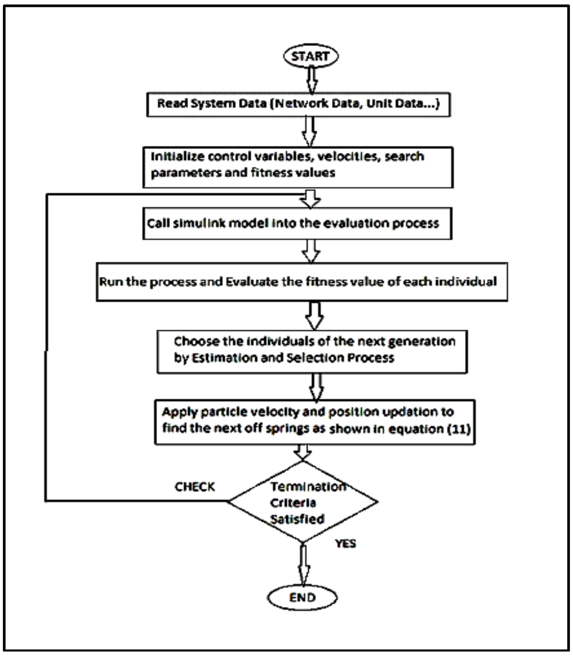

Fig. 5. Flowchart of PSO algorithm

V. SIMULATION RESULT

The first step was to simulate a non-linear load. The most critical load among all the non-linear loads, three phase rectifier was simulated. FFT analysis of the harmonics is carried out for source current and the THD values are noted. Then simulation of the non-linear load with shunt active power filter by using wavelet transforms (*Daubechies db6*), and wavelet transforms with PSO is carried out.

Without SAPF the illustration of THD of source current is 28.23% and is shown in fig. 6.

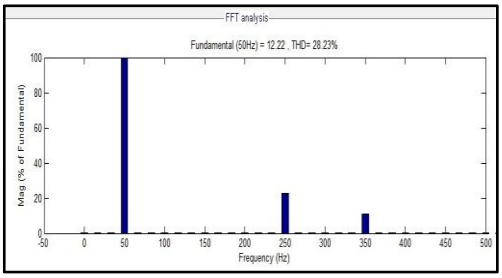

Fig. 6. THD representations Without Shunt Active filter

With SAPF using PQ theory, THD of source current is reduced to 2.05% and is shown in fig. 7.

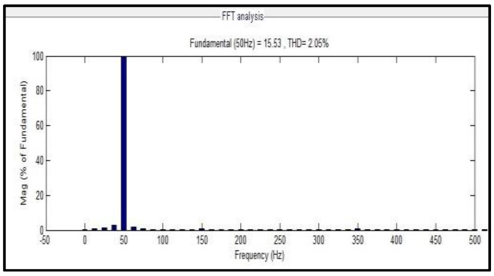

Fig. 7. THD representations With SAPF Using PQ Theory

With SAPF using Wavelet Transforms, THD of source current is further reduced to 0.54% and is shown in fig. 8.

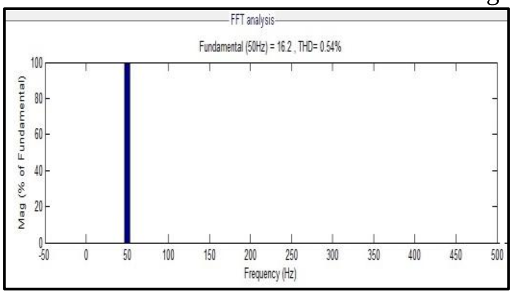

Fig. 8. THD representations With SAPF Using Wavelet Transforms

With SAPF using Wavelet Transforms & PSO controller the illustration of THD in source current this is reduced to 0.45% and is shown in fig. 9.

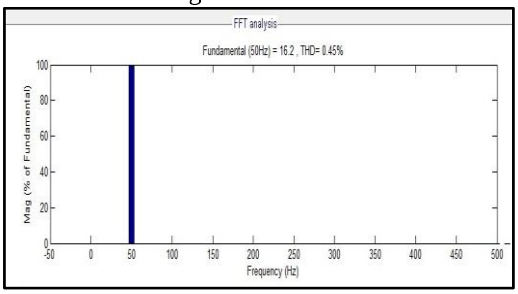

Fig. 9. THD representations With SAPF Using WT – PSO

In Table 1 source current THD is given for different controllers.

TABLE I. THD COMPARISON.

S.NO	Controllers	THD
1	Without Filter	28.23%
2	With SAPF Using PQ Theory	2.05%
3	With SAPF Using Wavelet Transforms	0.54%
4	With SAPF Using Wavelet Transforms & PSO (C1=2,C2=2)	0.45%
5	With SAPF Using Wavelet Transforms & PSO (C1=1,C2=3)	0.45%
6	With SAPF Using Wavelet Transforms & PSO (C1=1.5,C2=2.5)	0.45%

THD convergence illustration of WT-PSO algorithm with acceleration constants C1=2 & C2=2, C1=1 & C2=3 and C1=1.5 & C2=2.5 respectively by making Kp and Ki ranging from (0 - 150). The Convergence of THD is shown in Fig.10. The PI-PSO optimization has been run for 50 iterations.

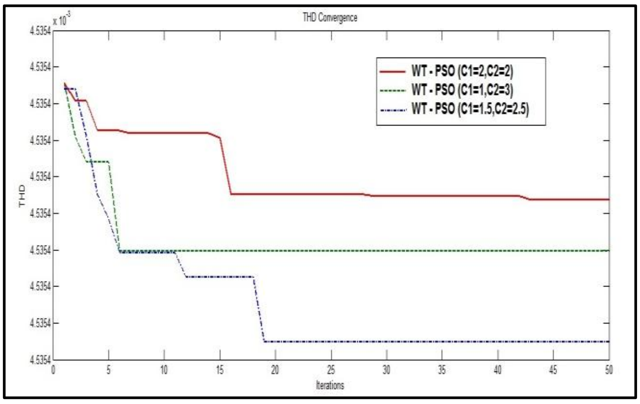

Fig. 10. THD Convergence illustration from WT – PSO

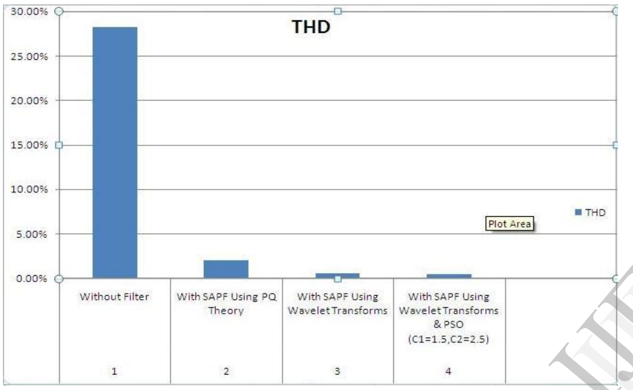

Fig. 11. THD in Bar Chart

THD convergence illustration of WT-PSO algorithm and THD analysis of source current in bar graph representation are shown in fig.10 and fig.11 respectively. DC Link voltage of Shunt Active Power Filter (SAPF) With PQ, WT and WT-PSO is shown in fig.12.

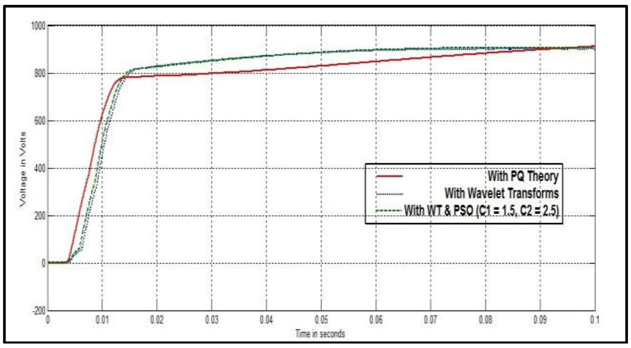

Fig. 12. DC Link voltage of PQ, WT and WT-PSO

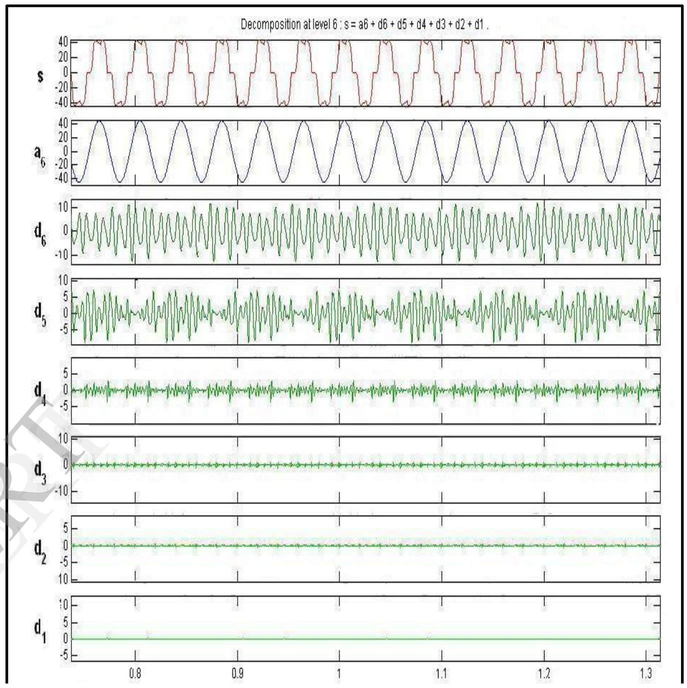

Fig. 13. Results of db6 in Full Decomposition Mode.

Fig. 13 Shows the results of mother wavelet transforms db6 approximations and details of load current in full decomposition mode and which makes the source current sinusoidal. From Fig. 14 we can observe that the signal is decomposed into approximations and details using db6 in separate mode. The approximation gives filtered signal i.e. fundamental waveform. The detail gives unwanted signal i.e. harmonics of the load current.

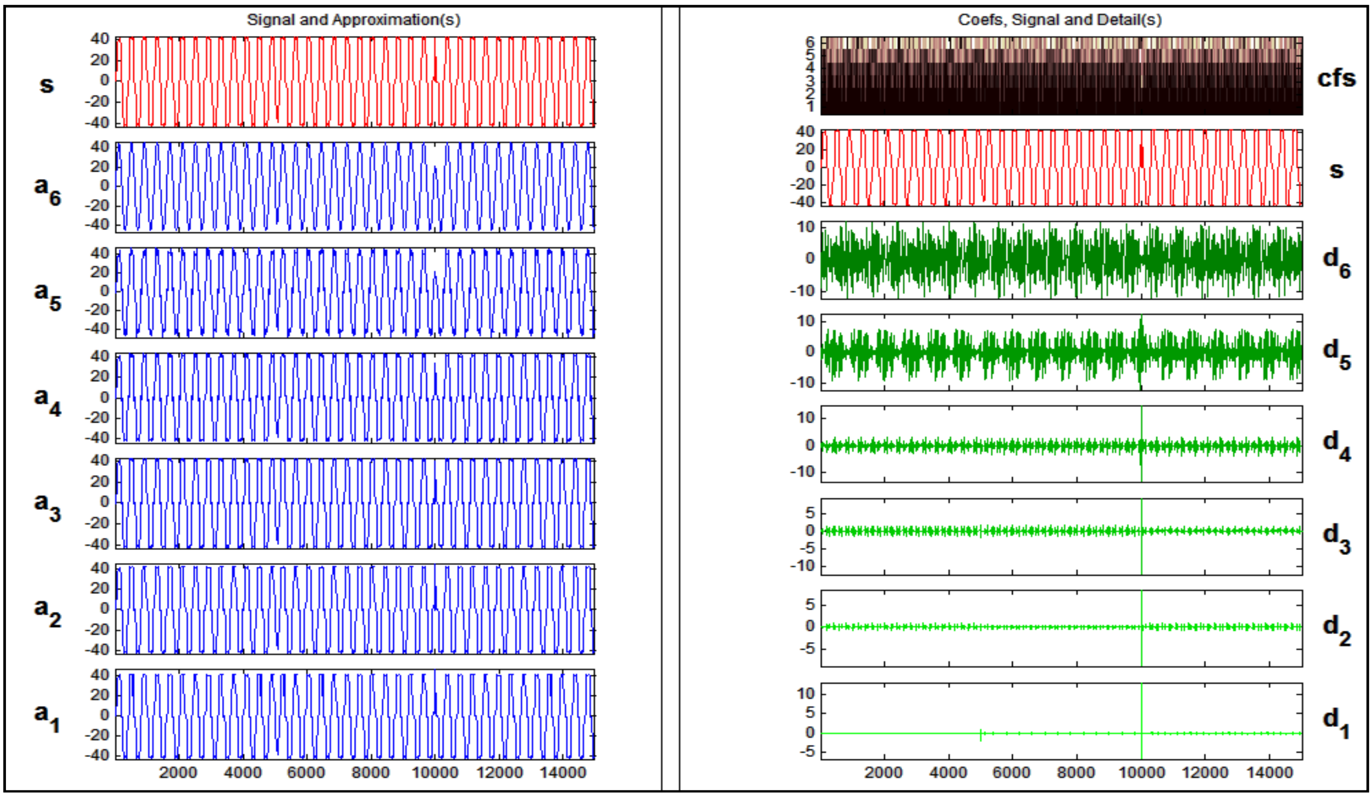

Fig. 14. Results of db6 approximations and details in separate mode.

VI. CONCLUSION

In this paper Wavelet Transform - based technique has been presented to generate reference currents to control Shunt Active Power Filter which is used to compensate reactive power and harmonic currents. The simulated results demonstrate their effectiveness under various operating conditions. The THD values shows that the distortion for source current is bring down near to zero by using Shunt Active Power Filter with Particle Swarm Optimized - Wavelet Transform Technique (PSO-WT). The dc bus voltage has been maintained constant equal to the reference voltage by all PQ Theory, Wavelet Transforms, and PSO-WT controllers.

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