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A Novel Approach for Noise Extraction from harmonic Polluted Currents applied to Power Filters

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ABSTRACT

Discrete Wavelet Transform (DWT) is one of the most popular and powerful methods for extraction of noise and harmonic detection in field of digital signal processing. Extraction of fundamental component from harmonic polluted currents and voltages using wavelet transformation and multi resolution analysis are discussed in this paper. The proposed method uses current signals directly converted into frequency domain for extraction of noise from them. The fundamental component of signal thus obtained is compared with the traditional instantaneous reactive power theory based synchronous reference frame algorithm. The Daubechies wavelet (db25) is used for analysis with decomposition level of 8. The proposed method has been simulated and verified using MATLAB/ SIMULINK toolbox. Simulation results are presented in this paper and confirm the ability of this technique in power system harmonic extraction and fundamental component re-construction.

KEYWORDS: *Wavelet Transform, Harmonic Detection, dq0 Transformation.*

I. INTRODUCTION

Current harmonics that are produced due to the non linear loads connected in power systems will cause many undesired effects like unnecessary heating of conductors, increased losses, and reduced efficiency of the apparatus. These problems are most seriously to be considered when these nonlinear loads are supplied with isolated generating units like diesel generator sets. As the source current contains harmonic components, these harmonic currents when flows through the windings of alternator cause undesired effects in the machine, in turn disturb the equilibrium of the machine. Passive LC filters are the most commonly used for mitigating the current harmonics that were present in the source current. The drawback of these filters is that its size increases as the magnitude of current that it is to be compensated increases and increases its cost also. So it becomes uneconomical to use passive filters for current filtering purposes. One of the other available options is to use active power filter (APF).

APFs are used for the same purpose in place of a passive filter and are economical when compared to passive filters of same power rating [1]. Schematic diagram of a Three Phaseshunt APF is shown in Figure 1.1. For the schematic it is evident that the circuit of a shunt APF contains a Voltage Source Converter (VSC) and a Control Circuit to control the switches of VSC. Many researches have proposed control schemes for control of switches based on time domain approach and instantaneous reactive power theory using αβ0 transformations or dq0 transformations. The control strategies that are used are classified into two groups. The first groups of strategies are used to for parameter detection and the second groups of strategies are meant for derivation of switching functions for Shunt APFs. The parameters that are to be identified for implementation are voltage or current. For a shunt APF current is to be detected. This group is divided into time domain and frequency domain analysis.

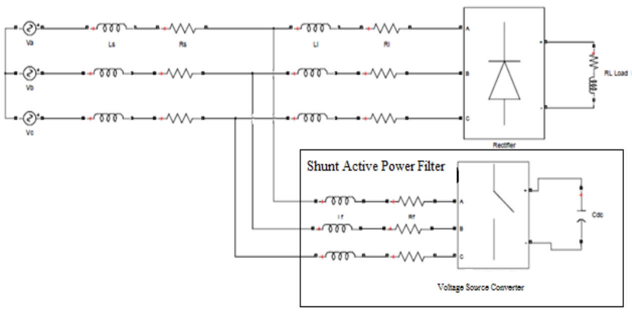

Figure 1.1: Schematic of a Three Phase Shunt APF.

The most common analysis that were used in time domain analysis are [4] High Pass Filter method, Low Pass Filter method, Instantaneous Reactive Power Algorithm [5], Modified Instantaneous Reactive Power Algorithm [6], Synchronous reference Frame Method [7], Modified Synchronous reference Frame Method [8], Unity Power Factor Method [9], Sliding Mode Control [10], Passivity Based Control [11,12], Proportional and Integral Control, Flux Based Control [13] and Sine Multiplication Method [14].

Frequency domain analysis is based on Fast Fourier Transformations (FFT). The harmonic content in voltage or current is obtained by removing the fundamental component by a Low Pass Filter. Using Fast Fourier Transformation the harmonic analysis is carried out on the coefficients of each harmonic are computed. The disadvantage of these methods is large computation time and time delay. For Calculation of the Fast Fourier Transform one whole period of waveform is needed. This is valid only for waveforms that are symmetric over half or quarter of the period [15, 16].

Several methods have been developed and used for generating switching schemes. The important methods in second group are Hysteresis and Pulse width Modulated current or voltage control. Each method has its own merits and demerits. Motivation of investigating this research work is to figure out the importance of the First group of control strategies than the second group of controls.

The paper is organized as follows:inSection 2 modeling concepts of Shunt APF are presented, Section 3 discusses the modeling aspects of Wavelets and their decomposition techniques for harmonic extraction. In section 4 simulation circuits and results are presented, conclusions are included in Chapter 5.

II. Model of Shunt APF

Figure 1.1 shows a three phase shunt APF [4] used for compensating current harmonics of a nonlinear load. The load is supplied with a balanced three phase supply. The basic equations of the active filter and the system are written as

$$V_{fa} + R_f i_{fa} + L_f R_f = Va$$

$$V_{fb} + R_f i_{fb} + L_f R_f = Vb$$

$$V_{fc} + R_f i_{fc} + L_f R_f = Vc$$

The time varying voltages or currents are converted into time independent quantities using synchronous rotating reference frame based method. In this method the load current and source voltages are converted into dqbase.The transformed values of values of current and voltages on to dq0 frame are given by

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

$$\begin{bmatrix} e_d \\ e_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix}$$

Where

$$\begin{bmatrix} e_\alpha \\ e_\beta \\ e_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 2 & 3 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \\ i_{L0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 2 & 3 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

And

$$\theta = \theta_0 + \int_0^t \omega t \, dt$$

For a balanced three phase three wire systems zero sequence components of current and voltage are zero. i.e $i_{L0} = 0$ and $e_0 = 0$.

The Currents i_{Ld} and i_{Lq} Contain DC and an AC part. The DC part of i_{Ld} is responsible for active power in the load and AC part $\tilde{i}_{Ld}$ is corresponds to the current harmonics. The DC part of i_{Lq} is responsible for reactive power in the load and AC part $\tilde{i}_{Lq}$ corresponds to the current harmonics. The reference currents for the active filter in d and q axis are given by

$$i_{df}^* = -\tilde{i}_{Ld}$$

and

$$i_{qf}^* = -\tilde{i}_{Lq}$$

i.e the AC Parts of i_{Ld} and i_{Lq}.

Block Diagram representation forextraction of fundamental Component of current from i_{Ld} and i_{Lq} are shown in Figure 2.1. The output is equal to fundamental component of source current.

III. Multi Resolution Analysis for Noise Extraction

The fundamental restriction in obtaining the time frequency information, particularly for short time records,is that we will not localize both time and frequency to arbitrary precision. Recent approaches are based on expressing signals in terms of wavelets (much just like the Fourier series)[17]. Wavelet transform (WT) has the advantage of employing a variable window size for various frequency components. This enables the employment of long time intervals to get additional precise low frequency information and shorter intervals for high frequency information [18]. Wavelet transform is a powerful tool in signal processing for computing time – frequency representation of signals [19]. This paper proceeds to investigate WT on load current harmonic and noise listed in [19, 20]. *Yalaan et al.* proposed a discrete WT based on fundamental positive sequence in order to obtain reference currents for APF. Discrete Meyer wavelet is used as mother wavelet due to its orthogonal and biorthogonal properties.

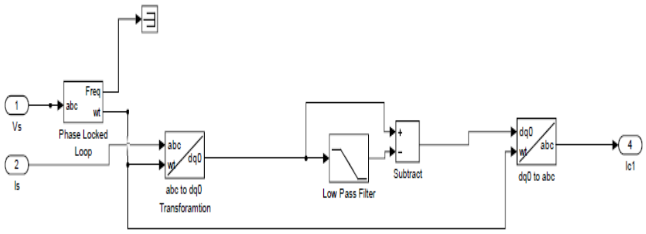

Figure 2.1: Block diagram for extraction of fundamental component of current.

3.1 Decomposition of error Signal from Load Current

Multi Resolution Analysis (MRA) is very similarto sub band decomposition where a signal is divided into a setof signals each containing a frequency band. In MRA the input at each level is decomposed into two bands in time. The higher band becomes one of the outputs, while thelower bandagain is further split into two bands. This procedure iscontinued till a desiredresolution is achieved [21].

Consider any arbitrary signal sequence x(n), n = 0, 1, 2,3 ....,n-1 with a low pass filter and high pass filter, the MRA based wavelet filter scheme decomposes x(n) into subband components of $d_n^1, d_n^2, d_n^3, \ldots\ldots\ldots\ldots d_n^L$ and c_n^L .The c_n^L is the DC component as L tends to ∞. So the signal x(n) mathematically represented as

$$x(n) = c_n^L + \sum_{i=1}^{L} d_n^i$$

The Source current of the supply is taken as the feedback signal for wavelet analysis. The digital filters g and h determine the wavelet basis function $\psi(t)$ and the associated scaling function $\phi(t)$. These two functions are represented with scale equations as follows

$$\phi(t) = 2\sum \bar{g}(l)\phi(2t - i) \text{ and}$$

$$\psi(t) = 2\sum \bar{h}(l)\phi(2t - i)$$

For perfect reconstruction of a dyadic wavelet, the coefficients respectively must satisfy the relationship

$$g(l) = \bar{g}(p - 1 - l)$$

$$h(l) = \bar{h}(p - 1 - l)$$

Where the delay $p-1$ is the filter order of the chosen filter and is related to wavelet basis function as

$$c_n^L = \int s(t)\phi_{Ln}(t)dt$$

$$d_n^i = \int s(t)\phi_{Ln}(t)dt$$

With

$$\phi_{Ln}(t) = 2^{-\frac{L}{2}}\phi\left(\frac{t}{2^L} - n\right)$$

$$\psi_{in}(t) = 2^{\frac{(i-2)}{2}}\sum h(l)\phi\left(\frac{t}{2^{i-1}} - p + 1 - 2_n\right)$$

3.2 Decomposition of Time Varying Signal

Figure 3.1 shows symmetrical decomposition and symmetrical reconstruction of a signal using a two stage wavelet filter bank and unsymmetrical decomposition using threestage filter bank is shown in Figure 3.2. Decomposition of a signal using wavelets divides the input signal into two different parts a part of Low frequency components another part is high frequency components.This phenomena can be represented with the help of two wavelet functions a Low Pass Filter and a High Pass Filter. The high pass filter is dual of low pass filter. Down sampling operation (↓2) of output of filter signal scales down wavelet by a factor 2. Uniform division of the input signal is possible throughout frequency spectrum of the input signal. Asymmetrical decomposition and asymmetrical reconstruction are presented in Figure 3.2.

IV. SIMULATION & RESULTS

20kVA rectifier load connected to a balanced three supply system with X/R ratio equal to 10 and 440V rms value, operating at 50Hz frequency. The load introduces harmonics into supply system with Total harmonic distortion equal to 20.06%.

The source currents are measured and these currents are given as input to a dyadic multi resolution filter by taking 2^8 samples at a time. An eight level db25 wavelet is taken for decomposition of current signal. The decomposed signal is again reconstructed with the help of db25 wavelet with eight levels. The mother wavelet function and the scaling functions taken for analysis of current signals are shown in Figure 3.1.

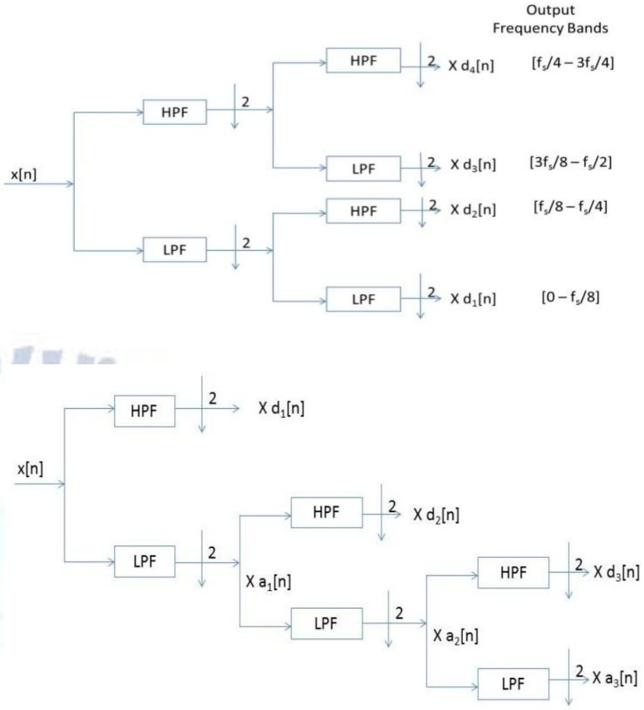

Figure 3.1: (a) 2 Level symmetrical decomposition of an input signal using wavelet transform (b) Reconstruction of input signal using a two stage asymmetrical wavelet packet filter bank.

Source current signal shown in Figure 4.3 is decomposed using scaling and mother wavelet functions shown in Figure 4.1. The decomposed and reconstructed low pass and high pass signals are given in Figure 4.2.

It has been observed that the total harmonic distortion (THD) of original current is 20.02% and THD in current signal reconstructed using synchronously rotating frame of reference is equal to 1.07%. The same current signal is reconstructed with the help of block diagram Multi Resolution analysis and THD of reconstructed signal is equal to 0.01%.

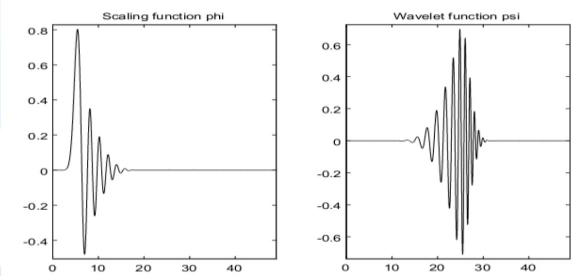

Figure 4.1: Scaling and wavelet functions of db25 wavelet

The scaling and wavelet functions of mother wavelet taken for analysis current signal are presented in figure 4.1. The decomposed and reconstructed current signals are presented in figure 4.2.

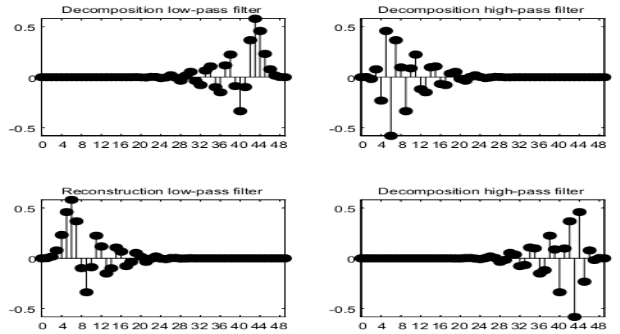

Figure 4.2: Decomposition and reconstruction of current signals.

Original and reconstructed current signals along with wavelet tree with 5000 sample points of current signal is shown in Figure 4.3.

Reconstructed fundamental component of source current using Synchronous rotating reference frame transformation and using wavelet transform along with original source current and extracted noise extracted using wavelets are presented in Figure 4.4 and 4.5.

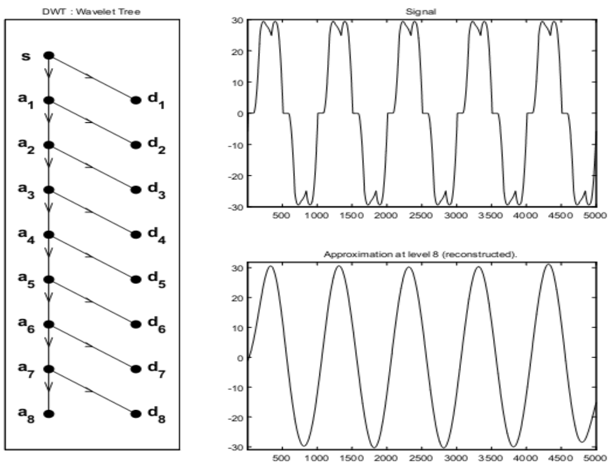

Figure 4.3: Wavelet decomposition tree, Source current and reconstructed current signal with 8 level db25 wavelet.

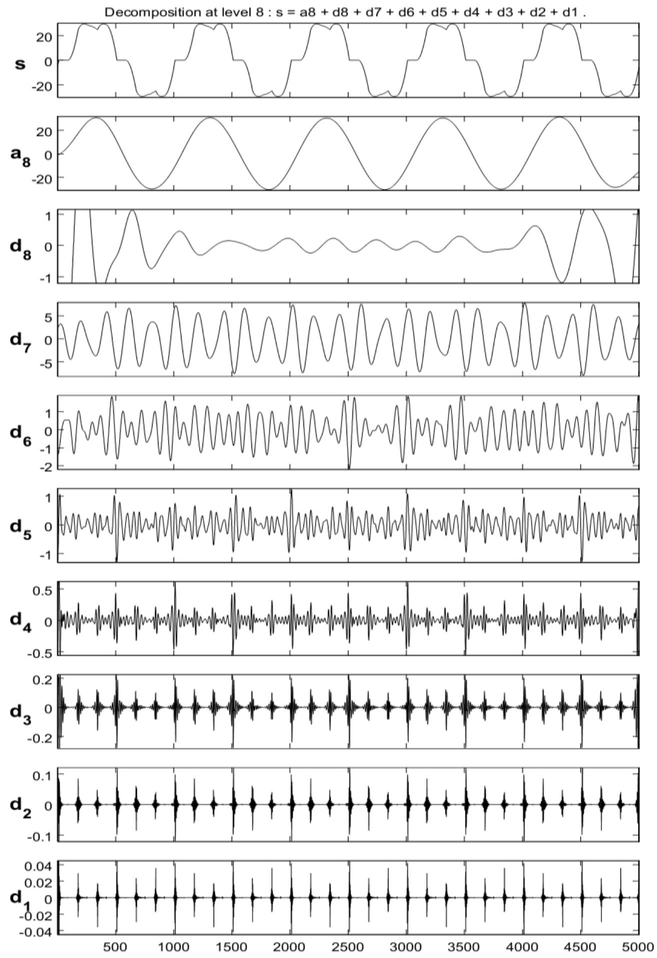

Figure 4.4: Eight level db25 wavelet with 5000 samples applied to phase A current

Figure 4.5: Reconstructed, original current signals and noise signal (extracted using wavelets) of Phase A current.

V. CONCLUSION

A wavelet transform based noise extraction technique for harmonic polluted currents using an eight level db25 wavelet is implanted in MATLAB. It has been observed that the multi resolution analysis based wavelet filters effectively extracts fundamental frequency components from harmonic polluted currents effectively when compared to synchronously rotating frame of reference based method of extraction. The primary advantage of MRA is that in this method the control algorithm effectively applied to localized frequencies as a result better dynamic response can be achieved. This proposed method and simulation results will be beneficial and helpful for effective extraction of fundamental and noise components and these extracted signals are used for compensating the currents in compensating devices like Shunt Active power filters or STATCOM.

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