# Wavelet Transformation Based Current Harmonic Mitigation

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***Abstract***

The power Electronic circuits and other non linear elements produce harmonics in the source. Harmonics results in power quality problem and reduction of system stability. A new approach to reduce current harmonics by Wavelet Transform based Single Phase Shunt Active Filter is proposed. The Wavelet Transform is used for extracting reference current from the distorted source current for the filter. The simulation results show that the proposed model is valid and stable for non linear loads.

***Keywords****- Harmonics, Wavelet Transformation (Key Words)*

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## 1. Introduction

A parameter is defined as totals harmonic distortion (THD) for the metering and comparison of harmonic contents of waveforms. THD is defined for current harmonics as follows: $\mathrm{THD}_{I} = \dfrac{\sqrt{(\sum I_h^2)}}{I_1} \times 100$

Above factor can be defined for voltage harmonics as follows

$$\mathrm{THD}_{v} = \frac{\sqrt{(\sum V_h^2)}}{V_1} \times 100$$

Where,
$I_h$ is the $h^{th}$ harmonic current and
$V_h$ is the $h^{th}$ harmonicvoltag, $w_0$ is the fundamental angular frequency

## 2 Effects of Harmonics

Most of the electrical loads are sensitive to harmonics.
1. Disturbance to Electric and electronic Devices
2. Higher Losses
3. Extra neutral Current
4. Improper Working of Metering Devices.
5. Resonance Problem

## 3. Harmonic Mitigation Methods

The cancellation of harmonics is done using passive or active filters.

### 3.1Passive filters

Passive filters comprise of capacitors, inductors and damping resistors. Passive filters based on their characteristics are divided into four categories namely low pass, high pass, band pass and band rejection filters. There are certain problems associated with the passive filters as follows

- Large size and weight
- Higher cost
- Fixed compensation
- Resonance problem with loads and networks

The increased sensitivity of power quality problems and other problems as mentioned above have required focus on power electronic solution that is active filters.

### 3.2 Active filters

The active filters are applicable to compensate current based distortions such as current harmonics, reactive power and neutral current. They are also used for voltage-based distortions such as voltage harmonics, voltage flickers, voltage sags and swells and voltage imbalances.

#### *3.2.1Classification of active filters*

**i.** The active filters can be broadly classified into two categorizes i.e. single phase and three phase active filters. Three phase active filters are used for high power non linear loads such as adjustable speed drives and converters.

**ii.** Based on the topology there are two kinds of active filters. i. e the filter utilizes either current source inverter (CSI) or voltage source inverter(VSI).The CSI based active filters employ an inductor as the energy storage device .The VSI based active filters employ a capacitor for the energy storage.

**iii.** Based on the application point of view the active filters are classified as shunt active filters and series active filters.

#### ***3.2.2*** CURRENT SOURCE ACTIVE FILTERS

Nonlinear loads draw non-sinusoidal current. This current when passed through AC source impedance produce voltage harmonics. The active filters are designed to generate the harmonic current equal to the harmonic current of the load but opposite in phase. Therefore the current of the AC source is free of harmonics.

### 3.2.3 VOLTAGE SOURCE ACTIVE FILTERS

These types of active filters are lighter, less expensive, and easier to control compared to the current source inverter. Their losses are less than current source active filters. These can be used in multilevel and multistep configurations.

In this category the energy storage in the capacitor must be greater than the maximum line voltage. For the proper operation of the active filter, at any instant, the voltage of the DC capacitor which is serving as the energy storage should be 1.5 times that of the maximum line voltage.

### *3.2.4 Shunt Active Filters*

A shunt active filter can be single phase or three phases, voltage source or current source. Shunt active filters are used to compensate current harmonics of non-linear loads to perform reactive power compensation and to balance imbalance loads. The filter injects a current into the system to compensate for current harmonics or reactive load. The shunt active filters were found to have approximately half of the switch power rating of the series active filters.

The shunt active filter acts as current source. The sum of its current and load current is the total current that flows through the source. Therefore controlling the output current of active filter, controls the source current.

### *3.2.5Series Active Filter*

The series active filter can compensate voltage harmonics and current harmonics of the non-linear load. But it is mostly used for the compensation of voltage harmonics produced by the non-linear loads. This is also utilized for voltage regulation and voltage imbalance compensation. Series active filters are located in series between the source and loads.

The series active filter senses the load side voltage and produces the harmonic of the load in the negative direction and makes the voltage of the point of common coupling ( point of connection between the source, load and the active filter) free of harmonics.

### *3.2.6 Hybrid active filter*

This filter combines the properties of both active and passive filters. It is mainly used to reduce the initial cost of filters and improve the efficiency. A number of combinations of active and passive filters are available. Out of which the combination of shunt passive filter and series active filter proposed by Akagi and Peng was proved to be better.

### *3.2.7 Unified Power Quality Conditioners (UPQC)*

This is also known as universal active filters, which are effective devices to improve power quality. This is formed by a combination of series and shunt active filters. Series active filters suppress and isolate voltage harmonics whereas shunt active filters cancel current harmonics .Here the energy storage device is shared between the two filters either in current source or in voltage source configuration.

There are two kinds of UPQC. In the first type a shunt active filter is placed near the source and a series active filter is placed near the load and the other type is vice versa.

## 4. Control Strategies

This section deals about the different control techniques available for the control of the active filters. There are two main groups of control methods namely time domain techniques and frequency domain techniques. Both these methods are used to generate a reference parameter (voltage or current).

The time domain methods are based on the instantaneous derivation of the compensating commands in the form of either voltage or current.

Under the time domain analysis the following methods are available.

1. High pass filter method
2. Low pass filter method
3. Instantaneous reactive power algorithm
4. Modified instantaneous power algorithm
5. Synchronous reference frame method
6. Unified power factor method
7.Sliding mode Control
8.PI controller
9.Flux based controller
10.Sine multiplication method

These time domain techniques are having some disadvantages as follows.

The p – q theory is not applicable to drive any mitigating device in the distribution system because it assumes that the harmonics of the three phases are identical in all respects. But this assumption is not realistic for distribution systems. The d – q orthogonal coordinates technique does not give any indication about the reactive power compensation or zero sequence compensation.

The synchronous detection method is not valid if the voltage were distorted and unbalanced. And this technique is very complicated from the practical point of view.

Most of time domain techniques depend on passive filters to extract the fundamental or the disturbance from the signal, these filters produce some phase shift in angle and attenuation for the extracted signal.

### A. Fourier transform (FT)

In Fourier transform the given time domain signal is multiplied with sine and cosines series and the product obtained is integrated. This calculation is done for each frequency (f).

Mathematically Fourier transform can be represented as

$$X(f) = \int_{-\infty}^{\infty} x(t)\, e^{-j2\pi ft}\, dt$$

X(f) is a Fourier transform of time varying signal x(t).

### B. Short time Fourier transform

In short time Fourier transform the non-stationary signals are divided into short duration stationary signals, during which
the signal is said to be stationary i.e. the frequency will remain unchanged. The length of the window is chosen such that signal within the window is stationary. Short-Time Fourier transform of a signal x(t) can be obtained as

STFT (t,f)= _ x(t) *w(t-t')*e-jwt dt.

where,

x(t) is the time domain signal to be analyzed.

w(t-t') is the window function.

t' is the time shift.

### C. Wavelet transform

The wavelet transform is a mathematical tool, much like a Fourier transform in analyzing time localized stationary signal, which decomposes a signal into different scales with different levels of resolution by dilating a single prototype function. Wavelet transform provides a local representation (i.e. bothtime and frequency) of a given signal. Hence it is suitable for analyzing a signal where time- frequency resolution is needed such as power quality disturbances, where the characterizingeach type of disturbances is different. By analyzing the frequency content of the voltage/current waveform of non stationary signal and the time of occurrence of these frequencybands, it is possible to tell the sources of the disturbances, thusdiscriminating the varies power quality disturbances.

### D. Continuous wavelet transform(CWT)

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

φ

$$CWT_x(\tau, s) = \frac{1}{\sqrt{|s|}} \int x(t)\, \varphi^* \frac{(t-\tau)}{s}\, dt$$

where,

Scale represents the compressed or stretched form of the mother wavelet, which is different for each type of PQdisturbance. Position represents position of the wavelet in the time – domain during the convolution operation. The result of the CWT is many wavelet coefficients C, which are a functionof scale and position. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal.

### E.Discrete wavelet transform (DWT)

It is the sampled version of continuous wavelet transform(CWT), and the information provides is highly redundant as faras data storage and reconstruction is possible. The discrete wavelet transform (DWT), on the other hand, provides sufficient information both for analysis and synthesis of the original signal, with a significant reduction in the computation time.

Real wavelets:

Daubechies, Symlets, Coif lets, Haar, Biorthogonal, Meyer,Discrete Meyer, Gaussian, Mexican hat, Morlet .Complex wavelets are classified as,

Complex Gaussian wavelets,
Complex Morlet wavelets.
Complex Shannon wavelets,
Complex Frequency B-spline

As the time resolution and frequency resolution problems exist regardless of the transform used it is possible to analyze any signal by using an alternate approach known as Multiresolution analysis based on which the Wavelet Transform has been developed. This analyzes the signals at different frequencies with different resolutions. Hence this technique gives good time resolution (but poor frequency resolution) at high frequencies and good frequency resolution (but poor time resolution) at lower frequencies.

Discrete Wavelet Transform is given by,

$$A_k = \sum h_m S_{2k+m-1}$$

m= 0,1,2……….2N-1

$$D_k = \sum(-1)^m h_{2N-m-1} S_{2k+m-1}$$

m= 0,1,2……….2N-1

where

$A_k$ = approximate coefficient
$D_k$ = detailed coefficient
N = No. of samples
k = Order of the coefficient

In this case discrete filters of different cutoff frequencies are used to analyze the signal at different scales. The signal is passed through a series of high pass filters to analyze the high frequencies and it is passed through a series of low pass filters to analyze the low frequencies. The low frequency components are called approximations and the high frequency components are details. The above equation for DWT is nothing but the decomposition as well as down sampling by a factor of 2 after the decomposition. The decomposition process can be iterated with successive approximations being decomposed in turn so that one signal is broken down into many lower resolution components.This is called wavelet decomposition tree(fig)

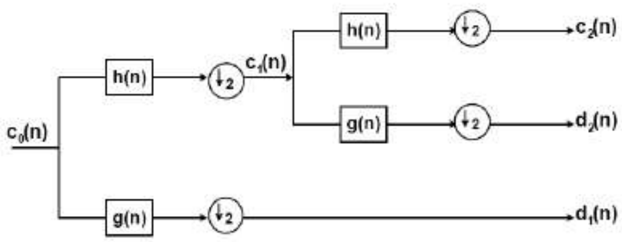
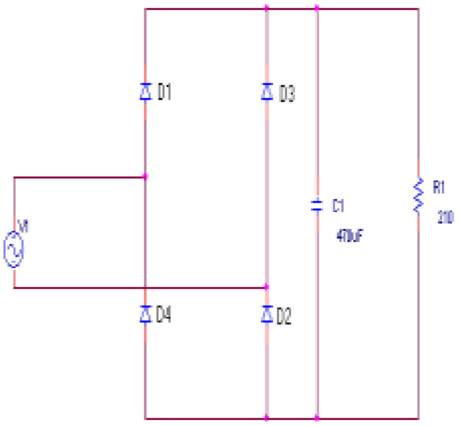



Fig. 2. Multiresolution of signal $c_0(n)$ in 2 level.

### 4.1Non Linear Load




### 4.2Inverter model

The figure shows the inverter, which is used as the active filter. The switches present support unipolar voltage and bipolar current. These switches are operated in a manner which forces the inductor current to follow whatever shape is necessary such that the total current drawn by the filter and the non-linear load is of the correct magnitude and of the same shape as the input voltage.

With the assumption that the capacitor voltage $V_c$ is greater than the peak value of the ac source i.e. $V_c > | v_s |$.

During the positive half cycle of the source voltage, the current IL can be made more positive by making the voltage Vs = 0; and IL can be driven towards zero by making Vs =Vc.

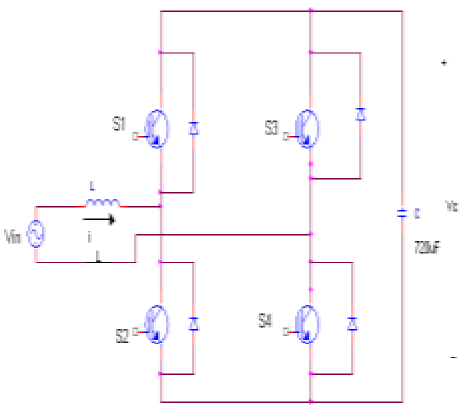



**Figure4.1 Shunt Active Filter**

During the negative half cycle of the source voltage IL can be made more negative by making Vs=0; IL can be driven towards to zero by making Vs= - Vc.

It is concluded that the two switches in each leg of the inverter can be used for different tasks. The switches $S_3$ and $S_4$ are used to force $Vx \leq 0$ and $Vx \geq 0$ respectively, while the switches $S_1$ and $S_2$ actively shape IL.

### 5 Non Linear Control Law

The table 3.1 and 3.2 give the switching of the inverter under various conditions. The reference current $i_s^*$ can be generated using the reference current generation block.

**Table 5.1Switching states of S1 & S2**

| | $i_s < i_s^*$ | $i_s > i_s^*$ |
|---|---|---|
| S1 | 0 | 1 |
| S2 | 1 | 0 |

**Table5.2 Switching states of S3 & S4**

| | $V_s < 0$ | $V_s > 0$ |
|---|---|---|
| S3 | 1 | 0 |
| S4 | 0 | 1 |

As per the table 3.1 if $i_s < i_s^*$ means that the capacitor will supply the reactive power to the source. Similarly $i_s > i_s^*$ means that the capacitor will absorbs the reactive power from the source.

As per the table 3.2 in positive half cycle switch S4 and negative half cycle switch S3 will operate.

By using the above switching law the distorted source current is forced to have the same shape as reference current. The reference current is generated by WT.

### 6 Simulation Results

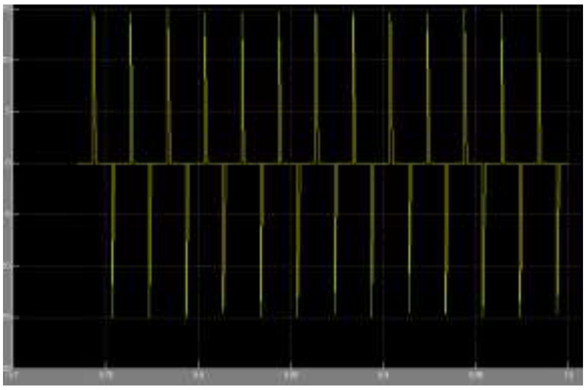


**Fig.6.1Distorted Source current of non linear load**

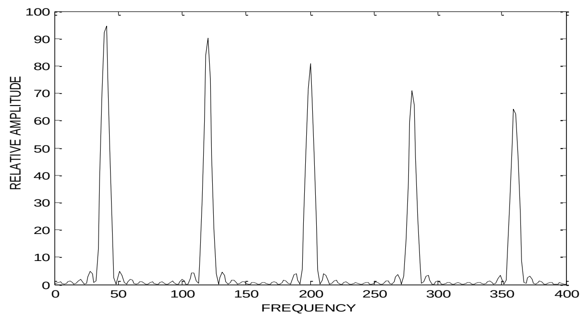



**Fig.6.2 Frequency component of distorted source current.**

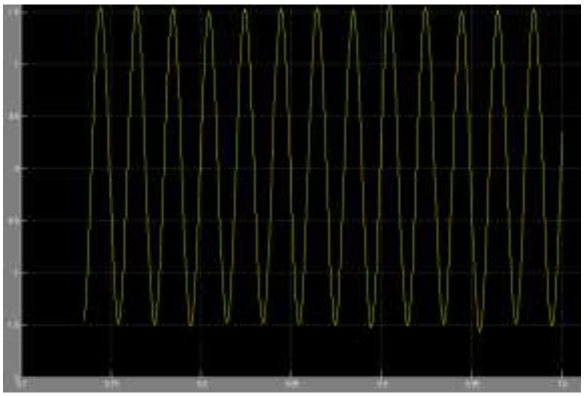


Fig 6.3 Reference current generated using Wavelet Transform

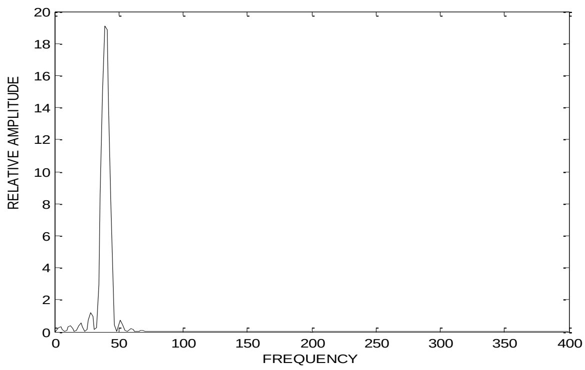



**Fig. 6.4 Frequency component of reference current.**

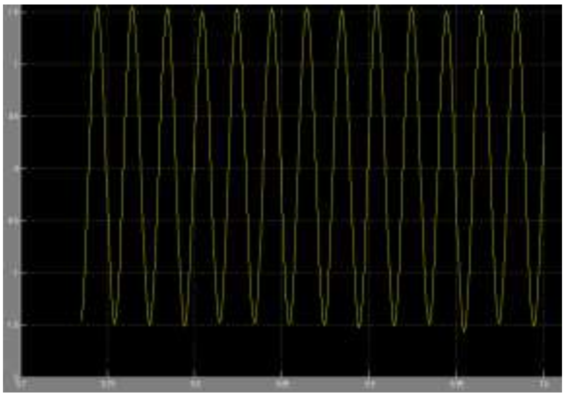


**Fig.6.5 Compensated Source current**

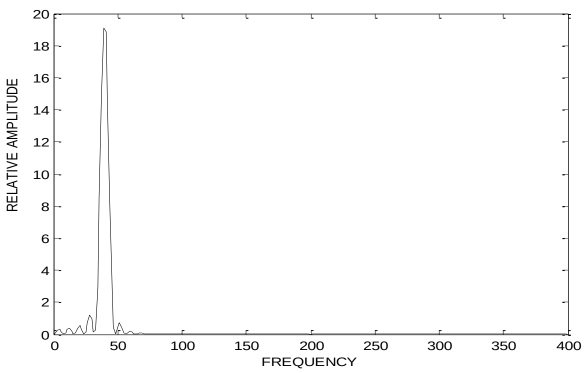



**Fig.6.6 Frequency component of compensated source current**

**Table 6.1**
**Total Harmonic Distortion(THD) of source current**

| System Parameter | THD |
|---|---|
| Source Current Before Compensation | 3.5 |
| Source Current After Compensation | 0.6 |

## 7.Conclusion

Hence it is proved that from the simulation results that, With the proposed system it is not possible to improve the power factor but it is possible to shape the distorted source current due to non linear load as the original source current. Also it is seen that the THD value is reduced after filtering.

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