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Study of APLC Using Discrete Wavelet Transform & Fuzzy Controller

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***Abstract*-This paper describes a Wavelet transform technique with Fuzzy controller to analyze power system harmonics. To propose a novel power system disturbance identification technique with features such as fast and accurate detection of time varying fundamental and harmonic components in power system quantities. Low computational complexity so that it is more suitable for real time applications. Also this paper presents design a power system signal processing system that estimates the constituent components, total harmonics distortions and power factor based on the proposed identification method.**

I. INTRODUCTION

The widespread application of power electronics is increasing the number of electrical loads which distort the current and voltage supplied by the ac line. Reactive power flow derates the power handling capability of distribution equipment. The unwanted effects of power system harmonics are well-documented. Sensitive electronic loads such as measurement devices, hospital diagnostic and treatment equipment, industrial process controllers, and computers may malfunction or fail to operate when connected to an ac line which has harmonics. Electric utility transmission and distribution equipment may be susceptible to ac line harmonics. Transformers and transmission lines have higher operating losses, capacitor banks may catastrophically fail and protective relaying may not function at the predetermined set point.[3]

Ideally, the ac line current is sinusoidal with frequency and phase equal to the frequency and phase of the source voltage. This results in the most efficient and reliable operation of the power system. A number of methods have been suggested to maintain sinusoidal, in-phase ac line current: passive filtering, control of converter switching, and active power line conditioning. Passive filtering is presently the predominant means of suppressing harmonics and improving power factor. Research is currently being performed to develop fuzzy controller with DWT which minimize the harmonic current of the ac line current.

Many conventional frequency-domain control approaches have been developed. However, when the control law is piecewise linear and/or when the quantity to be controlled varies over a wide range, both of which are the case in our work, conventional control schemes become too complex and costly to be practical. An increasingly attractive alternative is to use intelligent control scheme involving such tools as an expert system, fuzzy logic.

A fuzzy system is a knowledge-based system which utilizes fuzzy if-then rules and fuzzy logic in order to obtain the output of the system. When the system is considered as a fuzzy block, the computing algorithm can be divided to three parts: fuzzification, reasoning and defuzzication. Fuzzy system Fuzzy sets of the inputs are defined by the membership functions. The sets can be labeled by adjectives which represent the meaning of the sets.

The membership function gives the grade of the membership which tells how well the current input value belongs to the fuzzy set. The part of the algorithm where the grades are calculated is usually called fuzzification. After fuzzification the computing handles only the grades and the exact input values are ignored. The above is a practical definition of fuzzification. In fuzzy set theory, however, it is argued that the input itself can be a fuzzy set. Or if the input is a crisp value, it can be fuzzified regarding the uncertainty related to it, e.g., by bell-shaped membership functions.

Thus the input value is transformed to a fuzzy set before any processing with actual input membership functions. This is a theoretical definition of fuzzification, which is not utilized in this thesis. The reasoning is performed based on the if-then rules and the grades calculated in the fuzzification. In the design stage, different input fuzzy sets are combined together with fuzzy connectives, and a certain area of the input space can be detected, where only one rule is active. Selecting suitable values for the outputs in the situation and choosing them as consequences of the rule, the fuzzy system can be constructed element-by-element. Mamdani reasoning usually produces a fuzzy set as a consequence. It must be converted to an exact value before it can be used.[4]

A fuzzy system is operating based on fuzzy if-then rules. In practice it is important that the rule base has a rule for each possible situation. This property is called completeness of the rule base. Definition is related to linguistic completeness. In semantic level it has a rule for each possible situation. However, in practical applications numerical completeness is more important. The center-of-gravity defuzzification assumes that at least one rule is always fired. Commonly, certain input regions of the input domain are not of interest and therefore are not defined at all.

One alternative to the DFT is the Short Time Fourier Transform (STFT), which is a sliding window version of the DFT and performs the DFT on each windowed signal. This provides some time information in addition to the frequency information. However, because of its constant width that is not adjusted to individual frequency components.

Since 1994, the use of Wavelet Transform (WT) theory has been introduced to identify particular harmonics sub-bands of interest. The use of the WT has emerged as an alternative to both the DFT and STFT for the analysis of non-stationary phenomena because WT is used to decompose the signal in different frequency bands and characterize them separately. Wavelets perform better with non-periodic signals that contain short duration impulse components as is typical in power system disturbances.[7] .However, the estimation efficiency and accuracy of the wavelet transform depends on the choice of the mother wavelet and the wavelet type should be chosen accordingly to the specific event being studied.

II. FUZZY CONTROLLER

A fuzzy controller is a fuzzy system, which is used to control a target system or it is used for supervisory control. The fuzzy controller has a linguistic interpretation which can be expressed with help of fuzzy sets, membership functions, and fuzzy rules. However, it processes exact input data and produces exact output data in a deterministic way. Fuzzy controllers can be used when nonlinear control action is needed, or when the controller is to be tuned manually. In many cases where fuzzy control is applied the control has been performed before manually. However, this does not mean that fuzzy control is a superior alternative to automate control tasks. Fuzzy controller is a static mapping

$$F : R^{nx} \; ! \; R^{nz}$$

between the inputs x and the outputs z. Dynamical behavior of the controller is implemented in pre-filtering and post-filtering parts to obtain delayed signals, differences, integral actions, etc.

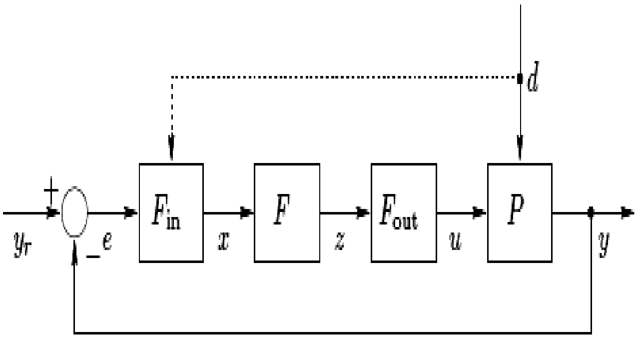

Fig. 1 A fuzzy controller in a basic feedback loop controlling a process P

The fuzzy system F is a static mapping and the dynamical behavior is obtained by a pre-filter Fin and a post-filter Fout. If process disturbances d are known they can be optionally used as inputs of the fuzzy system. All the signals can also be multivariable. [5] Fuzzy controller is nothing more than a fuzzy computing system designed for a control application. The purpose of the system makes it a controller. In fuzzy control applications the controller is implemented mostly in digital form. Analog implementations are also possible but very rarely.

Thus this thesis deals with digital implementations only. This can be seen in the notation where the symbol k denotes time.

A. Design of the fuzzy controller

Design of the fuzzy controller means selection of fuzzy rule base structure, including the number of fuzzy sets for each input and output. After that places and shapes of the membership functions are tuned to obtain behavior of the controller as wanted. Often the tuning must be done on a trial-and-error basis which is time-consuming and needs patience. With fuzzy logic, very versatile control strategies can be implemented.

B. Controller Design with DWT

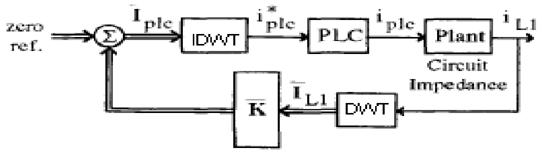

Fig.2 Controller block diagram

Fig.1 is a block diagram showing the principle of operation of the controller. The primary control sequence for realizing is to sense the line current I_{L1}, compute the frequency components of the line current i_{Ll} using the, multiply the frequency components by optimized gain constants K, calculate the desired PLC waveform i^*_{plc} using the Inverse Discrete Wavelet transform (IDWT), and generate the PWM switching pattern for the current source inverter.

III. ANALYSIS OF SIGNALS USING WAVELET TRANSFORMATION METHOD

A. Definition of Wavelet Transform

Wavelets, little wave like functions, are used to transform the signal under investigation into another representation which presents the signal information in a more useful form. This transformation of the signal is known as the wavelet transforms (WT). Mathematically, WT is defined as the inner product of wavelet function $\psi(a,b)$ and Real signal s (t):

$$T\ (a,b) = \int_{-\infty}^{+\infty} S(t), \psi^*{}_{(a,b)}(t) \qquad (1)$$

where,

$$\psi_{(a,b)}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right)$$

The parameters a and b are called dilation and translation parameters respectively.

B. Why Wavelets for Power Quality

The occurrence of power quality events should be detected and located in time, the content of these events should also be monitored accurately so as to classify the events and carry out appropriate mitigations techniques to alleviate HARMONICS problems. There is a need for a powerful tool that can be used to classify the HARMONICS events both in time and frequency domain. Wavelets satisfy this need and scores over other Time-Frequency methods such as Short Time Fourier Transform (STFT). These advantages are explained in more detail in the following sections of this chapter.[9] Also, Wavelet basis functions have compact support, which means that basis functions are non-zero over a finite interval, unlike sinusoidal Fourier basis functions which extend infinitely. This property along with unique property of wavelet basis to be squeezed (dilation) and movement along axis (translation) gives greater flexibility in analyzing localized features of analyzing signal.

Furthermore, recent advances in HARMONICS mitigation techniques are based on extraction of harmonic components instead of traditional fundamental component. Thus, time- frequency domain based techniques come into picture as they give a distinct advantage of eliminating selected harmonics, subject to availability of accurate information on individual harmonic components.

C. Advantages of Wavelet Transforms

As presented in the previous section, traditional signal processing tools have some serious drawbacks for harmonics applications. A more viable alternative is the use of wavelet transform. The wavelet transform has good localization in both frequency and time domain. This makes it an attractive option for harmonics applications. WT is option for studying non-stationary power waveforms. Unlike, the sinusoidal function used in FT, wavelets are oscillating waveforms of short duration with amplitude decaying quickly zero at both ends and thus are more suitable for short duration disturbances. The wavelet's dilation and translation property gives time and frequency information accurately. Apart from it this process of shifting enables the analysis of waveforms containing nonstationary disturbance events.

To enhance the electric power quality, sources of disturbances must be detected and then appropriate mitigation techniques have to be applied. In order to achieve this, a real-time harmonics analyzer with an ability to do time-frequency analysis is required. Hence wavelets transforms with its ability to give good Time-Frequency resolution is suitable for harmonics analysis. Another important application in harmonics is data compression. A single captured event recorded for several seconds using monitoring instruments can produce megabytes of data. This increases the cost of storing and transmitting data. Again, WT comes into picture. Its ability to concentrate a large percentage of total signal energy in a few coefficients helps in data compression. Thus, it reduces the need to store huge voluminous of data and reduces costs associated with it.

In this project, Discrete Wavelet Packet Transform (DWPT), popularly called DWPT, an enhancement of multi resolution algorithm (MRA) using Discrete Wavelet Transform (DWT) has been used as a tool for harmonics analysis.DWPT has many inherent advantages over DWT, which are explained in more detail after a formal introduction to discrete wavelets in the following sections.

D. Discrete Wavelet Transform

In the previous section, wavelet transform was defined as the inner product of wavelet function $\psi\,(a,b)$ and real signal s (t):

$$\mathrm{T}\ (\mathrm{a},\ \mathrm{b}) = \int_{-\infty}^{+\infty} S(t), \psi^{*}{}_{(a,b)}(t) \qquad (2)$$

Where,

$$\psi_{(a,b)}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right)$$

and the parameters a and b are called dilation and translation parameters respectively. This is called continuous wavelet transform (CWT). Discrete wavelet transform is defined for a continuous time signal, s(t) where discrete values of a and b are used. The DWT is thus the discredited counter part of CWT, which is defined as,

$$\mathrm{T}\ (\mathrm{a},\mathrm{b}) = \frac{1}{\sqrt{am}} \sum_{n} S(t) \Psi\left[\frac{k - nb_o a_o^{m}}{a_o^{m}}\right] \qquad (3)$$

Where,

The integer's m and n control the wavelet dilation and translation respectively; a_o is a specified fixed dilation step parameter set at a value greater than 1; and b_o is the location parameter which must be greater than zero. But, common choices for discrete wavelet parameters ao and bo are 2 and 1 respectively. This type of scaling is popularly called 'dyadic grid' arrangement.

When certain criteria are met it is possible to completely reconstruct the original signal using infinite summations of discrete wavelet coefficients rather than continuous integrals. This leads to a fast wavelet transform for the rapid computation of the discrete wavelet transform and its inverse. DWPT, which is used in this research project is based upon discrete wavelet transform. It allows for adaptive partitioning of the time-frequency plane. It is a generalization of multi resolution algorithm explained in the following section.

E. Wavelet Packets and Multi Resolution Algorithm

MRA was initially developed to decompose the signal into various resolution levels to facilitate a very fast time-frequency analysis. A multi-stage filter bank is used to decompose the signal into various levels using a Low Pass(LP) filter and a High Pass(HP) filter as shown in the figure 2. The LP filter will result in approximate coefficients of the original signal and the HP filter in detailed coefficients of the signal.

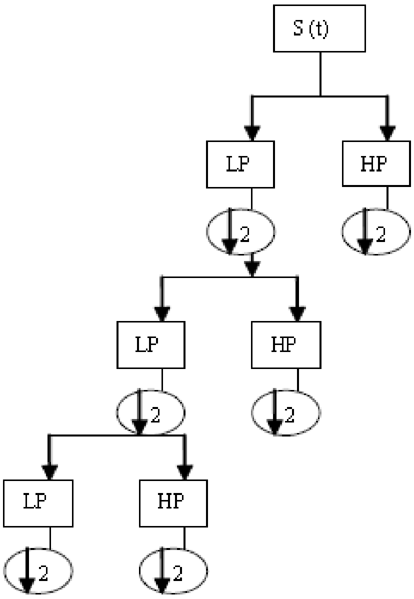

Fig. 3: MRA using LP and HP

DWPT, as stated earlier, is a generalization of the DWT. The difference is that in the WP signal decomposition, both the approximation and detailed coefficients are further decomposed at each level. This leads to a decomposition tree which is shown in Figure 2. This will lead to an array of wavelet packet coefficients with M levels and each containing N coefficients. A total of N coefficients from this M*N array can be selected to represent the signal.

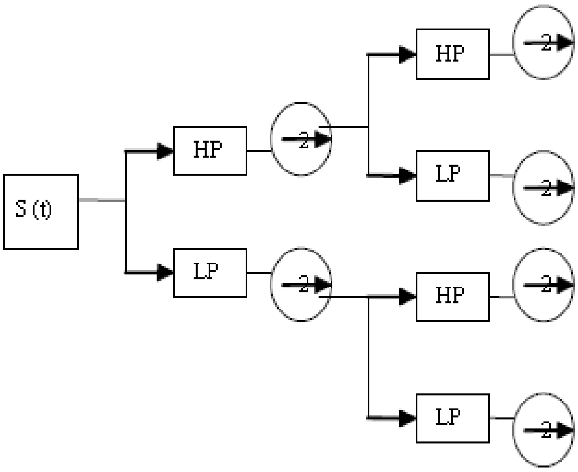

Fig. 4: Depicting DWPT filter bank implementation of a signal.

The main advantage of DWPT is better signal representation than decomposition using MRA. The DWT technique is not suitable for harmonic analysis because the resulting frequency bands are not uniform. In DWPT, with clever manipulation of sampling frequency, the important harmonics such as odd harmonics can be made center frequency of the resulting frequency bands. [8] Furthermore, DWPT gives uniform bands is important for harmonic identification purposes. A level 2 decomposition using DWPT filter bank can be depicted as in fig.4 Similar to DWT, LP filter gives approximation coefficients and HP filter gives detailed coefficients.

F. Selection of appropriate Wavelet Transform

More often than not power researchers tend to neglect the choice of appropriate wavelet filter for their application. The selection of wavelet assumes more importance if one wants to implement their algorithm in DSP and develop an instrument out of it. It is a general trend among researchers to take db10 (more appropriately higher order db coefficients) to study harmonics and db4 or db3 to study transient related phenomena. In this project, we have made an effort to study various wavelet families, which exist in the literature, suitable to study HARMONICS problems and to suggest a suitable wavelet filter that can be used to study harmonics in particular.

G. Introduction to Wavelet Families

Today, there are a number of wavelet families which exist. Each one of them has a particular application. In fact, one can develop a wavelet family to suit ones particular needs. But to study HARMONICS phenomena there are some wavelet families like Daubechies etc which already exist in the literature. Some of the widely used wavelet families that can be used to study the HARMONICS phenomena are

1. Daubechies
2. Symlets
3. Coiflets
4. Biorthogonal Wavelets.

H. Analysis of Harmonics in Time-Frequency Plane

In the analysis of harmonics in time-frequency plane, it is very important to exactly localize the harmonics in the frequency plane. The DWPT algorithm (as explained in the previous chapter) partitions the time-frequency plane, one partition for every decomposition. It allocates the lower interval to low pass filtered part and higher frequency interval to the high pass filtered part. Thus, it is very important to select an appropriate wavelet filter appropriate whose frequency is close to an ideal filter.

IV. SIMULATIONS AND RESULTS

Consider the system which consists of two three-phase PWM voltage source converters connected in twin configuration The inverter feeds an AC load (1kW, 500 var 50Hz) through a three-phase transformer. Harmonic filtering is performed by the transformer leakage inductance (8%) and load capacitance (500 var).Each of the two inverters uses the Three-Level Bridge block where the specified power electronic devices are IGBT/Diode pairs. Each arm consists of 4 IGBTs, 4 ant parallel diodes, and 2 neutral clamping diodes. The inverter is controlled in open loop. Pulses are generated by the discrete 3-Phase Discrete PWM Generator block. This block is available in the Extras/Discrete Control Blocks library. This PWM generator or modulator can be used to generate pulses for 3-phase, converters using one bridge or two bridges (twin configuration). In this demo, the PWM modulator generates two sets of 12 pulses (1 set per inverter) at P1 and P2 outputs. Open the 'Discrete 3-phase PWM Generator' menu. Notice that the generator can operate either in synchronized or un-synchronized mode. When operating in synchronized mode, the carrier triangular signal is synchronized on a PLL reference angle connected to input 'wt'. In synchronized mode, the carrier chopping frequency is specified by the switching ratio as a multiple of the output frequency.

Three sinusoidal 0.85 pu modulating signals are provided by the 'Discrete 3-phase Programmable Source' to obtain a modulation index of 0.85. The carrier signals are synchronized on the modulating signals. In the PWM Generator block, you can instead select ‘Un-synchronized' and ‘Internal generation of modulating signals'.

In such a case the magnitude (modulation index), frequency and phase angle of the output signals are specified directly inside the PWM Generator block menu. For this example the DC bus voltage is 400V (+/- 200 V), chopping frequency is 1080 Hz (18*60 Hz), magnitude of the three modulating signals is 0.85 (corresponding to a modulation index m = 0.85) and the frequency of the three generated signals is 60 Hz. In order to allow further signal processing, signals displayed on the Scope block (sampled at simulation sampling rate of 3240 samples/ cycle) are stored in a variable named 'psb3phPWM3level_str' (structures with time).

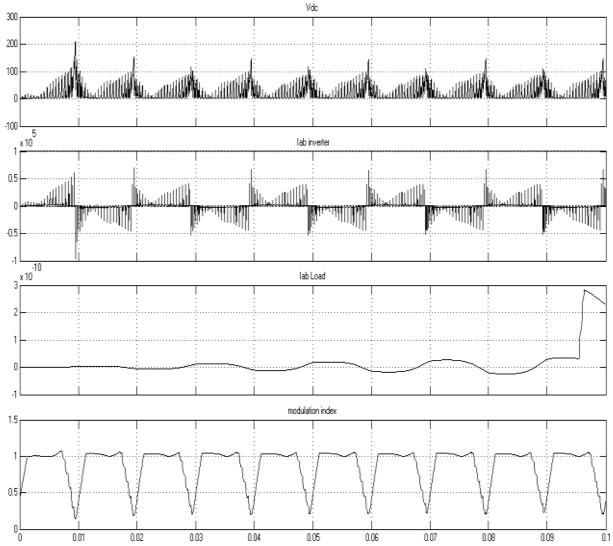

Fig. 5 APLC with DWT transformation and Fuzzy controller scope output.

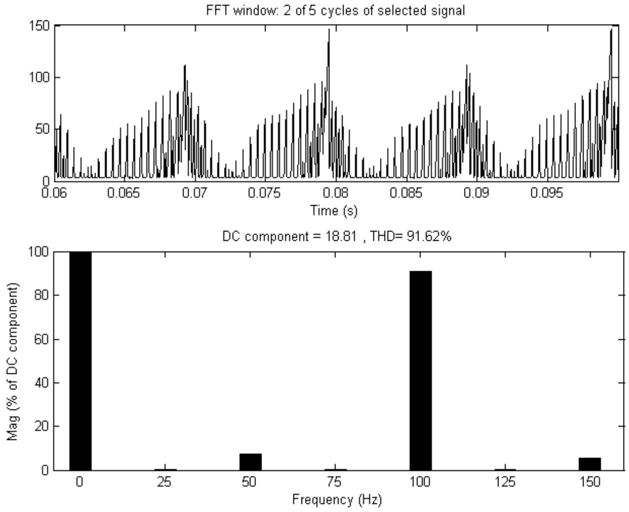

Fig.6 APLC with DWT transformation and Fuzzy controller 3rd harmonic

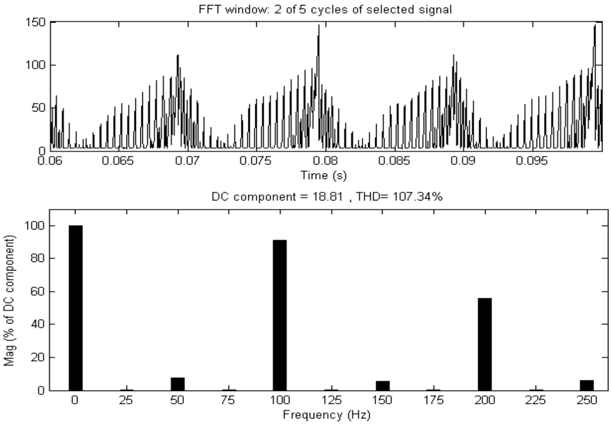

Fig. 7 APLC with DWT transformation and Fuzzy controller 5th harmonic

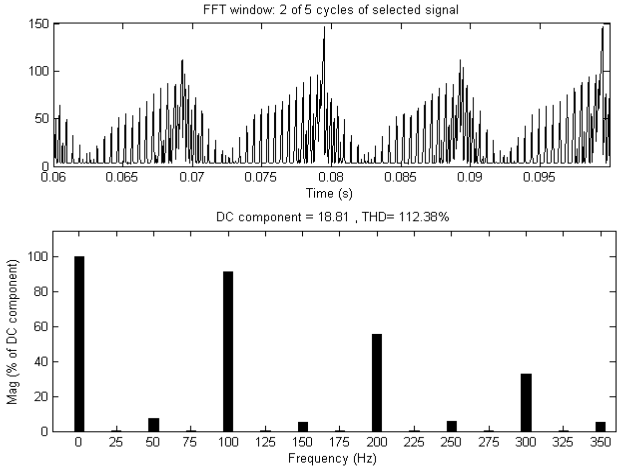

Fig.8 APLC with DWT transformation and Fuzzy controller 7th harmonic

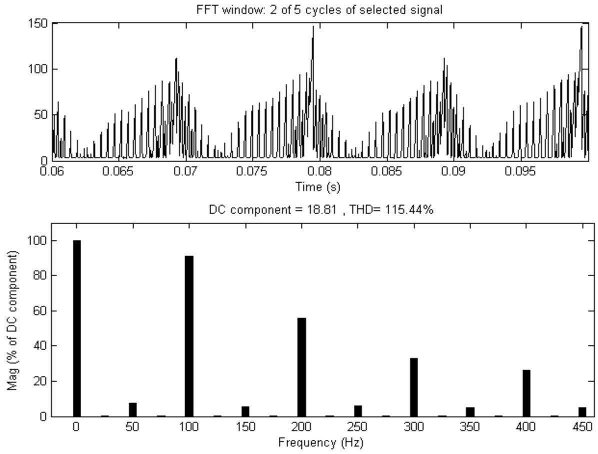

Fig. 9 APLC with DWT transformation and Fuzzy controller 9thharmonic

Simulation Result for APLC

Table 1

Transform/controller	VDC	Mod. Index
DWT +Fuzzy	200 V	1.0

Table 2

From Frequency Domain Analysis Output

Transform /controller	Fundamental freq	No. of harmonics	DC component	THD %
DWT +Fuzzy	50Hz	3rd	18.81	4.18
	50Hz	5th	18.81	4.30
	50Hz	7th	18.81	4.37
	50Hz	9th	18.81	4.52

V. CONCLUSION

An adaptive Switched Active Power Line Conditioner Using DWT with Fuzzy controller has implemented and observes the comparative analysis.

- From APLC with DWT and FUZZY controller it concludes that the results show significant reduction of the harmonics in the line current and correction of the modulation index (displacement power factor) effectively to unity. The PLC design accomplishes this with an innovative three phase PWM switching algorithm which allows the use of a six switch converter. Risk of system harmonic resonance is minimized with the adaptive frequency control.
- The voltage-type APLC with a FUZZY controller can compensate a highly distorted line current by creating and injecting an appropriate compensation current. The well defined fuzzy rules requires only a two cycles of the line voltage to collect and process data, and returns an appropriate set of current-compensating switch control signals.

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