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Elimination of Harmonics using Filters Incorporating Neural Network Control

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Abstract
Harmonics in power systems is becoming a crucial issue with the abrupt rise in the use of nonlinear loads these days. A Filter that removes these harmonics is one of the best solutions to this problem.This is done by injecting compensatory currents which counteract them at the Point where seclusion from non linearities of the load has to be provided. In order to infuse these
Compensatory currents aptly, by the inverter within, it requires gating signals that trace the reference currents precisely which is provided by a controller. The reference currents is a measure of harmonics. Consequently, perfect calculation of these reference signals foster generation of proper gating signals for the inverter.
Accurate estimation is done using the P-Q theory, D-Q theory as well as the
Adaline for Shunt and Hybrid Power Filter. DC Voltage across the capacitor is regulated
using the PI controller and the Neural Network based control..

Keywords: Adaline, p-q theory, d-q theory,reference current,compensatory current,Power Quality, Harmonics.

1. Introduction

With the copious number of electronic equipments flooding the markets and their increased use, the pollution in the electric lines induced by the consumers is on the rise too. Enough attention needs to be provided in this area, though conditioning systems of power lines, FACTS based devices, etc. are prevalent at the transmission and distribution sides. Hence the phrase Power Quality is deeply important today and its mitigation techniques have become profuse since late 1980s.

In simple terms power quality harmonics can be defined as wholesome multiples of the fundamental voltage or current frequencies at which a system operates. In the power domain the fundamental frequency used could be 50 Hz. Second harmonic
refers to twice the fundamental while a third refers to thrice the fundamental voltage or current frequencies, similarly a fourth, fifth and so on. Often many orders of harmonics are observed to be present together in the system rather than a single harmonic being present..

With increasing number of nonlinear loads being used today, the problems caused by harmonics have been aggravated. In fact Harmonics cause myriad problems. Hence analysis of the harmonics in fact gives us a revelation about the current drawn by these non linear loads which use transformer less power supplies in most of the equipments like computers, the Light emitting diodes, variable speed drives, refrigerators etc.

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2. Literature Survey

Power problems due to poor power quality are indeed overwhelming . Power quality is categorized by parameters that express harmonic pollution, flow of the reactive power in the lines and unbalance in the load [1]. Power Quality has a direct effect on the running cost and the efficiency of the devices connected to it. The most suitable and viable solutions to each of these problems are considered and the control systems are studied in detail. The effects of harmonics in power systems are devastating [2]. Mainly heating effects, false tripping etc.[3]

In the design of active filters estimating the harmonics present in the line currents play an important role and power theories are used for this purpose.One of the widely used theories the P-Q theory was put forward by Akagi et.al. in 1983, [3],[4] "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as the instantaneous power theory , or P-Q theory.

Unlike traditional power theories which considers a three-phase system as three single-phase circuits, the P-Q Theory deals with all the three phases at the same time, as a single unit and makes use of the Clarkes transform.The zero sequence components are seperated from the phase componets [5] [6] The practical question that arises is the cost effectiveness of these shunt active filters, Few of the orthogonal methods used to calculate the compensating currents is compared in [7].[8] puts forth a cost effective solution by using digital method of control. The advantages and simplicity of P-Q theory makes it tempting to use it in calculations [9].

The P-Q theory can well exploit the symmetries in power waveforms to simplify its application [10][11] . In [12] a fully fledged Laboratory prototype of Shunt Active Filter is presented where a good performance is delivered by the filter. Under distorted main voltage attempt has been made to improve the efficiency [13]By low pass filtering the measured mains voltage and hence obtain a sinusoidal shaped waveform The Filter current and the reference current are compared and a PWM signal is produced by the Hysteresis Controller[14] Shunt Active filter as one of the custom power devices which purges the harmonics present in the current and also perks up the power factor [15].

Both a series and shunt active filter is demonstrated making use of an Artificial Neural Network Predictor based D-Q axis [16]. The training of the neural network is done by giving to it a huge set of experimental input in steady-state and target output data. The Levenberg–Marquardt (LM) which is a back-propagation method, in combination with the gradient descent method of learning is utilized for training the network. It's proposed to use predictive and adaptive Neural Networks to estimate the harmonic currents in a faster way. The dc link voltage and its dynamics are used for prediction in [17]

3. Elimination of Harmonics

The Principle of injection of harmonics into the line currents by the non linear loads is shown in Fig.1 The Load current essentially splits as fundamental current and the Harmonic . We split the nonlinear load producing harmonic current as the summation of the fundamental current component 'i_{fL}' and the harmonic current 'i_{hL}' yielding (1) :

$$i_{fL} + i_{hL} = i_L \qquad \text{... (1)}$$

Then the current to be furnished by the Shunt Filter is

$$i_{FILTER} = i_{hL} \qquad \text{... (2)}$$

$$i_S = i_L - i_{FILTER} = i_{LFILTER} \qquad \text{... (3)}$$

The source current is given by the Eq (3) above.

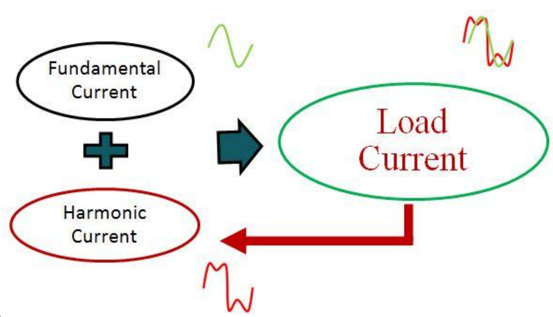

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Fig. 1 Principle of Harmonic injection

3.1 Reference Signal Estimation

Comparisons of various schemes for Shunt Active Filter (SAF) are shown. Which are P-Q theory, D-Q theory ,Adaline and its variants using LMS, Leaky LMS, Signed LMS, and RLS algorithms employed for reference current estimation. Each of these schemes is to be simulated and the Total Harmonic Distortion (THD) and the Power Factor (PF) is to be measured and tabulated as well. Furthermore the conventional PI controller is to be compared with the Neural Network (NN) based PI controller.

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The conventional methods of p-q,d-q theories are used in general for estimation but incorporating a neural network in its most simple form is proposed.

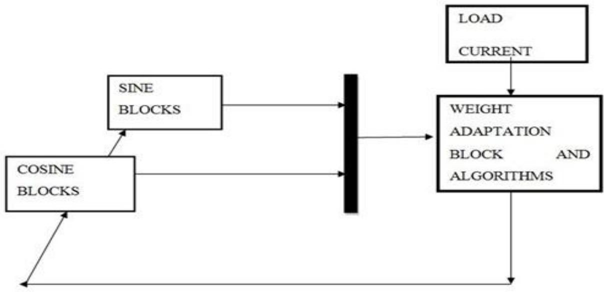

Fig 2. Adaline Simplified Blocks

Each and every harmonic component can be estimated using the Adaline. Sine and Cosine components added together with appropriate weights give a perfect estimate of harmonic content. The optimum weights are adjusted using the mean square error algorithms. The adaline simplified block is shown in Fig.2 with sine and cosine blocks .Each sine or cosine block contains many frequency multiples of the fundamental frequency values.

3.2 DC Voltage Control and Hysteresis Controller

A controller to regulate the DC voltage across the capacitor of an inverter plays a very important role . An active energy storage component of the Voltage Source Inverter is the Capacitor which both regulates the DC voltage across the capacitor which supplies for the non linear loads reactive power requirements. Capacitors are very prominent in this area as even capacitor banks form an important source of power compensation in Power Systems.

What essentially happens is when a nonlinear load demand for the extra power the power converters or simply the inverter is the device that has to supply this power demand that way the capacitor voltage fluctuates as per changes in the load. Keeping this voltage

A PI controller is proving to be an optimum solution to tackle the problem of DC voltage regulation. Extracting harmonic components and DC voltage regulation reference calculation has to go hand in hand. The PI controller has to work in unison with the reference calculation methods. Artificial Intelligence by the virtue of Neural networks especially have gone down to the grass root levels in Electrical Science and Power Engineering. The scope of using Neural Network to regulate the DC voltage by providing proper gain to the error signals and appropriate processing is well explored as well.

Weighted sum of input signal plus an integral of the input signal is the essence of the PI controller. At times a derivative of the input controller is also considered in which case it would be a PID controller. The PI controller regulates the error of the voltage at the DC side with respect to the reference voltage. This is accomplished by sensing the DC side capacitor voltage and comparing with the reference voltage. Generally Reference voltage has to be twice or thrice that of the source voltage. PI controller's output is nothing but the peak value of reference current. It has a Proportional gain and Integral gain which has to be suitably adjusted to maintain the desired response. A higher value of proportional gain means faster response which is essential for responding to quick changes. Although for good dynamic response its required to have a high Proportional gain , too high a value will also lead to instability in the system. The proportional mode is responsible for response to error.

The Integral gain plays a vital role in removing the offsets and resolving time. It helps in resolving the steady state error. Recent set of errors are looked into by the Integral part. In simple terms, rather the sum of errors reduction. The weighted sum of both proportional and integral gains contribute to eliminating the errors of the system.

$$\text{Compensation Formula} = P + I * Ts * 1/(z-1) \quad \textbf{... (4)}$$

Where P is the proportional gain, I is Integral gain , Ts is the sampling time and z indicates the delay. If there exists any noise during any measurement of currents or voltages ,when practically applied the presence of derivative control will be affected by this noise. The advantage of having an integral gain along with proportional gain, is that the response is faster as it considers the sum of the errors and duration of the error.

Another method used is the Neural Network based control In order to train the network, the DC voltage reference of 800V is fixed and stored in variable 'r' , the actual DC Voltage across the capacitor is measured and stored in the variable 'y' ,the PI controller output is stored in the variable 'u' .The

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values 'r' and 'y' are fed as inputs while the target is the variable 'u'. With few load variations the appropriate gain values are found and the neural network is trained.

The training is gone about by using the Leveenberg - Marquardte Algorithm. Thus, in the Back Propagation network along with this algorithm is a good training choice.

The final step of generating the compensatory currents is done by the inverter. Generally, when the inverter is employed in the circuits the main source of AC power will be the Utility power supply which is converted to a DC form essentially performed by the Hysteresis controller it is then again reverted back to AC signal using an inverter. The IGBT with a diode connected across it in the inverter serves as a bidirectional current carrying circuit. The inverter is fed by the DC voltage source which is a capacitor connected across.

The inverter is the heart of the filter. For the inverter to inject compensatory currents into the system, it has to be provided with appropriate gating signals .This Pulse Width Modulated Signals fed to the input of the inverter turn appropriate switches on and generates required AC signals. This is achieved by a Hysteresis Controller.

4.Results and Conclusion

Controller produces the input to the inverter. V_{dc} represents the DC voltage across the capacitor of the inverter. The Reference Voltage value is set as 800Volts.The value of the DC voltage is subtracted from the reference value. The error is fed to the PI controller. The PI controller is implemented as in Fig 3

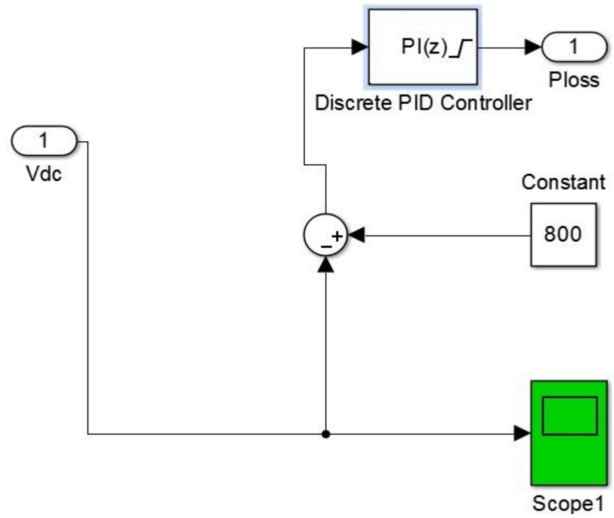

Fig 3 Implementation of PI controller

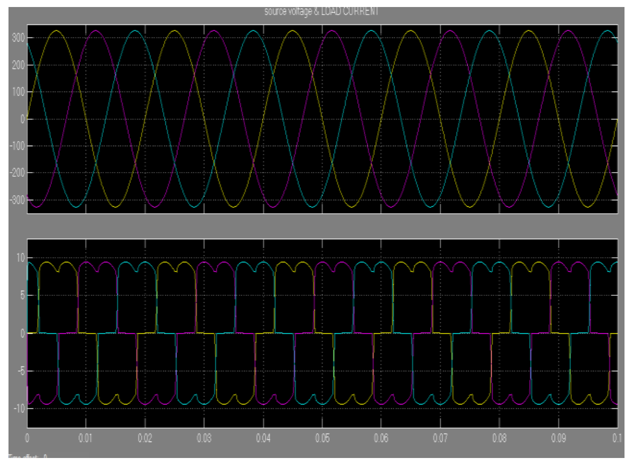

Fig 4 Harmonics due to non linear Load

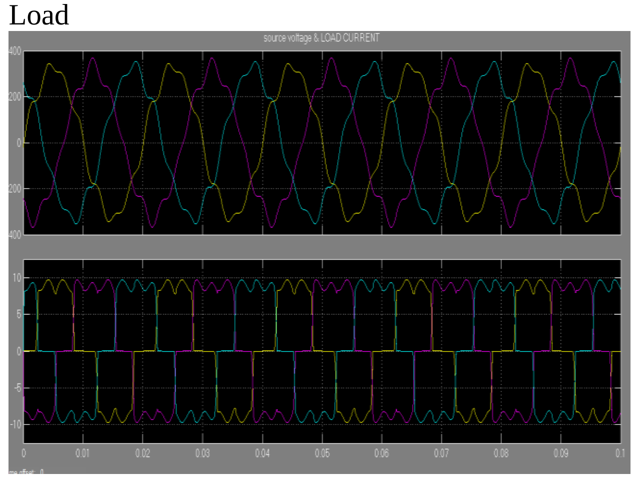

Fig 5 Harmonics in Source Voltage in addition to current harmonics

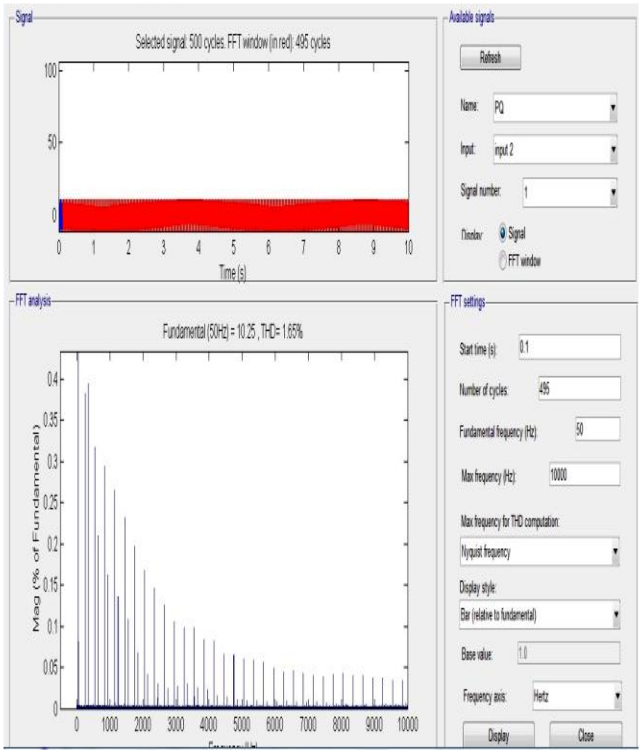

Fig 6 FFT Analysis for P-Q theory based Shunt Filter

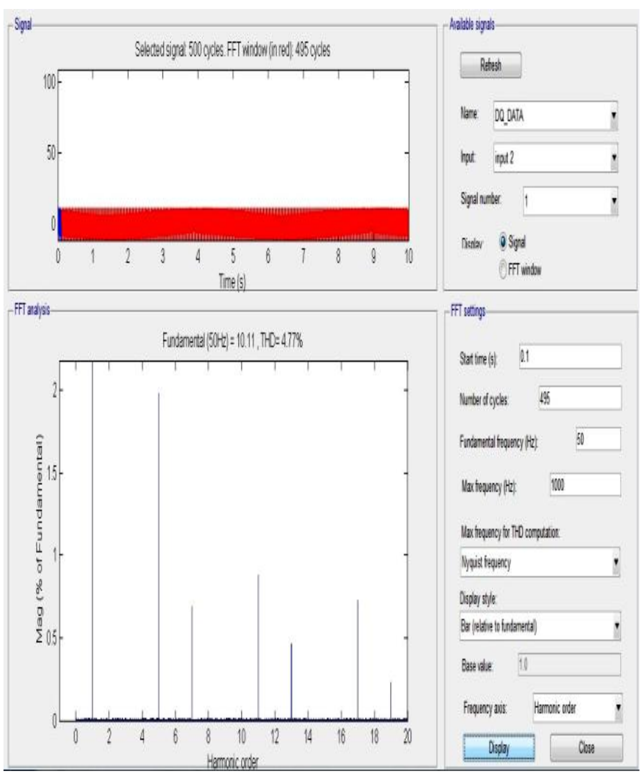

Fig 7 FFT Analysis for D-Q theory based Shunt Filter

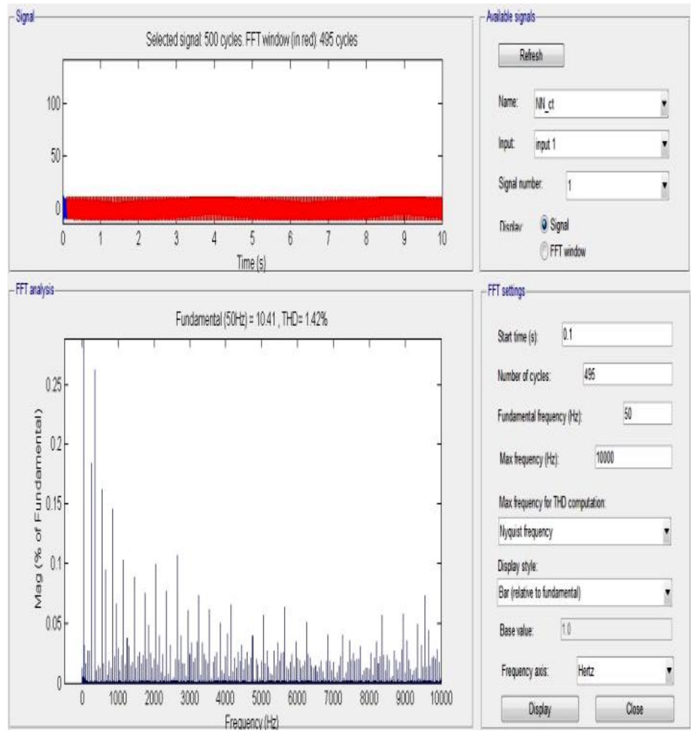

Fig 7FFT Analysis for Adaline -LMS based Shunt Filter

The FFT analysis of the filtered current is shown in Fig 6, Fig.7,Fig,8 .Out of all the methods above, estimation of harmonics using adaline with separate Sine and Cosine blocks to estimate different orders of harmonics is proven to be the best method as the Total Harmonic Distortion (THD) achieved is below 2 %. For Adaline method we get 1.42% of THD while p-q method is 1.65% and ford-q method it is 4.77%.Thus use of adaline in harmonics elimination is a promising option and filter is more efficient

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