A Review of Reduction of Harmonics with FUZZY Logic CONTROLLER Using Active Filter

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ABSTRACT

This paper explains the effects of Harmonics in the Power System and steps to reduce the effects of Harmonics. This paper will also explain how Harmonic distortion is one of the most important problems associated with power quality and creates several disturbances to the Power System. It includes the Harmonic reduction using active power filter to improve the power quality and it will also include the simulation for the same.

**Keywords:** Active Power Filters, Harmonics, fuzzy logic controller.

INTRODUCTION

Harmonics are one of the major concerns in a power system. Harmonics cause distortion in current and voltage waveforms resulting into deterioration of the power system. The first step for harmonic analysis is the harmonics from non-linear loads. The results of such analysis are complex. Over many years, much importance is given to the methods of analysis and control of harmonics. Harmonics present in power system also has non-integer multiples of the fundamental frequency and have a periodic waveform. The harmonics are generated in a power system from two distinct types of loads.

First category of loads is described as linear loads. The linear time-invariant loads are characterized such that application of sinusoidal voltage results in sinusoidal flow of current.

Non-linear loads are considered as the second category of loads. The application of sinusoidal voltage does not result in a sinusoidal flow applied sinusoidal voltage for non-linear devices. Harmonic current is isolated by using harmonic filters in order to protect the electrical equipment from getting damaged due to harmonic voltage distortion. They can also be used to improve the power factor.

The active filters are normally available for low voltage networks. The active filters consist of active components such as IGBT-transistors and eliminate many different harmonic frequencies.

Harmonic currents produced by non linear loads are injected back into power distribution systems through the point of common coupling. The controller is the main part of the active power filter operation and has been a subject of many researches in recent years. Conventional PI voltage and current controllers have been used to control the harmonic current and dc voltage of the shunt APF. However, the conventional PI controller requires precise linear mathematical model of the system, which is difficult to obtain under parameter variations, nonlinearity, and load disturbances. In recent years, fuzzy logic controllers have generated a great deal of interest in certain applications. The advantages of fuzzy logic controllers are: robustness, no need to accurate mathematical model, can work with imprecise inputs, and can handle non-linearity.

In this paper, fuzzy logic control schemes are proposed for harmonic current and inverter DC voltage control to improve the performance of the three levels shunt APF. The performance of fuzzy controller is evaluated through computer simulations under steady-state conditions. The obtained results showed that, the proposed active power filter controller have provided a sinusoidal supply current with low harmonic distortion and in phase with the line voltage.

Basic Active Power Filter

Figure (1) shows the basic compensation principle of the shunt active power filter. It is controlled to draw or supply a compensating current \(i_c\) from or to the utility, so that it cancels current harmonics on the ac side.

**Figure 1 Block diagram of basic active power filter.**

From figure 1 the instantaneous currents can be written as:

\[
i_s(t) = i_L(t) - i_c(t)
\]

The source voltage is given by

\[
v_s(t) = V_m \sin \omega t
\]
if a nonlinear load is applied, then the load current will have a fundamental component, and the harmonic components can be represented as:

\[ i_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \]

\[ i_L(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \]

Instantaneous load power can be given as

\[ p_L(t) = v_s(t) * i_L(t) \]

\[ p_L(t) = V_m I_1 \sin^2 \omega t \cos \phi_1 + V_m I_1 \sin \omega t \cos \omega t \sin \phi_1 \]

\[ + V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \]

\[ p_L(t) = p_f(t) + p_r(t) + p_h(t) \]

From equation real (Fundamental) power is drawn by the load

\[ p_f(t) = V_m I_1 \sin^2 \omega t \cos \phi_1 = v_s(t) * i_1(t) \]

From equation the source current supplied by the source, after compensation

\[ i_s(t) = \frac{p_f(t)}{v_s(t)} = I_1 \cos \phi_1 \sin \omega t = I_{sm} \sin \omega t \]

Also there are some switching losses in the PWM converter. Hence, the utility must supply a small overhead for the capacitor leaking and converter switching losses in addition to the real power of the load.

Hence, total peak current supplied by the source

\[ I_{sp} = I_{sm} + I_{sl} \]

If the active filter provides the total reactive and harmonic power then \( i_s(t) \) will be in phase with the utility voltage and pure sinusoidal. At this time the active filter must provide the following compensation current:

\[ i_r(t) = i_s(t) - i_1(t) \]

Hence for the accurate and instantaneous compensation of reactive and harmonic power, it is necessary to calculate \( i_s(t) \), the fundamental component of load current, as the reference current

**Estimation of Reference source current**

The peak value of the reference current \( I_{sp} \) can be estimated by controlling the dc side capacitor voltage. The ideal compensation requires the main current to be sinusoidal and in phase with the source voltage irrespective of the load’s current nature. The desired source currents after compensation can be given as

\[ i_{sa}^* = I_{sp} \sin \omega t, \]

\[ i_{sb}^* = I_{sp} \sin(\omega t - 120^\circ), \]

\[ i_{cb}^* = I_{sp} \sin(\omega t + 120^\circ), \]

Where \( I_{sp} = I_1 \cos \phi_1 + I_{sl} \) is the amplitude of the desired source current, while the phase angles can be obtained from the source voltages. Hence, the waveform and phases of the source currents are known only the magnitude of the source currents needs to be determined.

The peak value of the reference current has been estimated by regulating the dc side capacitor voltage of the PWM converter. This capacitor voltage is compared by a reference value and the error is processed in a PI controller. The output of the PI controller has been considered as \( t \) amplitude of the desired source current, and the reference currents are estimated by multiplying this peak value with the unit sine vectors in phase with the source voltage.

**Role of DC side Capacitor**

The dc side capacitor serves two main purposes (1) it maintains a dc voltage with a small ripple in steady state, and (2) it serves as an energy storage element to supply the real power difference between load and source during the transient period. In the steady state the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate for the losses in the active filter. Thus dc capacitor voltage can be maintained at a reference value. However, when the load condition changes, the real power balance between the source and the load will be disturbed. This real power difference is to be compensated for by the dc capacitor. This changes the dc capacitor voltage away from the reference voltage. In order to keep the satisfactory operation of the active filter, the peak value of the reference current must be adjusted to change proportionally the real power drawn from the source. This real power charged or discharged by the capacitor compensates for the real power consumed by the load. If the dc capacitor voltage
is recovered and attains the reference voltage, the real power supplied by the source is supposed to equal that consumed by the load again.

Thus, in this fashion the peak value of the reference source current can be obtained by regulating the average voltage of the dc capacitor. A smaller dc capacitor voltage than the reference voltage means that the real power supplied by the source is not enough to supply load demand. Therefore, the source current (i.e. the real power drawn from the source) needs to be increased; while a larger dc capacitor voltage than the reference voltage tries to decrease the reference source current. This change in capacitor voltage has been verified from the simulation results shown in figure 10. The real reactive power injection may result in the ripple voltage of the dc capacitor. A low pass filter is generally used to filter these ripples which introduce a finite delay. To avoid the use of this low pass filter the capacitor voltage is sampled at the zero crossing of the source voltage. A continuously changing reference current makes the compensation non instantaneous during transient. Hence this voltage is sampled at the zero crossing of one of the phase voltage. This makes the compensation instantaneous. Sampling only twice in a cycle as compared to six times in a cycle gives a little higher dc capacitor voltage rise or drop during transients, but the settling time is less. Here it is shown how harmonic elimination is done in Inverter by Pulse Width Modulation technique by solving the non linear equations. Equations are used to determine switching angles of an Inverter. Switching angles play an important role to produce the desired output by eliminating selected harmonics.

In order to form the equation set, fundamental component is given desired output value and all other harmonics are equated to zero. In my simulation I find the switching angles for the 5th, 7th and 11th harmonics. The equation which is derived for Total Harmonic distortion of the output voltage and current of an inverter is used in order to reduce the harmonics that are produced in the inverter. The percentage of the Total Harmonic Distortion is given by the following formula [15].

\[
\%THD = \frac{1}{a_1^2} \sum_{n=5}^{\infty} (a_n^2) \times 100
\]

Where \(n = 6i \pm 1(i = 1, 2, 3, \ldots)\)

**Fuzzy logic controller**

Over the past few decades, the use of fuzzy set theory, or fuzzy logic, in control systems has gained widespread popularity. FLC’s are an excellent choice when precise mathematical formula calculations are impossible. FLC’s actual operation can be divided into three steps:

1. Fuzzy fication
2. Fuzzy processing
3. Defuzzification

**Fig 2 Block diagram of fuzzy logic controller**

A Review

Shunt Active Power Filters (Shunt APFs) represent the most important and most widely used filters in industrial purposes, this is due not only to the fact that they eliminate the Harmonic current with a neglected amount of active fundamental current supplied to compensate system losses, but also they are suitable for a wide range of power ratings. Modern power electronic devices such as IGBTs allowed to configure non harmonic generating shunt APFs, this paper focuses on this type of configuration namely the voltage source inverter based three phase shunt active power filters aiming to present an overview on the matter.[1]

Shunt active power filters (APF) are commonly used for the reduction of current harmonics and improvement of the power factor in power systems with nonlinear loads, such as diode rectifiers. A pulse width modulation (PWM) power converter constitutes the main component of the APF. The low-order harmonics of the line current are attenuated, but the switch-mode operation of the converter results in electromagnetic interference (EMI) spreading to the grid. Specifically, clusters of harmonics appear in the frequency spectra of voltages and currents of the converter at multiples of the switching frequency. In this paper, transferring the discrete spectral power of those harmonics to the continuous spectral power density is proposed as means for mitigation of the EMI. It is accomplished by randomization of the switching periods using a novel random PWM method (RPWM II). In contrast to the existing random PWM methods, in RPWM II the sampling frequency of the digital modulator is constant and equal to the average switching frequency. Computer simulations and experimental investigation of an APF designed for shipboard power systems are described, and the results are presented. They demonstrate significant reduction of the EMI, a feat achieved at practically no expense.[2] These methods incorporate possible frequency deviation of the fundamental grid frequency. The proposed methods are an extension of a recently proposed synchronization method named Kalman Filter-PLL (KF-PLL). In this paper it is shown
that the KF-PLL can also be used to provide the current references for shunt active power filters. It is considered references generation for the following cases: harmonics cancellation, harmonics and displacement power factor correction, harmonics and unbalance compensation and harmonics with unbalance and displacement power factor correction.[3]

Unified power quality conditioners (UPQC's), which aim at the integration of series-active and shunt-active filters. The main purpose of a UPQC is to compensate for voltage flicker/imbalance, reactive power, negative sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. This paper discusses the control strategy of the UPQC, with a focus on the flow of instantaneous active and reactive powers inside the UPQC. Experimental results obtained from a laboratory model of 20 kVA, along with a theoretical analysis, are shown to verify the viability and effectiveness of the UPQC.[4]

Shunt active power filters are used to eliminate the current harmonics and to improve the power factor in systems with non-linear loads. At the present time, different methods exist to control active power filters. Some of them are based on instantaneous reactive power theory [1] and others are based on the synchronous reference frame using Park’s transformation [2]. The purpose of this paper is to present a new control method of shunt active power filters in unbalanced systems, both in load currents, and in AC supply voltage, with a high contents of harmonics. The method is based on the time domain analysis carried out by P. Filip ski. With this control method one can make that the set formed by the nonlinear load and the shunt power filter behaves every time like a resistance, UPF (with unity power factor), or that the current absorbed by the set is perfectly sinusoidal, by simply acting on a switch. The system has been simulated for different load and line conditions. Waveforms of the line currents are shown, with their harmonic distortion contents.[5]

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The most important part of the active power filters is generating of gate signal for inverters. This paper presents Single Phase Application of Space Vector Pulse Width Modulation for shunt active power filters. In conventional SVPWM, all of the phase’s currents are controlled together, but in this method each of phase currents is controlled independently from the measured currents of other phases. In another word, this method prevents from influence of other phase’s errors in the control of considered phase. In this method, the implementation of control logic will be simpler than the conventional SVPWM. For showing the performance of proposed method a typical system has been simulated by MATLAB/SIMULINK. At last, the results of proposed method are compared with the conventional SVPWM. The results show that proposed method have better performance in generating of the compensation current in active power filter.[7]

PWM inverters, a time delay between consecutive semiconductor switching are introduced to prevent a short circuit in the DC link. This action causes the dead-time effect, which is detrimental to the performance of inverters. This paper deals with a new technique that speedup the feedback loop in Shunt Active Power Filter, in order to compensate the dead-time effect. A simple method based on an average value theory can be used to compensate this effect. For Shunt Active Power Filters (SAPF), the compensation can be done in two different ways, one for the feed forward configuration and the other for the feedback one. This paper presents both techniques and discusses the details, advantage of the feedback implementation with a new fast feedback loop that guarantees the dead-time compensation and the overall stability. Experimental results are presented showing the effectiveness of the proposed technique.[8]

The analysis and the application of a current controller in an active power filter (APF) based on a PWM voltage-source electronic converter with three legs and four wires. The neutral wire is connected to the middle point of the DC-capacitor voltage. The controller proposed here is an extension of the one proposed for a three-wire Shunt Active Power Filter. The controller is a two-level nested controller. The outer loop generates the reference current for the inner-loop. The latter, is a state-feedback current controller with integral action. The former consists of (i) a selective harmonic elimination technique and (ii) a DC capacitor-voltage controller. This paper will focus on the neutral-wire current control and on the balance control of the DC-capacitor voltage. The performance of the control algorithm has been demonstrated using a test-rig with balanced and non-balanced non-linear loads.[9]

In recent years, the increase of non-linear loads in electrical power system has sparked the research in power, quality issue. The shunt active power filter (SAPF) is a power electronic device which has been developed to improve power quality. The current control of shunt power filters is critical since poor control can reinforce existing harmonic problems. Various control strategies have been proposed by many researchers. In this paper, a comparative evaluation of the performance of two current control techniques, resonant and predictive controller, is presented with identical system specification. The design procedure and principle of both current control methods are also presented in detail. Simulation results show the comparison of transient response, steady state control and performance in the presence of variation of supply impedance between two control techniques.[10]

CONCLUSION

A survey of harmonics present in the voltage and current waveforms is conducted with an objective to know the existing level of harmonic distortion present in the Power System and future trends. Harmonics injected by some very commonly used nonlinear loads are studied. In this thesis we explain harmonics of power system, inverter circuit and
shunt active filter for the three-phase circuit is simulated and the THD measured verifies the reduction of harmonics based shunt active filter. The Shunt AF is able to compensate balanced and unbalanced nonlinear load currents of a four-wire system with the neutral wire connected to the capacitor midpoint.

REFERENCES