Simulation Based Shunt Active Filter with Fuzzy Logic Controller

Nand Kishore[1]
Dpt. of Electrical & Electronics
LNCT Bhopal (M.P.)

Mala Yadav[2]
Department of Electronics & Communication Engineering
Mangalmay Institute of Engineering & Technology
Greater Noida, India

Amit Kumar Kesarwani[3]
Department of Electronics & Communication Engineering
Mangalmay Institute of Engineering & Technology
Greater Noida, India

Abstract: - **In this paper the troubles formed by non linear load as well as the solutions having been applied so far are briefly reviewed. A new simple and effective reference current generation method of a shunt active filter is proposed In this paper we developed MATLAB model of a typical power supply system with a nonlinear load and shunt active power filter is carried out and the results are presented which imply a better dynamic performance of the proposed scheme compared to the fuzzy logic controller for controlling voltage source inverter.**

Keywords: Active Power Filters, Harmonics, fuzzy logic.

INTRODUCTION

Modern electrical systems, due to wide spread of power conversion units and power electronics equipments, causes an increasing harmonics disturbance in the ac mains currents. These harmonics currents causes adverse effects in power systems such as overheating, perturbation of sensitive control and communication equipment, capacitor blowing, motor vibration, excessive neutral currents, resonances with the grid and low power factor As a result, effective harmonic reduction from the system has become important both to the utilities and to the users. The total harmonic distortion is the ratio between the RMS value of the sum of all harmonic components and the RMS value of the fundamental component, for both current and voltage. Traditionally, the simplest method to eliminate current harmonics is the usage of passive LC filters, but they have many drawbacks such as large size, tuning problems, resonance and fixed compensation characteristics. The solution over passive filters for compensating the harmonic distortion and unbalance is the shunt active filter. In order to compensate the distorted currents the APF injects currents equal but opposite with the harmonic components[1,4,6].

HARMONICS

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 aperiodic waveform. The harmonics are generated in a power system from two distinct types of loads.

First category of loads are described as linear loads. The linear time-invariant loads are characterized such that application of sinusoidal voltage results in sinusoidal flow of current. A constant steady-impedance is displayed from these loads during the applied sinusoidal voltage. As the voltage and current are directly proportional to each other, if voltage is increased it will also result into increase in the current. An example of such a load is incandescent lighting. Even if the flux wave in air gap of rotating machine is not sinusoidal, under normal loading conditions transformers and rotation machines pretty much meet this definition. Also, in a transformer the current contains odd and even harmonics including a dc component. More and more use of magnetic circuits over a period of time may get saturated and result into generation of harmonics. In power systems, synchronous generators produce sinusoidal voltages and the loads draw sinusoidal currents. In this case, the harmonic distortion is produced because of the linear load types for sinusoidal voltage is small.

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 a non-linear device. The non-linear loads draw a current that may be discontinuous. 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 harmful and damaging effects of harmonic distortion can be evident in many different ways such as electronics miss-timings, increased heating effect in electrical equipments, capacitor overloads, etc. There can be two types of filters that are used in order to reduce the harmonic distortion i.e. the active filters and the passive filters. Active harmonic filters are electronic devices that eliminate the undesirable harmonics on the network by inserting negative harmonics into the network. 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. The signal types can be single phase AC, three phase AC. On the other hand, passive harmonic filters consist of passive components such as resistors, inductors and capacitors. Unlike the active filters which are used only for low voltages, the passive filters are commonly used and are available for different voltage levels.[4][3]It should be noted that the single-phase equation underestimates the % of each harmonic and the three-phase equation overestimates the harmonic content in most cases. The current total harmonic distortion (THD), which is the weighted or rms assessment of all harmonics, approaches 100% for many of these devices [2,5]. The expression for THD is as follows:

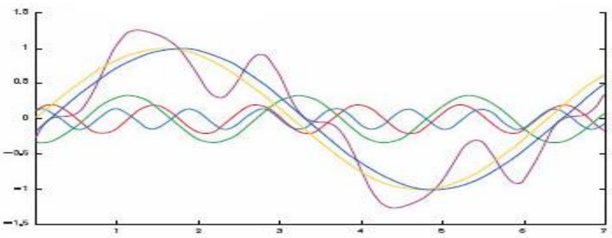


Fig.1 Harmonic distortion for electrical signals

(1)

where: THD_I = current total harmonic distortion
I_n = harmonic rms current (in amps or %)
I_1 = fundamental frequency rms current (in amps or 100%)
A similar equation for voltage THD results from V being substituted for I in the above. Using the values from Table 1-1, the THD_I for a single-phase converter is around 95% versus 30% for a three-phase converter, based on odd harmonics up to the 50^{th}. Up until now, because the typical system impedance up to a harmonic source is reasonably low and the typical harmonic source is a relatively small load, the resulting THD_V (in %) will usually be in the single digits. The harmonic content and THD can be obtained for different levels of load for some devices. For example, a battery charger has a variable load characteristic and the harmonic content and THD varies as a function of load. It us usually sufficient to note the THD and % of individual harmonics at rated load. At lower levels of load, the resulting percentages (of individual harmonics and THD) are usually offset by the lower base current at that load. For example, with two loads having the same base current, one that produces 20% THD_I at 50% load is no worse than one which produces 10% THD_I at 100% load. They both produce the same distortion in amperes. One of the way out to resolve the issue of harmonics would be using filters in the power system. Installing a filter for nonlinear loads connected in power system would help in reducing the harmonic effect. The filters are widely used for reduction of harmonics. With the increase of nonlinear loads in the power system, more and more filters are required.

SHUNT ACTIVE FILTERS

The basic compensation principle of the shunt active 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. shunt active filter can be used to eliminate current harmonics and reactive power compensation.

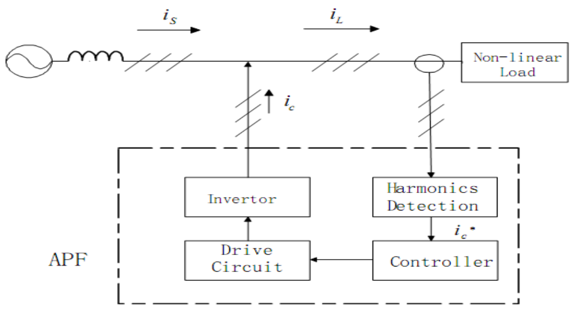


Fig.2 Block diagram of shunt active filter

from fig.2 the instantaneous currents can be written as

$$i_s(t) = i_L(t) - i_c(t) \quad (2)$$

The source voltage is given by

$$v_s(t) = V_m \sin \omega t \quad (3)$$

if a nonlinear load is applied, then the load current will have a fundamental component, and the harmonic components can be represented as;

$$i_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \quad (4)$$

$$i_L(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \quad (5)$$

Instantaneous load power can be given as

$$p_L(t) = v_s(t) * i_L(t) \quad (6)$$

$$p_L(t) = V_m I_1 \sin^2 \omega t * \cos\phi_1 + V_m I_1 \sin \omega t * \cos \omega t * \sin \phi_1 + V_m \sin \omega t * \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \quad (7)$$

$$p_L(t) = p_f(t) + p_r(t) + p_h(t) \quad (8)$$

From equation (4) real (Fundamental) power is drawn by the load

$$p_f(t) = V_m I_1 \sin^2 \omega t * \cos\phi_1 = v_s(t) * i_s(t) \quad (9)$$

From equation (6) the source current supplied by the source, after compensation

$$i_s(t) = \frac{p_f(t)}{v_s(t)} = I_1 \cos\phi_1 \sin \omega t = I_{sm} \sin \omega t \quad (10)$$

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

$$I_{sp} = I_{sm} + I_{sL} \quad (11)$$

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:

$$i_c(t) = i_L(t) - i_s(t) \quad (12)$$

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

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.

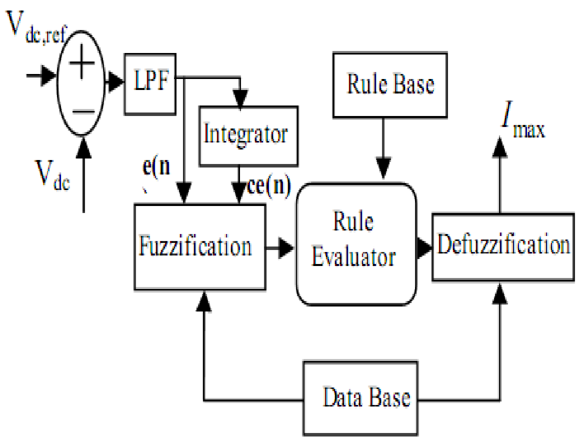
The peak value of the reference current has been estimated by regulating the dc side capacitor voltage of the PWM converter. This capacitor voltage is compared by a reference value and the error is processed in a PI controller. The output of the PI controller has been considered as t_e amplitude of the 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[8].

FUZZY LOGIC CONTROLLER

Fuzzy logic control is deduced from fuzzy set theory in 1965; where transition is between membership and non membership function. Therefore, limitation or boundaries of fuzzy sets can be undefined and ambiguous; FLC's are an excellent choice when precise mathematical formula calculations are impossible. Fig 2 shows block diagram of the fuzzy logic control scheme. In order to implement the control algorithm of a shunt active filter in a closed loop, the dc capacitor voltage V_{dc} is sensed and then compared with the desired reference value $V_{dc}ref$ .The error signal $e = V_{dc}ref - V_{dc}$ is passed through Butterworth design based LPF with a cut off frequency of 50 Hz; that pass only the fundamental component. The error signal) (n e and integration of error signal is termed as) (n ce are used as inputs for fuzzy processing. The output of the fuzzy logic controller limits the magnitude of peak reference current max I . This current takes care of the active power demand of the non-linear load and losses in the distribution system. The switching signals for the PWM inverter are generated by comparing the actual source currents Isa, Isb, Isc , ,with the reference current Isa^*, Isb^*, Isc^8 ,using the HCC method.

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

$$\begin{aligned} i_{sa}^* &= I_{sp} \sin \omega t, \\ i_{sb}^* &= I_{sp} \sin(\omega t - 120°), \\ i_{Sb}^* &= I_{sp} \sin(\omega t + 120°), \end{aligned} \quad (13)$$



Th c equipment to produce harmonic current components that cancel the harmonic current components that cancel the harmonic current components from the nonlinear loads.. In this configuration, the filter is connected in parallel with the load being compensated .Therefore the configuration is often referred to as an active parallel or shunt filter with fuzzy logic controller.

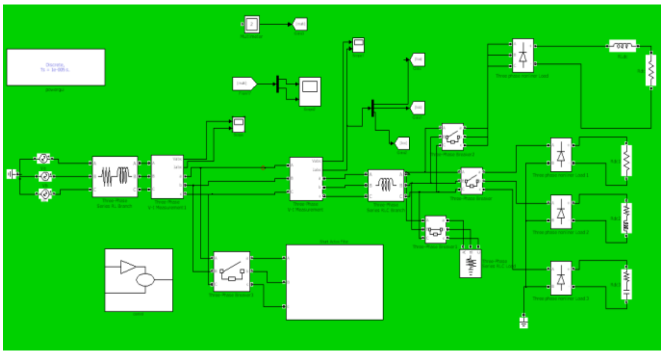


Fig.4 MATLAB model of shunt active filter

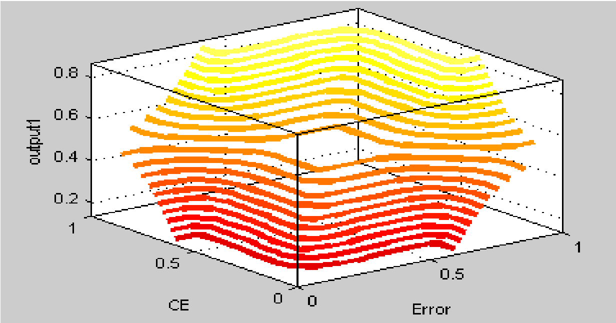


Fig.5 fuzzy logic surface viewer for fuzzy controller

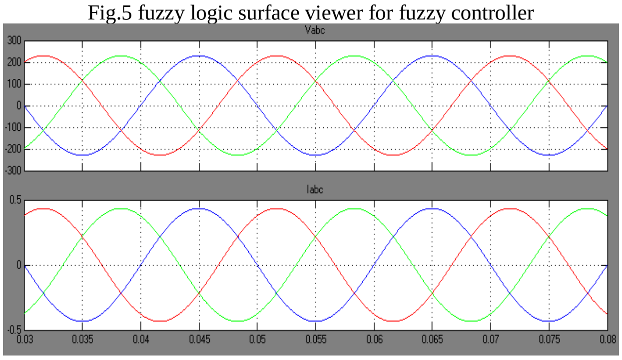


Fig. 6. Voltage and current waveform with connected liner load for CB1 closed

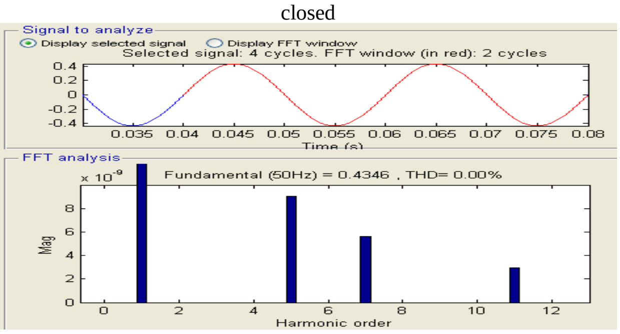


Fig.7.Order of harmonics of the current waveform with liner load CB1 closed (THD=0.0%)

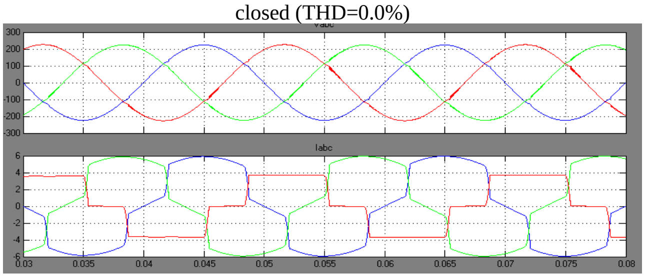


Fig. 8. Voltage and current waveform with connected non-liner load for CB2,CB3 are closed

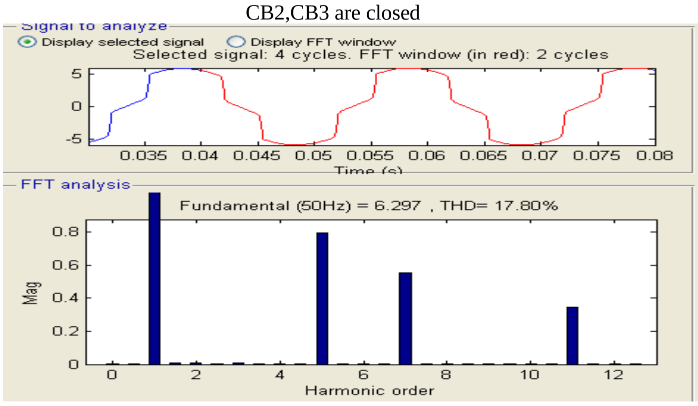


Fig. 9.Order of harmonics of the current waveform with connected non-liner load for CB2,CB3 are closed (THD=17.80%)

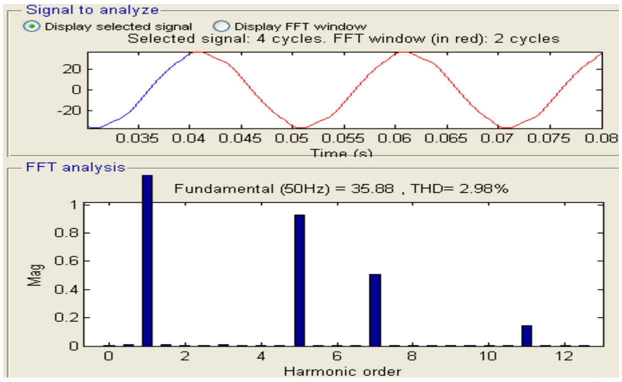


Fig. 10. Voltage and current waveform with connected shunt active filter for CB2,CB3 and CB4 are closed

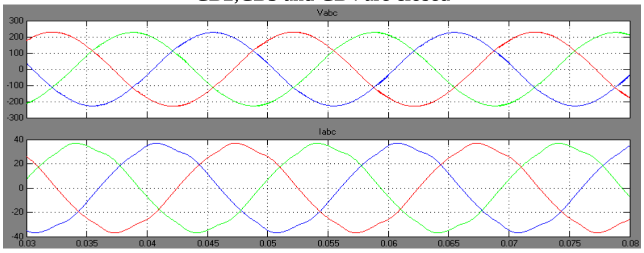


Fig.11.Order of harmonics of the current waveform with connected non-liner load for CB2,CB3 are closed (THD=2.98%)

Based on the above discussion, the proposed system is simulated in MATLAB®. The source voltage is three phase 230 V and 50 Hz with phase diffence 120 degree, with shunt active power filter and fuzzy logic controller. fig.5 shows fuzzy logic surface viewer for fuzzy controller for FIS system.Fig 6. Voltage and current waveform with connected liner load for CB1 closed and Fig. 7.Order of harmonics of the current waveform with liner load CB1 closed (THD=0.0%).Fig.8.Voltage and current waveform with connected non-liner load for CB2,CB3 are closed. Fig.9.Order of harmonics of the current waveform with connected non-liner load for CB2,CB3 are closed (THD=17.80%). Figure 10. Voltage and current waveform with connected shunt active filter for CB2,CB3 and CB4 are closed. Fig.11.Order of harmonics of the current waveform with connected non-liner load for CB2,CB3 are closed (THD=2.98%).

CONCLUSIONS

In this work we present an analysis and MATLAB® simulation of a shunt active filter. This system is used to eliminate current harmonics generated by a nonlinear load .We chose the shunt active power filter, because of its advantages such as its variation to active changes of the load. The shunt active power filter system is implemented with voltage source inverter and is connected at PCC for filtering the current harmonics.The performance of a Fuzzy logic controlled based shunt active filter is verified. Order of harmonics of the current waveform (THD=17.80%) with connected non-liner load reduced to (THD=2.98%) with connected shunt active filter with fuzzy logic controller. This approach brings behind the THD of the source current that is in observance with IEEE-519 necessary harmonic standards.

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