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Neuro-Fuzzy Control Technique in Hybrid Power Filter for Power Quality Improvement in a Three-Phase Three-Wire Power System

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Abstract

Hybrid power filters have proven to play a vital role in harmonic elimination as well as reactive power compensation in power systems concentrated with highly nonlinear loads which has in the last decade increased due to industrial automation and use of power converters based systems in industries and our homes. This paper presents an approach to hybrid shunt active filter for compensating voltage/current harmonics in a three phase three wire system. It is a combination of a shunt C-type high-pass filter in parallel with an active filter controlled by a Neuro-fuzzy controller. The C-type will help to reduce component rating for active filter and suppress the overall filter resonance while active filter compensate for the low order harmonics. A three phase converter supplying highly inductive load has been chosen as a typical nonlinear load for which a shunt hybrid power filter comprising of a shunt C-type high pass passive filter and a shunt active filter is employed to improve the power quality at the source end. Extensive simulation has been carried out and results obtained from the proposed approach gives comparatively better total harmonic distortion (THD) value.

Key words: Power Quality, Shunt Power Filter, C-type filter, Neuro-Fuzzy Controller, Total Harmonic distortion (THD).

1.0 Introduction

The widespread and increasing use of solid state devices in power systems which enhance the overall performance, efficiency, and reliability of industrial processes has lead to escalating ambient harmonic levels in public electricity supply systems. These harmonic levels must be reduced to IEEE 519 recommend THD levels, in order to safeguard consumers' plant and installations against overheating, overvoltage and other problems associated with harmonics. In three-phase three-wire systems with nonlinear loads a high level of harmonic currents in the three line conductors has been noticed in the existing systems commonly found in both homes and industrial setting. The effects of these currents in power distribution systems are not new, but only recently gained more research attention as clearly presented by (Czarnecki 2000). Advancement in semiconductor devices technology has also fuelled a revolution in application of power electronic devices over the last decade, and there are indications that this trend will continue according to (Akagi, 1994). Use of AC/DC and DC/AC power conversion commonly present in nonlinear loads such as converters, variable speed drives, arc equipment, uninterruptable power supply and many other household equipments are responsible for the rising problems related to power quality.

In their operation, nonlinear loads draw non sinusoidal periodic current even though sinusoidal voltage is applied.

1.1 Harmonic mitigation technique

Various harmonic mitigation techniques have been proposed to reduce the effect of harmonics. These techniques include passive filters, active power filters (APFs), and hybrid power filters (HPFs) among others. One of the most popular and effective HPFs is the shunt hybrid active power filter. It is mainly a APF (voltage source inverter) and high-pass passive filter, connected in parallel with the nonlinear load (Das, 2004. Tao, et al, 2006). Conventionally, a shunt APF is controlled in such a way as to inject harmonic and reactive compensation currents based on calculated reference currents, while the high passive filter attenuates high frequency generated by the APF switches. The injected currents are meant to cancel the harmonic and reactive currents drawn by the nonlinear loads.

On the other hand, artificial intelligence based controller has in recent time generated a great deal of interest in various applications, where control parameters change with time. Power electronic based systems inhibit these characteristics hence a combination of neural network which has learning ability and Fuzzy logic which has capability of capturing system nonlinearity can be used in APFs control (Koskal, 2009. Tsang and Chan, 2006. Shing and Jang, 1993). There are many ways of combining the two types of artificial intelligence as explain in (Delf, 1995), but in this paper ANFIS is used to control the APF.

The most important observation from the work reported by various researchers for power quality improvement is the design of active power filter under 'fixed load' conditions or for loads with slow and small variation (Sigh et al, 2006). As loads in practical life are mostly variable, there is the need to design an active power filter, which is capable of maintaining the THD well within the IEEE norms (IEEE 519-1992), under variable load conditions. This paper, therefore, presents an auto tuned active power filter using ANFIS-controller to control the harmonics under variable load conditions apart from balanced and unbalanced load conditions.

2.0 Shunt Active Filter (APF)

The concept uses power electronics technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load and provide reactive power required by the load. Fig. 1 shows the components of a typical APF system and their connections.

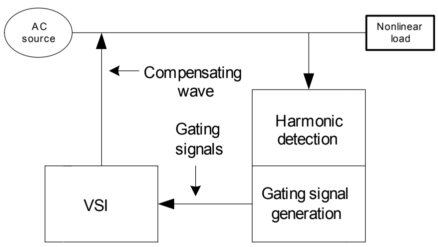


Figure.1. General structure of APF

The voltage-source-inverter (VSI)-based shunt active power filter has been used in recent years and recognized as a viable solution. The control scheme, requires compensating currents determined by sensing line currents only, which is simple and easy to implement. The scheme has been using a conventional proportional plus integral (PI) controller and recently fuzzy controller, for the generation of a reference current which depends heavily on mathematical and human expert respectively.

2.1 APF compensation principle

This is achieved by "shaping" the compensation current waveform (i_f), using the VSI switches. The shape of compensation current is obtained by measuring the load current (i_l) and subtracting it from a sinusoidal reference. It is then used as control signal for controller that controls the switches of the VSI as shown in fig.2.

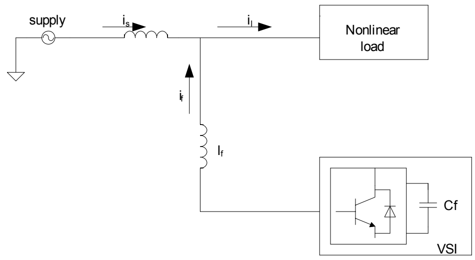


Figure 2. VSI-based APF currents flow

Figure 2: VSI-based APF currents flow

The aim of shunt APF is to obtain a sinusoidal source current (i_s) as illustrated in (1)

$$i_s = i_f + i_l \tag{1}$$

Thus the resulting total current drawn from the ac mains is sinusoidal. Ideally, enough reactive and harmonic current to compensate the nonlinear loads in the line should be generated.

2.2 APF control strategy

The performance of the active filter mainly depends on the methodology used to generate the reference current and the control strategy for the generation of the gating pulses.

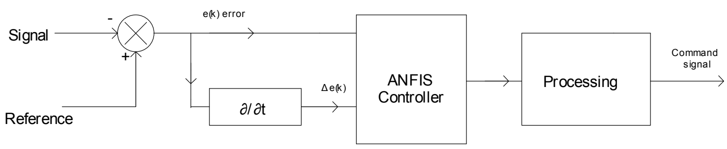


Figure 3: shunt APF control block diagram

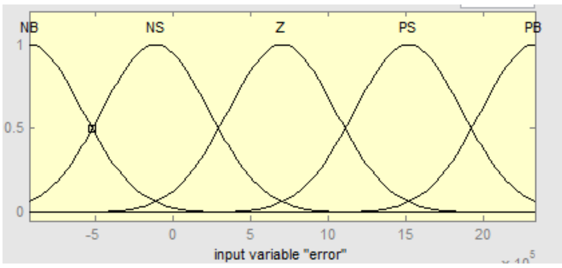
The shunt active filter Control block diagram of the proposed scheme is presented in Fig. 3. The task of the control block is to produce appropriate gating signals for the switching transistors (IGBTs). The control strategy is implemented in three stages. In the first stage, the essential current signals are measured to gather accurate system information. In the second stage compensation currents are derived based on ANFIS. In the third stage the gating signals for the solid-state devices are generated using PMW technique.

2.3 ANFIS Controller in APF

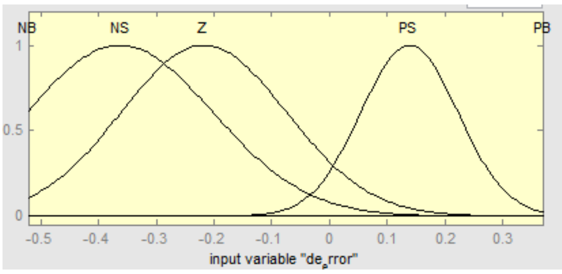
To design the ANFIS controller, variables which can represent the dynamic performance of the plant is chosen as the inputs to the controller. It is common to use the error (*e*) and the rate of error (*de*) as controller inputs and one control output. Since ANFIS is based on Sugeno type FIS, the output may be linear or a constant. In the case of compensation current control, the two inputs are defined by;

$$e(k) = i_{ref} - i_f$$
$$\Delta e(k) = e(k) - e(k-1) \quad (2)$$

Where the i_{ref} is the reference current, i_f is the actual filter output, *e(k)* is the error and $\Delta e(k)$ is the change in error. The training data has been obtained using a PI controller. The inputs are converted into linguistic variables. Five bell shaped fuzzy membership functions; negative big (NB), negative small (NS), zero (Z), positive small (PS) and positive big (PB) were randomly assigned for the two inputs. The membership functions used for the inputs used after training are shown in fig. 4.



(a) Error membership functions



(b) Change in error membership function

Figure 4: Input membership function after training; (a) Error membership functions
(b) Change in error membership function

Using input/output data set obtained from PI controller, ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using a back-propagation algorithm. Five generalized bell membership functions were assigned but after training, inputs membership functions were adjusted as show in fig. 4. Associated rules are given in table 2. The controller is then used to generate control signal for the voltage source inverter that compensate distorted line voltage.

Table 1: Fuzzy rules generated by ANFIS

e(k) / Δe(k)	NB	NS	Z	PS	PB
NB	MF1	MF2	MF3	MF4	MF5
NS	MF6	MF7	MF8	MF9	MF10
Z	MF11	MF12	MF13	MF14	MF15
PS	MF16	MF17	MF18	MF19	MF20
PB	MF21	MF22	MF23	MF24	MF25

2.4 Gating pulse generation

In order to generate the compensation current that follows the current reference signal, the PMW strategy is adopted. The PMW can be carried out using numerous techniques. However, carrier-based PMW has been employed in this paper. It compares a high frequency periodic triangular waveform (the carrier signal) with a slow-varying waveform from the ANFIS controller (modulating signal). The carrier signal has a periodic waveform with period T_s and swings between -1 and 1. The signal is then passed through a relay or hysteresis comparator in order to eliminate noise which may be present. The output of the relay drives switches S_i and through inverter for S_i in each arm of the VSI as illustrated in fig.5, where, the switching action is defined by (3).

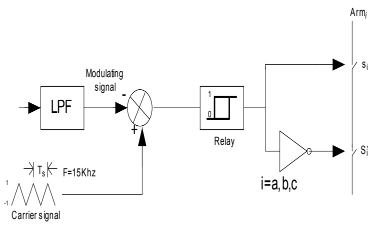


Figure 5: PMW comparator diagram

$$s(t) = \begin{cases} 1 & S_i \text{ on} \\ 0 & S'_i \text{ off} \end{cases} \quad (3)$$

3.0 C-type passive filter

The C-type HPF topology is employed in the proposed hybrid power filter. It consists of a capacitors C_a, C_b, an inductor L and an inductor bypass resistor R that must be determine. This filter will shunt a large percentage of high frequency harmonic components at or above the resonant frequency of 450Hz, which is the design frequency for this work. In designing this filter, it is necessary to specify the $I_{pf}(h_r)$, the maximum harmonic current allowed to flow into the system at h_r, and the tuned harmonic frequency. It is also known that the impedance of the C-type passive filter varies with harmonic order. If the reactive power supplied by the filter is known, the value of C_a can determine as follows;

$$X_{C(a)} = \frac{3V_{CN}^2}{Q_C}, \quad C_a = \frac{1}{2\pi f_1 X_c} \tag{4}$$

Where f_1 is the fundamental frequency. V_{CN}, and Q_C are system phase voltage and reactive power respectively.
The other parameters of the C-type high pass filter has been determined using current transfer function since the filter will inject current through source current, this can be determine as follows;

$$H_{hp}(s) = \frac{A}{s(\frac{s}{\omega_p}+1)} \cdot \left[\left(\frac{s}{\omega_\circ}\right)^2 + \frac{1}{Q}\left(\frac{s}{\omega_\circ}\right) + 1\right] \tag{5}$$

$$A = \frac{1}{C_a}, \quad \omega_\circ = \frac{1}{\sqrt{LC_a}}, \quad \omega_p = \frac{R}{L}, \quad Q = R\sqrt{\frac{C_a}{L}}$$

Where, A is the gain coefficient, ω_o is the series resonant frequency, ω_p is pole frequency and Q is HPF quality factor. It is assumed at the tuned frequency the X_{Cb} and X_{Lf} are equal. The parameters used for this case are as shown in table 2.

Table 2: C-type high-pass filter parameters

C_a	470µF
C_b	10µF
L_f	12mH
R	2Ω

The source parameters are Vs=415V, 50Hz system with 0.1Ω and 1mH source resistance and inductance, respectively.

4.0 Simulation results

This section presents the details of the simulation carried out to demonstrate the effectiveness of the proposed control strategy and topology for hybrid power filter in a three-phase system to reduce harmonics induced by nonlinear load

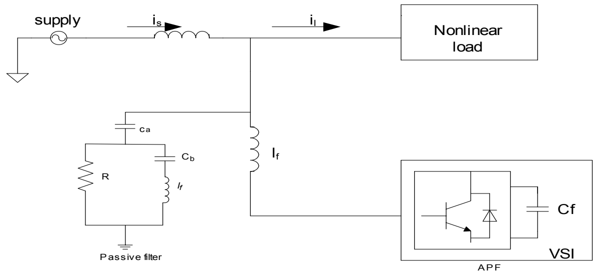


Figure 6: Single phase equivalent of the system

Fig.6 show single phase equivalent of the system used to carry out the analysis. It consists of a supply system, nonlinear load with uncontrolled rectifier and the proposed hybrid power filter. The active filter has been connected to the test system through inductor (l_f). MATLAB/SIMULINK environment was used to model and simulate the test system with and without the proposed filter as shown in appendix A.

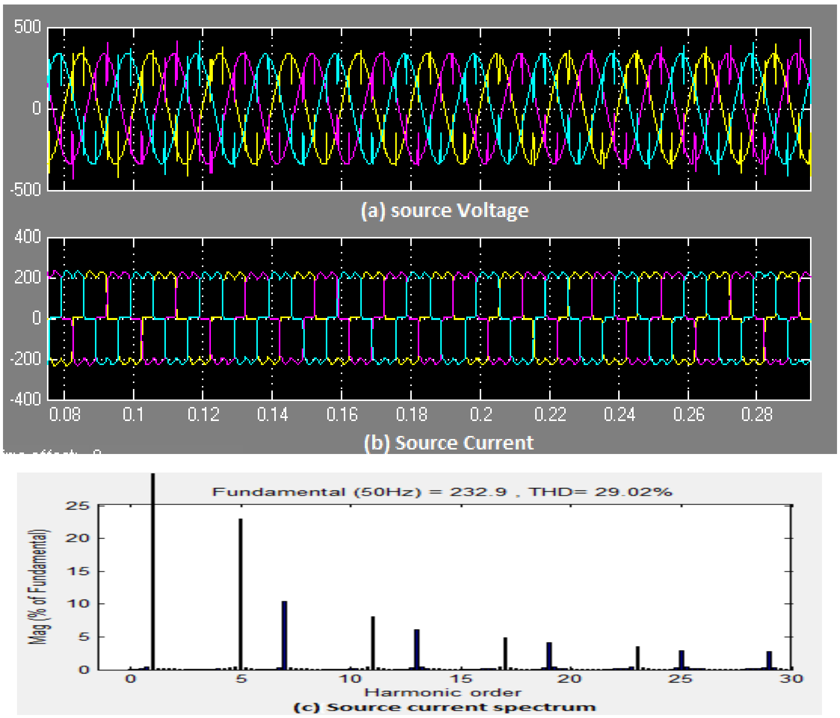
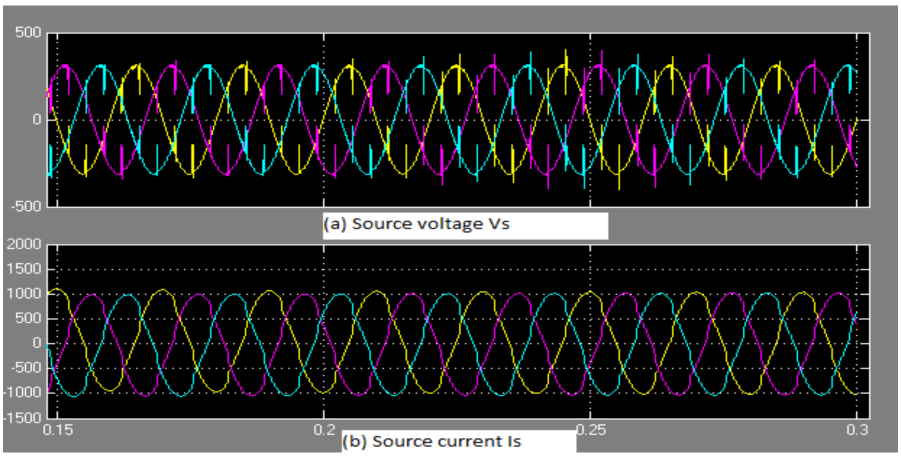


Figure 7: Simulation results without filter; a) Line voltage, b) Line current and c) Line current THD

Fig.7 (a),(b) shows the three-phase voltage and current respectively in absence of filter, it is clear that with nonlinear load such as DC drive connected to utility system, the supply waveforms deviate away from the sinusoidal. While, fig. 7(c) shows the harmonic spectrum of the distorted current waveform. The THD of the distorted line current is 29.02%. From this, it is evident that the supply current is distorted due to presence of $6n \pm 1 \; where \; n = 1,2,3 \ldots$ order harmonics in the line.



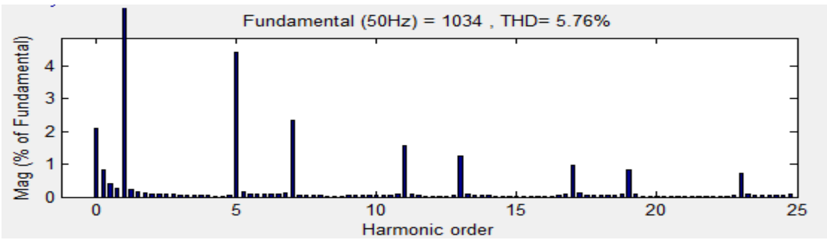


Figure 8: simulation results with APF connected

The simulation results of the system with shunt APF are shown in Fig.8 When the shunt APF is applied, the injected compensation current forces the source current to become a near sinusoidal waveform. It can also be seen that the source current waveform is in phase with the source voltage waveform, resulting to a unity power factor. Also, appreciable amount of high frequency harmonics can still be notice. This is due to the high frequency switching ripple of the compensation current and the presence of inductor (l_f). When the high frequency switching ripple is injected into the point of common coupling (PCC), it distorts the source voltage, and source current waveforms to some extend hence need for the C-type high passive filter to attenuate high frequency present in the power line.

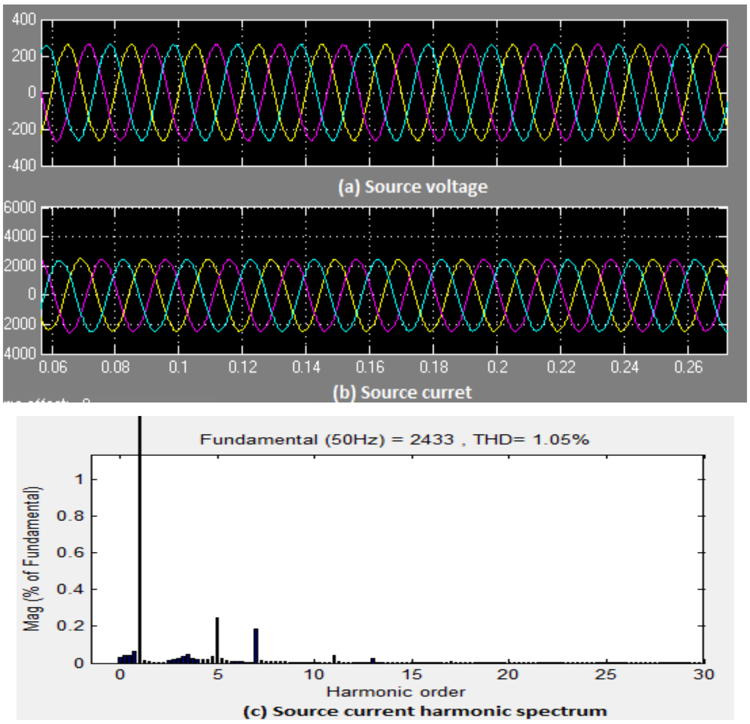


Figure 9: Simulation results with proposed HPF

C-type passive HPF is placed in parallel with the shunt APF at the PCC. The C-type HPF provides a path for high frequencies higher than the tuned frequency to flow through it. Fig.9 shows the simulation results with the proposed hybrid power filter, the total harmonic distortion has reduced drastically to 1%. Compared to simulation results without C-type filter shown in Fig.8, the switching ripples in the source current are greatly reduced. The filter provides a path for the high frequency switching ripple to flow as it can be evident by harmonic spectrum through the C-type filter as shown in fig.10.

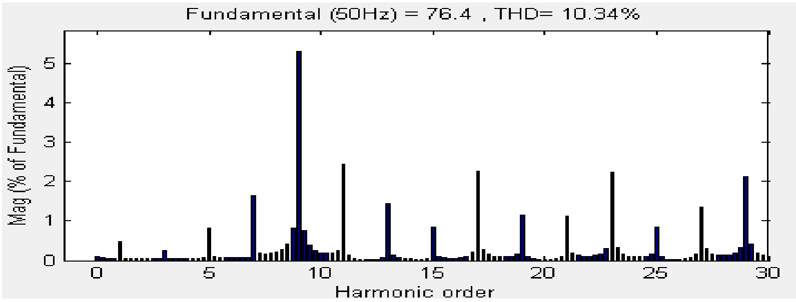


Figure 10: C-type passive filter harmonic spectrum

The filter was also tested under unbalanced and variable loads conditions which gave effective THD reduction as summarized in table 3.

Table 3: THD under different load conditions

Load conditions	THD	
	Without filter	With filter
Balanced	24.23%	1.45%
unbalanced	35.02%	2.00%
Variable	29.09%	1.02%

5.0 Conclusion

This paper has presented a new topology of power filter that can be used in a three-phase three-wire system, that consist of C-type high pass filter and APF controlled by ANFIS controller. The proposed Shunt Hybrid Filter can compensate for balanced and unbalanced nonlinear load currents. It captures effectively system parameter hence improved filtering performance. Results show that system limits THD percentage of source current from 29.02% to 1.05% which is much less that the prescribed value under IEEE-519 standard of 5%. Power factor and Reactive power compensation are also improved.

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