520 *Journal of Electrical Engineering & Technology, Vol. 3, No. 4, pp. 520~528, 2008*

Harmonic Mitigation and Power Factor Improvement using Fuzzy Logic and Neural Network Controlled Active Power Filter

V.Suresh Kumar†, D.Kavitha*, K.Kalaiselvi and P.S.Kannan***

Abstract – This work focuses on the evaluation of active power filter which is controlled by fuzzy logic and neural network based controller for harmonic mitigation and power factor enhancement. The APF consists of a variable DC voltage source and a DC/AC inverter. The task of an APF is to make the line current waveform as close as possible to a sinusoid in phase with the line voltage by injecting the compensation current. The compensation current is estimated using adaptive neural network. Using the estimated current, the proposed APF is controlled using neural network and fuzzy logic. Computer simulations of the proposed APF are performed using MATLAB. The results show that the proposed techniques for the evaluation of APF can reduce the total harmonic distortion less than 3% and improve the power factor of the system to almost unity.

Keywords: active power filter, fuzzy logic, harmonics, neural network, power quality

1. Introduction

The purpose of a active power filter (APF)/power line conditioner is to compensate the utility line current waveform so that it approximates a sine wave in phase with the line voltage when a nonlinear load is connected to the system. Classically, shunt power line conditioner (shunt passive filter) consists of tuned LC filters and/or high pass filters are used to suppress harmonics and power capacitors are employed to improve the power factor of the utility/mains. But these conventional methods have the limitations of fixed compensation, large size and can also excite resonance conditions [1,2]. Hence shunt active power filters are introduced as a viable alternative to compensate harmonics and improve power factor. Two fundamental approaches to improving power quality with APFs are correction in the time domain and correction in the frequency domain.

In early APF designs, PWM based methods such as constant frequency control [3-5], sliding mode control [6-8], hysteresis control [9,10], and triangular waveform control [11-13] are used to control the switches in the APF with time domain approach. The main shortcoming of this method is that, in order to obtain optimum results, relatively high switching frequencies are needed, which subsequently leads to high switching losses. Frequency domain methods include predetermined harmonic injection [14] and PWM based techniques such as optimized injection method [15] and adaptive frequency control [16] are proposed as alternative to time domain approach. The switching frequencies for frequency domain methods can be much lower than time domain schemes, resulting in much lower switching losses. The main disadvantage of frequency domain method is longer computational time than time domain methods. Nowadays high speed processor available to reduce computational time in practical.

Whether it may be time domain or frequency domain approach, the conventional APFs are too complex and costly in practical, when the quantity to be controlled varies over a wide range [17-19]. Hence an increasingly attractive alternative is to use artificial intelligent (AI) control schemes such as fuzzy logic, neural network, embedded system etc. In this work, fuzzy logic and neural network based single phase APF is proposed using frequency domain approach. Initially, compensation current to eliminate harmonic components in the line current is estimated using adaptive neural network. Using the estimated current, the proposed APF is controlled using fuzzy logic and neural network techniques.

2. AI Based Active Power Filter

The block diagram representation of APF set up is shown in Figure 1. First, the required compensation current is estimated using ANN algorithm [23]. Then, an APF is used to generate estimated compensation current. The switching functions of APF is controlled by fuzzy logic and neural network based controller such that the actual compensation current ($I_{C,}$ actual) and reference

---

† Dept. of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai, India (vskeee@tce.edu)
* Dept. of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai, India
** Dept. of Computer Science and Engineering, Sethu Institute of Technology, Madurai, India (shanthkalai@yahoo.co.in)

Received 29 February 2008 ; Accepted : 28 May 2008

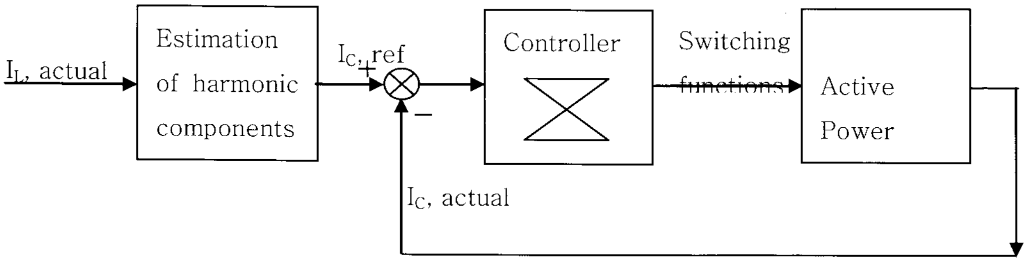

Fig. 1. Block diagram of AI based APF set up

Table 1. AC side output voltage VAB of the APF

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$V_{AB}(n)$	-1.4	-1.2	-1.0	-0.8	-0.6	-0.4	-0.2	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4
Sw	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
d_3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1
d_2	1	1	0	0	1	1	0	0	0	1	1	0	0	1	1
d_1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

compensation current (I_C, ref) are equal.

The APF studied here is illustrated in Fig. 2 [20]. Basically, it consists of two primary components, a variable DC voltage source (VDVS), which provides several levels of DC voltage, and a DC/AC converter, which applies a positive or negative polarity to the variable AC voltage. Because of the current-voltage relationship at inductor L_{com}, this arrangement provides a positive or negative slope to the compensation current i_{com} (t).

The VDVS is composed of six bidirectional AC switches (S_{d1} - S_{d6}), three isolated DC voltage sources (V_1 - V_3), three control signals (d_1 - d_3), and three NOT gates. The bidirectional AC switches allow both positive and negative current to flow through the VDVS in order to provide an alternating compensation current. Voltage sources V_1 - V_3 consist of three different levels of DC voltage, so that the VDVS can provide up to eight different levels of voltage V_D. This allows for more precise tracking of the reference compensation current at a given switching frequency than would a fixed DC output voltage, as is used in [3], and [16-18]. The switch control signals d_1 - d_3 and the three NOT gates shown in Figure 2 determine which combination of sources V_1 - V_3 will be used at any instant of time.

The DC/AC converter consists of two switch-pairs (S_1, S_4) and (S_2, S_3), control signal sw, and two NOT gates. The switch pairs operate in either of two complementary modes, depending on the status of control signal sw. In Mode I, sw = 1, switches S_1 and S_4 are on, S_2 and S_3 are off, and the converter's AC side output voltage is $V_{AB} = +V_D$. In Mode II, sw = 0, both switch-pair states are opposite their Mode I status, and $V_{AB} = -V_D$. If V_1, V_2 and V_3, in the VDVS have per unit values of 0.2, 0.4, and 0.8, respectively, voltage V_{AB} can have any of the fifteen possible values ($V_{AB}(n)$,n = 1.. .15) as shown in Table 1, which correspond to the states S(n) of the four control signals sw, d_1, d_2, and d_3.

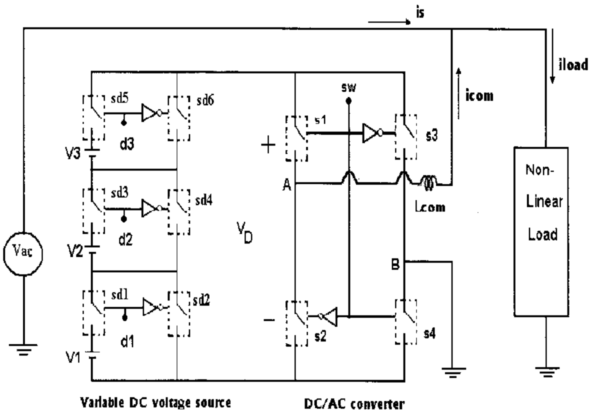

Fig. 2. Voltage type APF

FFVS control method [20] associated with the mathematical model of the system is used to determine the i_{com}. The switching principle of the FFVS method at a fixed sampling frequency is shown in Fig. 3. Where, i^*_{com} is the desired (reference) compensation current and i_{com} is produced (actual) compensation current. The compensation current at a specific sampling point, for example, $i_{com}(T_3)$ at t = T_3, can be determined from the previously determined current, $i_{com}(T_2)$.

The compensation current, i_{com} is obtained by calculating voltage across inductor L_{com}. The voltage across the L_{com} is,

$$V_{AB} - V_s(T_n) = \frac{L_{com}}{T}\{I_{com}(T_{n+1}) - I_{com}(T_n)\} \tag{1}$$

From (1), the current at n+1th instant is given by,

$$I_{com}(T_{n+1}) = \{V_{AB} - V_s(T_n)\} \times \frac{T}{L_{com}} + I_{com}(T_n) \tag{2}$$

Where T_n is the current instant of time at which $i_{com}(t = T_n)$. The APF attempts to produce an $i_{com}(t)$ that tracks

i^*_{com} (t) by controlling the ten switches shown in Fig. 2 to produce the value of $V_{AB}(T_n)$ from Table 1 that gives the best value of $i_{com}(T_{n+1})$ as determined with (2). Then at each successive sampling point, i.e., at $t = T_{n+1}$, where the reference compensation current i^*_{com} $(t = T_{n+1})$ is known, (2) is solved for $i_{com}(T_{n+1})$ fifteen times.

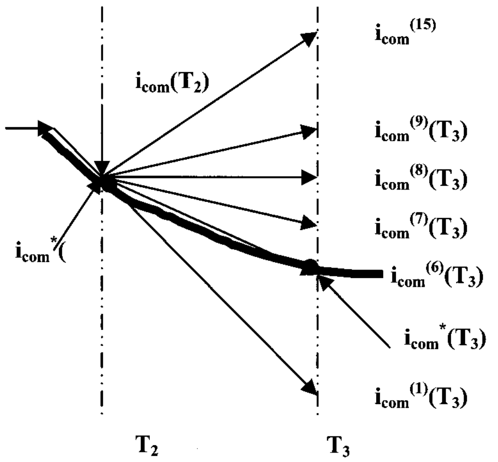

Fig. 3. Operation of FFVS control

For each possible value of V_{AB} followed by application of the IF – THEN rule: IF $| i^*_{com}(T_{k+1})\text{-}i_{com}(n), n=1,2....15|$ is minimum, THEN the control signal set for sw, d_1,d_2, and d_3 in Fig. 2 is S(n) from Table 1. The result of the process is that $i_{com}(t)$ consists of a sequence of short connected linear segments, one for each sampling interval, as shown in Fig. 3, each of which is the solution of (2) in that interval. By applying this method to the entire set of samples from an entire period of the 50 Hz frequency, all the control signal sets needed to produce the compensation current are determined.

3. Fuzzy model of APF

3.1 Fuzzification

Fuzzification converts input data into suitable linguistic values. That is, the process of converting crisp values to fuzzy values is known as fuzzification. Each sensor input is compared to a set of possible linguistic variables to determine membership.

Fig. 4 shows the fuzzy variable quantization scheme used. It is composed of seven triangular shaped membership functions with the relevant linguistic labels shown. The seven fuzzy variables taken are negative large, negative medium, negative small, zero, positive small, positive medium, positive large. In this problem, the values to be converted are the difference in reference compensation current between two time instants. Initially, the APF output required for different reference compensation current is estimated using FFVS technique and it is used as a knowledge data for fuzzy modeling. The maximum difference in reference compensation current is found to be 45A and the range from - 45 to + 45A is chosen as a crisp values. Each value falls under two fuzzy variables. The membership values for the two variables are determined. The fuzzification function is given by, $f:[-a,a]\rightarrow\{0,1\}$ is applied to the variable $I_{com}(T_{n+1})$ - $I_{com}(T_n)$ in order to approximate their measurement uncertainties with values between 0.0 and 1.0.

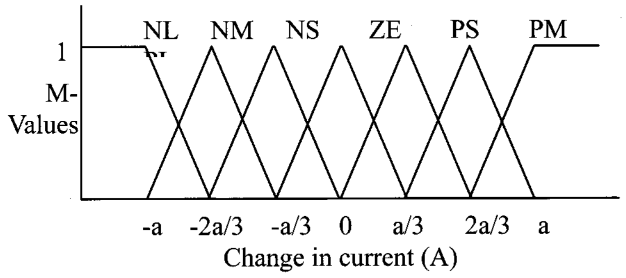

Fig. 4. Fuzzy variable quantization

3.2 Fuzzy Rule Base

It consists of a database with the necessary linguistic definitions (rule set). Each rule has an antecedent statement with an associated fuzzy relation. Degree of membership for antecedent is computed.

IF (ANTECEDENT) THEN (CONSEQUENCE)

In this problem, it is known that,

$$\{I_{com}(T_{n+1}) - I_{com}(T_n)\} \propto \{V_{AB} - V_s(T_n)\} \tag{3}$$

Then,

$$\{I_{com}(T_{n+1}) - I_{com}(T_n)\} + V_s(T_n) \propto V_{AB} \tag{4}$$

In this case, the variable to be determined is V_{AB}.

Let
$$T = V_{AB} - V_s(T_n) \tag{5}$$

Then,

$$I_{com}(T_{n+1}) - I_{com}(T_n) \propto T \tag{6}$$

From the data base provided by the FFVS technique, the V_{AB} and Vs(Tn) values are known for particular load. From the analysis, a rule base is formed as shown in Table 2.

Table 2. Fuzzy Rule Base

NL	NM	NS	ZE	PS	PM	PL
-0.3	-0.2	-0.1	0	0.1	0.2	0.3

3.3 Defuzzification

Defuzzification creates a combined action fuzzy set which is the intersection of output sets for each rule, weighted by the degree of membership for antecedent of the rule and produces a non-fuzzy control action that represents the membership (function of an inferred fuzzy control) action.[21,22].

The one most often used is called the center of gravity method in which the inferred (numerical) value of the control action is given by [21],

$$T = \frac{\sum_{i=1}^{P} m_i T_i}{\sum_{i=1}^{P} m_i} \qquad (7)$$

Where, T_i is singletons of the control action set and m_i, are the corresponding degree of fulfillment. P is the number of effective rules. In this case, defuzzification is done using the centroid method and the control values T are calculated. Now, the required APF output is obtained by the following equation.

$$V_{AB} = T + V_s(T_n) \qquad (8)$$

3.4 Results and Discussions

The system is modeled as fuzzy. The performance of the proposed APF is studied using computer simulation with MATLAB. In the test case, a typical six pulse rectifier with RLC is used as the nonlinear load. Harmonic components at frequencies higher than 650 Hz (13th order) are neglected, since they can be easily eliminated.

First, the output of APF (V_{AB}) is obtained as shown in Fig. 5 using (8). The APF output is generated according to the existence of harmonic components. Second, the compensation current (I_{com}) is generated and injected in to the line. The comparison between reference compensation and actual current of APF at sampled instants is shown in Fig. 6. Then, the line current is obtained before and after compensation at different load levels. For example, with fundamental current (I_1) of 250A, the line current before and after compensation is obtained as shown in Fig. 7. The line current before compensation is highly distorted, but the compensated line current is more nearly sinusoidal. After injecting the compensation current through the APF, the total harmonic distortion (THD) is reduced to 3.56% from 14.06 and the power factor is improved from 0.866 to 0.991. The harmonic spectrum of line current before and after compensation is shown in Fig. 8 and Fig. 9.

Similarly, the line current is obtained with I_1 of 195A. The current before and after compensation is shown in Fig. 10 and corresponding harmonic spectrum is shown in Fig. 11 and Fig.12. The THD is reduced to 3.80% from 17.28%.

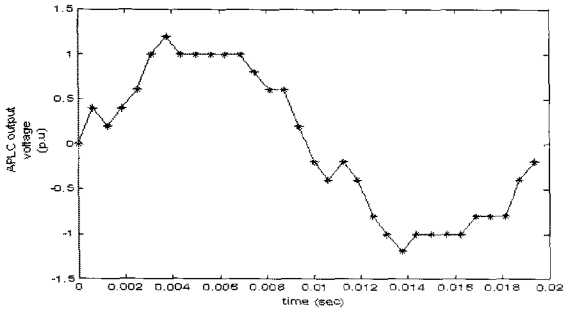

Fig. 5. Output of APF for one cycle

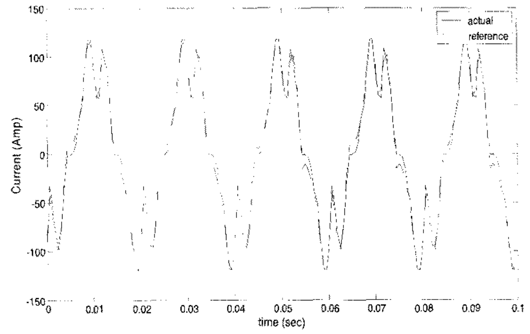

Fig. 6. Comparison between reference and actual current

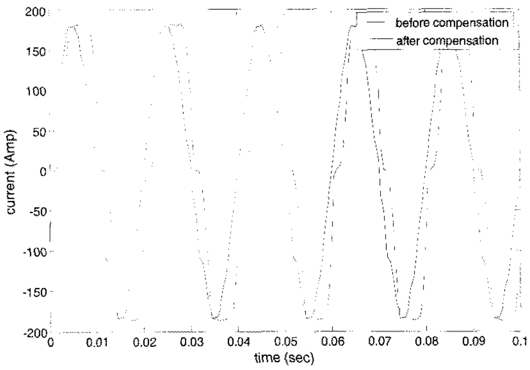

Fig. 7. Current before and after compensation at 250A

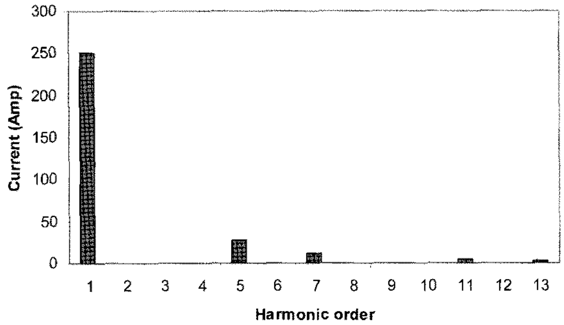

Fig. 8. Current spectrum before compensation at 250A

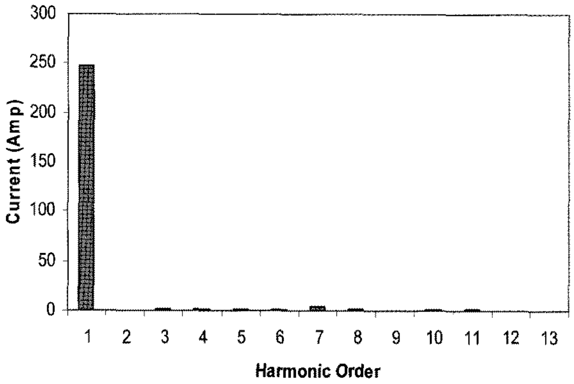

Fig. 9. Current spectrum after compensation at 250A

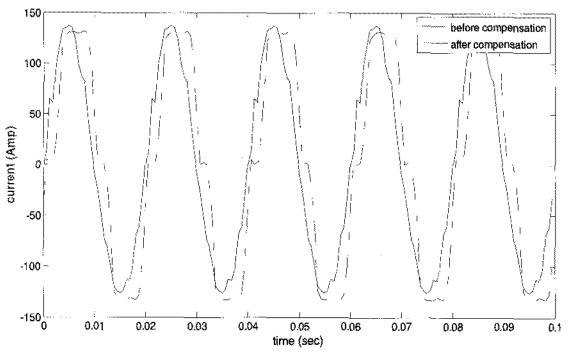

Fig. 10. Line current before and after compensation at 195A

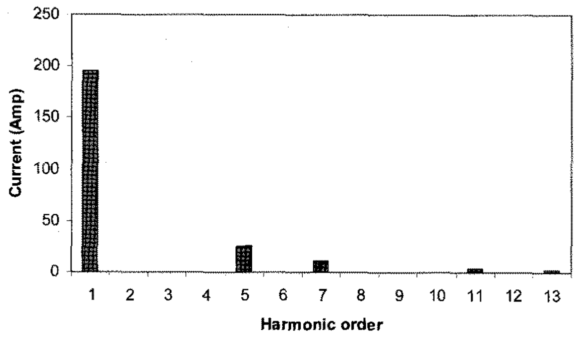

Fig. 11. Current spectrum before compensation at 195A

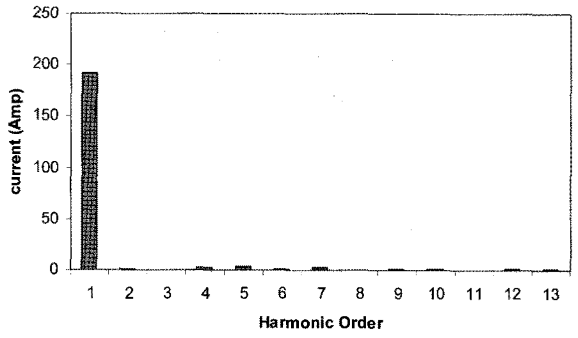

Fig. 12. Current spectrum after compensation at 195A

4. Neural Network Controlled APF

A neural network is a system composed of neuron like processing elements and their interconnections. The processing elements are interconnected by gain coefficients called weights. Changing the weights of the elements will alter the behavior of the network. The arrangements and strengths of the inter neuron connections determine the over all behavior of the neural network. A desired input - output relationship can be obtained by training the neural network (NN). The proposed APF uses feed-forward NN and back-propagation algorithm [19] for training the NN.

4.1 Neural Network Control

The neural network controller for the proposed APF consists of a single hidden layer in a feed forward structure and controls the ON and OFF states of the switches in the variable DC supply and the DC/AC inverter. Figure 13 illustrates a two layer feed forward neural network with n inputs and m outputs. The hidden layer consists of p neurons. The fully connected weight matrices W and V are initially non zero. The neural network is implemented in software and trained off line using the FFVS control scheme described below to obtain the training data, and the back propagation algorithm is used for training.

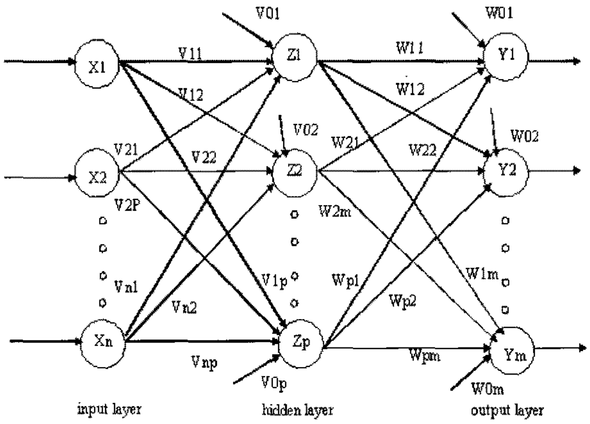

Fig. 13. Single hidden layer feed forward neural network

The training data obtained with the FFVS method are built up from a collection of 400 typical nonlinear load current waveforms obtained from the case studies. Back propagation training produces optimum weight matrices for the neural network to be used in on line control. In this problem, the values of n = m = p = 32. These numbers are fixed based on number of switching to be given to APF. For a 50 Hz system, the switching frequency is 50*32 = 1600Hz.

4.2 Results and Discussion

For on-line operation, the APF monitors both the source current and the load current. When it determines that the source current THD is higher than allowable limit, the well trained NN controller takes a number of equally spaced samples from one 50Hz cycle of the load current and produces control signals for the 10 switches. in the APF.

The output of NN controller and the output current of APF for those control signals are evaluated and compared with the compensation current are shown in Figure 14. The samples of load current are given as input to NN controller and the output is the AC side output voltage of APF. After injecting the compensation current through APF, the source current is estimated. The line current before and after compensation with fundamental current (I_1) of 250A is shown in Fig. 15. The line current before compensation is highly distorted, but the compensated line current is almost sinusoidal. After injecting the compensation current through the APF, the THD is reduced to 2.06% from 14.06% and the power factor is improved from 0.866 to 0.999. The harmonic spectrum of source current before and after compensation is shown in Fig. 8 and Fig. 16.

Similarly, the line current is obtained with I_1 of 195A. The current before and after compensation is shown in Fig. 17 and corresponding harmonic spectrum is shown in Fig. 11 and Fig. 18. The THD is reduced to 2.34% from 17.28%. Since the neural network is well trained and tested for different nonlinear load conditions, the line current becomes almost sinusoidal as shown in Fig. 17 even the load current is reduced.

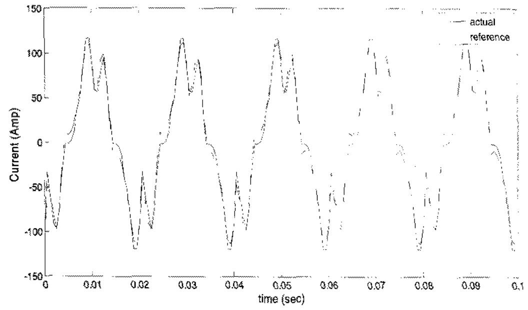

Fig. 14. Comparison between reference compensation and actual current (NN)

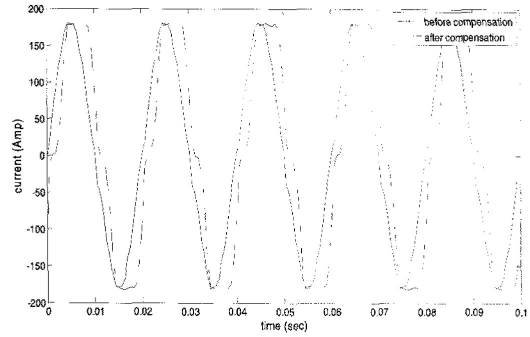

Fig. 15. Current before and after compensation at 250A

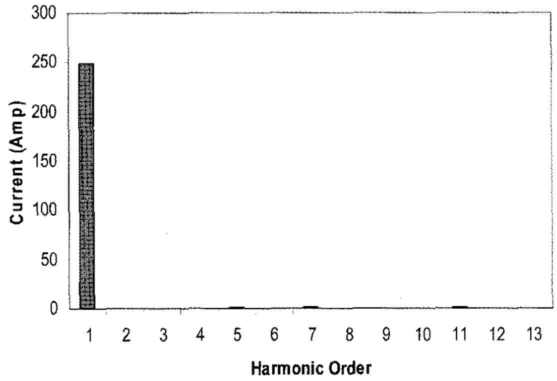

Fig. 16. Current spectrum after compensation at 250A

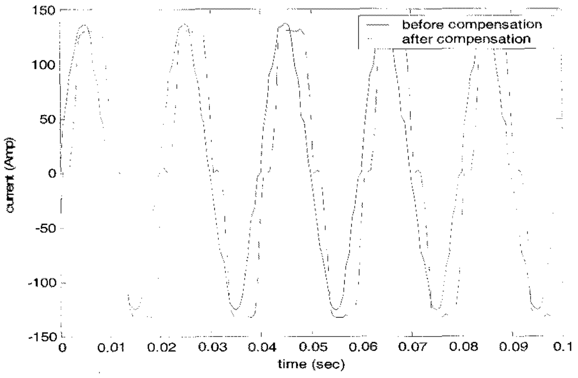

Fig. 17. Line current before and after compensation at 195A

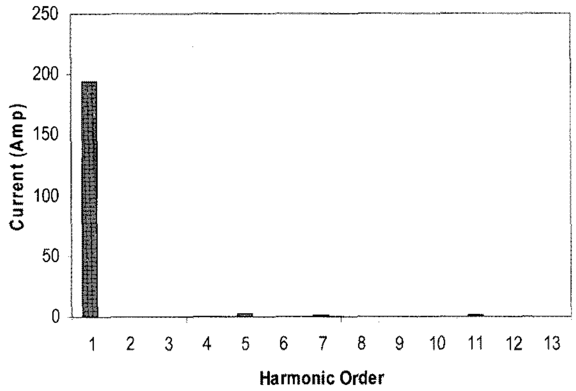

Fig. 18. Current spectrum after compensation at 195A

5. Fuzzy Logic and Neural Network based APF: A Comparison

Both fuzzy logic and neural network algorithms are implemented to control the APF such that the line current is sinusoidal in the case of nonlinear load. Even though both fuzzy logic and neural network based APF reduces the THD below 5% limit, the NN controller perform well comparatively. The comparison of THD and power factor before and after compensation is shown in Table 3 and Table 4 for two different load conditions. It is noticed that some interharmonic components are induced as shown in

Fig. 9 and Fig. 12 after the installation of APF with fuzzy logic control scheme. But the magnitude of these inter-harmonic components is negligible.

The mean absolute percentage error (MAPE), while estimating the actual compensation current through APF is given in Table 5. Since neural network is already well trained, the NN based APF takes very less time for execution. Also it is identified that the neural network controlled APF performs well irrespective of the loading conditions.

Table 3. Performance parameters before and after compensation with I_l of 250A

Parameter	Before compensation	After compensation	
		Fuzzy logic	ANN
THD (%)	14.06	3.56	2.06
Power factor	0.866	0.981	0.999

Table 4. Performance parameters before and after compensation with I_l of 195A

Parameter	Before compensation	After compensation	
		Fuzzy logic	ANN
THD (%)	17.28	3.80	2.34
Power factor	0.8423	0.987	0.999

Table 5. Mean absolute percentage error (MAPE)

Control Technique	Time for execution (seconds)	MAPE (in APF output states) (%)	MAPE (in injected compensation current) (%)
Fuzzy logic	4.2340	6.98	14.5
ANN	0.0106	3.38	11.6

6. Conclusion

A fuzzy logic and neural network based shunt active power line conditioner is investigated. The conventional technique requires an exact input-output relationship. Where as in ANN, it is not necessary to establish specific input- output relationships, but they are formulated through a learning process or through an adaptive algorithm. The neural network controller is developed based on the linguistic description and does not require mathematical model of the system, therefore offer more freedom of design. Similarly, while modeling the system as fuzzy, no accurate relationship is required.

Exhaustive simulations are carried out with different load conditions. Based on the simulation results, it can be concluded that, the fuzzy logic and ANN based active power line conditioner perform satisfactorily, for the compensation of harmonics and reactive power. Even though both fuzzy logic and ANN based APF perform well, comparatively the performance of ANN controlled APF is well and the THD of the source current was always reduced less than 3% and power factor was improved to almost unity. Neural networks have self-adapting and super-fast computing features that make them well suited to handle nonlinearities, uncertainties and parameter variations that can occur in the system.

References

[1] H.Akagi, "New trends in active filters for power conditioning", *IEEE Transactions on Industry Application*, Vol .32, pp 1312- 1322, Nov. 1996.

[2] H.Akagi and H.Fujita, "A new power line conditioner for harmonic compensation in power distribution systems," *IEEE Transactions on Power Delivery*, Vol.10, No.3, pp.1570-1575, July 1995.

[3] N. Mohan, "A novel approach to minimize line-current harmonics in the interfacing power electronics equipment with 3-phase utility systems," *IEEE Transactions on Power Delivery,* Vol. 8, pp. 1395–1401, July 1993.

[4] H. Akagi, A. Nabae, and S. Atoh, "Control strategy of active power filters using multiple voltage-source PWM converters," *IEEE Transactions on Industry Applications,* Vol. IA-22, pp. 460–465, May/June 1986.

[5] R. M. Duke, "The steady-state performance of a controlled current active filter," *IEEE Transactions on Power Electronics,* Vol. 8, pp. 140–146, Apr. 1993.

[6] D. A. Torrey and A. M. Al-Zamel, "A single-phase active power filter for multiple nonlinear loads," *in Proceedings of IEEE Applied Power Electronics Conference,* pp. 901–908, 1994.

[7] S. Saetieo, R. Devaraj, and D. A. Torrey, "The design and implementation of a three-phase active power filter based on sliding mode control," *IEEE Transactions on Industry Applications,* Vol. 31, pp. 993–999, Sept./Oct. 1995.

[8] H. D. Battista and R. J. Mantz, "Harmonic series compensators in power systems: Their control via sliding mode," *IEEE Transactions on Control System,* Vol. 8, pp. 939–947, Nov. 2000.

[9] H. Akagi, Y. Kanazawa, and A. Nabae, "Instantaneous reactive power compensators comprising switching devices without energy storage components," *IEEE Transactions on Industry Applications,* Vol. IA-20, pp. 625–630, May/June 1984.

[10] W. McMurray, "Modulation of the chopping frequency in DC choppers and PWM inverter having current-hysteresis controllers," *IEEE Transactions on Industry Applications,* Vol. IA-20, pp. 763–768, July/Aug. 1984.

[11] S. Kim, P. Enjeti, D. Rendusara, and I. J. Pitel, "A new method to improve THD and reduce harmonics generated by a three phase diode rectifier type utility interface," *in*

Proceedings of IEEE Industrial Applications Society Annual Meeting, pp. 1071–1077, 1994.

[12] L. A. Moran, J. W. Dixon, and R. R. Wallace, “A three-phase active power filter operating with fixed switching frequency for reactive power and current harmonic compensation,” *IEEE Transactions on Industrial Electronics*, Vol. 42, pp. 402–408, Aug. 1995.

[13] J.W. Dixon, J. J. Garcia, and L. Moran, “Control system for three-phase active power filter which simultaneously compensates power factor and unbalanced loads,” *IEEE Transactions on Industrial Electronics*, Vol. 42, pp. 636–641, Dec. 1995.

[14] A.Ametani, “Harmonic reduction in thyristor converters by harmonic current injection,” *IEEE Transactions on Power Application System*, Vol. PAS-95, pp. 441–449, Mar./Apr. 1976.

[15] G. H. Choe and M. H. Park, “A new injection method for AC harmonic elimination by active power filter,” *IEEE Transactions on Industrial Electronics*, Vol. IE-35, pp. 141–147, Feb. 1988.

[16] S. M. Williams and R. G. Hoft, “Adaptive frequency-domain control of PWM switched power line conditioner,” *IEEE Transactions on Power Electronics*, Vol. 6, pp. 665-670, Oct. 1991.

[17] W. R. A. Ibrahim and M. M. Morcos, “Artificial intelligence and advanced mathematical tools for power quality applications: A survey,” *IEEE Transactions on Power Delivery*, Vol. 7, pp. 668-673, Apr. 2002.

[18] A. Kumamoto, T. Hikihara, Y. Hirane, K. Oku, O. Nakamura, S. Tada, K. Mizuki, and Y. Ogihara, “Suppression of harmonic voltage distortion by neural network controlled active filter,” *in Proceedings of IEEE Industrial Applications Society Annual Meeting*, pp. 754-761, 1992.

[19] A. Medina-Rios, and H. A. Ramos-Carranza, “An Active Power Filter in Phase Coordinates for Harmonic Mitigation,” *IEEE Transactions on Power Delivery*, Vol. 22, NO.3, pp. 1991-1993, July 2007.

[20] Phumin Kirawanich and Robert M.O’connell, “ Fuzzy Logic Control of an Active Power Line Conditioner,” *IEEE Transactions on Power Electronics*, Vol.19, No.6, pp.1574-1585, Nov. 2004.

[21] D.Driankov, H.Hellendoorn, and M.Reinfrank, An Introduction to Fuzzy control, *Narosa Publishing Co.*, New Delhi, 1996.

[22] Timothy J.Rose, Fuzzy Logic with Engineering Applications, *McGraw-Hill*, New York, 1996.

[23] V.Suresh Kumar, D.Kavitha, K.Kalaiselvi, and P.S.Kannan, “Optimal Estimation of Harmonics in Power System using Intelligent Computing Techniques,” *in Proceedings of IEEE Neural Networks conference*, Orlando, USA, August 2007.

V. Suresh Kumar

He graduated in Electrical & Electronics Engineering from Madurai Kamaraj University, India in 1994 and post graduated in Power systems from National Institute of Technology, Tiruchi, India in 1995. He then obtained his Ph.D. in Power quality & Harmonics from Madurai Kamaraj University in 2006. In the year 2007, he visited the Pennsylvania State University, USA for post doctoral research. From 1997 he has been faculty of Electrical and Electronics Engineering at Thiagarajar College of Engineering, Madurai, India and currently working as Associate Professor. He has published 24 papers in national and international journals and conferences. His fields of interest include power quality and power electronics.

D. Kavitha

She graduated in Electrical & Electronics Engineering and post graduated in power system engineering from Madurai Kamaraj University, India in 2003 and 2005 respectively. She is working as Lecturer in Electrical Engineering at Thiagarajar College of Engineering, Madurai, India. Her area of interest is power system and power quality.

K. Kalaiselvi

She received B.E. degree in Computer Science & Engineering from Bharathidasan University, India in 2000 and post graduate degree in Computer Science & Engineering from Anna University, India in 2004. She is working as Lecturer in Computer Science & Engineering at Sethu Institute of Technology, Madurai, India. Her area of interest is artificial intelligence techniques.

P. S. Kannan

He graduated in Electrical & Electronics Engineering and post graduated in power system engineering from Madurai Kamaraj University, India in 1976 and 1979 respectively. He then obtained a Ph.D. in power system control from the same university in 1995. From 1979 he has been faculty of Electrical Engineering at Thiagarajar College of Engineering, Madurai, India and currently working as professor and Dean of the department. He has published more than 100 papers in national and international journals and conferences. His fields of interest include power systems, power quality improvement and energy management.