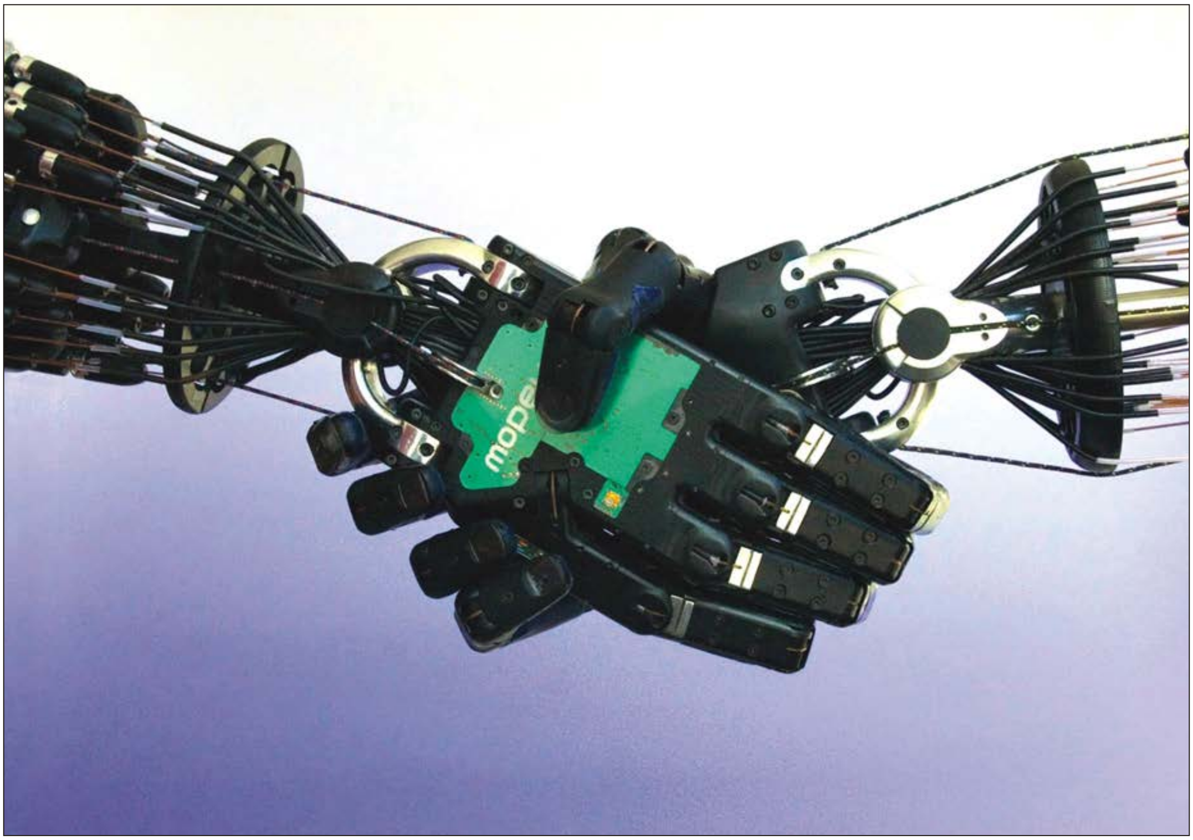

Journal of Artificial Intelligence

ISSN 1994-5450

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Artificial Intelligence 5 (1): 26-36, 2012
ISSN 1994-5450 / DOI: 10.3923/jai.2012.26.36

Fuzzy Logic Controller Optimization Based on GA for Harmonic Mitigation

[1]Rachid Dehini, [2]Brahim Ferdi and [1]Benaissa Bekkouche
[1]Department of the Sciences and Technology, University (Center) of Relizane, Algeria
[2]Department of the Sciences and Technology, University of Oran, Algeria

Corresponding Author: Rachid Dehini, Department of the Sciences and Technology, University (Center) of Relizane, Algeria

ABSTRACT

In this study, a pulse generation method to trigger the MOSFETs of a shunt active power filter (SAPF) inverter is examined. The proposed method is aimed to compensate current harmonic, as well as reactive power compensation, in power systems with a large concentration of non-linear loads. Design of optimal fuzzy logic controller by genetic algorithm method is presented. Some parameters defining the fuzzy controller (membership functions, fuzzy rules) are optimized simultaneously. In order to investigate the performance of this control method, all studies have been carried out using simulation with the MATLAB Simulink power system toolbox. The results of simulation study of new SAPF control technique presented in this paper are found to be quite satisfactory by assuring good filtering characteristics and high system stability.

Key words: Genetic algorithm, optimal fuzzy controller, membership functions, fuzzy rules, shunt active filter, total harmonic distortion

INTRODUCTION

Nowadays, with the widespread increase of power electronic loads in industry, significant non-linear loads appear in a considerable amount in harmonic injection and low power factor of power systems. They tend to introduce harmonics in voltage and current waveforms at the point of common coupling. The existence of current and voltage harmonics in power systems increases lines losses, decreases the power factor, and can cause timing errors in sensitive electronic equipments (Lopez *et al*., 2003; El-Mofty and Youssef, 2001).

Rapid improvement in power semiconductor device makes high-speed, high-power switching usable for the harmonic compensation modern power electronic technology (Ahmed, 2004). Active Power Filters (APF) have been considered as an effective solution for this issue and have been widely used.

The SAPF working is to sense the load currents and extract the harmonic component of the load current to produce a reference current (Liu *et al*., 2006). A block diagram of the system is illustrated in Fig. 1.

To control SAPF, many techniques are used, among them the classical PI controller and the relatively recent one the fuzzy controller. It is difficult to get satisfied control characteristics by using a normal linear proportional plus integral (PI) controller due to the nonlinearity of the system (SAPF + fast nonlinear load variations). Also, fuzzy controller design is not obvious process due to the fact that there is not a known systematic design techniques presently exist. Although the

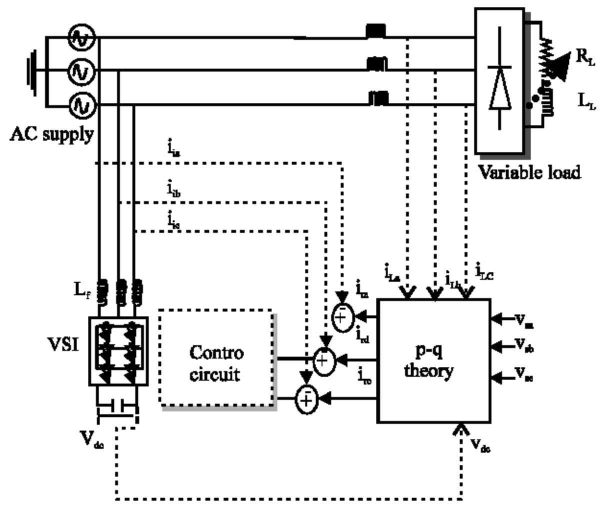

Fig. 1: Schematic diagram of shunt SAPF

functions of fuzzy systems have the advantage of being relatively easy to understand, the systems become complex because more design parameters are required such as number of input variables, number of fuzzy sets, rules, membership functions and the input and output gains. It is possible to build a fuzzy controller with parameters determined by intuition or experience, which provides better performance than a conventional PI controller, but it may not be exactly an optimal one. Since the optimal system is generally the goal of controller researchers, this work is an attempt to undertake a systematic study of the problem to provide some design guidelines for the optimal design of a fuzzy controller based on Genetic Algorithm (GA) (Berbaoui *et al.*, 2010; Wang and Kwok, 1992). The proposed controller is applied to Shunt Active Power Filter (SAPF) current control with fast nonlinear load variations.

METHODS

Control by FLC: As illustrated in Fig. 2, the input of the FLC is e(t) and Δe(t). y (t) is the perfect output of the FLC (Dixon *et al.*, 1999). I_i (t) is the actual output of the SAPF:

$$e\,(t) = I_r(t) - I_i\,(t) \tag{1}$$

The output of the FLC y (t) is used over the reference currents (ira, irb, irc) and sensed load currents (ila, ilb, ilc) to generate switching signals for the MOSFETs of inverter. In response to switching signals generated by controller, the SAPF shapes the supply currents to sinusoidal and compensates the power factor, current harmonics and the unbalance of the nonlinear load.

Mathematical formulation of the problem: The amount of distortion in the current waveform is quantified by means of an index called the total harmonic distortion (THD). The THD in current is defined as:

$$THD_I\% = 100 \bullet \sqrt{\sum_{n\neq 1}\left(\frac{I_{sn}}{I_{s1}}\right)^2} \tag{2}$$

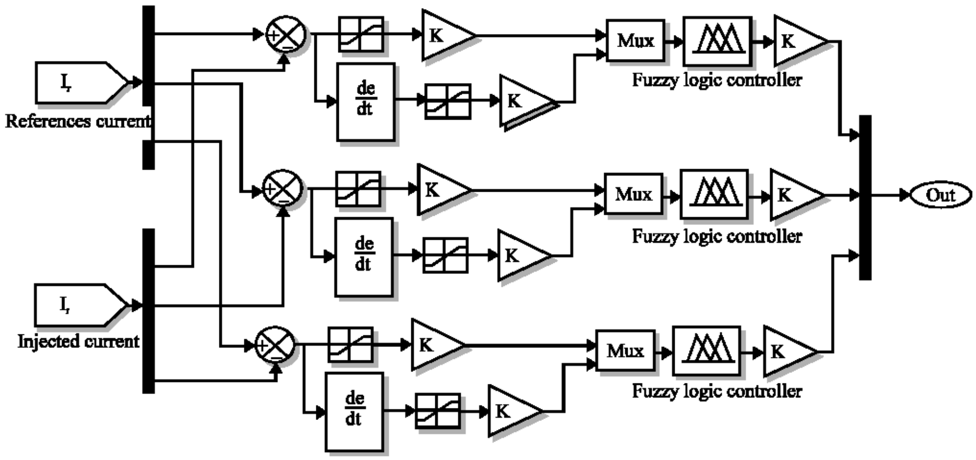

Fig. 2: The optimum fuzzy controller

where, I_{sn} represents the RMS value of rank n harmonic component. I_{s1} represents the RMS value of fundamental component.

Interpreting the THD of the current supply of each phase associated with such FLC design used for pulse generation. The objective function is presented in:

$$f(x) = THD_I \quad (3)$$

The problem is to minimize multiple objective functions under the following constraints:

$$\left(\sum_{n=1}^{n=7} dx_n\right) \le S^{max} \quad (4)$$

where, dx_n distance in Membership functions, as shown in Fig. 3.

For the application of genetic algorithm, we use the minimization method under constraints, which is the method of penalty.

$$g_i(x) \ge 0 \quad i = 0......m \quad (5)$$

We transform the problem into a penalty function which is presented as follows:

$$f(x_n, r_k) = \sum_{n=1}^{3} THD_{in} + r_r \sum_{i=1}^{m} \left[\frac{1}{g_i\left(\sum_{n=1}^{n=7} x_n\right)} \right]^2 \quad (6)$$

where, r_k is the coefficient of penalty.

Optimization of fuzzy controller parameters using GA: The operation of a FLC depends on a large number of parameters (functions membership, fuzzy rules, rules inference, defuzzification)

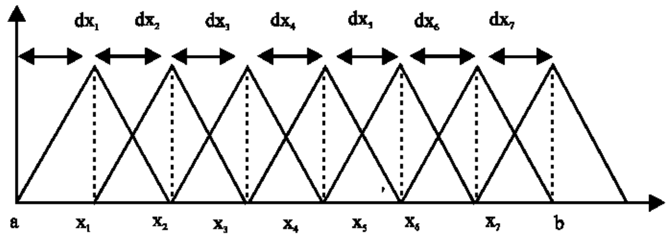

Fig. 3: Membership functions using the apexes differences

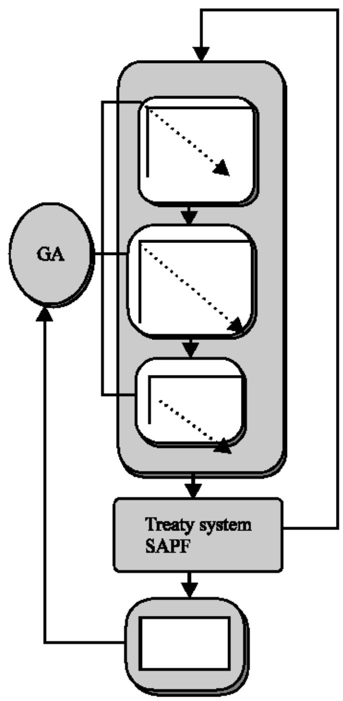

Fig. 4: Hierarchical structure of the GA approach for optimized FLC

which must be settled at the design. Since these parameters influence each other, it is unlikely that a synthesis method dealing separately with each FLC subsystem can provide optimal results (Wang and Kwok, 1992). Several design methods for specifying the different parameters for the functioning of a fuzzy system have been described in literature with the aim of ensuring the best usefulness of parameters for a given controller structure. In this section, we present the automatic method for the designation of fuzzy systems that enable to determine the optimal fuzzy system; this method is shown in Fig. 4.

Membership functions: In an FLC, the reasoning rules are applied to the linguistic terms. These terms, which can specify a linguistic variable are defined via membership functions. There are various methods for the implementation of membership functions. In our case we use adjacent triangular membership functions and show how to present it on a chromosome using binary coding.

Figure 3 represents a fuzzy partition defined by seven triangular membership functions. This type of linguistic variable has been proposed by Yubazaki *et al*. (1995). A partition with n fuzzy linguistic terms is completely defined by n points (x1 = a, x2,.....xn = b) using the triangular membership functions as follows:

$$\mu_{A1}(x)=\begin{cases}0\,, & x \prec x_1\\ \dfrac{x_2-x}{x_2-x_1}, & x_1 \le x \le x_2\\ 0\,, & x \succ x_2\end{cases} \tag{7}$$

$$\mu_{Ai}(x)=\begin{cases}0\,, & x \prec x_i\\ \dfrac{x-x_{i-1}}{x_i-x_{i-1}}, & x_{i-1} \le x \le x_i \quad i=2,3......,n-1\\ \dfrac{x_{i+1}-x}{x_{i+1}-x_i}, & x_i \le x \le x_{i+1}\\ 0\,, & x \succ x_{i+1}\end{cases} \tag{8}$$

$$\mu_{A1}(x)=\begin{cases}0\,, & x \prec x_{n-1}\\ \dfrac{x-x_{n-1}}{x_n-x_{n-1}}, & x_{n-1} \le x \le x_n\\ 0\,, & x \succ x_n\end{cases} \tag{9}$$

The fuzzy partition can be represented by encoding n points:

$$C_{[a,b]}(x_1)\cdots C_{[a,b]}(x_i)\cdots C_{[a,b]}(x_n)$$

with the boundary conditions:

$$\{\, a=x_1\,, x_1 \le x_2\,, x_2 \le x_3\,,......, x_n=b\,\} \tag{10}$$

This representation limits the treatments effectiveness, by raison of the (n-1) inequalities managing the boundary conditions. In order to reduce the number of inequalities that manage the boundary conditions we choose a presentation based on dx_i differences between two abscissas of two successive apexes x_{i+1} and x_i, as shown in Fig. 5.

This leads to the following representation:

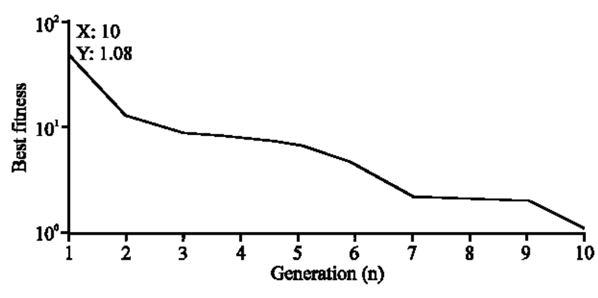

Fig. 5: The best THD variation of supply current waveform according to the generation number (n)

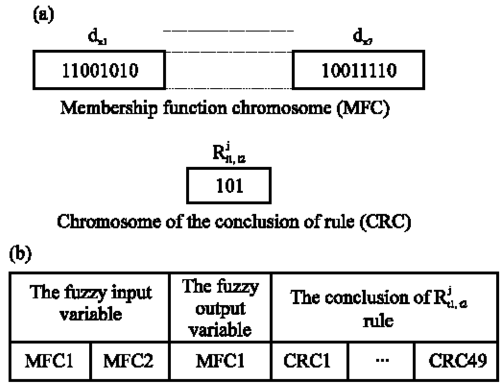

Fig. 6(a-b): Representation of fuzzy gene system. (a) Composition of chromosome and (b) Architecture of a gene

$$C_{[0,(b-a)]}d_{x1} \;\cdots\cdots\; C_{[0,(b-a)]}d_{x7}$$

where, $C_{[0,(b-a)]}d_{x1}$ is a binary encoding of the dx_i variable that takes its values in the interval [0, (b-a)]. The coded values must respect a single boundary condition:

$$dx_1 + dx_2 + dx_3 + dx_4 + dx_5 + dx_6 + dx_7 \leq (b-a) \tag{11}$$

The following equation is used to calculate the abscissas:

$$\{x_1 = dx_1, \quad x_i = x_{i-1} + dx_i\} \tag{12}$$

Fuzzy rules: While our FLC possesses the two inputs that command a single output, each fuzzy rule contains two premises and one conclusion. A rule is expressed as follows:

$$\text{Rule } i_1, i_2: \text{if } x_1 \text{ is } A_{1i_1} \text{ and } x_2 \text{ is } A_{2i_2} \text{ then } y \text{ is } B_{jk}$$

where, each index i_k ranges from 1 to N_{ti} (the number of the input linguistic terms) and each index j_k ranges from 1 to N_{to} (the number of the output linguistic terms), A_{qp} refers to the qth linguistic term describing the output number p and B_{mn} refers to Nth linguistic term correspond to the output number m (in our case, we have single output thus m = 1). We can define the maximum B_{ti}^{Ni} fuzzy rules of FLC which contain N_i input, each input represented by N_{ti} linguistic terms. In our case, we have a two inputs system each composed of seven membership functions and one output contains seven membership functions 7^2 or 49 rules. For the output indicated by the index j which equal 1, we create a table of results corresponding to all possible configurations of premises. The conclusion of a rule identified by the indices i_1, i_2, is represented by a number $R^{j}_{i_1,i_2}$ defined by:

$$R^{j}_{i_1,i_2} = \begin{cases} 0, \text{if the rule is useless} \\ k \text{ if the conclusion of } (i_1, i_2) \text{ rule's is } B_{jk} \end{cases} \tag{13}$$

where, $k \in \{1 \ldots N_{to}\}$.

The representation of all rules is obtained by scanning tables that consist of all fuzzy controller outputs:

$$R^1_{11},\ R^1_{12}, \cdots, R^1_{1N_{ti}}, \cdots,\ R^1_{N_{ti}N_{ti}}$$

The rules represented by a binary string, in which each element $R^j_{i_1,i_2}$ takes its values in the set {1...N_{to}}, being coded on u bits where:

$$u = f(\log_2(N_{to}+1))\ \text{Bits} \tag{14}$$

where, f (x) is the integer part of x.

As shown in Fig. 6a and b, the total number of parameters to encode of the fuzzy system is 21 (7 differences of membership functions for each input and output) +49 conclusion of a rule $R^j_{i_1,i_2}$.

For the representation of the simple AG, the differences between the apexes are coded to 08 bits and the $R^j_{i_1,i_2}$ are encoded to 03 bits.

RESULTS AND DISCUSSION

The performance of the proposed synthesis FLC method was examined through simulations. The system model was implanted in MATLAB Simulink environment. The SAPF was designed to compensate harmonics caused by nonlinear loads. The system model parameters are shown in Table 1.

A three-phase diode rectifier with an RL load was used as a harmonic producing load. The initial load (resistance was 10/3 Ω and the inductance 60 mH.) In the first place, the load power were raised with the following percentage 25, 50, 75% at 0.2, 0.4, 0.6, then the total harmonic distortion has been taken up to 2.5 kHz for each case. A phase-a load current waveform is presented in Fig. 7.

For the defuzzification operation, the center of gravity (also known as centroid) is used; this method allows us to express analytically the output of fuzzy system, to simplify implementation and also to reduce the computing time. The output expressing in this method given by equation:

$$u = \frac{\int x \cdot u_R(x)\, dx}{\int u_R(x)\, dx} \tag{15}$$

The seven values of difference membership function of each input and the output are encoded and grouped in a single chromosome, as shown in Table 2.

The GA which provides optimization of fuzzy controller is used only during the FLC synthesis phase. It is no longer involved in the system during normal operation. The parameters chosen for GA are: Initial population = 25; Selection function: Rolette; Crossover function: Two point; Crossing probability = 0.6; Mutation function: uniform; Mutation probability = 0.001, Maximum generation number = 10.

Table 1: System parameters

Active filter	Parameters
Supply phase voltage U	220 V
Supply frequency fs	50 Hz
DC link capacitor Cf	0.768474 mF

Table 2: Membership functions differences of each FLC variable

Input	Coding	Constraint
e	0 0.2513 0.3492 0.3995 0.2619 0.5291 0.209	$(\sum_{n=1}^{n=7} d_{X_n}) \le 2$
Δe	0 0.2407 0.3334 0.4259 0.2831 0.4603 0.2566	$(\sum_{n=8}^{n=14} d_{X_n}) \le 2$
Output		
Uref PWM	0 0.2513 0.508 0.2407 0.4153 0.1958 0.3889	$(\sum_{n=15}^{n=21} d_{X_n}) \le 2$

Table 3: Fuzzy rules of the optimum FLC

e/Δe	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NM	ZE	PS	PM	PB	PB	PB
PB	NS	PS	PM	PB	PB	PB	PB

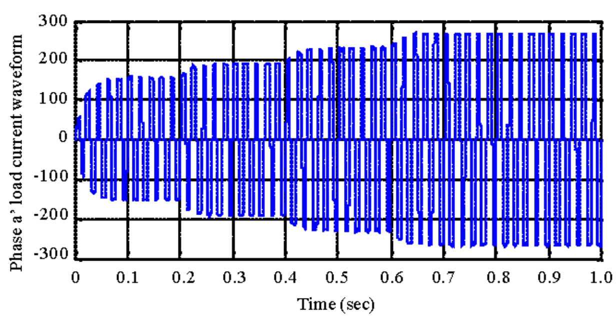

Fig. 7: Phase'a' load current waveform

The differences in membership functions for each variable of FLC resulting data are illustrated in Fig. 8 and Table 3.

The result of simulation makes clear that the increase of the load current value yield to exceed of the harmonic in supply current or the conventional controller can not react enough against the variation of load, as shown in Fig. 11.

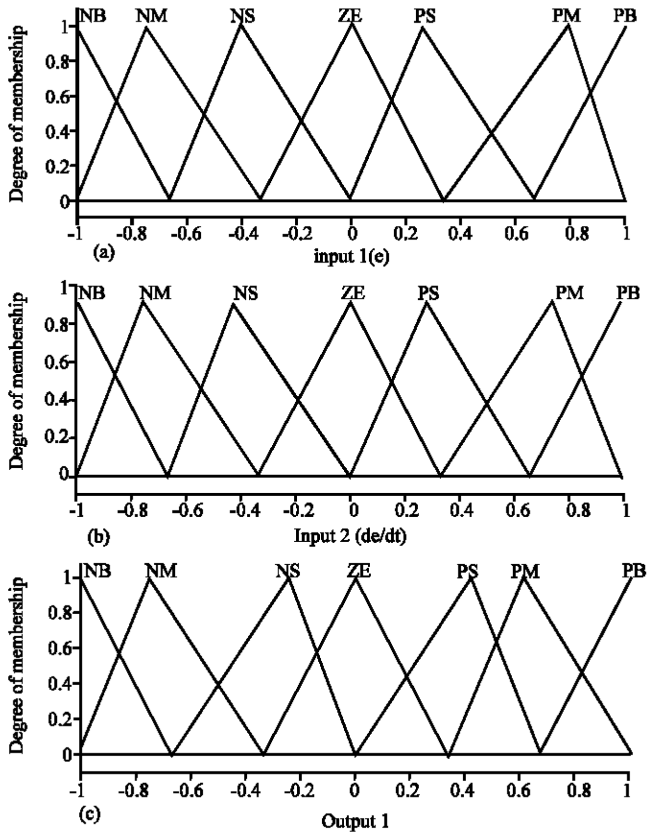

Fig. 8: Membership function of (a) e(k) input (b) Δe(k) input (c)the output

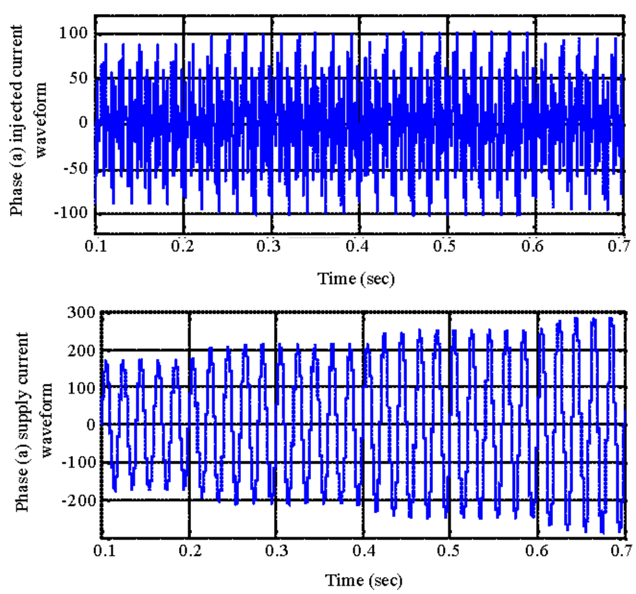

Fig. 9(a): Phase'a' injected current waveform,(b) phase 'a' supply current waveform with the(CPI)

According to Fig. 5, it is observed that the genetic algorithm which designing the Fuzzy controller decrease the THD when the number of iterations increases. The filtering result can be

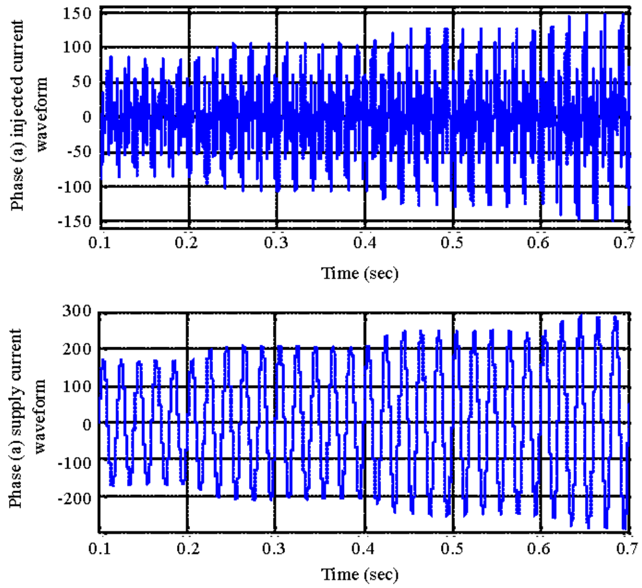

Fig. 10(a, b): (a) phase'a' injected current waveform, (b) phase 'a' supply current waveform with the optimum FLC

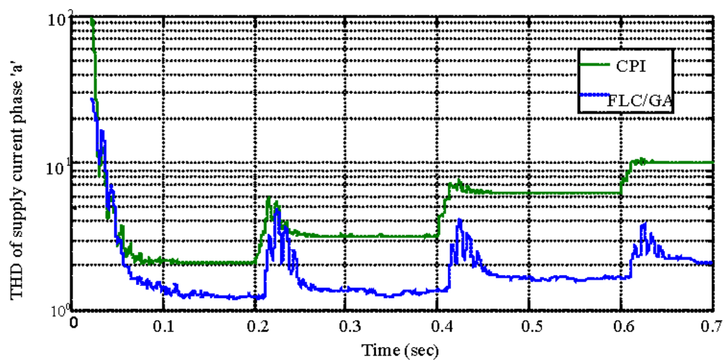

Fig. 11: Supply current THD, comparison between optimum FLC and CPI

seen in Fig. 9-11. The deformations have now been reduced and the harmonic has been weakened with the optimum FLC where the THD calculated up to 2.5 kHz remains less than the case of conventional PI controller throughout the growth of the load.

CONCLUSION

With the variation of non-linear loads, the harmonics and reactive power are deteriorating the performance of the utility network. In this paper, a synthesis method of fuzzy controller parameters is presented to substitute the supplied analysis by a human expert. The controller designed according to fuzzy logic rules and the optimal adjustment of the membership functions are realized by using GA optimization FLC.

A control strategy based on FLC/GA for high performance three-phase SAPF has been proposed and confronted with CPI controller. The efficiency of the proposed FLC was verified through simulation studies with MATLAB. FLC/GA has an important effect on the convergence of the problem to best solutions at load changing and also at the steady state and can act positively on performance of SAPF. FLC/GA is also found extremely satisfactory to mitigate harmonics and reactive power components from utility current.

REFERENCES

Ahmed, M., 2004. Sliding mode control for switched mode power supplies. D.Sc. Thesis, Department of Electrical Engineering, Lappeenranta University of Technology, Lappeenranta.

Berbaoui, B., B. Chellali, R. Dehini and B. Fardi, 2010. Optimization of shunt active power filter system fuzzy logic controller based on ant colony algorithm. J. Theor. Applied Inform. Technol., 14: 117-125.

Dixon, J.W., J.M. Contardo and L.A. Moran, 1999. A fuzzy-controlled an Active front-end rectifier with current harmonic filtering characteristics and minimum sensing variables. IEEE Trans. Power Electron., 14: 724-729.

El-Mofty, A. and K. Youssef, 2001. Industrial power quality problems. Proceedings of the 16th International Conference and Exhibition on Electricity Distribution, Part 1: Contributions, June 18-21, 2001, CIRED, Amsterdam, Netherlands, pp: 5.

Liu, H., G. Liu and Y. Shen, 2006. A novel harmonics detection method based on wavel et al gorithm for active power filter. Proceedings of the 6th World Congress on Intelligent Control and Automation, June 21-23, 2006, Dalian, China, pp: 4479-4483.

Lopez, M., L. Moran, J. Espinoza and J. Dixon, 2003. Performance analysis of a hybrid asymmetric multilevel inverter for high voltage active power filter applications. Proceedings of the IEEE Industrial Electronics Conference, November 2-6, 2003, Roanoke, Virginia, USA., pp: 1050-1055.

Wang, P. and D.P. Kwok, 1992. Optimal fuzzy PID control based on genetic algorithms. Proceedings of the International Conference on Industrial Electronics, Control, Instrumentation and Automation, November 9-13, 1992, IEEE Press, San Diego, pp: 977-981.

Yubazaki, N., M. Otani, T. Ashida and K. Hirota, 1995. Dynamic fuzzy control method and its applications to positioning of induction motor. Proceedings of 1995 IEEE International Conference on Fuzzy Systems, International Joint Conference of the 4th IEEE International Conference on Fuzzy Systems and The 2nd International Fuzzy Engineering Symposium, March 20-24, 1995, Yokohama, Japan, pp: 1095-1102.