HIERARCHICAL NEURO-FUZZY CURRENT CONTROL FOR A SHUNT ACTIVE POWER FILTER

Mehmet Tümay e-mail: mtumay@cu.edu.tr
M. Uğraş Cuma e-mail: mehmet@eemb.cu.edu.tr
K. Çağatay Bayındır e-mail: cbayindir@isdemir.com.tr
Çukurova University, Faculty of Engineering and Architecture, Department of Electrical & Electronics Engineering, Balcalı, Adana, Turkey

Key words: Neuro-fuzzy logic, active power filter

ABSTRACT

This paper presents the design of a hierarchical neuro-fuzzy current control scheme for a shunt active power filter compared with a single fuzzy controller scheme. A single fuzzy controller scheme is presented first and an ANFIS based neuro-fuzzy controller is connected hierarchically to the first one to improve the performance. The method of switching controller development is new and can be applied to other converter applications.

I. INTRODUCTION

In recent years there has been an increasing interest in the subject of harmonic generation and its effects on power systems. The effects of harmonics are becoming a growing problem facing the utilities now and in the future. This is attributed to extensive use of nonlinear power electronic devices and power plant components which are capable of producing considerable harmonic distortion in the network. As the tendency in the use of more and more nonlinear power components increases, the need for a reliable method of harmonic mitigation becomes an important matter in power system planning, analysis and operation. The active power filter appears to be a viable solution for eliminating harmonic currents as well as for reactive power compensation.

Fuzzy logic and neural network techniques are now being increasingly applied to power electronics [1-7]. The integration of fuzzy logic with neural networks and genetic algorithms is now making automated cognitive systems a reality in many disciplines. The power of fuzzy systems when integrated with learning capabilities of neural networks and genetic algorithms is responsible for a new commercial products and processes that are effective cognitive systems.

In this paper a hierarchical neuro-fuzzy current control scheme for a shunt active power filter is presented. Fuzzy based control and neural network based control for active power filters are reported in [3-5]. However application of hierarchical neuro-fuzzy control is not reported in the literature. In the paper first a single fuzzy controller based active power filter is presented. In order to improve the performance of the single fuzzy controller system an increase in the number of inputs and membership functions was necessary. A neuro-fuzzy controller, which we call hierarchical neuro-fuzzy control, is connected hierarchically to the output of the first fuzzy logic controller to improve the performance. Since standard fuzzy logic controllers suffer from exponential increase in the number of rules with the number of input variables, we opt to employ hierarchical fuzzy systems that are known to reduce the computational burden. Fuzzy logic controllers are computationally intensive, thus requiring a very powerful processor for real-time implementation. Nonetheless, hierarchical fuzzy logic controllers are much less computationally demanding than standard fuzzy logic controllers without compromising the controller performance [7]. The method of current controller development is very interesting here and this may be applied to other power electronic converter applications.

Since the load harmonics to be compensated may be very complex and changing rapidly and randomly, the active power filter has to respond quickly and work with high control accuracy in current tracking. Moreover, in order to keep high safety and efficiency in active power filter operation, the required voltage source inverter switching frequency and dc source voltage, which are highly relevant to the current tracking method used, should be as low as possible. It is clear that active power filter current control technique is the key issue of its performance and efficiency [8]. The proposed current controller scheme provides a superior current tracking capability.

II. SINGLE FUZZY CONTROLLER BASED ACTIVE POWER FILTER AND PROBLEM DEFINITION

The typical components of an active power filter system are the mains supply, a nonlinear load, a reference current estimator, a PWM current controller and a voltage source inverter with an interface reactor. The information regarding the harmonic current generated by a nonlinear load is supplied to the reference current estimator together with information about other system variables. The reference signal from the current estimator, as well as the other signals provides the control for the PWM current controller. The output of the PWM current controller controls the voltage source inverter via a suitable interface reactor [9].

The main components of an active power filter system with the proposed hierarchical neuro-fuzzy current controller is shown in Fig. 1.

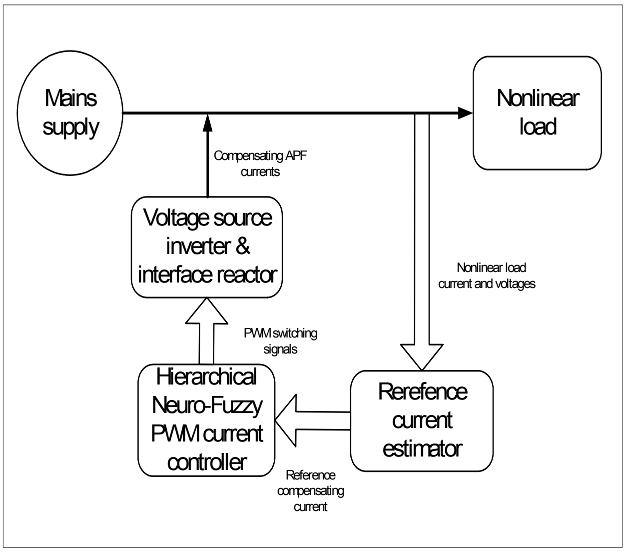

Fig. 1

The fuzzy controllers for the single fuzzy controller scheme are characterized as follows:

- 3 fuzzy sets for each of the 2 inputs
- 3 fuzzy sets for the output
- Triangular and trapezoidal membership functions
- Implication using the "*min*" operator
- Mamdani fuzzy inference mechanism based on fuzzy implication
- Defuzzification using the "*centroid*" method

The linguistic rules for the fuzzy logic controller are as follows:

I. If error is big and error rate is high then actuatingsig is dec
II. If error is zero and error rate is high then actuatingsig is dec
III. If error is small and error rate is high then actuatingsig is inc
IV. If error is big and error rate is zero then actuatingsig is dec
V. If error is zero and error rate is zero then actuatingsig is constant
VI. If error is small and error rate is zero then actuatingsig is inc
VII. If error is big and error rate is low then actuatingsig is dec
VIII. If error is zero and error rate is low then actuatingsig is inc
IX. If error is small and error rate is low then actuatingsig is inc

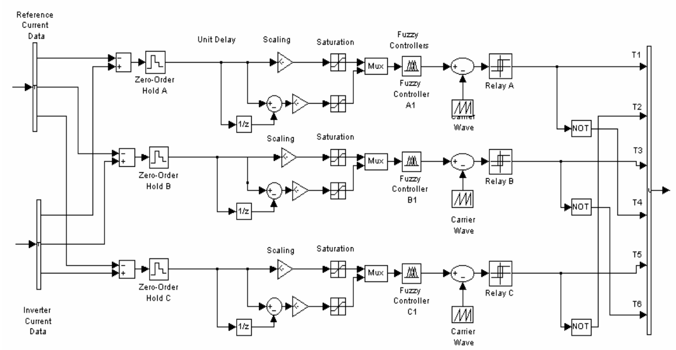

Fig. 2 (Single Fuzzy Current Controller)

The fuzzy logic controller has two inputs, named error and error rate and one output named actuatinsig. Error is the difference between voltage source inverter current data and reference current data for each phase.

$$Error = I_{Inv} - I_{Ref}$$

Fig. 3 explains the generation process of switching signals in the model. The output of the fuzzy controller is the actuating signal and this output is compared with a carrier signal. The relay element is set to give output when the input of itself is greater than 0. The output of the fuzzy controller is set to take values between –0.622 to 0.622. The carrier signal is set to take values between –0.55 to 0.55.

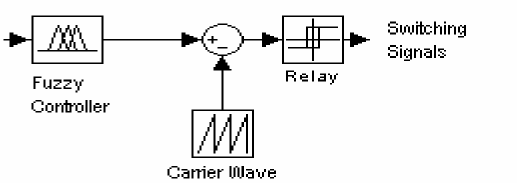

Fig. 3

Load current and compensated source current waveforms are obtained for the single fuzzy controller scheme. These are presented in Fig. 4, 5 together with the table of magnitudes of harmonics in % of the fundamental component. Load current THD is 25.10% while the source current THD is 0.66%. The 5^{th}, 7^{th}, 11^{th}, 13^{th}, 17^{th} and 19^{th} harmonics are the harmonics that are affecting the system.

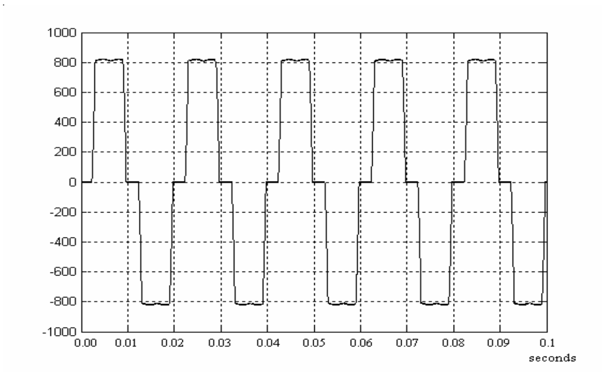

Fig. 4

Table 1

Harmonic Number	Frequency (Hz)	Magnitude in % of fundamental
1st	50	100
5th	250	19.27
7th	350	12.67
11th	550	6.99
13th	650	5.28
17th	850	2.99
19th	950	2.23

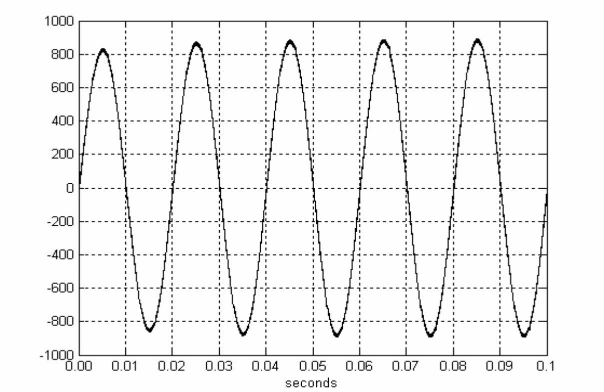

Fig. 5

Table 2

Harmonic Number	Frequency (Hz)	Magnitude in % of fundamental
1st	50	100
5th	250	0.28
7th	350	0.19
11th	550	0.25
13th	650	0.17
17th	850	0.22
19th	950	0.08

However, the single fuzzy control scheme described above have some error points. To understand these error points, consider the Table 3 given below. In the table, see the lines where actuating signal, the column named actsig is 0. As described in previous paragraphs about switching signal generation, the relay will give output 1 when the difference between actuating signal and carrier signal is positive and it will give output 0 when the difference between actuating signal and carrier signal is negative. The carrier signal, the column named Carrier in the table, is taking values between –0.55 to 0.55. From Table 1 while the carrier signal has taken values from –0.55 to –0.13 and actuating signal is 0 and relay output is 1. But as seen from the table, while the reference current (column named "Ref") is taking the values approximately 1.8 A, the inverter current (column named "Inv") goes up to 13A. This problem occurs at the positive and negative peak points of the source current and this is why the ripple content is higher at the peak points of source current as also seen in Fig. 5. This was the error point of the single fuzzy control scheme. This showed that there are some uncontrollable regions in PWM current control and current tracking capability deteriorates in these regions. Problem is that the carrier signal may take any value at a time interval for an error and error rate input. In other words, lets us assume that, the carrier signal given in the table is taking values between 0.13 to 0.33. Then the relay output will take the value 0 and the system will work properly. But without controlling the carrier signal, you cannot know which values it will take.

Table 3

Error	Erate	Actsig	Carrier	Switch	Source	Inv	Ref
0.000000	0.000000	0.000000	-0.550000	1.000000	0.024580	-0.004097	0
0.000000	0.000000	0.000000	-0.506000	1.000000	0.025934	-0.005577	0.020356
0.000000	0.000000	0.000000	-0.462000	1.000000	0.029978	-0.009893	0.020085
0.000000	0.000000	0.000000	-0.418000	1.000000	0.036720	-0.016951	0.019768
0.000000	0.000000	0.000000	-0.374000	1.000000	0.046258	-0.026798	0.019459
-0.002227	-0.000167	0.000000	-0.330000	1.000000	0.058421	-0.039238	0.019182
-0.002227	-0.000167	0.000000	-0.286000	1.000000	-2.040276	3.303284	1.262922
-0.002227	-0.000167	0.000000	-0.242000	1.000000	-4.562605	6.349692	1.786908
-0.002227	-0.000167	0.000000	-0.198000	1.000000	-7.328792	9.223032	1.893955
-0.002227	-0.000167	0.000000	-0.154000	1.000000	-10.23006	11.99813	1.767674
-0.002227	-0.000167	0.000000	-0.132000	1.000000	-11.70665	13.36586	1.658751
0.483468	0.036260	-0.497250	-0.110000	0.000000	-13.19166	14.72650	1.534331
0.483468	0.036260	-0.497250	-0.066000	0.000000	-11.94503	10.72168	-1.223740
0.483468	0.036260	-0.497250	-0.022000	0.000000	-9.794603	7.333499	-2.461381
0.483468	0.036260	-0.497250	0.022000	0.000000	-7.166234	4.270843	-2.895562
0.483468	0.036260	-0.497250	0.066000	0.000000	-4.259626	1.396168	-2.863529
0.483468	0.036260	-0.497250	0.088000	0.000000	-2.742780	0.001188	-2.741616

III. PROPOSED CONTROLLER

As described in the previous part, the single fuzzy control scheme has some uncontrollable regions, which are found by analyzing the inputs, output and switching signals of the model. Taking the carrier signal into the fuzzy control scheme as an input could solve this problem. At this point, it is the time to introduce the second group fuzzy controllers. The second group fuzzy controllers have an actuating signal and a carrier signal as inputs and they are connected hierarchically to the first group fuzzy controllers. In Fig. 6, the error and error rate values, the feedback signals coming from the system, are connected to the first group fuzzy controllers introduced before. The output of these controllers then becomes an input for the second group fuzzy controllers. The hierarchical model comes into play here; an output of a fuzzy controller is connected to another fuzzy controller's input. The other input of the second group controllers is carrier signal. The outputs of these fuzzy controllers are used in the generation of PWM switching signals of the voltage source inverter. The switching signals are generated by means of comparing the carrier signal with the output of the second group fuzzy controllers.

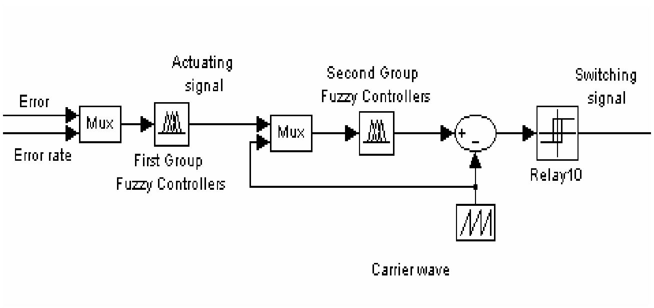

Fig. 6

The important point here is that the second group controllers employed in the model are *Adaptive Neuro Fuzzy Inference Systems.* They are developed by using the ANFIS tool of the MATLAB Fuzzy Logic Toolbox. They are employed to correct error points of the first group controllers. As explained before, without controlling the carrier signal, it may not be known, what the switching signals are, if the error or error rate is not high enough to make the output value high enough to pass the carrier signal. To correct this, a training data has been developed that includes the input/output data pairs of the neuro-fuzzy controllers in the second group. This training data is based on the input-output characteristics of the first group fuzzy controllers. In this training data, at the error points, by using the reference signal input, the correct output values are trained to neuro-fuzzy controllers.

IV. SIMULATION RESULTS

In this part, simulation results for the single fuzzy control scheme and hierarchical neuro-fuzzy control scheme are presented and compared for different cases. In tables 4 and 5, compensated source currents for the single fuzzy controller scheme and hierarchical neuro fuzzy control scheme are given with the table of magnitude of harmonics in % of the fundamental component. The firing angle of the three-phase six-pulse fully controlled rectifier is 10° for this case

Table 4 (Single Fuzzy Scheme)

Harmonic Number	Frequency (Hz)	Magnitude in % of fundamental
1st	50	100
5th	250	0.28
7th	350	0.19
11th	550	0.25
13th	650	0.17
17th	850	0.22
19th	950	0.08

Table 5 (Hierarchical Neuro-Fuzzy Scheme)

Harmonic Number	Frequency (Hz)	Magnitude in % of fundamental
1st	50	100
5th	250	0.11
7th	350	0.18
11th	550	0.09
13th	650	0.11
17th	850	0.11
19th	950	0.12

In Table 6, the comparison of magnitudes of harmonics in % of fundamental component of compensated source currents for the single fuzzy controller scheme and hierarchical neuro-fuzzy control scheme for the cases where firing angle of the six-pulse fully controlled rectifier is 10°, 30°, 45° and 60°.

Table 6

Harmonic	Single Fuzzy Control Scheme				Hierarchical Control Scheme			
Angle	10º	30º	45º	60º	10º	30º	45º	60º
1th	100%	100%	100%	100%	100%	100%	100%	100%
5th	0,28%	3,15%	2,68%	2,46%	0,11%	1,78%	1,98%	2,35%
7th	0,19%	2,55%	2,08%	2,71%	0,18%	1,44%	1,48%	2,82%
11th	0,25%	2,39%	2,73%	3,09%	0,09%	1,59%	2,14%	2,86%
13th	0,17%	1,67%	1,84%	2,94%	0,11%	1,51%	1,69%	2,96%
17th	0,22%	1,27%	2,39%	2,86%	0,11%	1,34%	1,90%	2,76%
19th	0,08%	0,77%	1,28%	2,76%	0,12%	1,18%	1,40%	2,78%
THD	0,66%	5,35%	6,10%	8,78%	0,46%	4,01%	5,22%	8,72%

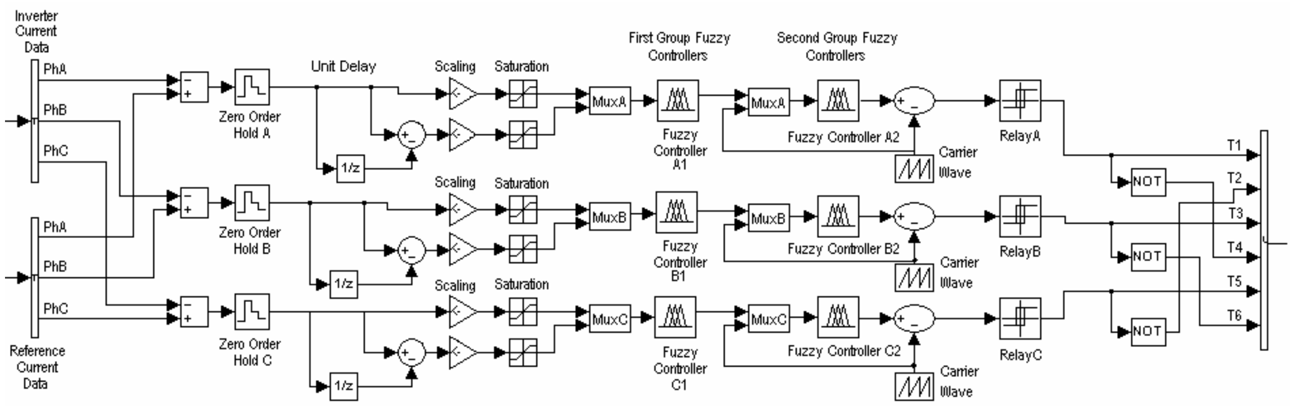

Fig 7. (Hierarchical Current Controller)

V. CONCLUSIONS

This paper focused on applying a hierarchical neuro-fuzzy current control scheme to shunt active power filter. Problems faced on performance improvement of the single fuzzy control scheme are overcome by developing an ANFIS based neuro-fuzzy controller connected hierarchically to the first fuzzy controller. Combining neural-nets and fuzzy logic, the ANFIS controller minimizes system cost by optimizing the number of rules and membership functions, reduces memory requirements and creates fuzzy solution in the form of if-then rules, which is more robust and reliable and can work well under a wider range of operating conditions. Simulation results show that proposed method provides a superior current tracking capability and an improved filtering performance.

REFERENCES

1. Pawel Z. Grabowski, Marian P. Kazmierkowski, Bimal K. Bose and Frede Blaajberg, " A Simple Direct –Torque Neuro-Fuzzy Control of PWM-Inverter-Fed Induction Motor Drive", IEEE Transactions On Industrial Electronics, Vol. 47, No. 4, August 2000, pp. 863-870.
2. S. K. Jain, P. Agrawal and H. O. Gupta, "Fuzzy Logic Controlled Shunt Active Power Filter for Power Quality Improvement", IEE Proc. Electr. Power Appl. Vol.149, No.3, September 2002, pp. 317-328.
3. Chakphed Madtharad, Suttichai Premrudeepreechacharn, "Active Power Filter for Three-Phase Four-Wire Electric Systems Using Neural Networks", Electric Power Systems Research 60 (2002), pp.179-192.
4. M. A. Awadallah, "Switch Fault Diagnosis of PM Brushless DC Motor Drive Using Adaptive Fuzzy Techniques", IEEE Transactions On Energy Conversion, Vol. 19, No. 1, March 2004, pp. 226-227.
5. Naser M. Abdel-Rahim, Abdel Latif Elshafei, "Hierarchical Fuzzy-Logic Control For A Single-Phase Voltage-Source UPS Inverter", The Fourth Annual U.A.E. University Research Conference, pp.152-156.
6. J. Zeng,C. Yu, Q. Qi,Z. Yan, Y. Ni, B. L. Zhang, S. Chen, F. F. Wu, " A novel hysteresis current control for active power filter with constant frequency", Electric Power Systems Research (2003), pp.1-8.
7. M. El Habrouk, M. K. Darwish, M Pehta, "Active Power Filters: A Review", IEE Proc. Electr. Power Appl. Vol.147, No.5, September 2000, pp. 403-413.
8. Raul Garduna-Ramirez, Kwang Y. Lee, "Wide Range Operation of a Power Unit via Feedforward Fuzzy Control", IEEE Transactions on Energy Conversion, Vol.15, No.4, December 2000, pp. 421-426.