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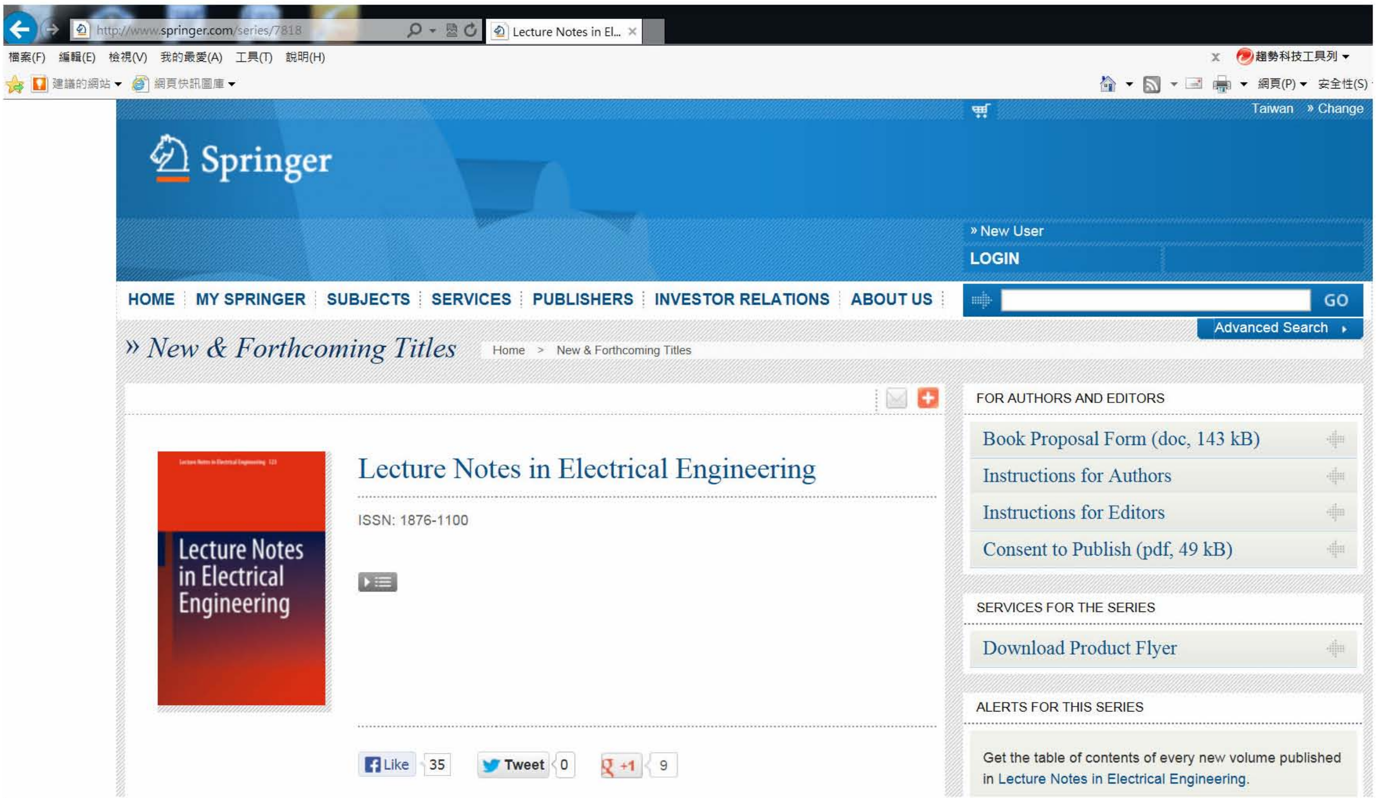

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Chapter 144
Harmonic Reduction Solution by Applying On-Line Trained Adaptive Neural Controller for Shunt Active Filter

Nguyen Thi-Hoai Nam, Chun-Tang Chao, Chi-Jo Wang and Cheng-Ting Hsu

Abstract This paper proposes an intelligent control method for shunt active power filter to compensate the harmonic distortion in three phase power systems. For electric power systems, harmonics contamination generated by the nonlinear nature of the load is a serious and harmful problem. Shunt active filter (AF) has been employed to mitigate line current harmonics. In the presented system, Fuzzy Logic Controller (FLC) is first designed to implement the AF. Then the initial training data with two inputs, the error and derivate of the error, and one output signal from FLC can be obtained. Finally, a Neural Network (NN) with on-line training features is designed by using S-function in Simulink to achieve better performance. Simulation results show the effectiveness of the proposed active power filter system which improves the power quality, reduces the current harmonics and obtains better transient and steady-state responses.

Keywords Active filter · Harmonics reduction · Neural network · On-line training

144.1 Introduction

In recent years, with the rapid economic development, all kinds of nonlinear loads based on power electronic devices (diode and thyristor rectifiers, electronic starters and arc furnaces, etc.) have been used in power systems and induced the appearance of dangerous phenomenon of harmonic currents flow in the electrical feeder networks, producing distortions in the current and voltage waveforms.

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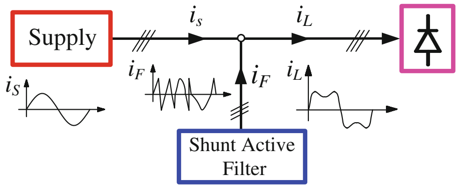

Fig. 144.1 Power system with nonlinear load and shunt AF

As a result, harmful consequences occur: equipment overheating, malfunction of solid state material, interferences with telecommunication systems, etc. The quality of powersupply is seriously reduced, so power quality distortion has become a serious problem in electrical power systems due to the increase of nonlinear loads drawing non-sinusoidal currents. Nowadays, Shunt active filter (AF) have been widely used for harmonic mitigation as well as reactive power compensation, load balancing, voltage regulation, and voltage flicker compensation [1, 2]. Neural Network (NN) based control methodologies have emerged in recent years as effective means of solving nonlinear control problems [3–5]. The proposed design is based on the control model that uses on-line trained adaptive NN controller to control the AF for reducing the harmonics of the electrical power systems. It does not exceed the thresholds fixed by the IEEE 519 standards [6]. Research results have been simulated and verified in the Matlab/Simulink software environment.

144.2 Mathematical Model of Shunt Active Filter

AF is a power electronics device based on the use of power electronics inverters. The Shunt Active Power Filter is connected in a common point connection between the source of power system and the load system. The AF will prevent the source of the polluting currents circulating in the power system lines, as shown in Fig. 144.1 [7].

Suppose that i_L, i_F, i_S are receiver absorbed current, desired power supply current and the current AF must provide, respectively. Then we have the relationship among them in formula given by:

$$i_F = i_L - i_S \tag{144.1}$$

If we let

$$i_L = i_f + i_H \tag{144.2}$$

where i_f is the fundamental component of load current, also the desired power supply current i_S, and i_H is the harmonic current generated in load branch. From Eqs. (144.1) and (144.2), we obtain Eq. (144.3)

$$i_F = i_H \tag{144.3}$$

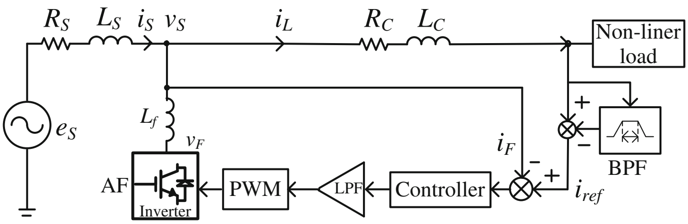

Fig. 144.2 The active filter control structure

Eq. (144.3) indicates that shunt active power filter is intended to generate exactly the same harmonics contained in the polluting current i_L but with opposite phase.

144.3 Control System Design

144.3.1 Control Structure of Active Filter

To control AF to produce current tracking with the load current harmonic, the control structure as shown in Fig. 144.2 is used [7, 8], where BPF is a band pass filter, LPF is a low pass filter, and PWM is pulse width modulation. In this paper, we apply the method of notch filter which consists of two identical band-pass filters in series. The fundamental frequency is set to 50 Hz. The transfer functions of the BPF and LPF are given by Eq. (144.4).

$$H_{BPF}(s) = \frac{K_{BPF}.B.S}{s^2 + B.s + \omega_c^2}; H_{LPF}(s) = \frac{K_{LPF}}{\tau s + 1} \tag{144.4}$$

144.3.2 On-Line Trained Adaptive Neural Controller Design

In the paper, the proposed on-line trained adaptive neural controller is designed to control the AF for harmonic mitigation as well as reactive power compensation for three phase power system, as shown in Fig. 144.3, where i_{ref} is the harmonic current generated in power system and it is also the reference signal for the controller to track. The output current of the AF (i_F) is expected to have the same harmonic current value contained in the polluting current but with opposite phase. Both signals are compared to generate error (e) as the input of on-line trained adaptive neural controller. The output of on-line trained adaptive neural controller u_N, which passes through LPF, is compared with carrier signal (v_s), and the

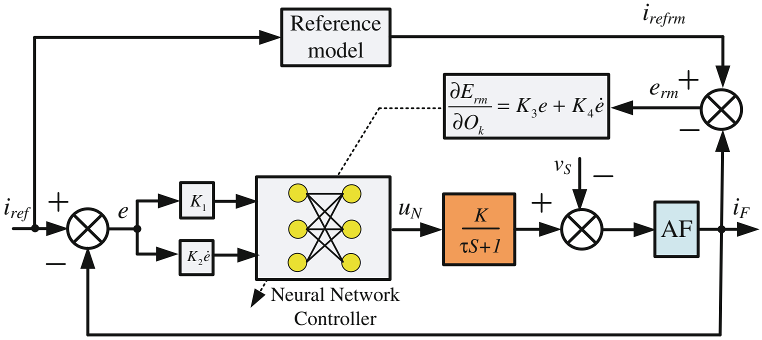

Fig. 144.3 On-line trained adaptive NN controller diagram

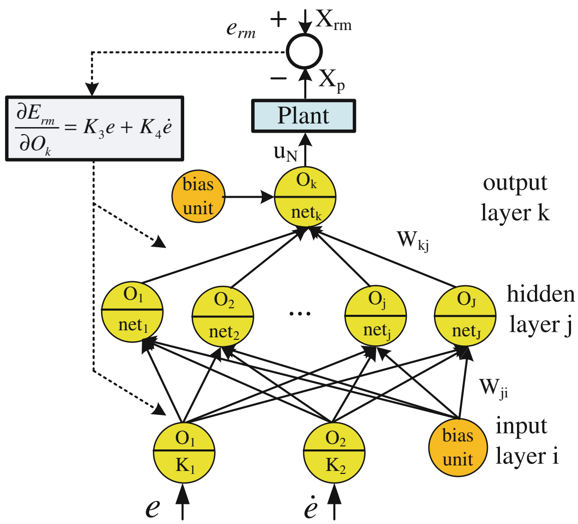

Fig. 144.4 Schematic diagram of the proposed NN controller

resulting signal is used to switch 6 IGBTs of AF filter. The three-layer NN structure shown in Fig. 144.4 is adopted to implement the proposed NN controller.

The net input to a node j in the hidden layer is calculated according to the following equation.

$$net_j = \sum \left(W_{ji} \cdot O_i\right) + \theta_j \tag{144.5}$$

The output of node j is

$$O_j = f\left(net_j\right) = \tanh\left(\beta \cdot net_j\right) \tag{144.6}$$

where O_j represents the output of units in the hidden layers, net_j is the summed input to the units in the hidden layers, W_{ji} are the connective weight between input layers and hidden layers, $\beta > 0$ is a constant, and f denotes the activation function, which is a hyperbolic tangent activation function

$$f\left(net_j\right) = \frac{2}{1 + e^{-\beta \cdot net_j}} - 1; \quad \left(-1 < f\left(net_j\right) < 1\right) \tag{144.7}$$

The net input to a node k in the output layer is

$$net_k = \sum \left(W_{kj} \cdot O_j\right) + \theta_k \quad j = 1, 2, \ldots J, \quad k = 1, 2, \ldots K \tag{144.8}$$

The corresponding output of neural network is

$$O_k = f(net_k) = \tanh(\beta \cdot net_k) \tag{144.9}$$

The energy function E is defined as

$$E_N = \frac{1}{2}\left(X_{rmN} - X_{pN}\right)^2 = \frac{1}{2} e_N^2 \tag{144.10}$$

where X_{rmN} and X_{pN} represents the outputs of the reference model and the plant at the Nth iteration. The back-propagation algorithm is used to update the weights in the NN [9].

It should be claimed that before implementing the on-line trained adaptive NN in Fig. 144.3, a PD-like Fuzzy Logic Controller (FLC) has been designed to control the AF. The performance comparison can be found in the following section.

144.4 Simulation Results

Simulation results with methodologies of on-line trained adaptive NN controller is implemented by Matlab/Simulink, as shown in Fig. 144.5, for electrical power system with AF. Table 144.1 summarizes the simulation parameters. The training result of desired output and practical output is shown in Fig. 144.6 indicating that the practical output almost tracks the desired output with the error converging to 0 (Figs. 144.7).

The system simulation results applying on-line trained adaptive NN controller are shown in Figs. 144.8–144.10. The THD value drops to 1.03 %.

Figure 144.11 shows how AF current tracks the reference signal i_{ref} with on-line learning NN controller. In the first 0.01 s, the output of controller has not tracked its reference signal successfully, but after 0.01 s these two signals almost coincide. Once again, it indicates the active operation of AF that helps to eliminate the harmonics in power system. Moreover, consider that the motor runs in different conditions: heavy load, medium load, and light load, the respective fundamental currents are 700, 470, and 280 A. Table 144.2 reports the THD values in each case.

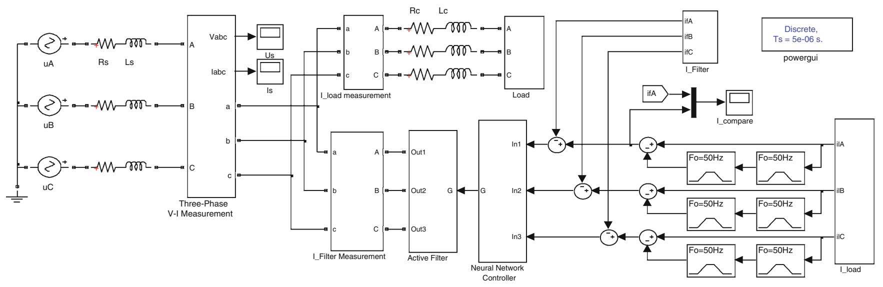

Fig. 144.5 The simulation model of electrical power system with AF

Table 144.1 Simulation parameters of electrical power system

Parameter	Value
Supply's voltage $e_s$and frequency f_s	220 V, 50 Hz
Line's inductance $L_s$and resistance R_s	0.03 mH, 0.1 Ω
Impedance upstream of the rectifier $L_c$andR_c	0.07 mH, 0.3 Ω
Inductance L_{DC}, capacitor C_{DC}, resistance R_{DC}	0.3 mH, 470 μF, 0.45 Ω
Active filter input DC supply: capacitor C, E,r	3.46×10^{-3} F, 600 V, 5x10^{-4} Ω
Active filter output impedance L_f	1.2 mH
if_{iref}'s calculating, band-pass filter: damping factor ξ	0.707
LPF corrector: gain K, time constant τ	1, 5 e^{-6} s
Carrier signal's peak amplitude & frequency	10, 10 kHz

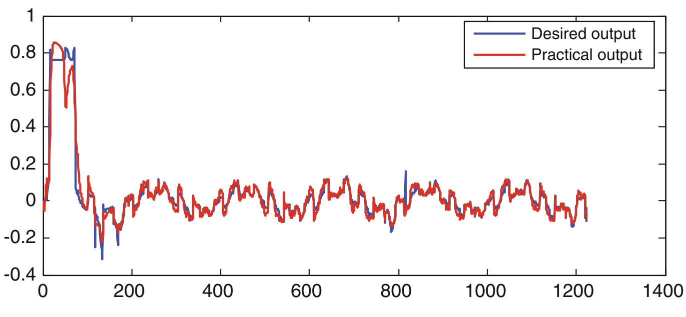

Fig. 144.6 Desired output and practical output

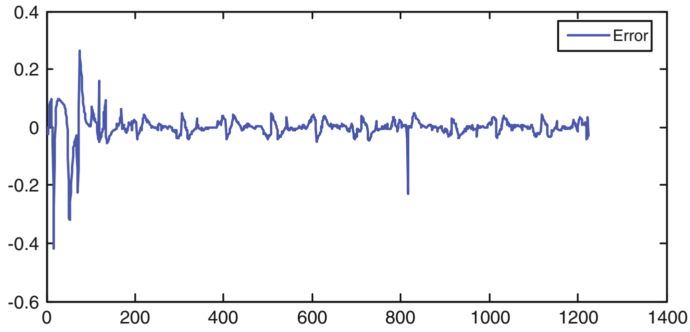

Fig. 144.7 Error after training

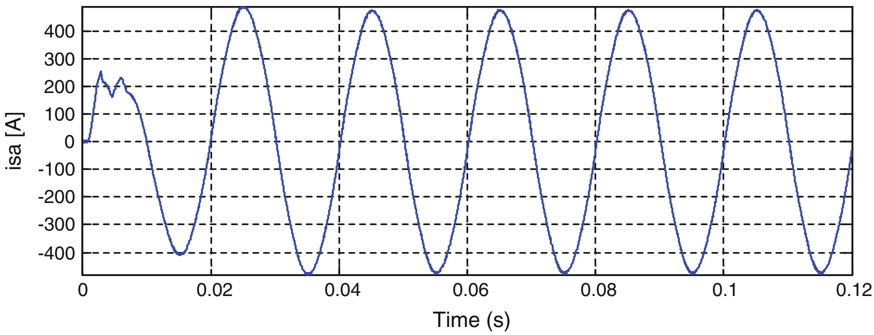

Fig. 144.8 Supply current i_{sa} with NN

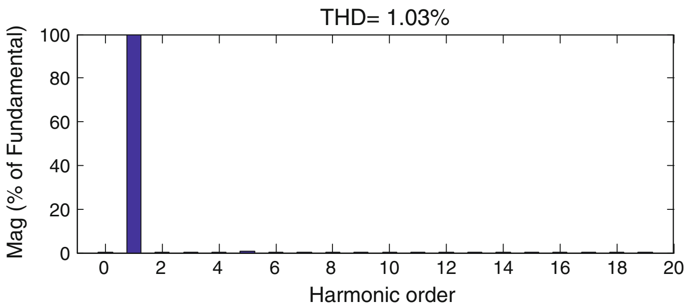

Fig. 144.9 Harmonic spectrum of i_{sa} with NN

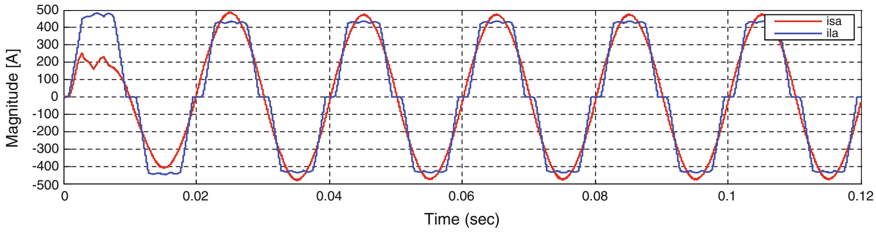

Fig. 144.10 Currents i_{sa} and i_{la} applying AF with on-line trained adaptive NN controller

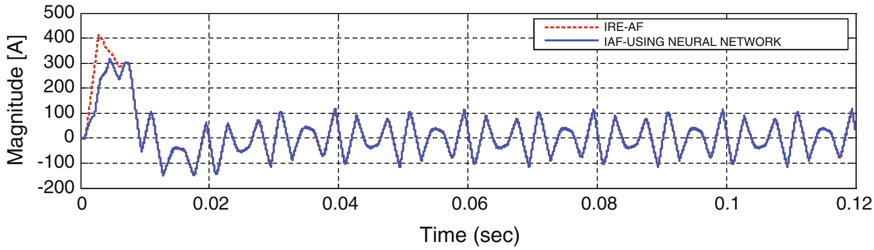

Fig. 144.11 AF current and its reference with on-line trained adaptive NN controller

Table 144.2 Total harmonic distortion (THD) (%) in different running conditions of load

Controller	Load		
	Heavy load: $R_{dc} = 0.07$	Medium load: $R_{dc} = 0.45$	Light load: $R_{dc} = 1.2$
Without active filter	THD = 3.46	THD = 12.54	THD = 20.33
With AF using FLC	THD = 0.49	THD = 1.04	THD = 3.23
With AF using NN controller	THD = 0.45	THD = 1.03	THD = 2.44

144.5 Conclusion

In this paper, the NN controller for AF is developed to reduce the harmonic current for nonlinear loads in electric power systems. It shows that with AF and on-line trained adaptive NN controller design, the system achieves abetter response under different running conditions of load. The simulations results also show that Shunt AF achieves good dynamic and steady-state responses. Furthermore, the THD value doesn't exceed 5 %, conforming to the IEEE 519 standards.

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