CURRENT HARMONICS COMPANZATION USING A FUZZY-PI CONTROLLED ACTIVE POWER FILTER WITH FUNCTION OF UNINTERRUPTIBLE POWER SUPPLY

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ABSTRACT

In this study, an active power filter with the function of uninterruptible power supply (UPS) is designed, and the effects on the system performance of the fuzzy-PI controller are analysed. For this purpose, the designed system is also controlled using PI controller. Simulation studies show that fuzzy-PI controlled system has better performance than PI controlled system.

I. INTRODUCTION

Power electronics circuits, such as frequency changers, motor-drive systems are electronic equipments widely used in industry. Such equipments produce harmonic currents on the utility due to their nonlinear characteristics [1]. Harmonic currents on the utility side causes well known adverse effects, such as undesired power losses, equipment overheating, capacitor fuses blown and excessive neutral currents. To avoid unwanted effects and obtain clean power [2-4], active power filters are used as an effective way. In respect of their functions, active power filters can be classified as series active power filter and shunt active power Filter. Shunt active power filter is widely used in industrial process due to current harmonics which are an important problem in these applications. One other problem in industrial applications is to obtain spare power requirement. Generally, diesel-engine generators are used as the spare power; however, they can not be started immediately. Therefore, this requirement is usually achieved by using uninterruptible power supply. In researches on the system which combines the functions of an active power filter and a UPS [5-8], researches have mainly focused on the topology and techniques used in the control of system to improve the performance of system. There have been little researches related to effects on the system performance of controllers.

Controllers have a major role on improving the performance of system. Conventional proportional-integral (PI), proportional-derivative (PD) and proportional-integral-derivative (PID) controllers have been dominating the control applications in industry for years. They are simple in structure, reliable in operation, and robust in performance. Especially, these controllers are effective for simple linear systems due to the gain parameter of controllers turned easily in these systems. However, the choice of gains parameters is a big problem when these controller are used in non-linear systems, high-order and time-delayed systems and complex systems [9-12]. One way to improve their control performance on nonlinear systems is to vary the controller parameters according to the process operating conditions. Recently, various types of modified PI, PD, and PID controllers such as self-tuning, and adaptive controllers have been developed for this aim [13]. Though the fuzzy-PI controllers, a membership of self-tuning controller class, have linear structure as the conventional PI controllers, their proportional and integral gains are varied according to the error in the output of system.

In this paper, fuzzy-PI controlled an active power filter with the function of UPS is proposed. The structure of the system and its model are given in Section 2. Section 3 presents the control of the proposed system by using fuzz-PI controller. Simulation results of system controlled by traditional PI controller and fuzzy-PI controller are given in Section 4. In the last section, the performance of the proposed controller is evaluated by using these results.

II. STRUCTURE AND MODEL OF THE PROPOSED SYSTEM

The basic circuit scheme of the proposed system is given in Figure 1. The system consists of a half-bridge switching mode rectifier, buck-boost DC chopper, battery group, nonlinear load, and AC switch used to select the operating mode of the system. The module which is composed of insulated gate bipolar transistors(IGBTs) Q1-Q2 and filter components L_f-C_d or filter components L_f-C_f represents the half-bridge switching mode rectifier, while the module which is composed of IGBT's Q3-Q4 and filter components L_b-C_b represents the buck-boost DC chopper. S_{mode} is a fast AC switch used to select the operating mode of the system.

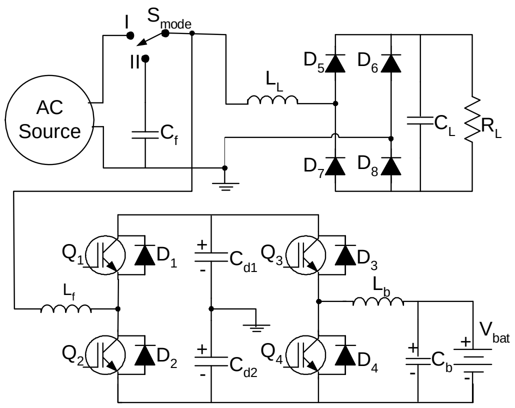


Figure.1. Basic circuit scheme of the proposed system

The system has two operating modes. In the first mode, when AC input power is available, half-bridge switching mode rectifier operates as an active filter. In this mode, the charging of the battery is achieved by using buck converter stepping down the output of the active filter to the voltage level of battery. The second mode works when there is a being cutting in the input power or a change over %30 in the input power. In this mode, half-bridge switching mode rectifier operates as an inverter, and the input of inverter is provided by boost converter stepping up the battery voltage to the voltage level of DC line. According to the operating modes, the equivalent circuit scheme of the proposed system has been obtained as shown in Figure 2. A single switch is used for each IGBT module in the system. Switches S_f, S_b, S_d and S'_d are models that demonstrates turn-on and turn off states of the IGBTs and diodes.

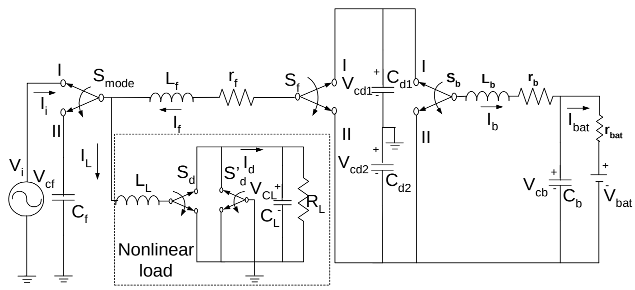


Figure.2. Equivalent circuit scheme of the proposed system

According to the operating modes, the current and voltage equations obtaining from equivalent circuit scheme in Fig.2 are given as follows;

$$\frac{di_f}{dt} = \frac{-v_i - i_f.r_f + S_f.v_{cd1} - (1-S_f).v_{cd2}}{L_f} \quad (1)$$

$$\frac{di_b}{dt} = \frac{S_b.(v_{cd1} + v_{cd2}) - i_b.r_b - v_{cb}}{L_b} \quad (2)$$

$$\frac{dv_{cd1}}{dt} = \frac{-S_f.i_f - S_b.i_b}{C_{d1}} \quad (3)$$

$$\frac{dv_{cd2}}{dt} = \frac{(1-S_f).i_f - S_b.i_b}{C_{d2}} \quad (4)$$

$$\frac{dv_{cb}}{dt} = \frac{i_b - (V_{cb} - V_{bat})/r_{bat}}{C_b} \quad (5)$$

$$|v_i| > v_{CL}, \quad \frac{di_d}{dt} = \frac{(|v_i| - v_{CL} - 1.4)}{L_L} \quad (6)$$

$$|v_i| <= v_{CL}, \quad i_d = 0 \quad (7)$$

$$\frac{dv_{CL}}{dt} = \frac{i_d - (V_{CL}/R_L)}{C_L} \quad (8)$$

The position I of switches used in the equivalent circuit is equal to 1 above equations, while the position II of them is equal to 0. 1.4 value in equation 6 represents the drop voltage of two conducting diodes.

III. CONTROL OF THE PROPOSED SYSTEM

The proposed system has been controlled by using current-based control techniques. The technique used in the control of active power filter is an algorithm obtained from the operating principle of active filter. Two step constant current-constant voltage charge control technique is used for charging the battery. The current mode control technique is used in the control of the inverter and boost converter. In these techniques, both traditional PI controller and fuzzy-PI controller are used to compare the effects on the system performance of fuzzy-PI controller. The structure of fuzzy-PI controller used in these techniques is shown in Figure 3. The proposed controller mainly consists of two sections. The first section is a digital PI controller determining the reference signal of PWM generator or current controller. The second section shows a fuzzy logic controller containing fuzzifier, inference engine, data base, rule base and defuzzifier units. In this structure, fuzzy logic controller works as a controller generating the proportional and integral gains (Kp, Ki) of PI controller, according to the voltage error and the change of voltage error.

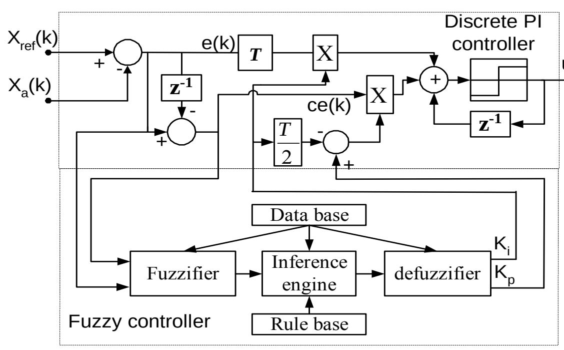


Figure 3. Structure of fuzzy-PI controller

PI and fuzzy logic controllers have two inputs, which are the voltage error and the change of voltage error in the inverter output. The outputs of the controllers are different from each other. While the output of PI controller is the change in the reference signal of PWM generator, the outputs of fuzzy logic controller are the proportional and integral gains of PI controller. Generally, the inputs and outputs of the proposed controller can be defined, respectively, as follows.

$$e(k) = X_{ref} - X_a(k) \quad (9)$$

$$ce(k) = e(k) - e(k-1) \quad (10)$$

$$u(k) = u(k-1) + cu(k) \quad (11)$$

where $X_a(k)$ is the sampled value from the system output at the kth sampling time, X_{ref} is the constant value representing the reference of output voltage or output current, and $cu(k)$ is the inferred change value for the reference of PWM generator or current controller at the kth sampling time. In the fuzzy logic controller, five fuzzy sets are chosen for each input, and these are defined with linguistic labels: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB). The membership function of fuzzy input variables e and ce are assigned as having a symmetric triangular form to be simple and efficient form for the studies. It is used two fuzzy sets with linguistic labels: Small (S) and Big (B) for the outputs of the controller. Figure 4 shows the input and output membership functions of the controller.

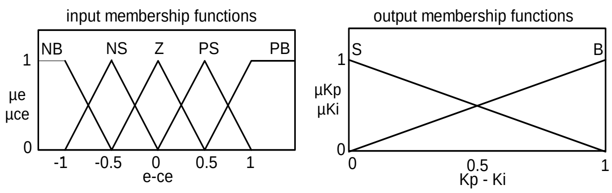


Figure 4. Input and output membership functions of the controller.

Fuzzy control rules are configured by using operator's experience and expertise. Each fuzzy rule is in form: Ri: IF e is Ai and ce is Bi THEN cu is Ci. where Ai, Bi and Ci are fuzzy sets in their universe of discourse. According to experiences in system action, 25 fuzzy control rules are used in design of the fuzzy logic controller, as given in Table 1.

Table 1. Rule base for determining the gain Kp and Ki

Kp

ce \ e	NB	NS	Z	PS	PB
NB	B	B	B	B	B
NS	S	B	B	B	S
Z	S	S	B	S	S
PS	S	B	B	B	S
PB	B	B	B	B	B

Ki

ce \ e	NB	NS	Z	PS	PB
NB	B	B	B	B	B
NS	B	S	S	S	B
Z	B	B	S	B	B
PS	B	S	S	S	B
PB	B	B	B	B	B

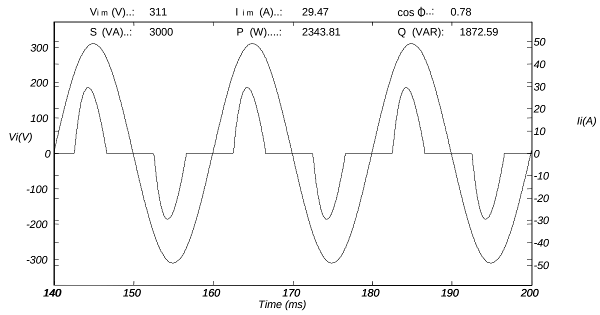
Fuzzy implication, connected to the rules, is realized by using Mamdani's MIN implication commonly used in implementation. Defuzzification procedure in the fuzzy logic controller is achieved by using the centre of gravity, which is also known as the centroid.

IV. SIMULATION STUDIES

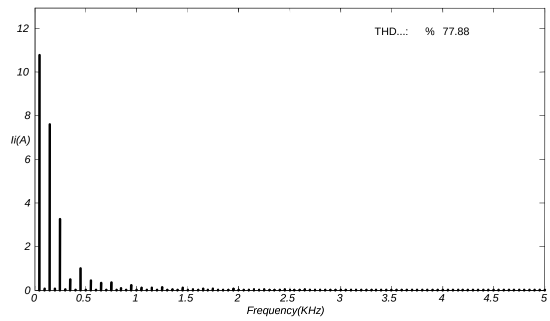
The simulation studies of the system are performed by a program written in C programming language. LC filters parameters used in the simulation studies are as follows: L_f=1mH, r_f=0.125 Ω, C_f=27µF, C_d=2000 µF, L_b=2mH, r_b=0.125 Ω and C_b=100 µF. Parameters of nonlinear load are L_L=0.1 mH, C_L=1000 µF and R_L=31 Ω. The sampling frequency of the current controllers and voltage controllers are set to 20 Khz and 10 Khz, respectively. The PWM switching frequency is 20 Khz.

Figure 5.a shows AC line voltage and AC line current waveforms for 3KVA nonlinear load, when the proposed system is not connected between AC line and nonlinear load. The active power and reactive power drawn in AC line and input power factor are calculated as 2343.81 W, 1872.59 VAR and 0.78 by using data of waveforms in figure 5.a, respectively. The harmonic spectrum of AC line current is given in Figure 5.b. There exists large harmonics at 150 Hz, 250 Hz, 350Hz…etc., and total harmonic distortion of AC line current is %77.88.

AC line voltage and AC line current waveforms of the PI controlled active power filter with the function of UPS and the harmonic spectrum of AC line current are shown in Figure 6. From waveforms in figure 6.a, it can be understood that reactive power drawn in AC line is reduced from 1872.59 VAR to 104.27 VAR, while the input power factor is corrected from 0.78 to 0.9992. Moreover, the total harmonic distortion of AC line current is decreased from %77.88 to %5.496.

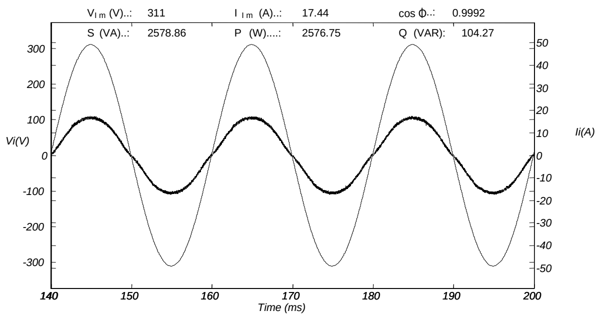


(a)



(b)

Figure 5. AC line voltage and AC line current waveforms and the harmonic spectrum of AC line current when the proposed system is not connected between AC line and nonlinear load: a. AC line voltage and AC line current waveforms, b: the harmonic spectrum of AC line current.



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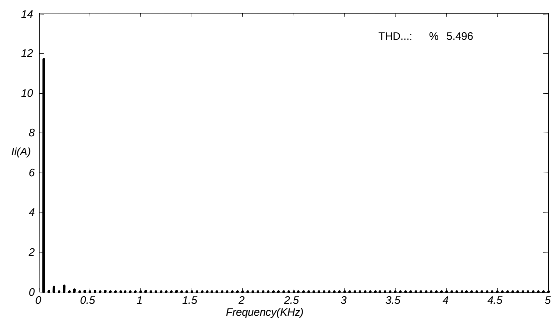
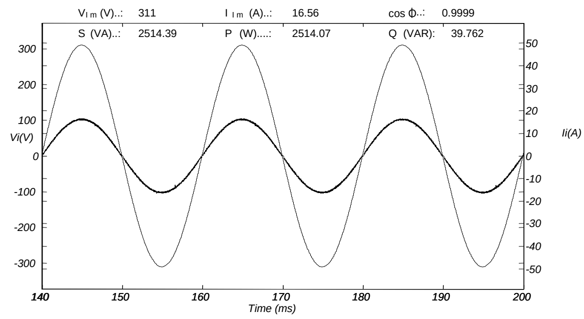


(b)

Figure 6. AC line voltage and AC line current waveforms of the PI controlled active power filter with the function of UPS and the harmonic spectrum of AC line current: a. AC line voltage and AC line current waveforms, b: the harmonic spectrum of AC line current.

Figure 7 illustrates AC line voltage and AC line current waveforms of the Fuzzy-PI controlled active power filter with the function of UPS and the harmonic spectrum of AC line current. For the Fuzzy-PI controlled system, the input power factor, reactive power drawn in AC line and total harmonic distortion of the AC line current are obtained as 0.9999, 39.762 VAR and % 2.03, respectively.

The compensation current waveform of the active power filter in the PI controlled system is given in Figure 8.a. From the figure, it can be seen that the active filter generates the waveform of 14.99 A peak value with opposite phase. Figure 8.b shows the compensation current waveform of the active power filter in the fuzzy-PI controlled system. This current value is obtained as 14.31 A.



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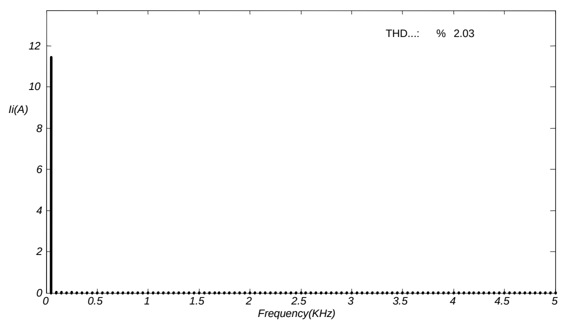
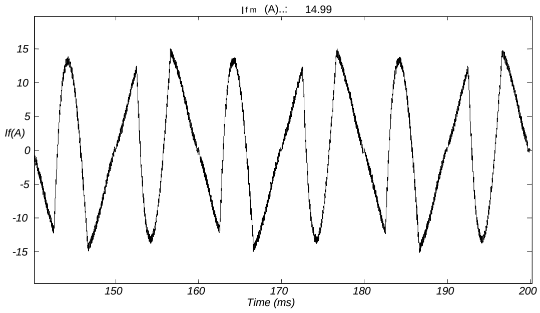


(b)

Figure 7. AC line voltage and AC line current waveforms of the fuzzy-PI controlled active power filter with the function of UPS and the harmonic spectrum of AC line current: a. AC line voltage and AC line current waveforms, b: the harmonic spectrum of AC line current.



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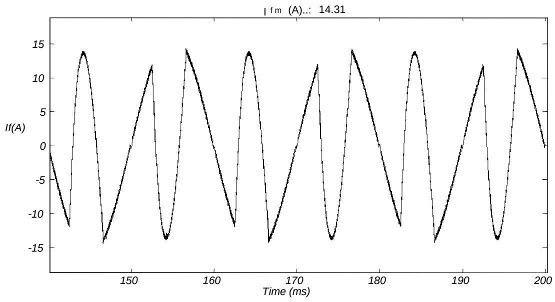

(b)

Figure 8. Compensation current waveforms of the active power filter: a. PI controlled system, b. fuzzy-PI controlled system.

V. CONCLUSION

In this study, fuzzy-PI controlled active power filter with function of uninterruptible power supply was designed and effects on the system performance of fuzzy-PI controller were analysed. Input power factor, total harmonic distortion of the input current and reactive power components were taken as the performance parameters of system. To observe effects on the system performance of the fuzzy-PI controller, the system also was controlled by using traditional PI controller. Simulation results showed that the fuzzy-PI controlled system provides an improvement 64.5 VAR lower in reactive power compensation and %3.1 lower in the rate of total harmonic distortion of the input current than traditional PI controlled system.

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