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Analysis of Power System Filter Based on Fuzzy Control Technology

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Due to the large number of non-linear loads that are connected to the power system, the current power system is distorted and the operating efficiency is reduced. Given this situation, this study, is focused on the design of an active power filter based on fuzzy control technology. In this study, Δi_c and $\frac{d\Delta i_c}{dt}$ were used as the input part of the fuzzy control. After the fuzzy control, the main circuit driven by the PWM control signal is obtained and the closed-loop control system is formed. Simultaneously, MATLAB was used to model and simulate the fuzzy active power filter, and the correctness and feasibility of the improved system was verified by the comparison of simulation waveform diagrams and spectrogram results. The simulation results show that the active filter based on fuzzy control designed in this study effectively suppresses harmonics, and can be used as a valuable reference for subsequent research.

Keywords: fuzzy control; power system; filter; simulation waveform

1. INTRODUCTION

The rapid development of science and technology has promoted the further development of the power system and has achieved applications in various industries. At present, some advanced power systems have been applied to various fields. Although these electrical devices enhance people's productivity and lifestyle, they also generate a large number of harmonics and reactive currents which reduce the quality of electrical energy and pollute the environment of an otherwise safe, stable, and economical electrical system. By means of an active filter, power quality can be improved, and harmonics can be effectively controlled.

The development of active power filters can be traced back to the end of the 1960s. In 1969, J.F. Marsh and B.M. Bird attempted to reduce the harmonic current component in the grid current by injecting third harmonic currents into the AC grid, which is the core of active power filtering technology (Erjie, 2017); H. Sasaki and T. Machida firstly fully describe the basic working principle of active power filters (Sahu, 2015); L. Gyugyi et al. proposed an active power filter using PWM control converters and established the main circuit topology and current control method for active power filters. However, due to the low level of powered electronics technology and

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the low frequency and power of fully-controlled devices at the time, active power filter development was confined to laboratory research and was not applied to industrial and mining enterprises (Chen, 2014). After H. Akagi et al. proposed the instantaneous reactive power theory of a three-phase circuit in 1983, the harmonic and reactive current detection methods based on this theory have been successfully applied in active power filters and have greatly promoted the development and use of active power filters (Cao, 2014). At present, the instantaneous reactive power theory has become an important theoretical basis for active power filters.

At present, active power filters have been increasingly used in industrialized countries such as the United States, Japan, and Germany. In 1982, the world's first active filter (800k VA) consisting of a current-source PWM inverter was successfully developed and put into use in Japan (Xia, 2015); In 1986, Japan developed a current compensator for the compensation of three-phase rectifiers, which can provide up to 19 times of compensation. After nearly 30 years of development, the power range of active power filters that Japan has already put into use has become larger and larger and active power filters have undergone great development (Yuan, 2014). With the continuous decrease in the price of active power filters, its market share is increasing. The primary switching power devices in the PWM converters of early active power filters all use GTO or BJT. However, voltage-type active power filters nowadays generally use IGBT modules, so that the capacity of active power filters can be made larger and larger (Huang, 2014).

China's research on active power filters started late, and research did not appear in the literature until the end of the 1980s. The harmonic detection methods used in the paper were outdated and the compensation effect was not satisfactory. Since the 1990s, some universities and research institutes have begun to study active power filters, mainly represented by Zhejiang University and Xi'an Jiaotong University, and some units have developed prototypes and put them into trial operation. With the widespread use of powered electronic devices and our attention to power quality problems, the use of active power filters for harmonic control has great market potential and social significance, and active power filtering technology will be widely used in China.

With the widespread use of powered electronic equipment and the increasing demand for power quality in modern society, active power filters will be increasingly used. Although some active power filter prototypes have been developed and trialled, there are still many defects in the control of the power quality of the power grid, and there are many problems that need further study and solutions. Therefore, this paper takes the fuzzy control base as the basis for studying the power system filter.

2. RESEARCH METHODS

The structure of the fuzzy controller is shown in Figure 1. The fuzzy controller has four parts: knowledge base, fuzzification, reasoning judgment and clarity. As the name suggests, a knowledge base is a database for storing knowledge. It stores many years of knowledge and experience accumulated by experts or operators, membership values of all fuzzy subsets of input and output variables, and the rules of control followed in the fuzzy control process. It consists of a database and a rule base, which mainly provide data and control rules for reasoning judgments. Fuzzification is actually the input interface of the fuzzy controller, the main function of which is to change a precise input variable into a fuzzy quantity. Since the precise amount cannot be identified in the fuzzy control process, the precise amount will need to be transformed into the fuzzy control domain through this stage. Reasoning judgment is that by applying fuzzy concepts and control rules and introducing fuzzy mathematics, human language and thinking are quantitatively inferred and judged, and finally fuzzy output variables are obtained by solving equations. Reasoning judgment is known as the 'brain' function of a fuzzy controller, which is an important part of the controller. For clarity, the value of the fuzzy variable must be converted to an accurate variable value. Since the output of the fuzzy control is the amount of blur and the actuator needs precise quantities, the conversion between the values of the two variables is achieved through this stage (Mohanty, 2016).

The principle of fuzzy control is: First, the deviation between the actual measured value of the controlled object and the given value is determined as the controller's input quantity. Then this input is transformed into the fuzzy domain and expressed by fuzzy linguistic values. Next, the control rules are reasoned and judged to get the fuzzy output. Finally, the fuzzy output is converted into a precise quantity by clearing. It is summed up in four steps: (1) Select the input amount; (2) The input volume is converted into a fuzzy quantity; (3) According to the control rules, the fuzzy output is obtained through reasoning judgment; (4) The fuzzy quantity of output is converted to a precise quantity by clearing (Khalid, 2017).

Under normal circumstances, the deviation value e is used as the input variable of the fuzzy controller, and the deviation value is used to determine how the system is controlled. However, in practical applications, in order to obtain more accurate values, most fuzzy control systems still need to determine how to control the system by combining the deviation value e and the rate of change of the deviation value e. To enable fuzzy control of the system, the input must be converted into a membership function of the fuzzy universe, and the input value corresponds to the fuzzy set.

The input quantity of the fuzzy controller is the error value of the given value and the output quantity. When choosing language variables, we can consider the choice of output error, output error sum and so on. After selecting the variables, fuzzy partitioning of the variable space will begin. In the process of fuzzy partitioning, there will be overlap between the spaces, which will reduce the control performance of the system. This phenomenon is now avoided mainly by continuously experimenting with segmentation.

The variation range of the error value is determined as [-6,6], and its discretization is converted to 13 levels, namely {-6,-5,-4,-3,-2,-1,0,1,2 ,3,4,5,6}. The error range can be expressed in the form of the linguistic value of the fuzzy variable: {Negative, Large, Negative, Negative, Negative, Positive, Small, Positive, Positive, Positive}, which is commonly used in practical applications: {NB, NM, NS , Z, PO, PS, PM,

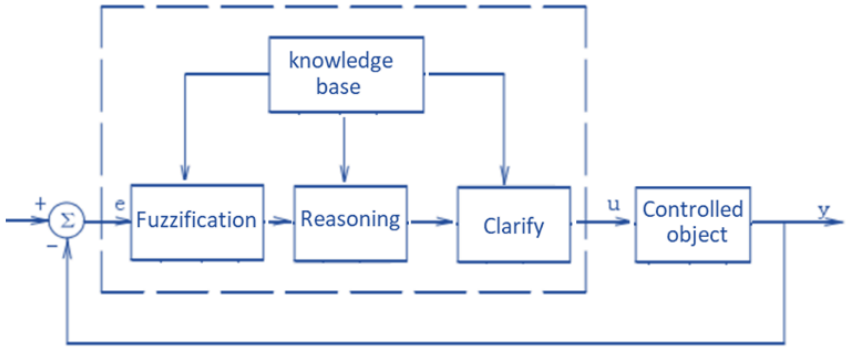


Figure 1 The principle of fuzzy control.

PB} as markers. Its meaning is as follows (Kouadria, 2015):

(1)

(2)

(3)

(4)

(5)

(6)

(7)

(8)

The 8 language values of fuzzy variables are equivalent to 8 subsets. The fuzzy condition is usually described by the membership function $\mu_A(x)$. When the membership function is represented by a Gaussian function, the membership function value of the fuzzy variable e is as shown in Table 1.

After the harmonic currents are detected, a series of processes are required to output the PWM control signals, so that the harmonic current of the power grid can be compensated for to reduce the distortion rate.

It can be seen from the figure above that the difference between the detected obtained by reversing the polarity of the harmonic current and the actual current value i_c can obtain Δi_c. The fuzzy control output signal is sent to the hysteresis comparator and processed to obtain the PWM signal. Through this signal, the switching components of the main circuit are controlled to achieve the purpose of compensating for the harmonics of the power grid. This paper does not use this most primitive method; instead, it adds an input method, that is, the method of changing rate $\frac{d\Delta i_c}{dt}$ of Δi_c. The two-dimensional fuzzy control module diagram used in this paper is shown in Figure 3.

The Δi_c and $\frac{d\Delta i_c}{dt}$ are regarded as the input part of the fuzzy control, abbreviated as E and EC, and the driving main circuit of the PWM control signal after fuzzy control is obtained, abbreviated as U. In this way, a closed-loop control system is formed, which improves the real-time and high accuracy of system control and reduces the complexity of hardware operations. After the input variable is determined, it needs to be transformed into fuzzy control domain [-1,1]. The general approach is to perform Gain factor quantization and Saturation clipping of the input. The variation range of the error E and the error rate EC is set to [a, b], and the range of change of the input amount of the fuzzy controller is set to [c, d]. Then the conversion formula is:

(9)

Among them, x represents the accurate error value, its value range is a, b, and y represents fuzzy controller input quantity, its value is c, d. Hence, the quantified factors obtained for E and EC are k_1 and k_2, respectively. The output variable U is then reduced by the scale factor Gain.

Following the above analysis, MATLAB was used to model and simulate the fuzzy active power filter, and the correctness and feasibility of the improved system were verified through the comparison of simulation waveform diagrams, spectrum diagrams and analysis results.

3. RESULTS

This study compared the filter control of a power system based on fuzzy control technology with that of traditional filter control, and conducted a simulation experiment of DC bus voltage control of the active power filter in MATLAB/Simulink. The simulation results are shown in Figure 4.

Using MATLAB to model and simulate the fuzzy active power filter, the correctness and feasibility of the improved system are verified by comparing the simulation waveform diagram, spectrum diagram and analysis results. The system-side current waveform diagram and frequency domain analysis diagram are shown in Figure 5(a) and (b). Figure 5(a) is the current waveform diagram of the system side, and Figure 5(b) is the frequency domain analysis diagram.

After adding the active filter to the system, the current waveform and frequency domain analysis diagram at the system side are shown in Figure 6.

Figure 6(a) is the current waveform diagram of the system side after adding the active filter, and Fig. 5(b) is the frequency domain analysis diagram after adding the active filter.

Table 1 Membership Function Values of Fuzzy Variable e.

	-6	-5	-4	-3	-2	-1	-0	+0	+1	+2	+3	+4	+5	+6
PB											0.1	0.4	0.8	1
PM										0.2	0.7	1	0.7	0.2
PS								0.3	0.9	1	0.7	0.2		
P0								1	0.6	0.1				
ZO					0.1	0.6	1							
NS			0.2	0.7	1	0.9	0.3							
NM	0.2	0.7	1	0.7	0.2									
NB	1	0.8	0.4	0.1										

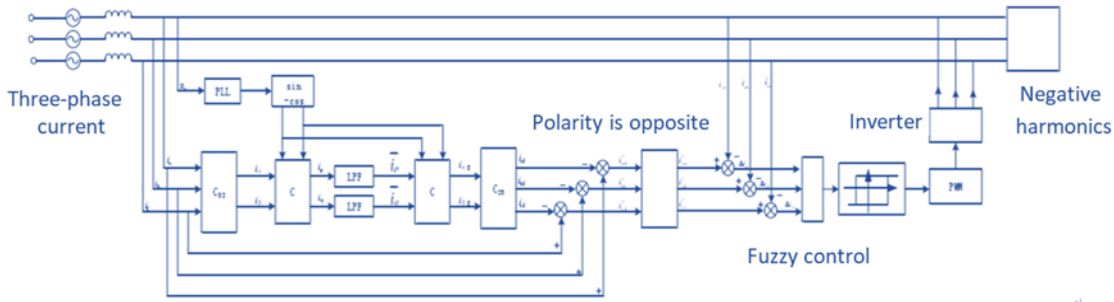


Figure 2 The signal processing and PWM control diagrams.

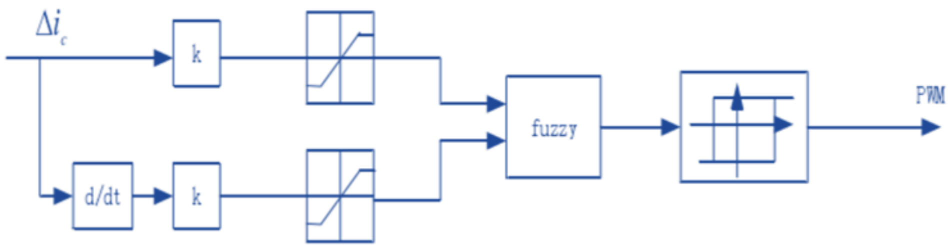
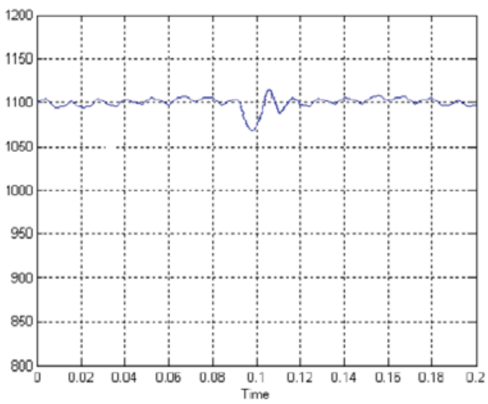
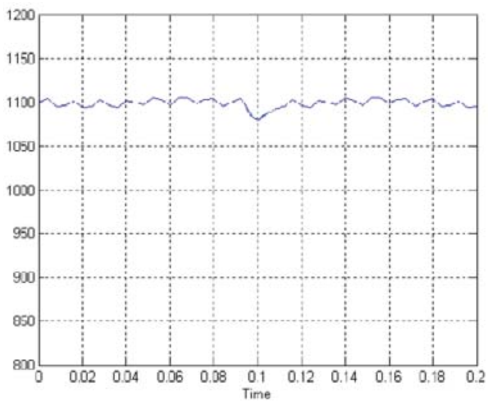


Figure 3 Two-dimensional fuzzy control module.

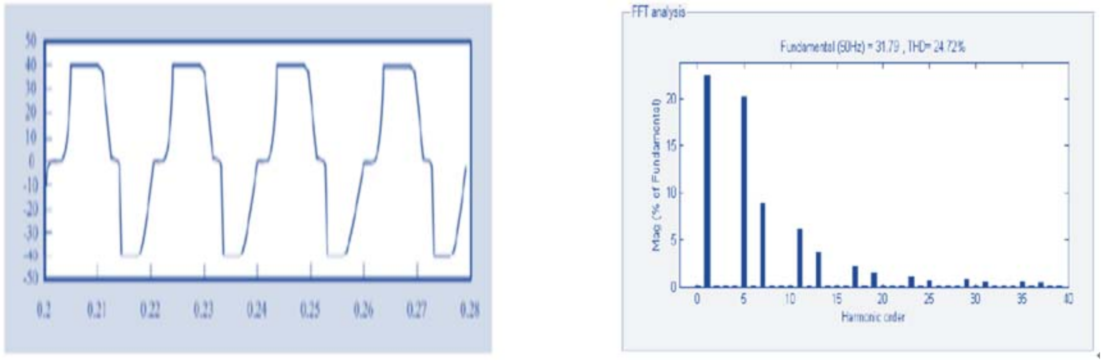


(a) Control results of the filter in this study



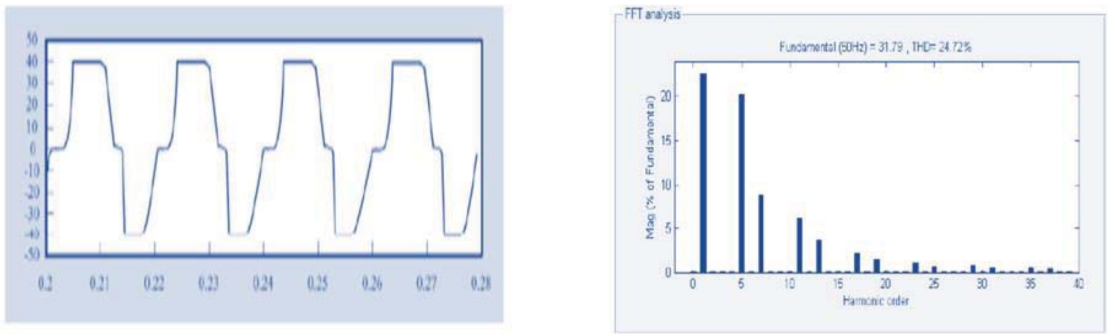
(b) Control results of conventional filter

Figure 4 Comparison and analysis of the control of this research filter and the traditional filter.



(a) Current waveform diagram of the system side (b) Frequency domain analysis diagram

Figure 5 The system-side current waveform diagram and frequency domain analysis diagram.



(a) Current waveform diagram of the system side after adding the active filter (b)Frequency domain analysis diagram after adding the active filter

Figure 6 Current waveform and frequency domain analysis diagram of the system side after adding an active filter.

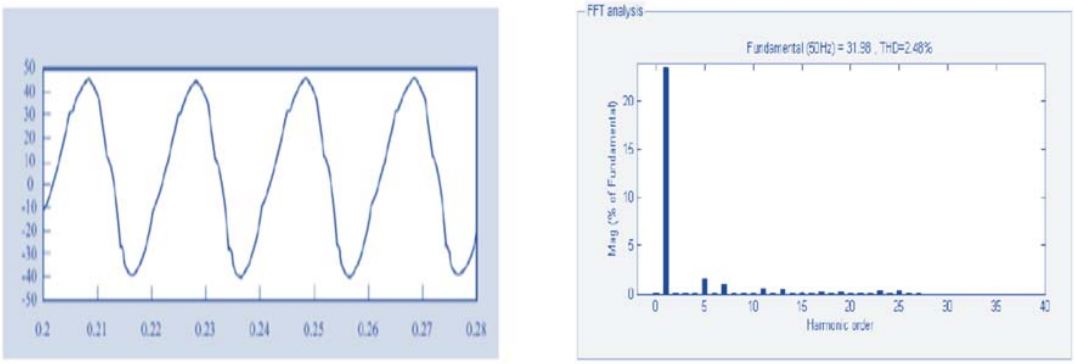
After the fuzzy control active filter is added to the system, the current waveform and frequency domain analysis diagram at the system side as shown in Figure 7. Figure 7 (a) is the current waveform diagram of the system side after adding the fuzzy control active filter, and Figure 7 (b) is the frequency domain analysis diagram after adding the fuzzy control active filter.

4. DISCUSSION AND ANALYSIS

The analysis of simulation results shows that the fuzzy control of this study has a good effect. Fuzzy control flow image: (1) Self-learning. In order to improve the performance of the fuzzy controller, it must be allowed to self-learn or self-organize, so that the fuzzy controller can add or modify the fuzzy control rules according to the set goals. (2) Record the operation mode. In many complex industrial systems, the use of general control theory does not guarantee its correctness. However, experienced operators can control the system well without having to understand complex theories or mathematical models. Therefore, the operation mode is recorded and converted to if...then form to obtain the control rule. (3) Expert experience and knowledge. By asking experienced experts to obtain systematic knowledge and changing the knowledge to if....then, the fuzzy control rules can be formed. At the same time, the rules of fuzzy control are not static. In order for the system to achieve the best control effect, it is necessary to modify the control rules several times.

The working principle of the shunt active power filter is: Current harmonic components existing in the power grid are detected by the detection circuit, and then value taken from the opposite polarity is used as the command signal to be compensated. Then, a certain type of current tracking control method is converted into the main circuit switching device's on-off function controlled by the PWM pulse instruction to obtain a compensation current that is equal in magnitude to the load harmonic current and 180° out of phase. Finally, the harmonic components of the grid load are offset until the current contains only the fundamental components, thereby ensuring that the voltage and current on the supply side are approximately sinusoidal, thus achieving the effect of suppressing harmonics. Hence, this study constructed a corresponding model and performed simulations, achieving good results.

From Figure 4(a), it can be seen that when the sudden increase in load causes the DC bus voltage to drop, the DC bus voltage will fluctuate greatly when traditional control strate-



(a) Current waveform diagram of the system side after adding the fuzzy control active filter (b) Frequency domain analysis diagram after adding the fuzzy control active filter.

Figure 7 Current waveform diagram and frequency domain analysis diagram of the system side after adding a fuzzy control active filter.

gies are used to regulate. From Figure 4(b), it can be seen that when the fuzzy control strategy is adopted, the DC-side capacitor voltage fluctuates less, and it will tend to regain stability quickly. It can be seen that the adoption of a fuzzy control strategy can buffer to a certain extent the fluctuation caused by the exchange of energy between the DC side capacitor and the AC side of the active power filter due to the fluctuation and uncertainty of the nonlinear load.

It can be seen from the simulation diagram in Figure 5 that the current at the end of the grid system is affected by the harmonic load, and its current is seriously distorted. In particular, the 5th, 7th, and 11th harmonic components are large, and the total harmonic distortion rate is as high as 24.72%. Figure 6 shows that after adding the active filter, the 5 times, 7 times, 11 times and more harmonic components are reduced and the total distortion of the harmonics is reduced to 6.84%. This shows that the overall harmonic suppression of the system achieves significant results. However, it does not achieve the expected best results, so it needs to be added to the fuzzy control technology in order to improve. After the improvement, it can be clearly seen that the grid current is similar to the sine wave, and the total distortion rate has also decreased to 2.48%, achieving the expected best effect. The operation effect diagram is shown in Figure 7. Based on the above, the designed active filter based on fuzzy control effectively suppresses harmonics, purifies power grid pollution, improves power quality, and achieves expected results. At the same time, the analysis results verify the feasibility and correctness of the design system.

5. CONCLUSION

Based on the fuzzy control base, the design of a power system filter is studied in this paper. The fuzzy controller has four parts: knowledge base, fuzzification, reasoning judgment and clarity. In fuzzy control, the deviation between the actual measured value of the controlled object and the given value is first determined as the controller's input quantity. Then this input is transformed into the fuzzy domain and expressed by fuzzy linguistic values. Then fuzzy control is used to determine the fuzzy output. Finally, the fuzzy output is converted to a precise quantity. Following the above analysis, MATLAB is used to model and simulate the fuzzy active power filter, and the correctness and feasibility of the improved system are verified through the comparison of simulation waveform diagrams, spectrum diagrams, and analysis results. The simulation results of the conventional system, the system after the addition of the active filter, and the fuzzy control of the active filter were compared with each other to obtain the results of the study. The simulation results show that the active filter based on fuzzy control designed in this study effectively suppresses harmonics, purifies power grid pollution, improves power quality, and achieves expected results. Moreover, the analysis results verify the feasibility and accuracy of the design system.

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