Application of Repetitive Control and ANFIS-PI Compound Control Strategy in APF

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Abstract. In order to effectively solve a series of problems caused by harmonics in power system, an active power filter based on ANFIS-PI and repetitive control is designed. The traditional single control method cannot balance control accuracy and response speed, so a compound control strategy is adopted. Repetitive control can produce the same output as the harmonic current, so it can achieve zero steady-state error tracking compensation for each harmonic, but its dynamic performance is not good. As a traditional control method, the PI control method has a fast response speed, but in the actual application process, when the load changes suddenly, that is, when the system parameters change, its tracking effect is not ideal. Therefore, a composite control strategy of ANFIS-PI and repeated control is proposed. It has been proved that its compensation accuracy and dynamic response speed have been significantly improved.

1. Introduction
There are a large number of non-linear loads in the power grid, which will cause the distortion of the current waveform and generate harmonic pollution, which will seriously affect the stable operation of the power grid and the power safety of users [1]. In the research of harmonic control, active power filter (APF), as one of the most effective means to suppress power grid harmonics, has broad application prospects [2-3]. The design principle is to obtain the corresponding harmonic current component by collecting the current content of the three-phase load in the system, subtracting the fundamental current value from it, and then sending it back to the power system to complete the suppression of the harmonics in the power grid.

Harmonic current is a high-frequency AC signal, and many scholars have done a lot of work on the control of harmonic current. At present, the compensation current control method of APF has triangular carrier control. This method is easy to implement and the switching frequency is fixed, but the control parameters are difficult to determine and it is easy to produce overshoot. The advantage of hysteresis comparison control is that it responds quickly and does not need a carrier. The disadvantage is that the hysteresis bandwidth is not easy to set. The traditional PI control is a very widely used control method, but the tracking effect is not good for high-frequency AC components such as harmonic currents [4]. The bandwidth of PI control is limited, the attenuation is severe in the middle and high frequency bands, and the phase lag is also obvious. The inability to track the signal in the full frequency band will make it difficult for the pi control to achieve zero error tracking control for the harmonic AC signal.

This paper adopts the compound control strategy of ANFIS-PI and repetitive control to realize the compensation of APF to the harmonic current [5-6]. The algorithm combines the advantages of fast
response speed of PI control with the advantages of zero steady-state error tracking of repetitive control to meet the requirements of APF for response speed and accuracy. ANFIS is used to adaptively adjust the parameters of PI controller to solve the problem of load mutation.

2. System model
The system adopts a four-leg circuit model, which is used to compensate the neutral current, and the other three legs track and compensate the corresponding phase current respectively [7]. Compared with the three-arm structure, the circuit is relatively simple. The structure diagram of APF is shown in figure 1.

![Figure 1. The structure diagram of APF.](image)

According to figure 1, Kirchhoff equation is as follows:

\[
\begin{align*}
L \frac{di_a}{dt} &= E_a - (U_a - U_n) \\
L \frac{di_b}{dt} &= E_b - (U_b - U_n) \\
L \frac{di_c}{dt} &= E_c - (U_c - U_n) \\
C \frac{dU_k}{dt} &= S_n i_{in} - (S_a i_{ia} + S_b i_{ib} + S_c i_{ic})
\end{align*}
\]

(1)

Where, \( S_a \), \( S_b \), \( S_c \) and \( S_n \) are state functions. \( U_a \), \( U_b \), \( U_c \), \( U_n \) are DC voltage values corresponding to IGBT output respectively. After coordinate transformation, it is transformed into dq0 coordinate system:
3. Compound control algorithm of ANFIS-PI and repetitive control

The composite control structure is shown in figure 2:

\[
\begin{align*}
\frac{d^2 i_{sd}}{dt^2} &= U_{sd} - (S_d U_k + \omega L_i_d) \\
\frac{d^2 i_{sq}}{dt^2} &= U_{sq} - (S_q U_k + \omega L_i_d) \\
\frac{d^2 i_{sk}}{dt^2} &= U_{s0} - S_0 U_k \\
0 &= \frac{3}{2} (S_d i_{sd} + S_q i_{sq} + 2S_0 i_{sk}) - C \frac{dU_k}{dt}
\end{align*}
\]  

(2)

3.1. PI control

As can be seen from figure 2, the closed-loop transfer function of PI part is:

\[
h(s) = \frac{K_p K / Lt}{s^2 + s / t + K_p K / Lt}
\]  

(3)

Where, \(K_p = 0.56\), \(k = 20\), \(L = 2\) mH, \(t = 10^{-4}\) s, so the expression of PI controller in z domain is:

\[
H(z) = 2.35 + \frac{0.05}{z - 1}
\]  

(4)

3.2. Repetitive control

Repetitive control is a high-precision control method [8-9]. The theoretical basis of this method is the internal model principle. The principle of repetitive control shows that it can track the input signal in any case with high precision and stability, and then realize no static error tracking. In other words, with the change of the input signal, when the change of the input signal tends to reduce the error, the
repetitive control can always maintain a reasonable and appropriate output, and then maintain a state without static error. The discrete model is as follows:

\[ G(z) = \frac{z^{-N}}{1 - z^{-N}} \]  

Where, \( z^{-N} \) represents the periodic delay link. The function of \( z^{-N} \) is to delay the error value of this period to act on the control quantity of the next period.

\( A_m \) is the compensator. It sets the parameters according to the specific characteristics of the \( P(z) \) of the controlled object, and compensates and corrects the phase and amplitude of the controlled object according to the errors measured in the previous period. The error of each cycle is superimposed until the error is zero. The model is as follows:

\[ A_m(z) = K_a z^k T(z) \]  

Where, \( K_a \) is the gain coefficient, which is used to maintain the stability of the system. \( z^k \) is used to compensate the phase. The function of \( T(z) \) is to correct medium and low frequency and high frequency to increase the stability of the system. The function of repetitive control in \( z \) domain is:

\[ R(z) = G(z) A_m(z) = \frac{z^{-N}}{1 - z^{-N}} K_a z^k T(z) \]  

Therefore, the function of compound control system in \( z \) domain is:

\[ Z(z) = z^{-N} \frac{z^k K_a T(z) G(z)}{z^{-N} - Q(z)} + H(z) G(z) \]  

The stability condition of the internal mold structure is \( |[1-P(z)]Q(z)z^{-N}|<1 \). In this paper, the sampling frequency is 10 kHz and the fundamental frequency is 50 Hz, so \( N = 200 \).

3.3. **ANFIS adaptively adjusts PI parameters**

ANFIS has good adaptability to nonlinear and multivariable system [10-11]. It can handle some uncertain data. It combines fuzzy logic and neural network organically, and has the advantages of both. It has three inputs: input value, output value and error. It has two outputs, P parameter and I parameter.

ANFIS has a five-layer structure. After the structure is determined, the initial value is selected and the learning rate is determined. The system continuously modifies the weights, so as to realize the adaptive adjustment of P parameter and I parameter.

- The first layer is the membership function layer.
- The nodes of the second layer are circular nodes labeled \( \Pi \).
- In the third layer, the ith node calculates the ratio of the ith rule’s firing strength to the sum of all rules’ firing strength.
- The fourth layer calculates the output of fuzzy rules.
- The fifth layer calculates the total output of all input signals.

4. **Results and simulation**

According to the above algorithm, the system model is built, and the PI control, PI-repetitive control and PI-repetitive control algorithm with ANFIS are simulated and verified respectively. Figures 3 and 4 show the compensation effect of APF under PI control and PI-repetitive control.
The simulation results show that under PI control and PI-repetitive control, total harmonic distortion (THD) after APF compensation is 10.47% and 3.41% respectively. Green, blue and red waveform curves represent three-phase currents of A, B and C respectively. According to the IEEE standard, for power systems below 6kv, THD should be less than 5%. Therefore, only PI control cannot meet the requirements of harmonic current tracking compensation in power system. Considering that the sudden change of load affects the system parameters and the control effect of PI controller, ANFIS is used to adaptively modify the PI parameters.

As shown in figure 5, under the strategy of ANFIS-PI and repetitive control, THD is 2.2% after APF compensation, which is better than the first two methods.

| Table 1. Compensation effect of APF under different control algorithms. |
|-----------------------------|------------------|
| Control algorithm            | THD              |
| PI control                   | 10.47%           |
| PI control and repetitive    | 3.41%            |
| ANFIS-PI and repetitive      | 2.23%            |
According to figure 5, it can be seen that at 0.2s, the load has a sudden change, and the current has a small fluctuation, which has little effect on the system. Therefore, the algorithm proposed in this paper has good superiority in the process of APF compensation for sudden changes in load.

5. Conclusion
In this paper, the compound control strategy of ANFIS-PI and repetitive control is used to compensate the harmonic current of active power filter (APF), aiming at the disadvantage that the traditional control strategy of APF can not track the harmonic current without error. PI control has fast response speed, but the tracking compensation degree of harmonic current is not high, and the total harmonic distortion (THD) after compensation often can not meet the requirements of the system. Repetitive control can track and compensate the zero steady-state error of each harmonic in the system, but it has time delay and poor dynamic performance. Therefore, it is combined with PI control to form a compound control strategy. However, considering the influence of sudden load change on PI control, ANFIS is used to adaptively adjust P parameter and I parameter. The simulation results show that the composite control strategy has high accuracy and fast dynamic response. It is an ideal APF harmonic current tracking compensation scheme.

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