Research and improvement of current control strategy of active power filter

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Abstract. With the continuous development of science and technology, there are many power quality problems which are different from those in the past. A large number of innovative electrical equipment will bring a lot of harmonics in the process of work, which will not only cause potential safety problems in the power system, but also cause serious harm and impact on the normal operation of all power dependent working equipment. In this paper, active power filter (APF) is studied for harmonic control of distribution network. A new APF current compound control method is proposed, which is based on Deadbeat and repeat plus LADRC in series. It improves the accuracy of harmonic compensation, enhances the anti-interference ability and dynamic performance, and achieves the purpose of precise control of current loop.

1. Introduction
With the increasing demand for energy conservation, emission reduction and sustainable development, more and more new energy has been connected to the power system. Based on this trend, people are no longer only in demand for electricity as before, but also have very strict requirements for the quality of electricity [1]. However, due to the development of science and technology, more and more harmonics have been produced, which has caused serious impact and harm to the whole power system [2]. This kind of harm and influence is more and more, followed by a large number of problems related to power quality in the distribution network [3]. For harmonic problems in power quality, this paper introduces active power filter, and puts forward an APF current control method of deadbeat and repetition + LADRC series connection, which improves the accuracy of harmonic compensation, improves the overall performance of active power filter, and is of great benefit to harmonic control in power quality [4].

As an important part of active power filter, current tracking control plays a decisive role in the harmonic suppression performance of APF. It is of great engineering significance to study the current tracking control strategy for improving the real-time and control ability of APF and the harmonic suppression performance of APF. The commonly used current control algorithms include hysteresis control, PI control, resonance control, repetitive control, etc [5].

2. APF current compound control strategy with deadbeat and repetitive LADRC in series
The core idea of repetitive control theory comes from the internal model principle. The internal model principle is essentially a feedback control system, that is, a dynamic model with external signals is implanted to build a feedback control system with high precision. Repetitive control can control the
AC signals without static error, but the dynamic response of the system is poor. Different from the traditional repetitive + PI control method, the patent of the invention proposes repetitive + LADRC current control method. Repetitive + PI control adds state feedback link to carry out current decoupling, which increases the complexity and additional loss of the system. Therefore, repetitive + LADRC is designed. The current coupling is treated as internal disturbance instead of state feedback, which simplifies the system and enhances the anti-interference performance of the system [6].

The mathematical modeling of three-level APF shows its state equation, as shown in (1)

\[ \frac{d i_{cd}}{dt} = -Ri_{cd} + \omega L i_{cq} - u_{cd} + u_d \]

\[ \frac{d i_{cq}}{dt} = -Ri_{cq} - \omega L i_{cd} - u_{cq} + u_q \]

If \( \omega_y = \omega L i_q - u_{ad} \), \( \omega_q = -\omega L i_d - u_{sd} \), equation (1) can be changed to:

\[ \frac{d i_{cd}}{dt} = -Ri_{cd} + \omega_d + u_d \]

\[ \frac{d i_{cq}}{dt} = -Ri_{cq} + \omega_q + u_q \]

It can be seen from (2) that the d-axis and q-axis components of three-level APF compensation current in DP coordinate system do not interfere with each other, so the coupling is relieved. In principle, \( \omega_d \) and \( \omega_q \) are observed and compensated as internal disturbances. In this paper, a linear ADRC is designed for the compensation current D and q axis components respectively. Since the design process of the two axes in the linear ADRC is exactly the same, the controller is designed with d axis as an example. Because the three-level APF is equivalent to a first-order system, only two first-order linear ADRC controllers are needed. In order to speed up the response of the system, the tracking differentiator is discarded and only the linear expansion observer and the linear error feedback rate are retained [7].

If \( x_i = i_{cd} \), then:

\[ \dot{x} = -R \frac{i_{cd}}{L} + \frac{1}{L} u_d + \frac{1}{L} \omega_d \]

Order \( b = \frac{1}{L} \), Then (3) can be written as:

\[ \dot{x}_i = -R \frac{x_i}{L} + b u_d + \frac{1}{L} \omega_d \]

(4)

It can be seen from equation (4) that the system needs a second-order extended state observer whose expression is:

\[ z_1 = z_2 - B_1 (z_1 - i_{cd}) + bu_d \]

\[ z_2 = -B_2 (z_1 - i_{cd}) \]

(5)

According to equation (5), LESO (Linear extended state observer) has two output variables. Among them, \( z_1 \) tracks the system feedback \( i_c \) and acts as the current feedback signal of the controller; \( z_2 \) is called disturbance compensation, which is directly introduced into the output of the controller to carry out feedforward compensation for the disturbance of the system[8].

LSEF (Linear state error feedback control law) is a first-order linear state error feedback control law. Its expression is as follows:
\[ u_0 = k_p (i_c - z_1) \]  \hspace{1cm} (6)

Therefore, the total output of the linear ADRC is:

\[ u = \frac{u_0 - z_2}{b} \]  \hspace{1cm} (7)

To sum up, the adjustable parameters of the linear ADRC are: the proportion coefficient \( k_p \) in LSET, the B1 and B2 in LESO. Compared with ADRC, linear ADRC greatly reduces the difficulty of design [9].

![Figure 1 Repetition + LADRC control structure block diagram](image)

The series compound control of deadbeat and repeat + LADRC control is carried out. Deadbeat control is a unique control method in digital system, because the output of the next beat of the system can always be expressed by the linear combination of the current input and the system state variables [10].

In the composite control system, there is only one sampling period delay between the output current and the reference current of deadbeat control, which can quickly track the command current signal; while the repetitive control has \( 1 / P \) cycle delay, and the output of repetitive control is almost the same as the previous sampling period. After \( 1 / P \) cycle, the repetitive control begins to play a role of correction. Therefore, the deadbeat control can improve the dynamic performance of the system at the moment of system sudden change; after \( 1 / P \) cycle, the repetitive control starts to output to ensure the stable performance of the system [11,12].

The difference equation of deadbeat controller can be expressed as

\[ i^*_{d}(z) = i_{d}(z) + \frac{T_s}{L} [U(z) - E(z) - i(z)R] \]  \hspace{1cm} (8)

Because of the uncertainty of inductance and resistance, the transfer function of deadbeat control can be modified to

\[ z_{d}(z) = i_{d}(z) + \frac{T_s}{Lr + \Delta L} (U(z) - E(z) - i(z)^* (R + \Delta R)) \]  \hspace{1cm} (9)

Obviously, it can be concluded from the above formula that the deadbeat control is stable as long as the system satisfies \( \Delta L \geq -0.5(L - T_s \Delta R) \)

The closed-loop transfer function of the current loop is:

\[ G(z) = \frac{z^{-N/p} k_r \frac{L}{T_s} z^k S(z) G_p(z)}{1 - z^{-N/p} [Q(z) - k_r \frac{L}{T_s} z^k S(z) G_p(z)]} \]  \hspace{1cm} (10)
3. Simulation
Comparative analysis of traditional repetitive + PI control and deadbeat repetitive + LADRC series composite control is analysed in the following, as shown in Figure 2 and Figure 3.

![Frequency spectrum analysis](image1)
(a) A phase network in repetitive + PI control mode

![Frequency spectrum analysis](image2)
(b) A-phase network side current of deadbeat and repeat + LADRC series control

Comparing the two figures, it can be seen that APF based on beat difference and repetition + LADRC series control has better harmonic suppression performance.

![Current waveforms](image3)
(a) Current of phase A network side during repetitive + PI load switching

![Current waveforms](image4)
(b) Current of A-phase network side during load switching between deadbeat and repeat + LADRC series

Figure 3. Current waveforms
It can be seen from the above two figures that when the reference current suddenly changes, the deadbeat and repeat + LADRC controller will respond immediately, and can reach a new steady-state dynamic in a cycle, showing better dynamic performance.

4. Conclusion
Compared with repetition + PI. The simulation results show that the APF current compound control method with deadbeat and repetition + LADRC series connection can improve the waveform quality obviously, restrain all odd harmonics effectively, and shorten the repetition control period with good response. The effectiveness of the control strategy proposed in this paper is verified, which can better suppress the harmonic.

Acknowledgments
This paper was supported by Science and Technology Project of State Grid Corporation of China (SGLNFX00YCJS2000598).

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