Research and EMTP Simulation of a New Control Strategy for Active Power Filter

Ying-cheng XUE
Yancheng Institute of Technology, Yancheng, Jiangsu 224001, China

Keywords: Active power filter, Harmonic suppression, Reactive power compensation, control method.

Abstract. A new control strategy of voltage source active power filter is presented in this paper. The control strategy is based on DC voltage control and reactive current feedback control, which directly controls output current and avoids complex computation of active and reactive power. The simulation results of EMTP-Scope view show that the new control strategy of the voltage source active power filter can effectively compensate the harmonic current and reactive current.

Introduction
With the wide application of power electronic devices in power systems, the problem of harmonic pollution in power system is becoming more and more serious. Improving power quality and harnessing harmonics become the key issues in power transmission and distribution technology. Active power filter (APF) has become a key technology to solve this problem.

Active power filter (APF) is an active compensation device, which has better dynamic performance. It can compensate for harmonic and reactive currents which are varied in size and frequency[1 ～ 3]. For APF, real-time and accurate detection of harmonic currents is very critical. The commonly used harmonic current detection methods include fast Fourier transform FFT (Fast Fourier Transform algorithm) method in frequency domain method, P-Q and ip-iq method based on instantaneous reactive power in time domain method, synchronous detection method and space vector method. Because the above methods need fast and real-time operation and large amount of computation, we must use high-speed digital microprocessors and high-performance A/D converters, which not only increases the cost of the system, but also has a complicated circuit structure, which reduces the stability of the system. Although some control methods that do not need to detect harmonic currents and intelligence have been proposed, such as single switch cycle control and sideband control, the technology is not mature enough[1 ～ 4].

This paper introduces a new control strategy based on dynamic reactive current detection technology and dynamic reactive power compensation technology. Based on DC voltage control and reactive current feedback control method, the control strategy directly controls output current by measuring reactive current, and avoids active and reactive power detection. The reactive power compensation can be realized without needing the complex calculation of reactive power and active current.

A New Control Strategy for APF

An Overview of APF Control Strategies
The performance of APF depends on the components of the main circuit and its control system. After the main circuit is determined, the control method of APF is the key to determine the performance and efficiency of APF output. The control system is the core of APF, which mainly includes the operation of harmonic current and the control of compensation current. In recent years, In recent years, some new detection methods of harmonic have been developed, such as the fast fourier transform and its improved algorithm, based on instantaneous space vector algorithm based on wavelet transform and adaptive theory, and some modern control methods based on neural network and sliding mode control and fuzzy control[2 ～ 4]
Though these new methods have been applied in engineering, some of these technologies are not mature. Relatively speaking, the compensation current detection method based on instantaneous reactive power theory has been mature and widely used in engineering design. The basic principle of compensation current instantaneous reactive power theory are: using the detection method based on instantaneous reactive power theory, to detect three-phase voltage and load current, calculate the instantaneous active power and instantaneous reactive power. After filtering the base wave component, the instantaneous active power and instantaneous reactive power of the high order harmonic are obtained, and the required compensation current instruction value is obtained. The method can quickly track compensation current and make timely compensation without the influence of voltage waveform distortion and load fluctuation.[3]

The PWM inverter control methods of APF mainly include triangular wave modulation, hysteresis control, periodic sampling and space vector method. The first 2 methods are widely used. The triangular wave modulation method is simple and fast. The switching frequency of this method is fixed, and the periodic sampling method and the space vector method are usually only studied in theory.

New APF Control Strategy Design

Single Phase APF Equivalent Circuit. The single-phase APF equivalent circuit is shown in Figure 1. The main function of the circuit is to make the main current $i_s$ in phase with the main voltage $u_s(t)$, that is, to make the power factor close to 1.

![Figure 1. Single phase APF equivalent circuit diagram.](image)

Suppose the main voltage $u_s(t)$ and the load current $I_L$ are:

$$u_s(t) = U_m \sin(\omega t)$$  \hspace{1cm} (1)

$$I_L = I_p \sin(\omega t + \theta) = I_p \sin(\omega t) + I_q \cos(\omega t)$$  \hspace{1cm} (2)

From equation 2 shows that if the current generated by the APF $i_s = -i_q = I_q \cos(\omega t)$, the fundamental reactive component can completely compensate the load of all the reactive current, the harmonic current of the injection system is completely eliminated, and the power factor of the system is 1.

If the current $i_q$ that contains all the harmonic components $i_H$ can be detected through a high
pass filter, the APF can compensate the harmonic in the load current separately. When the main voltage \( u_s(t) \) contains harmonic components, there is still a small number of harmonic components which are directly proportional to the voltage harmonics in the compensated system current. However, because the system voltage is close to the sine wave, APF can suppress most of the harmonic currents in the load current.

**Calculation of the Amplitude of Loss Current.** The compensation current \( T \) is divided into 2 parts, the active current and the reactive current, that is:

\[
i_c(t) = i_L(t) - i_s(t) = i_{pa}(t) + i_q(t)
\]

(3)

In the formula: \( i_q(t) \) is the reactive current of the load, which is generated by the compensator and the parallel load; \( i_{pa}(t) \) is the loss current of the compensator.

The average voltage of the DC capacitor can reveal the real-time power information and control the voltage of the DC capacitor, so the loss current amplitude is as follows:

\[
I_{pa} = (CU_{dc} \Delta U_{dc} + \frac{C(\Delta U_{dc})^2}{2})(\frac{T}{2} \Delta U_{sm})
\]

\[
= \frac{2U_{dc}C}{TU_{sm}} \Delta U_{dc} + \left( \frac{C}{TU_{sm}} \right)(\Delta U_{dc})^2
\]

(4)

When the system is in a stable state, the \( C, U_{sm} \), and \( T \) are determined, and the loss current amplitude can be calculated according to the formula (4). The phase of the loss current is the same as that of the main voltage.

**Calculation of the Amplitude of the Load Reactive Current.** The calculation method of average reactive current in \([t^0, t^0+T] \) at any time is:

\[
I_q = \frac{1}{T} \int_{t_0}^{t_0+T} u_s(t) i_L(t) dt = \frac{1}{T} \int_{t_0}^{t_0+T} U_{sm} \cos(\omega t) \{ I_p \sin(\omega t) + I_q \cos(\omega t) \} dt
\]

\[
= \frac{1}{T} \int_{t_0}^{t_0+T} U_{sm} \cos(\omega t) I_q \cos(\omega t) dt
\]

\[
= \frac{1}{2} U_{sm} I_q = \frac{1}{2} U_{sm} I_L \sin \theta
\]

(5)

The load of the reactive current amplitude \( I_q = I_L \sin \theta = 2q / U_{sm} \) passes through the phase-locked loop (PLL) and the delay controller, and \( \nu(t) = \cos(\omega t) \) is obtained. The voltage \( u_s(t) \) which lag main voltage 90 degree may be replaced by \( \nu(t) \), and the amplitude of reactive current can be expressed as \( I_q = 2q \) without calculating the magnitude of main voltage. The direction of the actual load current is to flow to the controller to provide the amplitude information of the reactive current.

**Control Block Diagram.** The control strategy is divided into 3 parts: the active current calculation, the load reactive current calculation and the hysteresis loop current feedback closed-loop control. Its configuration and control block diagram is shown in Figure 2.
Figure 2. Configuration and control block diagram of the APF control strategy.

The load current reference value $i_{L}$ in Fig.2 is compared with the actual output current 2 of the compensator, and the switching signal of the power converter is generated by current hysteresis control. The current generated by the APF can completely compensate all the reactive current of the load, and the power factor of the system will be close to 1.

The change of the average voltage of the DC side capacitance can reflect the transmission of the power between the main circuit and the load. Therefore, the desired power side current amplitude can be obtained by adjusting the capacitance voltage of the DC side, and the detected DC bus voltage is compared with the set voltage. The comparison of the difference passes through a PI controller to produce the expected amplitude of the active current $I_{pa}$. The load current $i_{L}$ is multiplied by the voltage $u_{s}$, then the results are averaged at any period of $[t^{0}, t^{0}+T]$ , and the amplitude of the load reactive current is obtained. the sum of $I_{pl}(t)$ and the output $I_{pa}$ of the PI controller, multiplied by the reference sinusoidal wave, the expected active current is obtained.

Simulation and Analysis of APF EMTP-Scope View

A Brief Introduction to EMTP-Scope View Simulation Software

EMTP (Electro-Magnetic Transient Program) is a general computing program for simulating the transient state of electromagnetic, electromechanical and control systems in multiphase power systems. Scope view is a mathematical and graphical data acquisition and signal processing software. EMTP-Scope view is used to check and process data from a variety of sources at the same time, and the results are shown in graphic form.

Simulation Block Diagram and Main Parameters of the System

Basic Block Diagram of APF System Simulation. The simulation block diagram of APF system is shown in Figure 3, which mainly includes the following subsystems: power supply, inverter circuit, nonlinear load, PWM waveform generator and harmonic current detection. In Figure 3, PLL is phase-locked loop. During the first period of simulation, the phase angle is the starting value of itself. Sampler is the sampling device, and when it is not sampled, it maintains the earliest value of input signal. When the sampling control signal SC > 0, the output executes the selected sampling
type. THD is a current harmonic distortion device, which is used to calculate the total harmonic distortion after the end of the window in 1 cycles.

![Simulation Parameters](image)

**Simulation Parameters.** The effective value of the power phase voltage of the APF system is 310 V, the injection resistance is 0.001 /0.01 mH, and the injection resistance capacity is 1 mΩ/50μF, $U_{SM} = 310V$, $C_0 = 10$ mF; RL1=0.001 Ω/0.01 mH, RL2= 0.3 Ω/75 mH, RL3=10 Ω/10 mH, RLC5=1mΩ/0/50μF, $K_p = -0.5$, $K_i = 0.019$.

**Simulation Waveforms and Results.** The simulation waveforms of the APF system are shown in Figures 4, 5, and 6.

![Figure 4](image)

**Figure 4.** Current waveform after compensation.

![Figure 5](image)

**Figure 5.** Energy storage capacitive current change waveform.
It can be seen from Figure 4 that the system transmission line current after compensation basically reaches the requirement of the sine wave. It can be seen from Figure 6, the system as a sinusoidal voltage when the system load current contains larger harmonic components, power supply system has a certain impedance to fundamental current and harmonic current ;when harmonic currents injected power supply system ,it will produce a pressure drop in the power grid, Thus, the system line voltage also contains harmonics. On the other hand, in the process of PWM, a large number of harmonic waves of carrier frequency multiplier are produced, and the superposition of these 2 kinds of harmonics will cause serious distortion of the current.

In order to ensure the effective operation of inverter and ensure the stability of the system, the trigger angle of IGBT must move in a limited range. In the simulation model, the voltage amplitude limit of angle shift is set to 0.1. If the angle moves more than a certain amplitude angle, APF can not only eliminate the effect of harmonic elimination, but may also lead to the instability of the system.

Conclusion

This paper introduces a new control strategy based on dynamic reactive power compensation detection technology and dynamic reactive current reactive power compensation device, to compensate the basic frequency of reactive current. Under the perceptual and capacitive condition, the control strategy's continuous dynamic compensation effect is satisfactory. The experimental results show that the control strategy has the characteristics of simple structure, rapid dynamic characteristics and good compensation performance, and has certain effectiveness.

References


