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Research on Control Strategy of Improved Single-phase Active Power Filter

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Abstract

Unipolar single-phase active power filter control strategies need to the transformers and adders. Moreover, the circuits to fulfill the control strategy are more complicated. In order to solve above problems, an improved unipolar modulation control strategy has been performed in this paper. The principle of control strategy was analyzed in detail in this paper and related simulation has been finished. The results of simulation show that this improved control strategy can simplify the structure of circuit without affecting the system performance index.

Keywords: *one-cycle control under unipolar modulation, active power filter (APF), improved control strategy*

1. Introduction

One-cycle control (OCC) theory is particularly suitable for the control of switching circuit, which basic concept is to force the average of the controlled switch-variable to be equal or proportional to the average of the control reference in each clock cycle [1, 2]. Its advantages are simple circuit structure, fast dynamic response and good stability without harmonic detection. Meanwhile, one-cycle control technology can automatically eliminate the stationary and transient errors in a cycle, without error synthesis [3-5]. Thus, one-cycle control technology can be adapted to the control application which requires high precision, high speed and high anti-jamming.

Active power filter (APF) is a kind of novel equipment for dynamic harmonic suppression and reactive power compensation. Due to lacking control strategies, the one-cycle control which is applied to single-phase shunt APF exits the problems of large ripple and DC component of AC current. In recent years, many scholars have dedicated to the study of APF with OCC, and proposed various improved control method [6-9], but most of them just compensate the DC component, without improving the ripple size. Unipolar modulation that contains the idea of multilevel active power filter can compensate the DC component and reduce ripple. However, the circuit structure is more complex [10, 11].This paper presents an improved control method to optimize circuit design of one-cycle control.

2. The Study of Unipolar Modulation Control Strategy

2.1. Single-phase Shunt APF

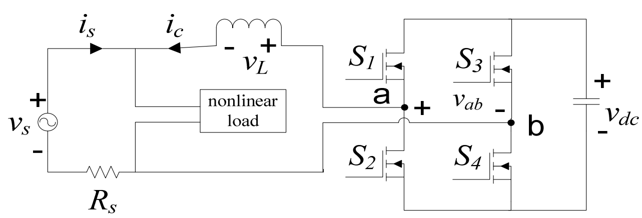

Figure 1. Single-phase Shunt APF Circuit Diagram

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Assume that v_s is AC input voltage, v_{dc} is DC output voltage, v_{ab} is inverter output voltage, v_L is the voltage across the inductor, i_s is source current, i_c is output current of filter, R_s is sampling resistance, d is duty ratio of switching device and $f_s = 1/T_s$ is switching frequency. The main circuit is shown in Figure 1.

2.2. One-cycle Control Strategy under Unipolar Modulation

Compensation idea of one-cycle control strategy under unipolar modulation is that single-phase active power filter is individually controlled in positive and negative half cycle of the power. However, in each half cycle, only two switches work at high frequency, as Table 1 shows.

Table 1. Switching Status of One-cycle Control Strategy under Unipolar Modulation

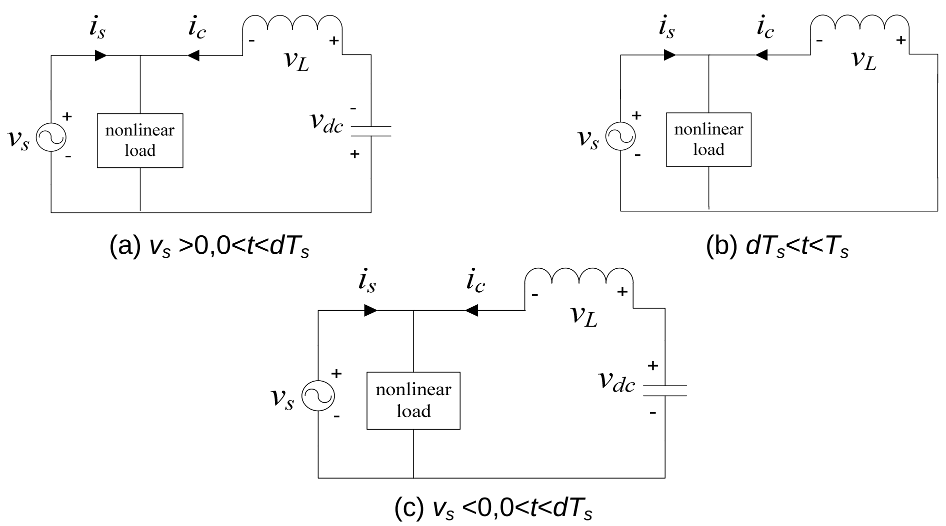
Time	*vs(t)>0*		$v_s(t)<0$	
Switching	$0<t<dT_s$	$dT_s<t<T_s$	$0<t<dT_s$	$dT_s<t<T_s$
S_1	Off	On	On	Off
S_2	On	Off	Off	On
S_3	Off		On	
S_4	On		Off	

The inverter circuit of one-cycle control under unipolar modulation contains the multilevel thought. In each cycle, there are three kinds of output levels and the output voltage reduces by half. So, reduce the size of current ripple. In addition, only two switches working at high frequency, one-cycle control strategy under unipolar modulation greatly reduces switching loss. Due to needing transformer equipment and logic control circuit, the circuit structure of one-cycle control under unipolar modulation is relatively complex.

3. Improve Unipolar Modulation Control Strategy

3.1. The Model of Improved One-cycle Control Strategy under Unipolar Modulation

Swap the sequence of switching status of S_1 and S_2 in the work process of single-phase shunt active power filter, which is with one-cycle control strategy under unipolar modulation. That is, when $v_s > 0$, $0 \sim dT_s$ is turn-on time of S_1; when $v_s < 0$, $0 \sim dT_s$ is of S_2. Equivalent circuit is shown in Figure 2.



(a) $v_s > 0, 0<t<dT_s$ (b) $dT_s<t<T_s$

(c) $v_s < 0, 0<t<dT_s$

Figure 2. Equivalent Circuit of Improved Unipolar Modulation One-cycle Control APF

The output current of the filter inverter circuit can be obtained from Figure 2(a).

$$i_c(t) = \frac{1}{L}\int_0^t v_L(t)dt = \frac{1}{L}\int_0^t [v_{dc}(t) - v_s(t)]dt \quad (1)$$

When vs>0, objective equation of one-cycle control can be achieved through analysis and derivation.

$$dv_m(t) = R_s * i_s(t) \quad (2)$$

Similarly, when vs <0, objective equation of one-cycle control can be deduced.

$$dv_m(t) = -R_s * i_s(t) \quad (3)$$

Control objective equation of improved single-phase APF with one-cycle control strategy under unipolar modulation can be got by consolidating Equation (2) and Equation (3).

$$dv_m(t) = R_s * |i_s(t)| \quad (4)$$

Equation (4) shows that in the improved unipolar modulation cycle control, control strategies of positive and negative half cycle are symmetrical. Convert a negative half cycle to the positive and compare the absolute values of currents. Therefore, the strategy of improved one-cycle control under unipolar modulation can compensate the DC component and reduce the size of ripple as same as the traditional strategy. Meanwhile, compared with the traditional one-cycle control under unipolar modulation, object equation of the improved one-cycle control is relatively simple and circuit design of one-cycle control is optimized.

3.2. Steady State Equation

According to objective Equation (4) of one-cycle control and switching status of APF, in the one-cycle control under unipolar modulation, swap steady state equations of positive and negative half cycle to obtain the improved steady state equations.

For the strategy of improved unipolar modulation one-cycle control, when v_s> 0, stability condition of the positive half cycle can be achieved.

$$v_s < \frac{Lv_m}{T_s R_s} + \frac{v_{dc}}{2} \quad (5)$$

When v_s<0, stability condition of the negative half cycle can be achieved.

$$-v_s < \frac{Lv_m}{T_s R_s} + \frac{v_{dc}}{2} \quad (6)$$

Consolidating Equation (5) and Equation (6), for the strategy of improved unipolar modulation one-cycle control, the total stability condition is:

$$|v_s| < \frac{Lv_m}{T_s R_s} + \frac{v_{dc}}{2} \quad (7)$$

Equation (7) shows that stability is related with v_{dc} in the strategy of improved unipolar modulation one-cycle control, as same as the traditional strategy. However, the stability of positive half cycle is same as the negative in the strategy of improved unipolar modulation one-cycle control. The larger the v_{dc} is, the more stable the system is. Thus, reduce the design requirement of filter inductance L.

4. Simulation Analysis
4.1. System Design of the Improved Control Strategy
Working process of improved single-phase shunt APF with unipolar modulation is as follow. A single-phase circuit with harmonic source provides work environment with harmonic current. One-cycle control circuit integrates the voltage in dc side voltage of converter and compares with the voltage of sampling resistor to generate compare signal to change the working status of the trigger. And then by the logic control circuit, turn the output signal of trigger into the driving signal of power switching device in the inverter circuit. Control on-off status of the switching device to change the output voltage of the inverter circuit with the driving circuit. Finally, use filter inductor to convert the output voltage of the inverter circuit into compensation current which amplitude is equal to the harmonic and phase is opposite. Inject compensation current into single-phase circuit and compensate harmonic current. Eventually make the current that flows into the grid to be close to the standard sine wave. Figure 3 shows the overall structure of the system.

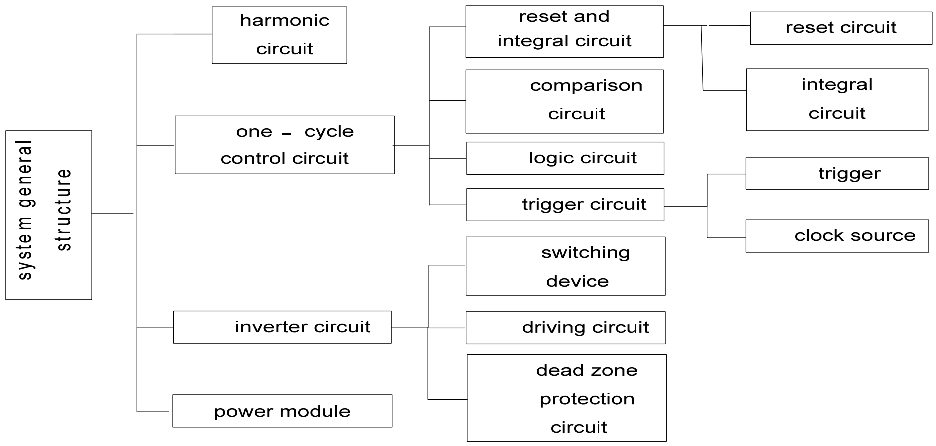


Figure 3. The Overall Structure of the System

4.2. Simulation Circuit
Figure 4 is the simulation circuit of single-phase shunt APF with one-cycle control under unipolar modulation. In the circuit, let inductive load K1=0.0228 and capacitive load K1=0.0385, half is the block signal of power voltage positive and negative half cycle, which is generated by comparison between the sampling voltage R_s*i_s(t) and ground.

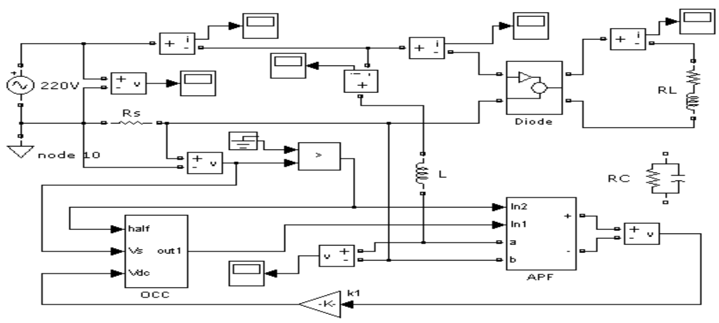


Figure 4. Improved Shunt APF Circuit Simulation

According to on-off status of power switching device of improved single-phase shunt APF with one-cycle control under unipolar modulation, its filter circuit is the same as the strategy of unipolar modulation with one-cycle control. Based on formula (4), design the circuit of improved one-cycle control under unipolar modulation where the integral coefficient of the integrator is K2=10000, shown in Figure 5. Compared with one-cycle control under unipolar modulation, the circuit of improved one-cycle control under unipolar modulation does not require transformer equipment and adders and circuit structure is greatly simplified.

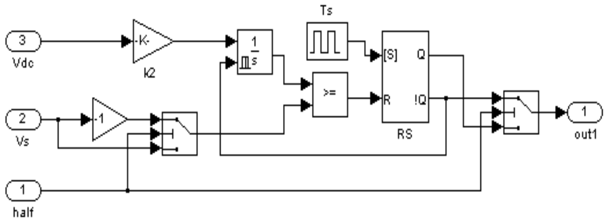
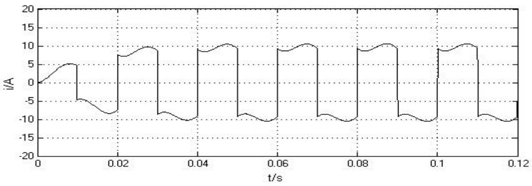
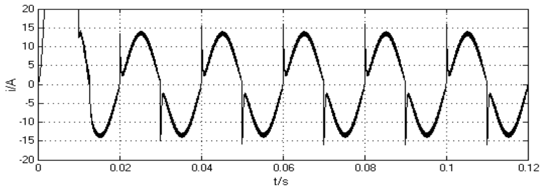


Figure 5. Simulation Circuit of Improved One-cycle Control Module under Unipolar Modulation

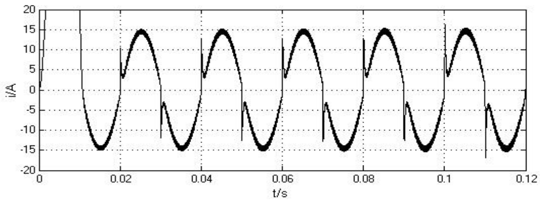
4.3. Simulation Results Analysis of Single-phase Shunt APF



(a) Source current waveform before APF compensation

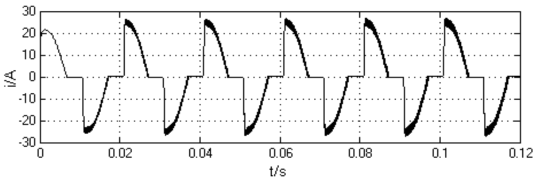


(b) After compensation with one-cycle control strategy under unipolar modulation

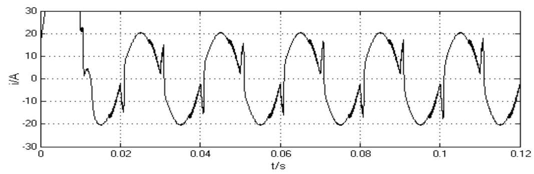


(c) After compensation with improved one-cycle control strategy under unipolar modulation

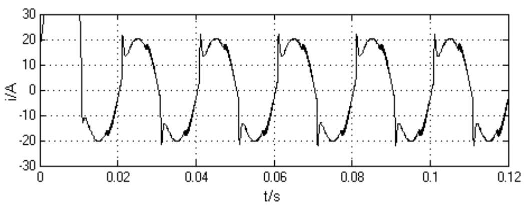
Figure 6. Source Current Waveforms before and after the Compensation of Inductive Load



(a) Source current waveform before APF compensation



(b) After compensation with one-cycle control strategy under unipolar modulation



(c) After compensation with improved one-cycle control strategy under unipolar modulation

Figure 7. Source Current Waveforms before and after the Compensation of Capacitive Load

Figure 6 and Figure 7 respectively describe inductive and capacitive load simulation results, in which Figure (a) describes source current waveforms before APF compensation, Figure (b) describes the waveforms after compensation with single-phase shunt APF and Figure (c) describes the waveforms after compensation with improved single-phase shunt APF. The following conclusions can be obtained from analysis of simulation results.

(1) Single-phase shunt APF with unipolar modulation or improved unipolar modulation has the effects of compensating harmonic and improving power factor.

(2) Single-phase shunt APF with unipolar modulation or improved unipolar modulation compensates DC component of source current.

(3) At the same switching frequency, compared with other control strategies, source current ripple that is compensated by the strategy of unipolar modulation or the improved unipolar modulation is much smaller.

(4) Control strategy of improved unipolar modulation that ensures the compensation effect of control strategy of unipolar modulation optimizes circuit structure of one-cycle control.

5. Conclusion

The inverter circuit of control strategy of unipolar modulation contains the multilevel thought. In each cycle, there are three kinds of output levels and the output voltage reduces by half. So, reduce the size of current ripple. Besides, only two switches working at high frequency, one-cycle control strategy under unipolar modulation greatly reduces switching loss. Due to needing transformer equipment and logic control circuit, the circuit structure of one-cycle control under unipolar modulation is relatively complex. However, control strategy of improved unipolar modulation that ensures the compensation effect of control strategy of unipolar modulation optimizes circuit design of one-cycle control.

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