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RESEARCH ON DOUBLE PEAK PULSE WIDTH MODULATION FOR ACTIVE POWER FACTOR CORRECTOR

Yihui Xia, Feng Yang, Zhihao Ye*,Xiaofeng Zhang, Xiao Han

Navel University of Engineering (Corresponding Author: Zhihao Ye)

ABSTRACT

Aiming at the defects of high harmonic distortion in input current and big volume of filter inductance of single pulse width modulation (PWM) for active power factor, a double peak PWM for active power factor corrector (active PFC) is proposed, and the working mode of which is analyzed. Input current harmonic characteristics with the single and double peak PWM are comparatively analyzed, theoretical analysis shows that the double peak PWM can significantly decrease input current harmonic. Simulation results indicate that the input current THD with the double peak PWM is lower than that of the single PWM, and the volume of the filter inductance is reduced. Simulation results verify that theoretical analysis is right and the proposed double peak PWM is feasible.

Keywords: single pulse width modulation, double peak pulse width modulation, input current harmonic, active power factor corrector

1. INTRODUCTION

The active power factor (ACTIVE PFC) is widely used in industrial and electric vehicle battery charges [1-3]. It is used to overcome harmonic pollution caused by the high penetration of traditional rectifiers. The harmonic pollution induces many problems such as high neutral currents, additional power losses, electromagnetic interference, and so on. Therefore, many topologies, modulation and control methods of the ACTIVE PFC are proposed to meet the regulatory requirements of input current harmonics, output voltage regulation, and implementation of the ACTIVE PFC.

Two-stage PFC converter with parallel structures are proposed in [4,5], which are used to increase the efficiency of the two-stage PFC and process the majority of power once and the remainder twice. A single-stage PFC integrating buck-boost and buck converters is analyzed in [6]. Another single-stage single-switch soft-switching PFC driven LED is proposed in [7]. In which all the semiconductors devices are soft-switched without employing any extra active switch, showing high efficiency under light load condition. The single-stage boost PFC operating in CCM mode following a diode bridge rectifier is preferable to maximum efficiency by minimizing conduction losses under high power. The advantages of the boost PFC is that it is very simple and it is very to realize almost unity power factor with proper control method. However, it has high-conduction loss in the diode bridge rectifier leading to localized heat management issues. To increase the efficiency of the PFC, the dual-boost or bridgeless-boost or totem-pole PFC with no diode rectifier are proposed in [8]-[12].

There are usually two methods to improve input current harmonic restrain performance. One is to improve the switches frequency, which limits the application of many advanced control methods and the switches frequency can't be too high with considering the switches characteristic. The other is increasing filter inductance, increasing volume and cost. To improve input current harmonic restrain performance and decrease the filter inductance volume and cost, a new pulse width modulation based on double peak applied in the bridgeless boost PFC converter is proposed.

This paper is organized as follows. In Section II, the basic structure of the active PFC converter and the double working mode of the double peak PWM are introduced. In section III, comparative analysis of input current harmonic characteristic with the single and double peak PWM are researched. In section IV, the control scheme of the active PFC with the input current amplitude limiting is presented. In section V, simulations

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are carried out with the single and double peak PWM, in order to test the effectiveness of the proposed double peak PWM. In section VI, experiments are carried out to verify the effectiveness of the proposed double peak PWM. In Section VII, the conclusions of this paper are drawn.

2. THE BASIC STRUCTURE OF THE ACTIVE PFC AND THE WORKING MODE OF DOUBLE PEAK PWM

Fig.1 shows the basic structure of the APC, which is bridgeless and has only one input filter inductance L1. The switches $S_1$and S_2 share the same PWM signal and it is not necessary to sense the polarity of the input voltage.

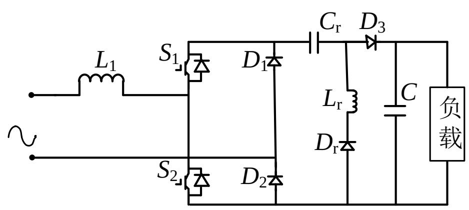


Fig.1 The basic structure of the ACTIVE PFC

2.1 The working mode of the single PWM

Fig.2 shows the working mode of the single PWM, T_{on}, T_{off}, and T are switches turn on time, switches turn off time, and switched period, respectively. It can be seen that the switches turn on and turn off once in a period T. Therefore, the ACTIVE PFC has two working states in period T. One of which is inductive energy storage. The other of which is charging capacitor.

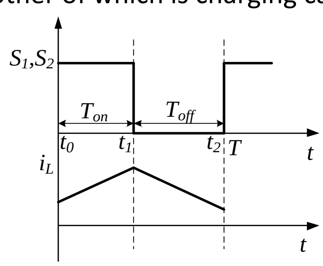
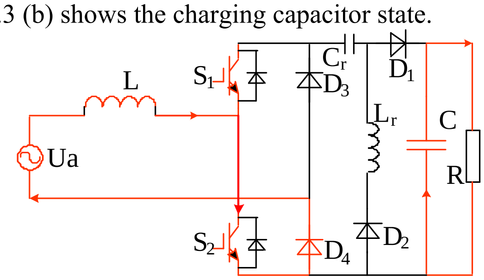
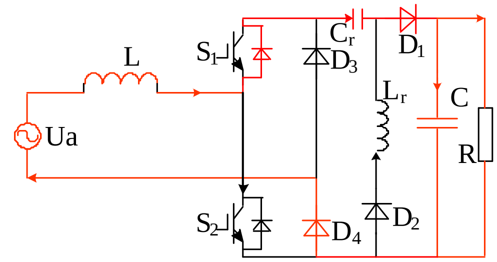


Fig.2 Two working mode of the single PWM

Assuming that input voltage polarity is upper '+' and under '-', the two states of the ACTIVE PFC can be shown in Fig.3 (a) and Fig.3 (b). Fig.3 (a) shows the inductive energy storage state and Fig.3 (b) shows the charging capacitor state.



(a) inductive energy storage



(b) charging capacitor

Fig.3 Two working states of the ACTIVE PFC with single PWM

t_0-t_1: both switches S_1 and S_2 turn on, the input filter inductance stores energy from power supply U_a, and the energy storage circuit starts with the power supply U_a through the filter inductance L_1, switch S_2, and diode D_4, and returns to the power supply U_a. Load is supplied by the capacitor C.

t_1-t_2: both switches S_1 and S_2 turn off, the input filter inductance releases energy and charges the capacitor with the power supply U_a. The charging circuit starts with the power supply Ua through the filter inductance L_1, diode of the switch S_1, and diode D_1, and the capacitor C, and diode D_4, and returns to the power supply U_a.

When input voltage polarity changes, the working states can be referenced as the above analysis.

2.2 The working mode of the double peak PWM

Fig.4 shows the working mode of the double peak PWM, T_{on}, T_{off}, and T are still switches turn on time, switches turn off time, and switched period, respectively. It can be seen that the switches turn on and turn off twice in a period T. However, the ACTIVE PFC still has two working states in period T. One of which is inductive energy storage. The other of which is charging capacitor.

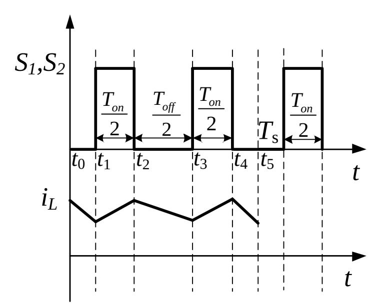
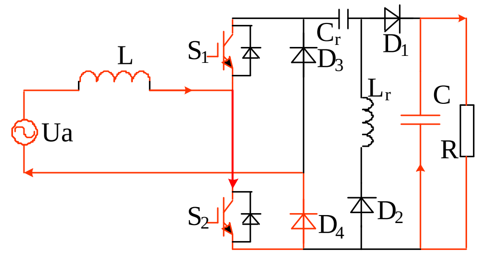
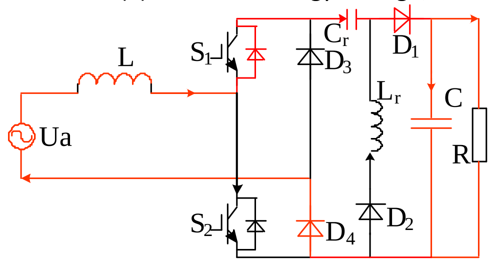


Fig.4 the working mode of the double peak PWM

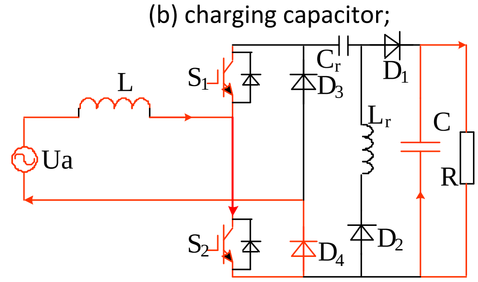
Assuming that input voltage polarity also is upper '+' and under '-', the two states of the ACTIVE PFC can be shown in Fig.5 (a) - Fig.5 (d). Fig.5 (a) and Fig.5 (c) show the inductive energy storage state. Fig.5 (b) and Fig.5 (d) show the charging capacitor state.



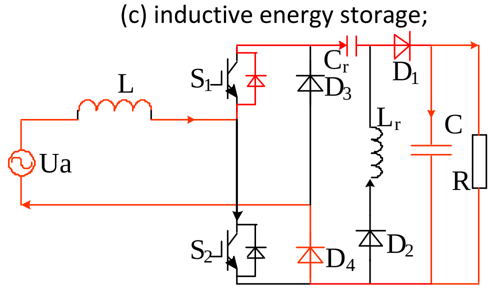
(a) inductive energy storage;



(b) charging capacitor;



(c) inductive energy storage;



(d) charging capacitor.

Fig.5 Working state of an active PFC using double PWM

t_0-t_1, t_2-t_3, and t_4-t_5: both switches S_1 and S_2 turn off, the input filter inductance releases energy and charges the capacitor with the power supply U_a. The charging circuit starts with the power supply Ua through the filter inductance L_1, diode of the switch S_1, and diode D_1, and the capacitor C, and diode D_4, and returns to the power supply U_a. The whole working state is the same as the charging capacitor state with the single PWM.

t_1-t_2 and t_3-t_4: both switches S_1 and S_2 turn on, the input filter inductance stores energy from power supply U_a, and the energy storage circuit starts with the power supply U_a through the filter inductance L_1, switch S_2, and diode D_4, and returns to the power supply U_a. Load is supplied by the capacitor C. The whole working state is the same as the charging capacitor state with the single PWM.

When input voltage polarity changes, the working states also can be referenced as the above analysis.

3. THE DOUBLE CLOSE-LOOP CONTROL SCHEME OF THE ACTIVE PFC WITH AMPLITUDE LIMITING

To realize input power factor at unity and output DC voltage stabilization, double closed-loop combing with feed-forward compensation control method is used for the active PFC, and the control scheme is shown as Fig.8. From Fig.6 it can be seen that there are two PI controllers, one of which is used for the output DC voltage control, and the other of which is used for the input current control including its power factor. The feed-forward compensation part is $1-\frac{|U_a|}{U_{dc\_ref}}$, which is used for improving dynamic response perormance. Limiting current amplitude Im is used for limiting the amplitude of the input current, reducing the impact of the input current on the power supply.

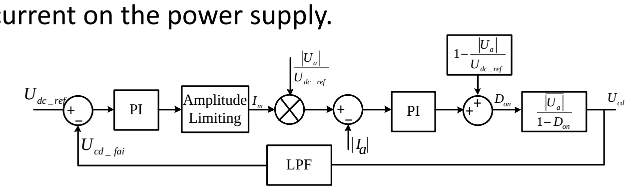


Fig.6 The control scheme of the ACTIVE PFC

Usually the ACTIVE PFC has very high efficient and greater than 0.95. In the paper the efficient η of the ACTIVE PFC is assumed as 0.95. The relation between input rated power P_{in} and outpour rated power P_{out} can be expressed as follows

$$P_{in}\eta = \frac{U_{im}I_{im}\eta}{2} = U_{dc\_av}I_o = P_{out} \quad (1)$$

where I_{im}, U_{dc_av}, and I_o are the amplitude of the input current, the output DC voltage average value, and the output current, respectively. Considering the safe operation of power devices and the dynamic response speed of the ACTIVE PFC, the input current limiting amplitude can be selected as follows

$$I_m = (1.5 : \ 2.0) I_{im} \quad (2)$$

4. SIMULATION RESULTS

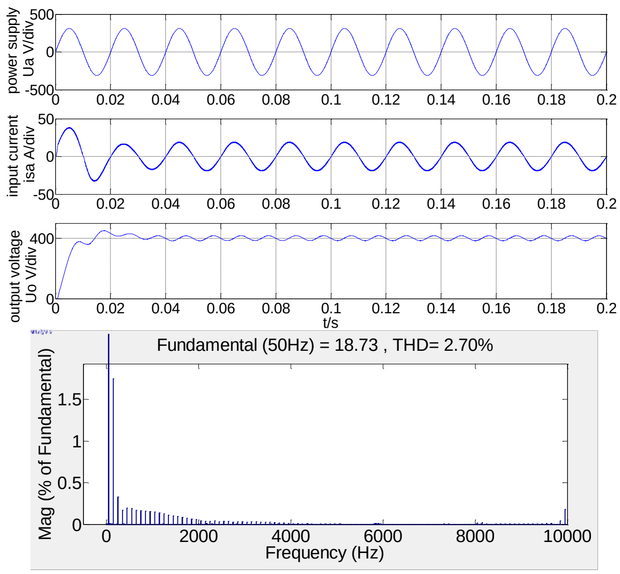
The simulation model of the active PFC with Matlab is built. The simulation parameters are listed in TABLE. I.

TABLE. I SIMULATION PARAMETERS

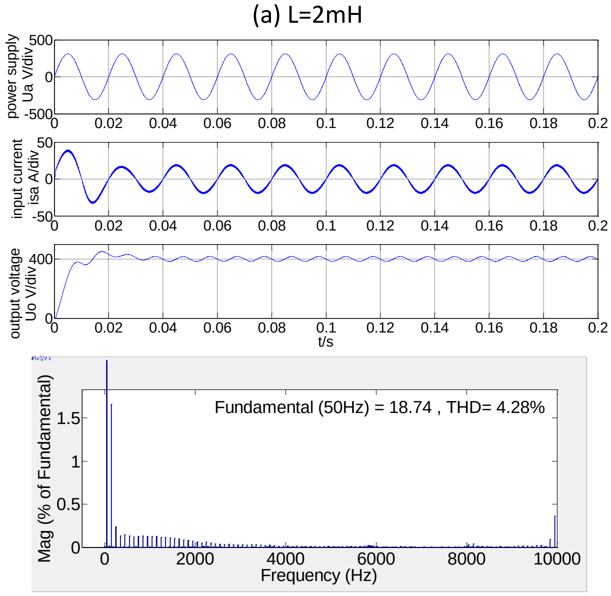
Supply power/frequency	220V/50Hz
Resonant parameters	L_f=2mH, C_f=11.25μF
Switch frequency	50kHz
Input filter	L_f=2mH, C_f=680μF
Load	R=50Ω, L=8mH

Fig.7 shows the waveforms of power supply U_a, input current i_{sa}, output voltage U_o and input current THD under different filter inductances with the single PWM. Fig.8 shows the waveforms of power supply U_a, input current i_{sa}, output voltage U_o and input current THD under different filter inductances with the dual PWM.

From Fig.7 and Fig.8 it can be seen that the input current THD is decreased with filter inductance increased with the single and dual PWM, and the input current THD with the dual PWM is lower than that with the single PWM. The ripple coefficient of the output voltage with the dual PWM is slightly smaller than that with the single PWM. Simulation results are consistent with theoretical analysis, indicating that the proposed dual PWM has better input and output performances of the bridgeless PFC and is right and feasible.

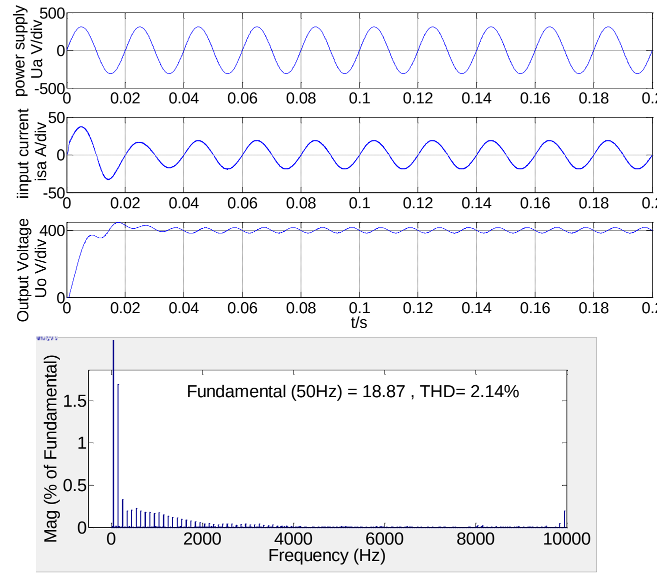


(a) L=2mH

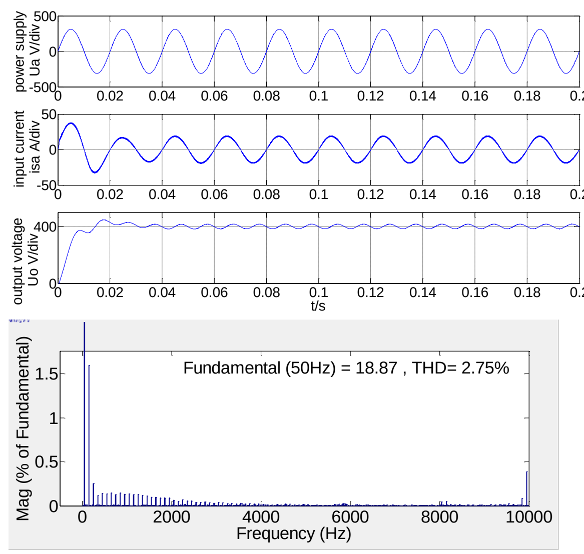


(b) L=1mH

Fig.7 The waveforms of power supply Ua, input current isa, and output voltage Uo, and isa THD with the single PWM



(a) L=2mH



(b) L=1mH

Fig.8 The waveforms of power supply Ua, input current isa, and output voltage Uo, and isa THD with the double peak PWM

5. CONCLUSION

In this paper, aiming at high harmonic of the input current and big volume of the filter inductance with the single PWM, a new PWM method based on double peak for the bridgeless boost PFC is proposed. The working mode of the double peak PWM method is described and the input current harmonic characteristic is comparatively analyzed between the single and double peak PWM methods. Theoretical analysis indicates that the proposed double peak PWM has lower input current harmonic than that of the single PWM method. The double close-loop control combing with amplitude limiting is introduced and applied in the bridgeless boost

PFC. Both simulation and experimental results verify that theoretical analysis is right and the proposed double peak PWM method is feasible.

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