ISSN: 2664-9640

Root Mean Square Current Control Technology of Boost PFC converter

Chen Chen, Yun Lin

School of Chongqing university of Posts and Telecommunications, Chongqing 400000, China

Abstract

The characteristics of Boost PFC converter in different conducting modes are different. This paper mainly discusses the boost PFC converter in CRM critical conducting mode and proposes a new current control method under the condition that the switching frequency is set fixed. The circuit control method is square root current control, which can better eliminate the effect of harmonics and improve the power factor of the circuit. In this paper, the new control circuit is proposed and the circuit is simulated on PSIM simulation software.

Keywords

Critical conduction mode (CRM); Power factor(PF); Boost converter.

1. Introduction

With the rapid development of power electronics in recent years, the use of switching power supplies can be seen in everyday life [1]. However, because switching power supplies are a type of nonlinear device, the input current waveform does not maintain its original waveform when connected to the grid. Some distortion of the input current occurs, i.e., harmonic currents are generated [2], which leads to a reduction in the overall performance of the circuit and greatly affects the overall power factor of the system. Therefore, the application of such nonlinear devices mostly fails to achieve satisfactory results. It is also because of the generation of current harmonics, power factor correction technology came into being, power factor correction technology can largely improve the impact of input current harmonics generated [3], reduce the impact of non-linear devices on the circuit system bad, help to improve the overall power factor of the system. Use the input current of the electrical device to try to synchronize with the voltage of the power-using device.

Power factor correction (PFC) converters have become popular in AC-DC power conversion applications to achieve the requirements of achieving high power factor (PF) and low harmonic distortion [4]. The methods to achieve PFC can be classified into active and passive types. Compared to passive PFC converters, active PFC converters can achieve higher power factor PF and smaller size. Analysis and comparison of active PFC circuits reveals that boost converters are widely used in commercial power supplies for their high performance in terms of continuous input current, lower cost, and higher efficiency, higher power factor, and ease of design.

The boost PFC converter is one of the most widely used power factor correction (PFC) converters with a simple structure, high efficiency, small current harmonics and very stable performance [5].

In active boost PFC converters, the output power has to be kept constant even if the input power is in the form of pulses. Therefore, the instantaneous power difference of the circuit needs to be balanced by a capacitor with a sufficiently large capacitance. Depending on the inductor current, there are three basic modes of operation: continuous conduction mode (CCM), critical conduction mode (CRM) and discontinuous conduction mode (DCM).

When the boost PFC converter operates in continuous conduction mode (CCM), the inductor current ripple is very small, so the root mean square of the current above the inductor and the switch is low [6]. However, there is a very fatal problem with the circuit. It is that the switch is in hard-switching mode, when the diode in the circuit will experience reverse recovery. The boost PFC converter in continuous conduction mode (CCM) is mainly used in high and medium power scenarios. In critical conduction mode (CRM) [7], the advantage over continuous conduction mode (CCM) is that the switch has zero current conduction. The diode does not have reverse recovery problem and can achieve high PF value. However, the circuit design of the inductor and EMI filter becomes more difficult because of the irregularity of the switching frequency in the circuit. The advantages of discontinuous conduction mode (DCM) [8] over continuous conduction mode (CCM) and critical conduction mode (CRM) include zero-current switching conduction, no reverse recovery of the diode, and its switching frequency operates at a constant value, which helps the design of inductor and EMI filters significantly and reduces the design difficulty to a large extent. However, its PF value is not high at high input voltages.

Techniques that want to extend the output power but do not compromise the benefits of a single converter include interleaving [9]. This technique reduces the input and output current ripple and eases the design of EMI filters. In the case of taking current-mode control, an open-loop method is used to synchronize the converter to the main converter's lead. A new control scheme, open-loop voltage modulation control scheme, is proposed in [10]. In [11] a two-phase interleaved boost PFC converter is proposed, controlled by a feedback loop with a phase-locked loop. In [12] a new driver topology is proposed to apply in the circuit to achieve adjusting the switch conduction and disconnection times without applying additional circuitry.

According to the input current control principle, it includes average current type, hysteresis current type, peak current type, voltage control type, nonlinear carrier control, single cycle control, and charge pump control. In CRM mode booster PFC converter, if the switching frequency is variable and the range of variation is large, it will cause huge loss of circuit energy under high input voltage conditions, so that the overall efficiency of the circuit system will be greatly reduced, so we propose a new booster PFC converter current control method under the condition that the switching frequency is fixed, the square root circuit current control booster PFC converter.

2. Boost PFC converter design

2.1. Active power factor correction techniques

The rise of active power factor correction technology [13] began in the mid to late 1980s. Power factor correction is the improvement of the circuit topology and the control of the circuit that generates harmonics, with the aim of reducing the generation of harmonics, expressed in the in-phase of the input current and the input voltage. There are various types of power factor correction, including single-phase power factor correction converters and three-phase power factor correction converters. At present, the more mature development and more widely used is the single-phase power factor correction converter [14], generally used in smaller wattage of small and medium frequency power equipment. For higher power applications look to the development of three-phase power factor correction converters [15]. Power factor is the ratio of active power P to apparent power S. The formula is expressed as follows.

$$PF = \frac{P}{S} \tag{1}$$

In real circuits, it is difficult to achieve a power factor of 1 because of the presence of harmonics in the circuit. The total harmonic distortion rate (THD) has the following effect on the power factor.

$$PF = \frac{1}{\sqrt{1+THD^2}}\cos\theta = \gamma\cos\theta \tag{2}$$

ISSN: 2664-9640

γ is the distortion factor indicating the degree of waveform distortion, and $\cos\theta$ is the phase shift factor. From the above equation, it is clear that improving the power factor can be achieved by increasing the phase shift factor and reducing the harmonic distortion rate of the input current.

2.2. Boost PFC converter circuit parameters design

The main circuit structure of the Boost PFC converter is shown in Figure 1, which includes MOSFET switching tubes, diodes, energy storage inductors, loads, and output capacitors. At the input side, there is a half-wave rectifier circuit and an LC filter circuit [16].

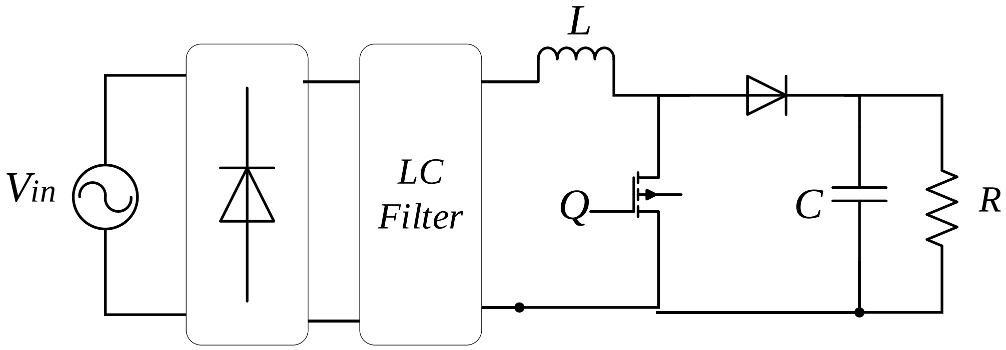

Fig.1 Boost PFC converter circuit

When the circuit is operating in CRM mode, the current waveform of the inductor during the switching cycle is shown in Figure 2.

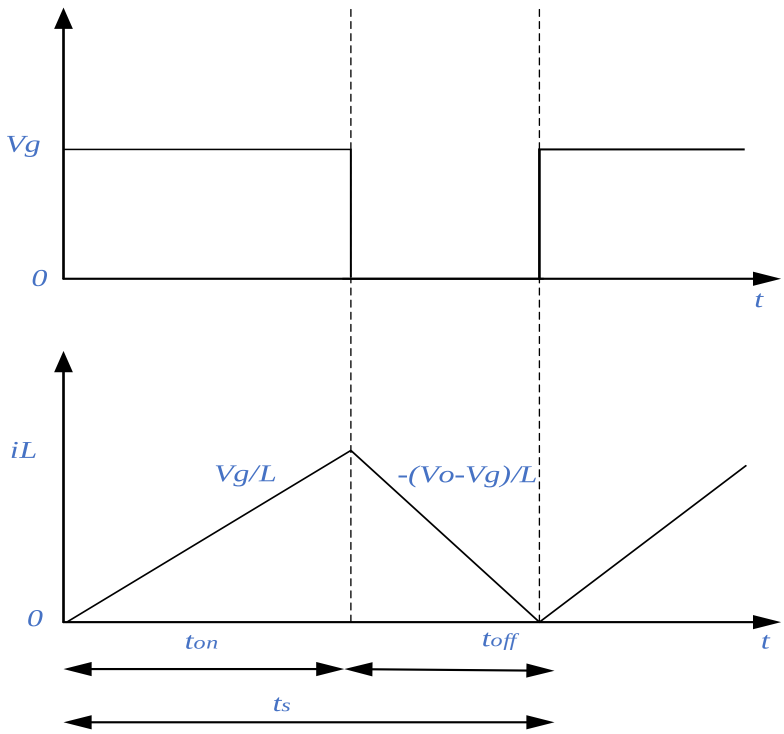

Fig.2 Current waveform of inductor

The input voltage value, the peak inductor current and the average inductor current during the switching cycle are calculated as shown in the following equation.

$$V_{in} = V_m \sin\omega t \tag{3}$$

$$i_{L_{pk}} = \frac{Vg}{L} t_{on} \tag{4}$$

$$t_{on} = \frac{4LP_o}{{V_m}^2} \tag{5}$$

According to equations (3), (4) and (5), it can be seen that the average input current is a sine wave with a PF value of 1 and the switching frequency can be expressed as:

$$f_s = \frac{V_o - V_m|\sin\omega t|}{V_o t_{on}} = \frac{V_m^2 (V_o - V_m|\sin\omega t|)}{4LP_o V_o} \tag{6}$$

The expressions for the maximum and minimum values of the switching frequency are derived as follows:

$$f_{s\_max} = \frac{{V_m}^2}{4LP_o} \tag{7}$$

$$f_{s\_min} = \frac{{V_m}^2}{4LP_o}\left(1 - \frac{V_m}{V_o}\right) \tag{8}$$

According to the above formula, the value of inductance can be obtained as follows:

$$L = \frac{{V_m}^2}{4f_{s\_min}}\left(1 - \frac{V_m}{V_o}\right) \tag{9}$$

3. The design and simulation of control circuit

In recent years, with the development of power factor correction technology, now power factor correction technology can well reduce the total harmonic distortion rate of the input current and at the same time improve the power factor of the system. The current control method is composed of two parts: voltage loop and current loop, which is a double closed-loop control strategy, and this control method can improve the performance of boost PFC converter system. The general principle of current control in PFC circuits is as follows: the average value of the circuit current is first taken and compared with the input AC current to achieve the goal of controlling the input AC current waveform to a standard sine wave. Alternatively, the input current waveform can be controlled by DC control of the switching tube conduction method. An approximation is taken in the expression for the control of the switching tube. The control circuit is shown in Figure 3.

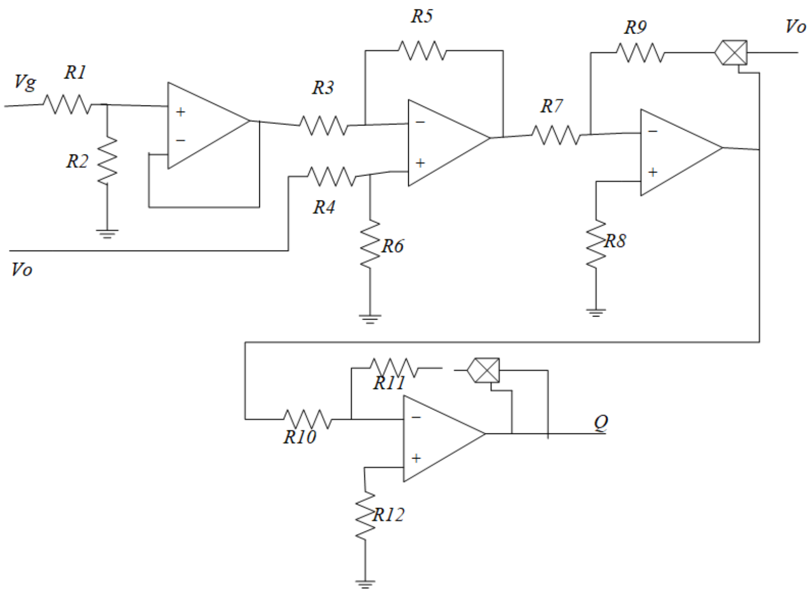

Fig. 3 Control circuit

In order to verify the validity of the theoretical analysis, the circuit model is established in PSIM software under the analysis of the working principle of boost PFC circuit as well as the control strategy in the above paper. The simulation circuit model is shown in Figure 4 below.

ISSN: 2664-9640

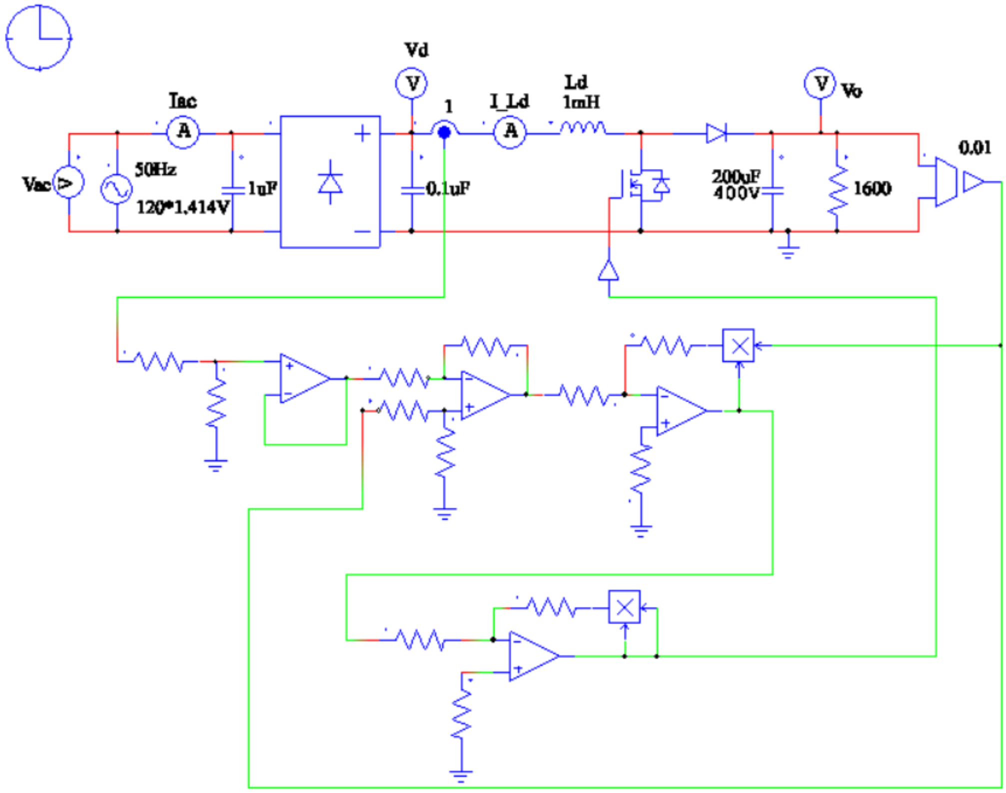

Fig.4 Simulation circuit

4. Summary

This paper proposes a new square root current control method that uses square root circuit current control to reduce the effect of input harmonics and improve the overall power factor of the circuit, based on the traditional current control method that compares the average value of the circuit current with the input AC current. It is able to reduce the harmonics in the input current so that it becomes a sine wave. The power factor correction is truly meaningful.

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