An Improved Buck PFC Converter with High Power Factor

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Abstract: In this paper, an improved buck power factor correction (PFC) converter topology is proposed in this paper. By adding an auxiliary switch and two diodes, the dead zones in ac input current of traditional buck PFC converter can be eliminated. An improved constant ON-time control is proposed and utilized in this improved buck PFC converter to force it that operates in critical conduction mode (CRM). In this paper of voltage source and current waveform in by using MATLAB/SIMULINK

Keywords: Buck Power Factor Correction (PFC), critical conduction mode (CRM), zero voltage switching (ZVS).

I. INTRODUCTION

Nowadays, most ac/dc power converters are forced to reduce the harmonic current to meet the special power products such as lighting equipment Power factor correction (PFC) is a good method for providing an almost sinusoidal input current. The boost converter is the most popular topology for PFC applications due to its inherent current shaping ability [1]–[2]. However, with universal input, usually a 400 V ac output voltage is required for the boost PFC. The boost PFC cannot achieve high efficiency at low line input because it works with large duty cycle in order to get high-voltage conversion gain. Therefore, it is hard to increase the power density of boost PFC converter due to the thermal concern at low line input. The Sepic converter [3], [4] and quadratic buck-boost [5], [6] can achieve high power factor (PF) and reduce the output voltage stress. But the voltage stress of switch in these two topologies is much higher than that in the boost PFC converter that reduces the efficiency and increases the cost. In this paper, an improved buck PFC converter is proposed, as shown in Fig.1. Compared with the conventional buck PFC converter, an auxiliary switch and two diodes are added in the improved buck PFC converter. The proposed converter has two different operation modes in a line period. When the input voltage is higher than the output voltage, the proposed converter operates in buck mode, which is same as the conventional buck converter. When the input voltage is lower than the output voltage, the proposed converter operates in boost mode. The buck PFC converter has some attractive merits. First, the output voltage of buck converter is always regulated lower than the boost converter. Second, the voltage across the main switch of the buck converter is almost clamped to the input voltage. Therefore, the buck PFC converter can achieve relatively high efficiency within the universal input voltage range and it has drawn more and more attention in the past years [9] How-ever, if the buck converter operates in hard switching mode, the switching loss especially at high input will be large, which deteriorates the merit of the buck converter. The buck dc–dc converter operating in critical continuous conduction mode (CRM) can eliminate the reverse recovery loss in diode and achieve zero voltage switching (ZVS) for the switch. The constant ON-time (COT) control for CRM buck PFC con-verter is introduced in With COT control, the peak current in the switch is almost proportional to the input voltage, and then high PF can be achieved.

II. PRINCIPLE OF OPERATION

In the proposed converter operates in CRM will be analysed in detail. To simplify the analysis, the transitions between the switches and the output diode are omitted. After that, there still exist eight operation stages in a line period. Fig. 2 shows the equivalent circuits of the stages easy into it.

A. Positive Buck-Boost Operation Mode

When the input voltage $V_{in}$ is in positive half cycle and the magnitude of $V_{in}$ is smaller than $V_o$, the proposed converter operates in buck-boost mode. During this mode, switch $Q_i$
keeps OFF and switch $Q_2$ keeps switching. There are two stages when the proposed converter operates under this mode:

**Stage 1:** When switch $Q_2$ is ON, the proposed converter operates in stage 1. The equivalent circuit of this stage is shown in Fig. 2(a). The inductor $L$ is charged by $V_{ac}$ through $D_1$ and $D_6$, and $i_L$ increases during this stage.

![Fig:2(a) Equivalent circuits of the proposed converter in First stages](image)

**Stage 2:** When switch $Q_2$ is OFF, the proposed converter operates in stage 2. The equivalent circuit of this stage is shown in Fig. 2(b). The inductor $L$ is discharged by $V_o$ through $D_6$, and $i_L$ decreases during this stage.

![Fig:2(b) Equivalent circuits of the proposed converter in Second stages](image)

**B. Positive Buck Operation Mode**

When the input voltage $V_{ac}$ is in positive half cycle and the magnitude is larger than $V_o$, the proposed converter operates in buck mode. During this mode, switch $Q_2$ keeps OFF and switch $Q_1$ keeps switching. There are two stages when the proposed converter operates under this mode:

**Stage 3:** When switch $Q_1$ is ON, the proposed converter operates in stage 3. The equivalent circuit of this stage is shown in Fig. 2(c). The inductor $L$ is charged by $V_{ac}$ through $D_1$ and $D_6$, and $i_L$ increases during this stage.

![Fig:2(c) Equivalent circuits of the proposed converter in Third stages](image)

**Stage 4:** When switch $Q_1$ is OFF, the proposed converter operates in stage 4. The equivalent circuit of this stage is same as that of stage 2, as shown in Fig. 2(b).

![Fig:2(d) Equivalent circuits of the proposed converter in Five stages](image)

The inductor $L$ is discharged by $V_o$ through $D_6$, and this section, the proposed converter operates in CRM will be analyzed in detail. To simplify the analysis, the transitions between the switches and the output diode $D_o$ are omitted. After that, there still exist eight operation stages in a line period. Fig. 2 shows the equivalent circuits of the stages separated into four operation stages defined as stages 5–8, and the equivalent circuits include Fig. 2(b), (d), and (e). The negative half cycle operation processes of the proposed converter are similar to those of the positive half cycle. For simplicity, the negative operation processes are not depicted in detail here.

![Fig:2(e) Equivalent circuits of the proposed converter in six stages](image)

An improved COT control is applied for the proposed buck PFC converter to force it that operates in CRM, as shown in Fig. 3. The output voltage is detected with a voltage reference $V_{fb}$, and the resistors $R_a$–$R_d$ are omitted. Some key waveforms are shown in Fig. 4. As shown in Fig. 3, the control signal $V_{fb}$ used to control the converter either in buck mode or buck-boost mode is achieved by comparing the detected $V_{in}$ signal $V'$ with a voltage reference $V_{bound}$. Usually, $V_{bound}$ is set to reflect the output voltage $V_o$ with the same ratio as that $V_{in}$ reflects $V_{in}$. $V_{fb}$ is high logic when $V_{in}$ is higher than $V_{bound}$ and is low logic when $V_{in}$ is lower than $V_{bound}$. The detected output signal $V_{FB}$ is sent to the negative input of the error amplifier $U_f$. The error between $V_{FB}$ and the set reference $V_{ref}$ is amplified by the compensation networks $C_f$ and an amplified error signal $V_{com}$ is achieved. The dc voltage signal $V_{com}$ applied to control the conduction period $T_{on}$ is achieved from $V_{com}$ through a control networks formed by resistors $R_1$ and $R_2$ and switch $S_1$. Switch $S_1$ is controlled by the control signal $V_{fb}$. The proposed converter operates in buck mode when...
S1 is OFF and operates in buck-boost mode when S2 is ON. \( V_{\text{comp}} - p \) is a step function controlled by \( V_{\text{ph}} \), as shown in (1)

\[
V'_{\text{comp}} = \begin{cases} 
V_{\text{comp}} & V_{\text{in}} > V_o \\
 k \cdot V_{\text{comp}} & V_{\text{in}} \leq V_o 
\end{cases}
\]

(1)

### III. SCHEMATIC OF THE PROPOSED BUCK PFC CONVERTER WITH AN IMPROVED COT

![Schematic of the proposed buck PFC converter with an improved COT control](image)

This level transition sets the driving signal from low level to high level. According to the aforementioned analysis, the rising slope of \( V_{\text{saw}} \) is constant due to the constant current source \( I_1 \) charging during the whole line period. Therefore, the ON-time (TON) of the switches is determined by \( V_{\text{comp}} \) proportionally. Smaller value of \( k \) leads to smaller TON and smaller peak values of \( i_L \) when the proposed converter is operating in buck-boost mode.

As shown in Figs. 3 and 4, the driving signals \( V_{G1} \) and \( V_{G2} \) are controlled by \( V_{\text{ph}} \) for the different operation modes alternately. Different coefficient \( k \) results in the different PF correction performance and the overall efficiency.

Where \( k \) is a coefficient equal to \( R_1 / (R_1 + R_2) \). Similar to the conventional COT control, a constant current source \( I_1 \), capacitor-tor \( C_1 \), and switch \( S_1 \) are used to generate a saw tooth wave form \( V_{\text{saw}} \). When \( V_{\text{saw}} \) reaches \( V_{\text{comp}} - p \), the output of comparator \( U_{c1} \) jumps from low level to high level. This level transition results the driving signal from high level to low level.

The zero-crossing point of the inductor current \( i_L \) is detected by the auxiliary winding of the inductor \( L \). This inductor current zero-crossing detection signal \( V_{ZC_D} \) can be applied in both buck and buck-boost modes. When the inductor current \( i_L \) falls to zero, the output voltage auxiliary winding \( V_{ZC_D} \) starts to fall. Once \( V_{ZC_D} \) falls to zero, the output of comparator \( U_{c2} \) jumps from low level to high level.

### IV. SIMULATION RESULTS

#### A. CONVENTIONAL CIRCUIT

![Conventional Circuit Buck PFC Converter with High Power Factor](image)

#### B. PROPOSED CIRCUIT

![Proposed Circuit Buck PFC Converter with High Power Factor](image)
V. CONCLUSION

The improved buck PFC converter topology proposed in this paper is easy to achieve as the structure of the topology is simple. To operate in CRM, an improved COT control is proposed. The main disadvantage of this proposed topology is that two diodes and a switch are required and the added switch needs a floating driving circuit. However, the cost and size increase little compared to the whole cost and size. In conclusion, this proposed converter is very suitable for industrial application.

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