AC/DC CRITICAL CONDUCTION MODE BUCK-BOOST CONVERTER WITH UNITY POWER FACTOR

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ABSTRACT

The buck-boost converter operating in critical conduction mode (CRM) is commonly utilized in various applications because of many advantages like protection against short circuit, minimum component count, low operating duct-cycle, and low voltage on MOSFETs. However, its input power factor (PF) is not high while operating in constant on-time control. To attain unity PF for universal input voltage range, a new control scheme of variable on-time control (VOTC) is proposed in this paper. The VOTC can be implemented by modulating the turn-on time of the buck-boost switch. The working principle and performance comparison of the converter is discussed with both types of control scheme. The input PF the converter is high in case of VOTC than the COTC. Simulation results are presented to verify the effectiveness of the proposed control strategy).

KEYWORDS

Buck-boost converter, Power factor, Critical conduction mode.

1. INTRODUCTION

Power electronic technology is employed in various sorts of modern equipment's which has made our life, simpler, easier and comfortable. However, with this comfort and easiness this technology brings power quality issues because it is centered on solid-state devices. These issues introduce harmonic contained current or distorted current which has several drawbacks like more power loss, voltage distortion and EMI compatibility issues etc. Therefore, the standards are set by various industrious like IEC61000-3-2 limit and IEEE 519 (IEC 61000-3-2:2014, 2014; Langella, Testa, & Alii, 2014) to limit these harmonics. In order to meet relevant harmonic standard and reducing input current distortion, power factor correction (PFC) converter has been widely applied (García *et al.*, 2003; Singh *et al.*, 2011; Memon *et al.*, 2017; Memon *et al.*, 2018; Memon *et al.*, 2019). Generally, conventional power converter topologies, such as boost, buck-boost and buck converters, can be used to achieve low cost single-stage PFC, and each converter topology has its own characteristics. The traditional boost PFC converter, with advantages of low input current ripple, high efficiency and inherent current shaping ability, is a good choice for PFC application. However, it cannot maintain high efficiency at universal input voltage. Buck converter can maintain high efficiency at all input voltages. However, there is no input current when the output voltage is less than input voltage (Memon *et al.*, 2018). The traditional buck-boost topology, with advantages of inherent current shaping ability, low cost, step-down and step-up voltage conversion, is a good choice compared with flyback, CUK and SEPIC converters. It is used in many applications such as wind energy control, Adaptive control applications, and power amplifier applications etc. However, when the on-time is constant, the power factor (PF) of buck-boost PFC converter is low.

For modifying the performance of buck/boost converter, various researchers have proposed various techniques and control schemes. In Ghanem, Al-Haddad, and Roy, (1996), a new control mechanism is presented to increase the PF near to unity for a cascaded buck-boost converter for the high-power application in continuous conduction mode (CCM). Comparative analysis between single stage buck converter and the single buck-boost converter in discontinuous conduction mode is given in Moschopoulos and Zheng (2006). The work in Wei *et al.* (2008) has done the comparative study between the bridged buck-boost PFC converter and bridgeless buck/boost PFC converter and proposed the bridgeless buck-boost PFC topology for improving the efficiency. In Jayahar and Ranihemamalini (2011), inductor average current control strategy is proposed for improving PF of CCM buck-boost converter. The work in Jayahar, Ranihemamalini, and Rathnakannan (2016) has given the solution to improve PF for CCM buck converter. The bridgeless buck-boost converter with switched capacitor for low power applications is put forward in Saifullah *et al.* (2017) for reducing the conduction losses and improving the efficiency.

In this paper, an improved control scheme for buck-boost converter operating under critical conduction mode (CRM) is proposed to realize unity PF.

This paper is divided into six sections. In section 2, the operation states of CRM buck-boost PFC converter are analyzed with traditional control. The proposed control scheme is introduced in section 3 to realize unity PF. Then the comparative analysis is discussed in section 4 in terms of input PF. In section 5, the effectiveness of proposed topology is evaluated by simulation results. Finally, some conclusions are drawn in section 6.

2. OPERATING PRINCIPLE OF THE CONVERTER

Figure 1 illustrates the power circuit of buck-boost converter in CRM mode. It comprises of bridge diode rectifier, a buck-boost switch (Q_{b-b}), a freewheeling diode (D_{fw}), an inductor (L) and an output capacitor (Co), etc.

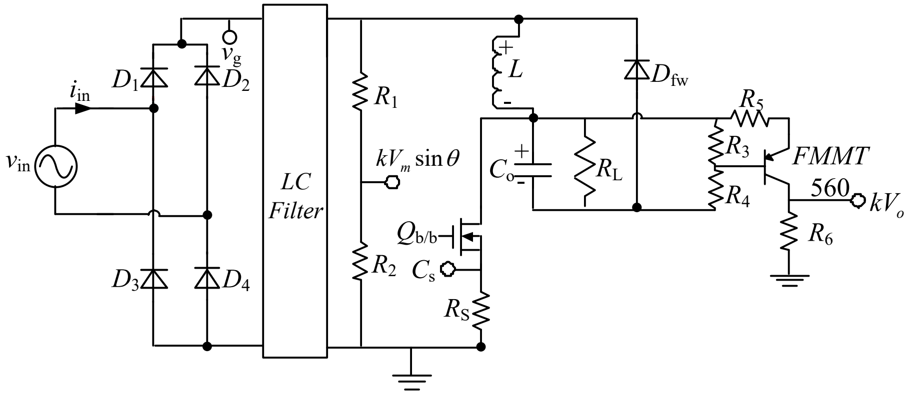

Figure 1. Power circuit of a buck-boost converter.

The instantaneous and rectified input voltage during half line cycle can be given as:

$$v_{in} = v_a = V_{pk} \sin\theta \tag{1}$$

Whereas "V_{pk}" represent the input voltage amplitude, θ represent the input voltage angle.

There are two switching cycles when buck-boost converter works in critical conduction mode (CRM). In case of first switching cycle, switch (Q_{b-b}) is ON, the inductor is charged as shown in Figure 2 and the value is given as

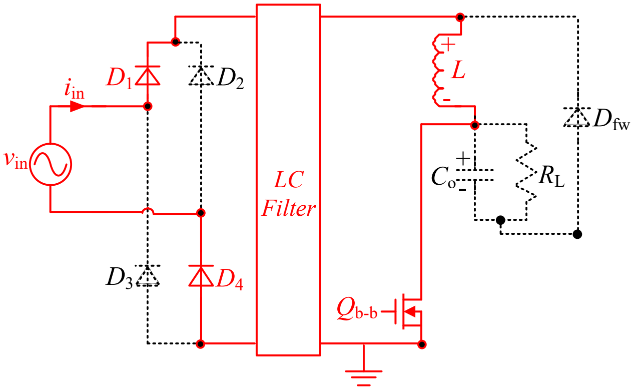

Figure 2. The Operation of converter during switching pattern 1.

$$\frac{di_L}{dt} = \frac{V_{pk}\sin\theta}{L} \tag{2}$$

$$i_{L\_pk} = \frac{t_{on}V_{pk}\sin\theta}{L} \tag{3}$$

During second switching cycle, (Q_{b-b}) is OFF; the inductor will discharge through load and output capacitor as indicated in Figure 3.

The expression for discharge time is:

$$t_{off} = \frac{V_{pk}\sin\theta}{L} t_{on} \tag{4}$$

Also,

$$t_s = t_{on} + t_{off} \tag{5}$$

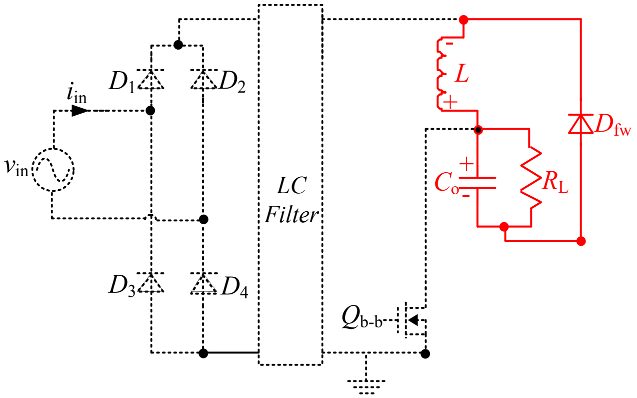

Figure 3. The Operation of converter during switching pattern 2.

The inductor and switch current waveforms are shown in Figure 4.

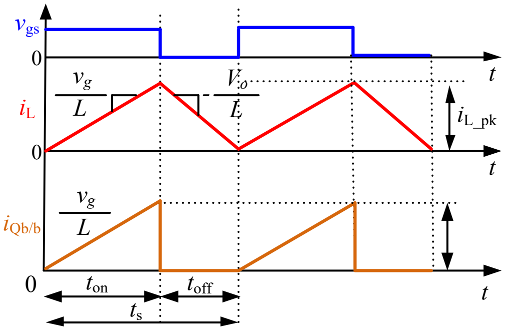

Figure 4. The inductor and switch current waveforms.

From (4) and (5), following relation is obtained:

$$t_s = \frac{t_{on}}{V_o}\left(V_o + V_{pk}\sin\theta\right) \tag{6}$$

The duty-cycle of buck-boost switch is expressed as:

$$D_{b\_b} = \frac{V_o}{V_o + V_{pk}\sin\theta} \tag{7}$$

With traditional control the input current of buck-boost converter is given as:

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$$i_{in(b\_b\_COTC)} = \frac{V_o V_{pk}\sin\theta}{2L\left(V_{pk}\sin\theta + V_o\right)} t_{on} \tag{8}$$

The expression of average input power is derived as:

$$P_{in\_COTC} = \frac{V_{pk}^2 V_o t_{on}}{2\pi L}\int_0^{\pi}\frac{\sin^2\theta}{\left(V_{pk}\sin\theta + V_o\right)}d\theta \tag{9}$$

The value of t_{on} is calculated from “ (9)” by assuming 100% efficiency:

$$t_{on} = \frac{2\pi L P_o}{V_{pk}^2 V_o \int_0^{\pi}\frac{\sin^2\theta}{\left(V_{pk}\sin\theta + V_o\right)}d\theta} \tag{10}$$

The input PF with traditional control scheme can be got by joining (1) and (8-10).

$$PF_{COTC} = \sqrt{\frac{2}{\pi}}\frac{\int_0^{\pi}\frac{\sin^2\theta}{\left(V_{pk}\sin\theta + V_o\right)}d\theta}{\sqrt{\int_0^{\pi}\frac{\sin^2\theta}{\left(V_{pk}\sin\theta + V_o\right)^2}d\theta}} \tag{11}$$

The table of input PF with traditional control is drawn in Table 1 with the help of equation (11) and the specification of the converter. It indicates low PF at high input voltage.

Table 1. Input PF with traditional control.

S.NO	VRMS	PF(COTC)
1	90	0.968
2	110	0.963
3	130	0.96
4	150	0.956
5	170	0.954
6	190	0.951
7	210	0.949
8	230	0.947
9	250	0.945
10	264	0.945

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Through Fourier analysis, the harmonics of the input current is calculated as:

$$I_n = \frac{2}{\pi}\int_0^{\pi} i_{in} \sin n\theta d\theta \qquad (n = 1,3,5.....) \tag{12}$$

Based on (9) and (12), Figure 5 is drawn. It indicates the comparison of measured current harmonic with IEC Class C limits. It can be observed that the 5th and 7th harmonic for converter is unable to meet the limit value. Specially, the 5th harmonic cannot meet the standard for universal input voltage range, while 7th harmonic at high input voltage.

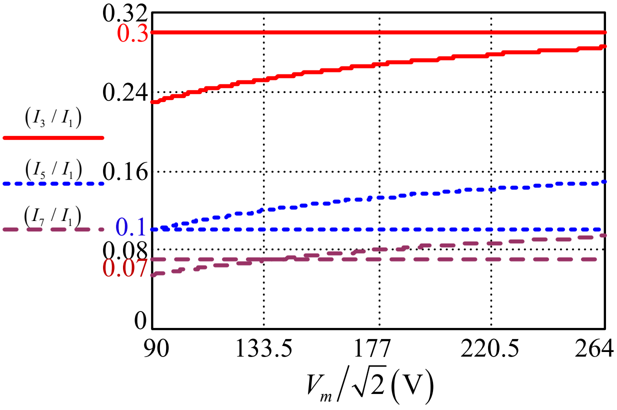

Figure 5. Input current harmonic.

3. PROPOSED VARIABLE ON-TIME CONTROL SCHEME TO IMPROVE INPUT PF

To achieve unity PF, the variation rule for t_{on} should be:

$$t_{on(b\_b)} = k_{on}\left(\frac{V_{pk}\sin\theta + V_o}{V_o}\right) \tag{13}$$

By substituting (13) into (8), we can get average input current with VOTC as:

$$i_{in(b\_b\_VOTC)} = \frac{V_{pk}\sin\theta}{2L}k_{on} \tag{14}$$

It shows shape of average input current is purely sinusoidal at all input voltage. Thus, unity PF can be realized.

From (1) and (15), the average input power is expressed as:

$$P_{in\_VOTC} = \frac{k_{on} V_{pk}^2}{4L} \tag{15}$$

Assuming converter to be 100% efficient, then k_{on} is calculated as:

$$k_{on} = \frac{4P_o L}{V_{pk}^2} \tag{16}$$

4. COMPARATIVE ANALYSIS

From (14), the input PF curve with proposed control scheme is drawn in Table 2, which also includes the PF values with traditional control scheme of Table. It can be concluded that the PF of the converter with proposed control is higher as compared to COTC. The percentage improvement of PF increases as the input rms voltage is increased.

Table 2. Input PF curve with proposed control scheme.

S.NO	VRMS	PF(COTC)	PF(VOTC)	% Improvement
1	90	0.968	1	3.30
2	110	0.963	1	3.84
3	130	0.96	1	4.00
4	150	0.956	1	4.40
5	170	0.954	1	4.82
6	190	0.951	1	5.15
7	210	0.949	1	5.38
8	230	0.947	1	5.60
9	250	0.945	1	5.80
10	264	0.945	1	5.82

5. SIMULATION VERIFICATION

For verifying the effectiveness of VOTC strategy, simulations are carried out. The input voltage range is 90-264VAC, and the output is 24V. For ensuring the current to be in CRM, L6561 IC is used. All the components in the circuit are selected as idea. The Simulation results in Figure 9 and Figure 10 shows that vin, and iin, for proposed converter with COTC and VOTC at 110VAC input, respectively. The input waveform shows that with VOTC the input current is sinusoidal as compared with COTC. Hence, the near unity PF can be realized by using proposed control scheme.

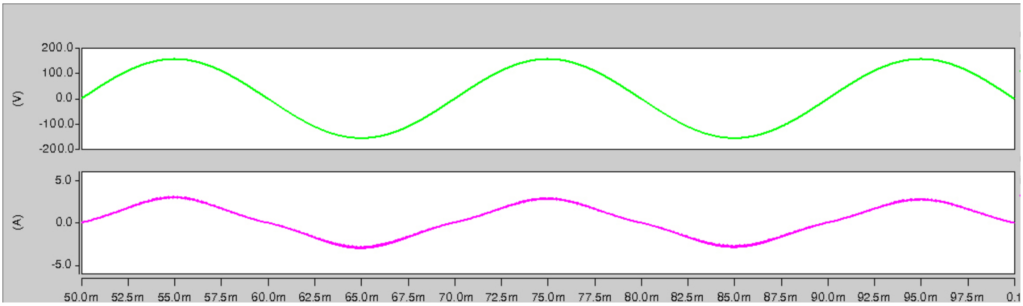

Figure 9. v_{in}, and i_{in}, with COTC.

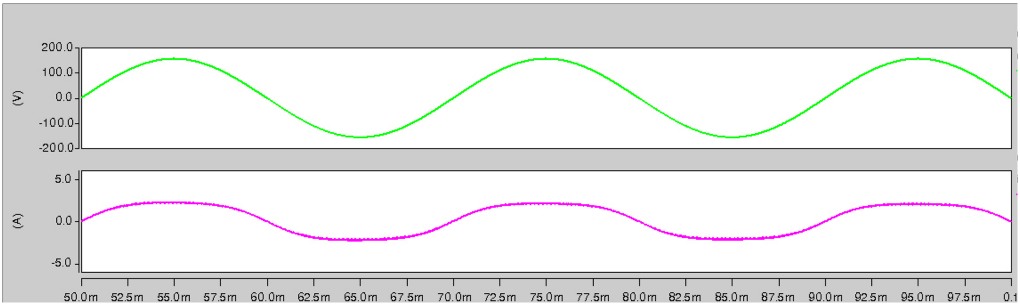

Figure 10. v_{in}, and i_{in}, with VOTC.

5. CONCLUSION

A variable on-time control scheme and the implementation circuit are proposed in this paper to make the shape of average input current purely sinusoidal for the CRM buck–boost PFC converter. The analysis and simulation results are given. Compared with that of the COT control:

1. Input current meets the harmonic standard.
2. PF is high
3. THD is low

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