

CRM BUCK CONVERTER WITH HIGH INPUT POWER FACTOR

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ABSTRACT

The buck converter is generally utilized in many applications because of various advantages like maintaining high efficiency for the wide range of input voltage, cost reduction, low output voltage, protection against inrush current and lifetime improvement. However, when on-time of buck converter is kept constant, the input voltage and current remains out of phase that cause's low PF and high total harmonic distortion (THD). Therefore a power factor improvement technique is implemented in this paper that permits the average input current sinusoidal without need of extra converter to work in cascade with buck converter. The critical conduction mode (CRM) buck converter operating with constant on-time (COT) control scheme have low PF because of harmonic contained input current waveform. So in order to make the input current waveform as a sinusoidal by changing the on-time of buck switch, a variable-on-time (VOT) control scheme for CRM buck converter is proposed in this paper. The theoretical analysis is given, and the simulation results confirm the advantages of the proposed control scheme. The object of the research paper is to propose the control scheme to realize high PF for CRM buck converter by only modulating the on-time of buck switch and without need of extra converter to work with buck converter.

KEYWORDS

Buck Converter, Critical Conduction Mode (CRM), Power Factor (PF), DC/DC Converters, Constant On-Time (COT), Variable On-Time (COT).

1. INTRODUCTION

Power electronic innovation is utilized in different types of present day equipment's which has made our life easier, lavish and simpler. However, this innovation depends on semiconductor devices, because of which the shape of average input current is distorted. The distorted current has different disadvantages, for example, increased power loss, noise and voltage distortion etc. So the industries have formed different standards like IEC61000-3-2 limit and IEEE 519. In order to meet relevant harmonic standard and reducing input current distortion, various researchers have proposed different types of power factor correction (PFC) converters (Memon *et al.*, 2020a, 2020b, 2020c). The DC/DC converters or choppers such as buck, boost and buck-boost etc. are normally employed for PFC application. Each converter has its own advantages and disadvantages. The buck converter now days have attracted the attention of the many researchers (Endo *et al.*, 1992; Memon *et al.*, 2019a, 2019b, 2019c 2019d, 2019e). Its advantages include less voltage stress on the switch, low component cost, low output voltage, low inrush current, protection against short circuit and high efficiency at universal input voltage. However, the input PF of buck converter is low because of dead zone in the average input current that is present until input voltage is more than output voltage. It causes the input current to contain large harmonic disturbances.

For modifying the performance of buck converter, various researchers have proposed various techniques and control schemes (Endo *et al.*, 2020; Memon *et al.*, 2019a, 2019b, 2019c 2019d, 2019e).

In Endo *et al.* (1992), buck converter is introduced for PF improvement. The application along with analysis and modeling operating in discontinuous current mode (DCM) is discussed in Lee *et al.* (1997). The work in Spiazzi *et al.* (2000) has put forward a converter to compensate the dead zone in buck converter. In Huber *et al.* (2009), the analysis and evaluation of DCM buck converter is given. The bridgeless buck converter is introduced to enhance the efficiency in Jang *et al.* (2010). The research in Wu *et al.* (2011) has discussed various aspects regarding the design of buck converter with constant on-time control scheme (COTC).

In Lamar *et al.* (2012), the AC/DC driver working in boundary current mode for tapped inductor buck converter is introduced to replace incandescent lamp by high brightness light emitting diode. For the reduction of input current harmonic for high brightness light emitting diode, a control scheme is proposed in Wu *et al.* (2012). In Ki *et al.* (2012), a new technique is introduced to reduce losses due to transformer in buck converter. The interleaved critical current mode (CRM) buck converter is introduced in Choi *et al.* (2012) to increase efficiency.

In Fardoun *et al.* (2014), a bridgeless buck is proposed to increase the efficiency. For compensating dead zone, double integrated buck converter is introduced for power supplies (Sichirrollo *et al.*, 2014). The integration of another converter with buck converter is discussed to enhance the PF in Liu *et al.* (2020). The works in Memon *et al.* (2016), Memon *et al.* (2018a, 2018b) and Memon *et al.* (2019a, 2019b, 2019c 2019d, 2019e) have introduced various control schemes and topologies for buck converter to attain high PF and efficiency.

In this paper, a PF improvement technique is implemented for CRM buck converter that permits the average input current to be sinusoidal. It can improve input PF without need of other converter to work with buck during dead zone time and also need only one feed forward circuit.

This paper is divided into six sections. In section 2, the operation states of CRM buck converter are analyzed with traditional constant on-time (COT) control scheme. The introduced VOT control scheme is discussed in section 3. Then the comparative analysis is discussed in section 4 in terms of PF. In section 5, the effectiveness of proposed topology is evaluated by simulation results. Finally, some conclusions are drawn in section 6.

2. RESEARCH METHODOLOGY

The research methodology is based on:

1. Mathematical analysis of the operating principle of the traditional control scheme for BCM IBBC with the help of MATHCAD software.
2. Analysis of input PF of BCM integrated BBC.

3. Introducing the proposed control scheme to obtain high PF with low THD.
4. Comparative analysis of the converter for COT control scheme and VOT control scheme strategy in terms of input PF and THD.
5. Developing the simulation model of the converter with traditional and proposed control scheme with the help of MATLAB software.
6. Confirming the results.

3. CONVENTIONAL COTCONTROL SCHEME FOR BUCK CONVERTER

Figure 1 shows the main circuit of the buck converter.

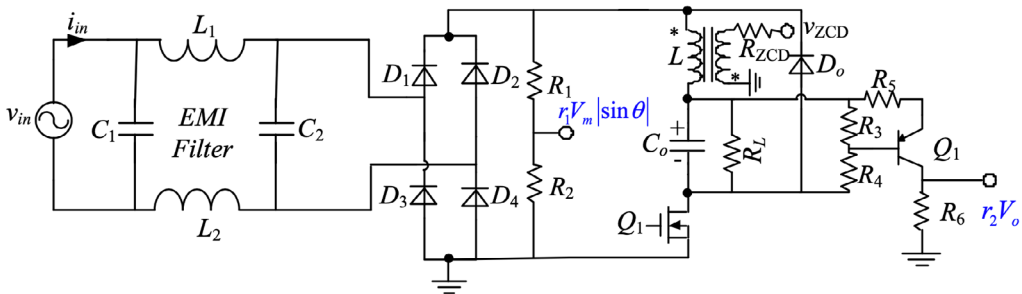


Figure 1. Schematic Diagram of Buck Converter.

Source: (Memon *et al.*, 2019a).

The input voltage and rectified input voltage is expressed as

$$v_{in}(\theta) = v_g = \sqrt{2}V_{rms} \sin \theta \tag{1}$$

Where V_{rms} is the rms value

When buck switch is on, the inductor voltage is expressed as

$$L \frac{di_L}{dt} = \sqrt{2}V_{rms} |\sin \theta| - V_o \tag{2}$$

where $\theta_0 = \arcsin \frac{V_{boundary}}{\sqrt{2} V_{rms}}$

So its peak value is

$$i_{L_pk}(\theta) = \frac{\sqrt{2}V_{rms} |\sin \theta| - V_o}{L} t_{on} \tag{3}$$

Where t_{on} is the on-time of the switch

While Q_{buck} is off, the inductor is discharged through load.

$$-L \frac{di_L}{dt} = V_o \tag{4}$$

For each switching cycle, the value of off-time is calculated from inductor’s volt-second balance

$$t_{off} = \frac{L}{V_o} i_{L(pk1)}(\theta) \tag{5}$$

From (3) and (5), the following relation is obtained

$$t_{off} = \frac{\sqrt{2}V_{rms} |\sin \theta| - V_o}{V_o} t_{on} \tag{6}$$

In addition

$$t_s = t_{on} + t_{off} \tag{7}$$

Substituting (6) into (7)

$$t_s = \left(\frac{\sqrt{2}V_{rms} |\sin \theta|}{V_o} \right) t_{on} \tag{8}$$

The value of average input current for buck converter is got as

$$i_{buck(avg)}(\theta) = \frac{i_{L-pk}(\theta)t_{on}}{2t_s} \tag{9}$$

Substituting (3) and (8) into (9)

$$i_{buck(avg)}(\theta) = i_{buck(COTCS)}(\theta) = \frac{t_{on} V_o}{2L} \left(\frac{\sqrt{2}V_{rms} |\sin \theta| - V_o}{\sqrt{2}V_{rms} |\sin \theta|} \right) \tag{10}$$

Based on (1) and (10), the input power of the buck converter is expressed as

$$P_{in(COTCS)} = \frac{V_o t_{on}}{2\pi L} \int_{\theta_0}^{\pi-\theta_0} (\sqrt{2}V_{rms} |\sin \theta| - V_o) d\theta \tag{11}$$

Now t_{on} can be calculated by assuming the efficiency of buck converter as 100%

$$t_{on} = \frac{2\pi P_o L}{\int_{\theta_0}^{\pi-\theta_0} V_o (\sqrt{2}V_{rms} |\sin \theta| - V_o) d\theta} \tag{12}$$

And input power factor can be calculated as

$$PF = \frac{P_{in}}{V_{rms} I_{rms}} \tag{13}$$

Based on (11-13) and specification, the curve of the input PF can be drawn and is given in Figure 2 from which it can be concluded that the input PF is low for universal input voltage range.

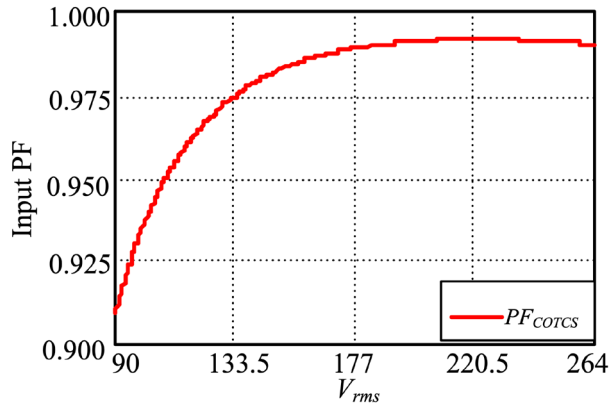


Figure 2. Input PF of COTCS [Mathcad eq:(10-14)].

3. PROPOSED VOT CONTROL SCHEME FOR CRM BUCK CONVERTER

For obtaining high PF for the buck converter, the on-time of Q_{buck} in (10) should vary as

$$t_{on(VORC)} = k_{on1} \frac{(\sqrt{2}V_{rms} |\sin \theta|)^2}{V_o (\sqrt{2}V_{rms} |\sin \theta| - V_o)} \tag{14}$$

Where k_{on1} is a constant

Substituting (14) into (10), the average input current of the buck converter is

$$i_{buck(VORC)}(\theta) = \frac{\sqrt{2}V_{rms} |\sin \theta|}{2L} k_{on1} (\theta_0 \leq \theta \leq \pi - \theta_0) \tag{15}$$

From (15), it can be seen that if the on-time of the buck converter varies as (14), the input current waveform looks like pure sinusoidal and the PF is high

Because of the power balance of the input and output, the input current for the unity PF can be expressed as

$$i_{in}(\theta) = \frac{\sqrt{2}P_o |\sin \theta|}{V_{rms}} \tag{16}$$

Based on (15-16), the input current at θ_0 can be written as

$$i_{in}(\theta_0) = \frac{k_{on1} \sqrt{2} V_{rms} |\sin \theta_0|}{2L} = \frac{\sqrt{2} P_o |\sin \theta_0|}{V_{rms}} \tag{17}$$

From (17), it can be concluded that

$$k_{on1} = \frac{2P_o L}{V_{rms}^2} \tag{18}$$

4. COMPARATIVE ANALYSIS

From (14), the input PF curve with proposed control scheme is shown in Figure 3 which also includes the PF values with traditional control scheme of Figure 2. It can be concluded that the PF of the converter with proposed control is higher as compared to COTC. It can conclude that improvement in PF is at all input voltage.

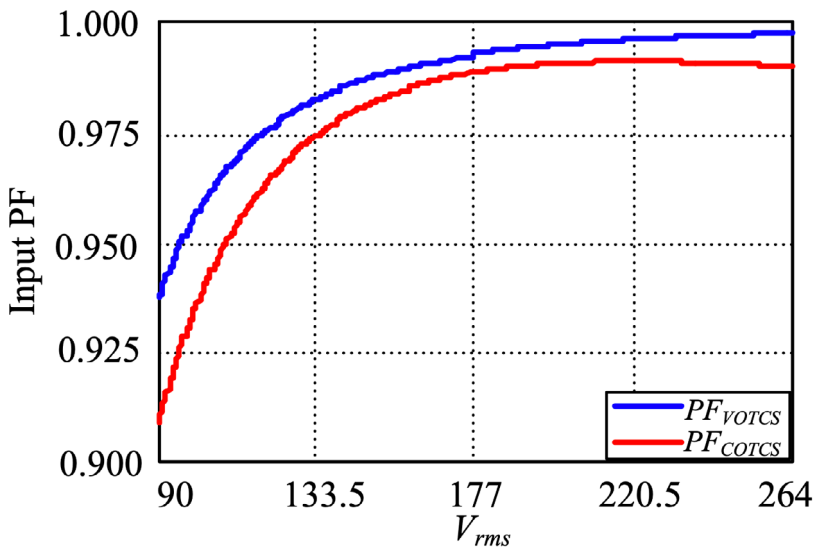


Figure 3. Input PF comparison between COT & VOT control scheme [Mathcad eq:(10-18)].

The THD comparison of the buck converter with COTCS and VOTCS is depicted in Figure 4. It indicates that THD is reduced in case of VOTCS as compared to COTCS.

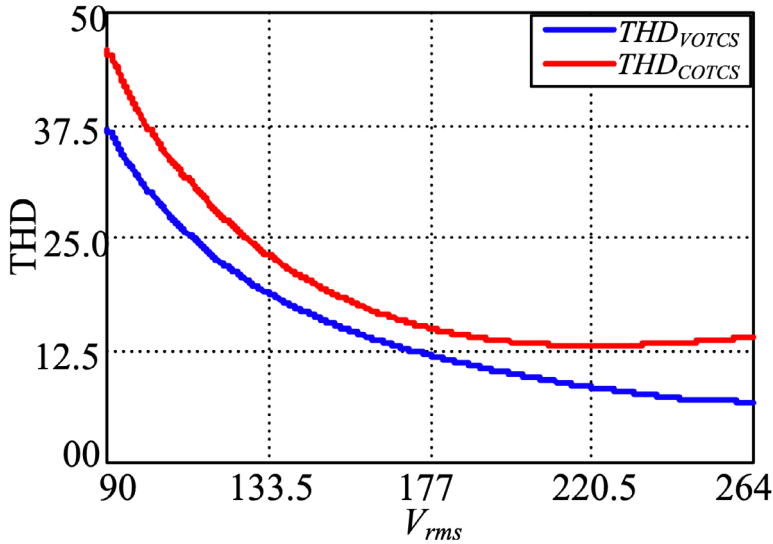


Figure 4. THD comparison between COT & VOT control scheme [Mathcad eq.(10-18) Relationship between PF and THD].

5. SIMULATION RESULTS

In order to verify the effectiveness of VOTCS, simulations results are given. The range of input voltage is 90-264 V_{rms} . The output voltage is selected as 80 V. The control IC 6561 will ensure the current to be in CRM. Ideal components are used in simulation

Figure 5 and Figure 6 show the simulation waveforms of v_{in} , & i_{in} of buck converter with COTCS and VOTCS at 220VAC inputs, respectively. It can be conducted that current is more sinusoidal in case of VOTCS as compared to COTCS. Thus VOTCS can attain high PF.

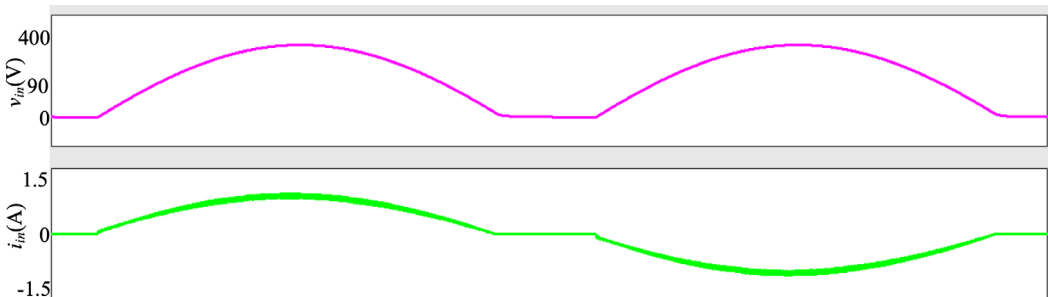


Figure 5. Input voltages and current of buck converter with COT control scheme [Saber Software].

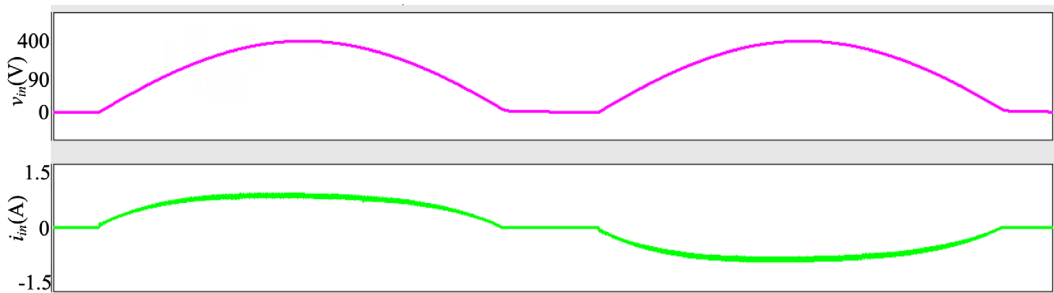


Figure 6. Input voltages and current of buck converter with VOT control scheme [Saber Software].

6. CONCLUSIONS

The buck converter is generally utilized in many applications because of various advantages. However, when on-time of buck converter is kept constant, the input voltage and current remains out of phase that cause's low PF and high total harmonic distortion (THD). Therefore, in this paper, a power factor improvement technique is implemented that permits the average input current sinusoidal without need of extra converter to work in cascade with buck converter. With COTCS, the input PF of the buck converter is low. In order to attain high input PF, VOT control scheme is proposed. Simulation results are presented for the verification of the analysis.

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