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A New Dual Soft Switch Control for Buck Boost PFC Converter Operating in Discontinuous Capacitor Voltage Mode

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Abstract - The PFC converters have been used for AC-DC converters and switched-mode power supplies according to demand on lowering current harmonics. This paper proposes the development of a new buck cascaded buck-boost power factor correction (PFC) converter of with a soft-switching technique. For its wide range of input voltage, it operates in both buck and boost modes. The parameters are properly selected to endure voltage and current stress in all operating ranges. In addition, the electromagnetic interference (EMI) filter is used to reduce the EMI noise and guarantee continuous input current in buck operation. Unlike the conventional methods, a mode detector is not required and consequently there is no hard transition between buck and boost modes. Although both converter switches are controlled, only one feedback control loop is required to obtain the desired power flow at a unity power factor. The principle of operation, theoretical analysis, simulation, and experimental results of a 1.6 kW prototype grid connected converter are presented. The results confirmed the validity of the proposed system under various operating conditions.it outperforms well compared to other conventional methods

***Key Words*: AC/DC Converter, cascaded buck-boost (CBB) converter, discontinuous capacitor voltage mode (DCVM), discontinuous conduction mode (DCM), Inductor current estimator, non-inverting buck boost, power factor correction (PFC), simultaneous duty cycle control.**

1. INTRODUCTION

Power electronic connected loads need to comply with specification restricted by harmonic regulations and IEEE standards, such as IEC 61000-3-2 and IEEE 519 [1], [2], in order to maintain the power quality of the grid. Thus, along with the wide spread applications of power electronic connected loads, the research on active power factor correction (PFC) techniques has taken on an accelerated path. Basic single stage up/down converter topologies such as buckboost, sepic, and cuk, with or without an isolation transformer, are widely used in PFC applications [3-7].

Although these converters provide simple configurations for wide range of input/output voltage conversion ratio, their active and passive elements suffer from high stresses [8]. Further, the output voltage polarity inversion of the buck-boost and cuk converters renders them unsuitable for high voltage applications. In an attempt to mitigate the high stress on converter components, research has focused on dual switch non-inverting buck-boost converters. The cascaded buck-boost converter (CBB) shown in Fig. 1 was proved to be one of the most promising non-inverting converters for high power applications [9-13]. The conventional CBB AC/DC converter control structure uses two complimentary modes of operation; buck and boost [14], [15]. The buck mode occurs by switching the buck switch ($S1$) while keeping the boost switch ($S2$) when the sinusoidal input voltage (Vi) is higher than the output voltage (Vo). The boost mode takes place when Vi is lower than Vo and it is implemented by keeping $S1$ on while switching $S2$. The main challenge facing such a structure is the need for a mode detector which requires fast and precise voltage sensors for the input and output voltages. The sensor delay, coupled with the unaccounted voltage drops in the converter components, lead to a discontinuity in the input current during the transition between the modes. Additionally, hard-switching between the two modes leads to high and unstable output voltage transients [16].

2. RELATED WORK

Basic single stage up/down converter topologies such as buckboost, sepic, and cuk, with or without an isolation transformer, are widely used in PFC applications [3-7]. Although these converters provide simple configurations for wide range of input/output voltage conversion ratio, their active and passive elements suffer from high stresses [8]. Further, the output voltage polarity inversion of the buck-boost and cuk converters renders them unsuitable for high voltage applications. In an attempt to mitigate the high stress on converter components, research has focused on dual switch non-inverting buck-boost converters. The cascaded buck-boost converter (CBB) shown in Fig. 1 was proved to be one of the most promising non-inverting converters for high power applications [9-13].

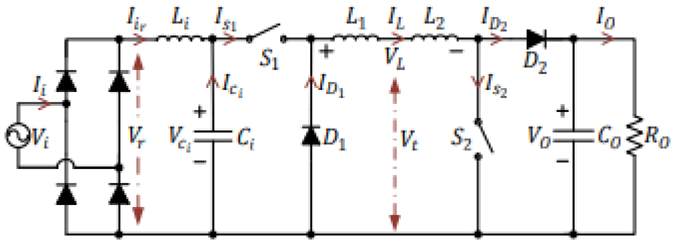

Fig 1 PFC converter

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3. PROPOSED SYSTEM

In this paper, a simultaneous dual switch control for PFC operation of the CBB converter is proposed. The proposed control structure eliminates the transition between the different modes, while using only one feedback control loop. Thus, there is no need for a mode detector or a precise output voltage sensor. The CBB converter provided in Fig. 1 operates in discontinuous conduction mode (DCM) with the proposed controller. Unlike continuous conduction mode (CCM), DCM operation provides inherent PFC features which significantly reduces the high switching frequency requirement [4], [13], [23-26].

Discontinuous inductor current mode (DICM) is a widely used DCM control technique applied on various PFC converters [18], [27-34]. However, DICM causes high current stress on the converter switches, and it faces a challenging design for the input capacitor required to balance the power and provide a continuous input current without imposing any inrush currents into the system. A dual alternative to DICM is applied in this paper by operating the converter in a discontinuous capacitor voltage mode (DCVM) [35]. DCVM is achieved by placing a small capacitor (Ci in Fig. 1) at the converter input and forcing it to discharge to zero voltage every switching cycle in order to obtain a unity power factor and a continuous input current. The proposed simultaneous control structure allows for an extended DCVM range of operation leading to the enhancement of the converter inherent PFC features. Moreover, the switching frequency is noticeably decreased while maintaining a high power factor and a low output voltage ripple. Further, the converter possesses a zero turn-off switching voltage and a zero turn-on diode voltage in the buck stage. Thus, the system efficiency is projected to increase.

3.1 DCVM PRINCIPLE OF OPERATION

The applicability of DCVM on single stage converters, such as buck and cuk converters, for PFC purposes has been studied in the literature [36-42]. The use of DVCM was also reported on the sheppard-taylor converter for the same purposes [43-45]. To the best of the authors' knowledge, DCVM operation for a dual stage converter has not appeared in the literature. CBB converter operation in DCVM is analyzed in this section based on a simultaneous dual switch control. The converter shown in Fig. 1 consists of two series converters, buck and boost. The buck converter is designed to work in DCVM while the boost converter is designed to work in CCM, as the inductor current is continuous. As explained in [46] there are three states for any DCVM converter, while there are only two complimentary states for CCM converters. In CCM mode, the converter state can be denoted according to the switch position, 1 means that the switch is on, and 0 means that the switch is off. In DCVM mode, the position of the switch and the diode are individually denoted by 1 and 0 (1 =on, 0 =off). Thus, the two stage converter states in the CBB can be expressed as $X1$- $X2$- Y. Where $X1$ represents the state of $S1$, $X2$ represents the state of $D1$, and Y represents the state of the boost converter.

The converter is analyzed assuming that the input current (Ii) is constant over one switching cycle, the capacitor (Ci) has a low enough capacitance to operate in discontinuous mode, the total inductance ($L = L1 + L2$) is big enough to ensure that IL is continuous. The characteristic waveforms of CBB converter over one switching cycle are presented in Fig. 2 and 3 for the buck and the boost portions respectively.

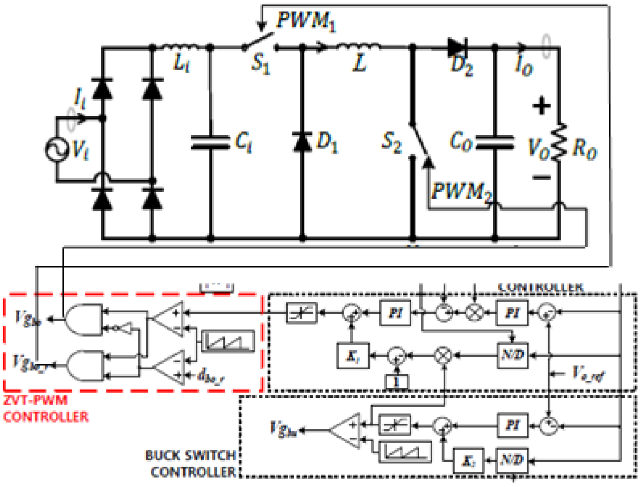


Fig .2 Proposed controls

In the conventional method in [7], two switches, which are the *Sbu* and *Sbo* in Fig. 1, operate with the same duty ratio. Also, they operate in their own modes for the control of output voltage and PF. Whenever the values of AC input and DC output voltages of PFC converter become similar, the buck or boost mode is changed to the other. For the smooth transition between two modes, the duty ratios, *dbo* and *dbu* (of boost and buck switches, respectively) must be controlled carefully. However, this control is difficult to realize in practice due to controller nonlinearities caused by the PWM comparators and the time delays of switches because they make the uncontrollable zone of input current, so called the dead-zone. During the dead-zone, it can cause the abrupt fluctuations of input current while resulting in the low PF [16]-[17]. To solve these problems, the buck switch controls the output voltage only with the different duty ratio from that of boost switch in a buck mode [18]. Also, in the proposed PFC converter, the input current becomes zero when the buck switch turns off without the EMI filter. Therefore, it is influenced by both the EMI filter and the *dbu* of buck switch. To analyze its effect theoretically, the proposed PFC converter with the EMI filter is modelled by the simplified circuit with a current source and a *LC* filter, as shown in Figure

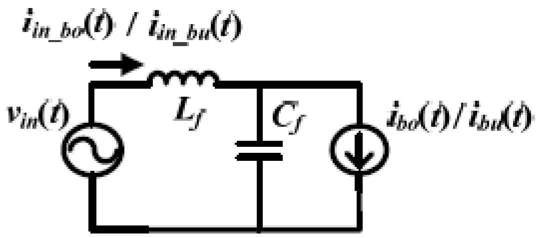
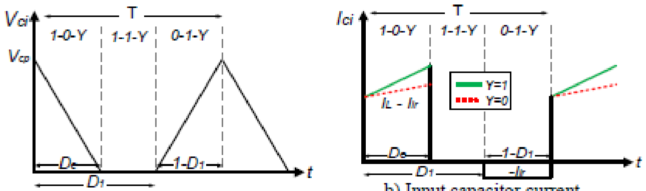
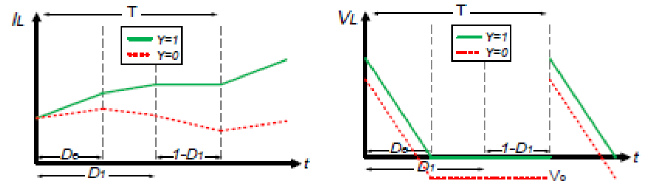


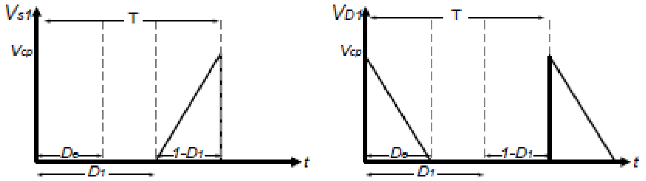
Fig 3.Simplified PFC converter



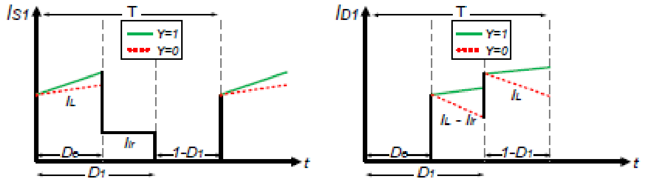
a) Input capacitor voltage. b) Input capacitor current.



c) Converter inductor current. d) Converter inductor voltage.

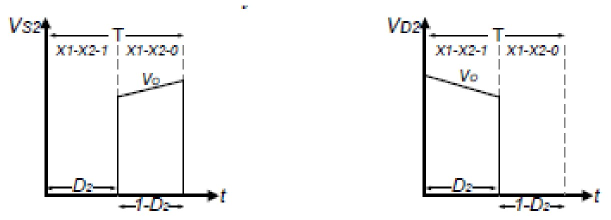


e) Buck switch voltage. f) Buck diode voltage.

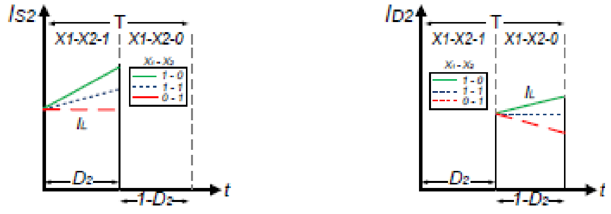


g) Buck switch current. h) Buck diode current.

Fig- 3 Buck converter intervals



a) Boost switch voltage. b) Boost diode voltage.



c) Boost switch current. d) Boost diode current.

Fig 4 Boost converter intervals

4. RESULT AND DISCUSSION

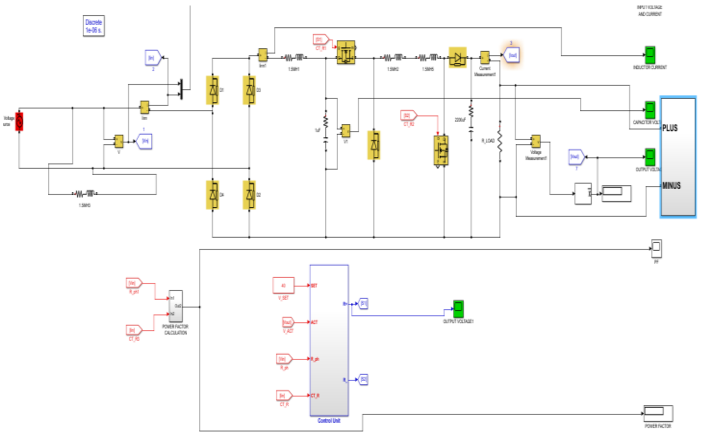


Fig 5 Simulation

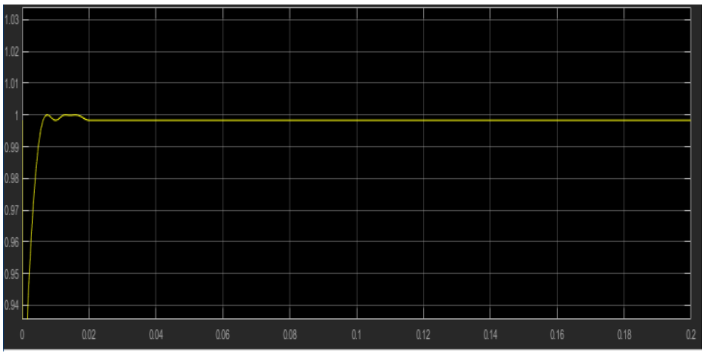


Fig 6 Power factor result

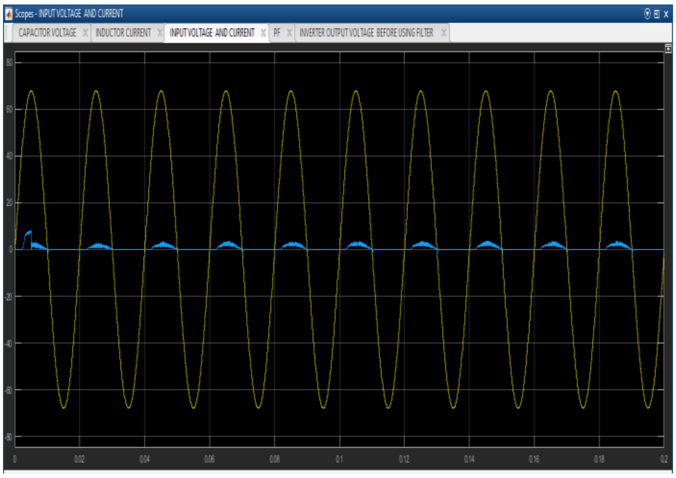


Fig 7 Output voltages & current

5. CONCLUSION

A CBB converter operating in DCVM is investigated in this paper for PFC purposes. Simultaneous dual switch control is applied on the two stages of the CBB converter. The proposed control is proved to enhance the inherent high power factor features of the used converter by the means of extending the DCVM duration while using only one feedback control loop. The applied control allows for a continuous sinusoidal input current on an overlapping input/output voltage range. Additionally, the converter possesses a zero turn-off switching voltage and a zero turn-on diode voltage. The converter modes of operation are analyzed and the design equations are derived, proving the contribution of the dual stage control technique. An averaging circuit model is used to develop the system low frequency model and the small signal transfer function. Simulations and experimental analyses are conducted. Both the steady state and the transient results proved the system dynamic ability and effectiveness over a wide range of power flow and varying conditions.

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