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Single-Inductor Dual-Output Buck-Boost Power Factor Correction Converter

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ABSTRACT: In this paper a single-inductor dual-output (SIDO) buck-boost PFC converter operating in critical conduction mode (CRM) is proposed. By multiplexing a single inductor, each output of SIDO buck-boost converter can be regulated independently. Compared with conventional two-stage multiple output converter, SIDO buck-boost PFC converter benefits from significant overall cost saving, small size and light weight. Moreover, the efficiency of SIDO buck-boost PFC converter can be improved due to single-stage power conversion. Control strategy and characteristics of the proposed converter are analyzed. The efficiency, power factor, total harmonic distortion (THD) and output accuracy are verified experimental results.

KEYWORDS: Critical conduction mode (CRM), Power factor correction (PFC), Single stage, Single-inductor dual-output (SIDO), Time multiplexing (TM).

I. INTRODUCTION

Multiple outputs ac/dc power converter has been becoming popular with fast development of consumer electronics and LED lighting[1]-[3], such as multi-level voltage supply system, current balancing for multiple LED string driving, RGB LED lighting, etc. IEC61000-3-2 Class C for lighting equipment establishes a strict requirement for input current harmonic content of power converter [4]. Power factor correction (PFC) is usually used to provide sinusoidal input current. Hence, research of multiple outputs ac/dc power converter with low cost and high power factor is important. In order to achieve high power factor (PF) and to accurately regulate output voltages or currents of multiple output ac/dc converter, conventional multiple output ac/dc power converter consisting of two-stage power conversion is utilized, as shown in Fig.1, where PFC pre-regulator provides dc bus voltage *vbus*, and parallel connected dc-to-dc regulators are used to regulate output voltage or output current from *vbus* [5]. The circuit configuration of multiple output ac/dc converter shown in Fig.1 is complex and suffers from high cost, with multiple inductors and controllers are required [6],[7]. Moreover, the two-stage power conversion with PFC pre regulator and dc-to-dc converters suffer from lower efficiency and higher volume and cost. However, single-stage PFC converter can achieve high PF and output current or voltage regulation at the same time [8], [9]. Hence, it has drawn more and more attention in recent years. Flyback PFC converter with multiple secondary windings is a typical single-stage multiple outputs converter, with only one output can be well regulated. Multiple secondary windings in the transformer leads to cross-regulation due to leakage inductance, forward voltage drop of diodes, and series resistance of the windings [10].

Fig.1. Block diagrams of a conventional multiple output ac/dc power converters with high power

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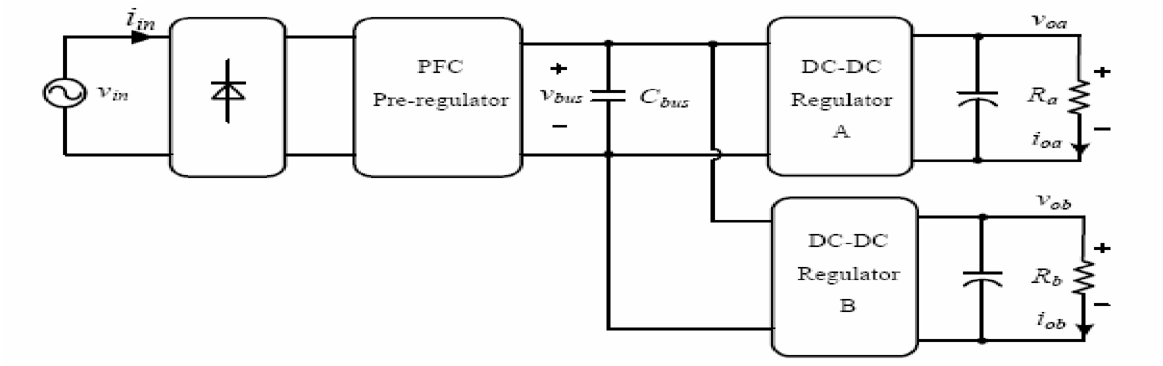

factor.

Fig.1. Block diagrams of a conventional multiple output ac/dc power converters with high power factor.

Moreover, only voltage output regulation can be achieved, while multiple current outputs are hard to regulate independently. In order to achieve high accurate regulation of multiple output converter, magnetic amplifier post-regulator approach is applied in [11], [12], but it still requires multiple inductors and windings.

Single-inductor multiple-output (SIMO) converter with only one inductor benefits from significant overall cost saving, small size and light weight, which make it as one of the most suitable and cost-effective solutions for multiple output power supplies. SIMO dc/dc converters in mobile application have been studied in recent years [13]-[17]. In some offline applications, such as LED lighting, single stage PFC converters are preferred. Single-stage buck-boost PFC converter has the advantage of low cost and high power factor, which make it widely applied in single-output non-isolated general lighting application [18]. In this paper, a novel single inductor dual-output (SIDO) buck-boost PFC converter operating in critical conduction mode (CRM) is proposed. Its control strategy and corresponding characteristics are analyzed. Independent regulation of each output can be achieved in this converter by multiplexing a single inductor. Compared with conventional two-stage multiple output converter, the proposed converter benefits with significant overall cost saving, small size, light weight and high power conversion efficiency due to single stage power conversion. The proposed converter can also be easily extended to realize SIMO buck boost PFC converter to fulfil different system requirements. This paper is organized as follows. In Section II, SIDO buck-boost PFC converter is proposed and analyzed. The design considerations and analysis are described in Section III. The experimental results including efficiency, power factor, total harmonic distortion (THD) and output regulation accuracy are given in Section IV, and Section V summarizes the conclusions drawn from the study.

II. PROPOSED SIDO BUCK-BOOST PFC CONVERTER

As shown in Fig.2 (a), the power stage of SIDO buck-boost PFC converter consists of a diode bridge *D*bridge, a input filter consists of *L*f and *C*f, three switch networks consists of *Q*1, *Q*2 and *Q*3 and their corresponding sense resistors *R*s1, *R*s2 and *R*s3, two freewheeling diodes *D*1 and *D*2, a time-multiplexing inductor *L* and two output filter capacitors *C*1 and *C*2. *Q*2 and *Q*3 are the time-multiplexing control switches of each output. When *Q*2 is turned on and *Q*3 is turned off, converter transfer power to output A, and when *Q*2 is turned off and *Q*3 is turned on, converter transfer power to output B.

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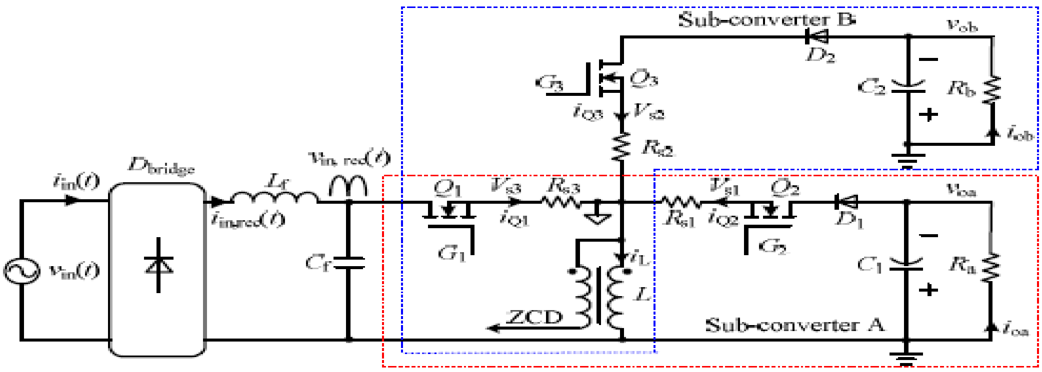

Fig.2. The proposed SIDO buck-boost PFC converter. Power stage

When $Q2$ is turned on and $Q3$ is turned off, converter transfer power to output A, and when $Q2$ is turned off and $Q3$ is turned on, converter transfer power to output B.

III. DESIGN CONSIDERATIONS AND ANALYSIS

In this section, the SIDO buck-boost PFC converter operating CRM is analyzed under the following assumptions.

1) All the components as shown in Fig.2 are ideal. 2) The switching frequency $f$sw is much higher than the line frequency 2fL, *i.e.* $f$sw>>2fL, input voltage can thus be considered as constant in a switching cycle. 3) The input voltage is a full-wave rectified sine wave, *i.e.*, $v$in, rec(t) = |vin(t)|=Vp|sin(_Lt)|, where Vp is the amplitude and _L = 2_fL is the angular frequency of AC input voltage. 4) The output voltage $v$oa and $v$ob are constant, *i.e.*, they have a negligible ac ripple in steady state. 5) As the bandwidth of the control loop of PFC converter is usually much lower than the rectified line frequency (2fL), the error voltage of each output ve[i] (i=1, 2) are constant within each half of a line cycle, *i.e.*, constant on time control can be achieved by controller.

IV. SIMULATION AND EXPERIMENTAL VERIFICATION

A 30.75W prototype of the proposed CRM SIDO buckboost PFC is built to verify the theoretical analysis. Each output current of the proposed CRM SIDO buck-boost PFC is constant. The prototype parametersI. From (10), coefficient k is 0.49 to 0.20, with input voltage varying from 100Vac to 240Vac, which is higher than 0.19. Therefore, according to Fig.5, the harmonic current in prototype can meet IEC limit. According to the analysis, L is designed as 180uH. Lf and Cf, which are used to provide switching noise attenuation and achieve low displacement angle between input voltage and current [19], are seriously affected by Fs_min at low input voltage. Low Fs_min requires low cutoff frequency of input filter, which will increase the size of filter. In this paper, Lf and Cf are designed as 1mH and 220nF considering wide input voltage.

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TABLE
CIRCUIT PARAMETERS OF SIDO BUCK-BOOST PFC CONVERTER

Variable	Definition	Value
*V*in	Input voltage	100~240Vac
*R*a	Rated load resistor of output A	300Ω
*I*oa	Current of output A	0.2A
*R*b	Rated load resistor of output B	300Ω
*I*ob	Current of output B	0.25A
L	Inductor/Bobbin	180uH/RM8
Q1	Power MOSFET	7N65
*Q*2, *Q*3	Multiplexing MOSFET	IRFR13N15D
D1, *D2*	Freewheeling diode	ES2J
*L*f	Input filter inductor	1mH
Cf	Input filter capacitor	220nF
*C*1,*C*2	Output filter capacitor	220uF

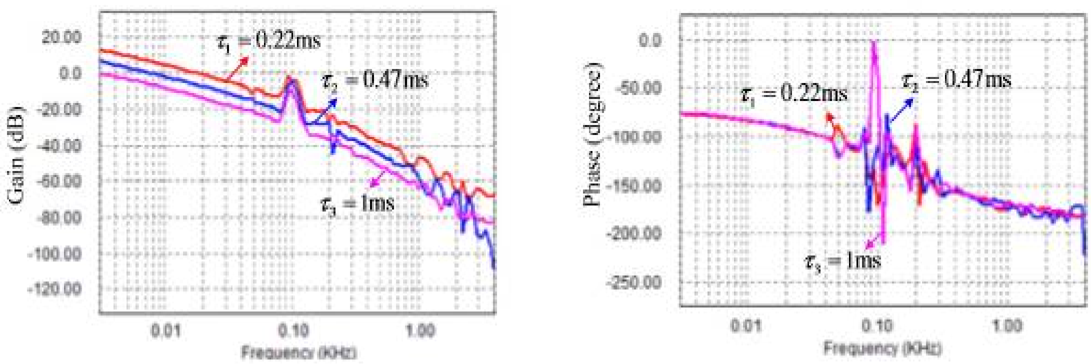

Fig.10. Loop gain simulation results of the sub-converter A with _=*R*e3*C*e3.

According to Fig.2, low pass filter, *R*e1 and *C*e1, *R*e2 and *C*e2 are used to filter inductor freewheeling current sense signal on *R*s1 and *R*s2. Due to low frequency (2*f*L) ripple on *R*s1 and *R*s2, the time constant of these low pass filters should be lower than 1/2*f*L. The capacitance and resistance of these two filters are designed as 100nF and 120k_ in this prototype. Two compensators (Op1, *R*e3, *C*e3, Op2, *R*e4 and *C*e4) are applied to achieve sufficient phase margin and low bandwidth for power factor correction. Fig.10 shows the loop gain of Psim simulation results at 100Vac for sub-converter A with different compensation parameters (_1, _2 and _3) by using the circuit parameters shown in Table I. It can be observed that when time constant _ =*R*e3*C*e3 is lower than 0.22ms, the phase margin is approximately 90 degree when the compensator is applied. The bandwidth will be lower than 20Hz, which can ensure acceptable power factor correction requirement, but
this low bandwidth severely affects the control loop dynamics [20], [21]. Poor transient performance will also cause poor transient cross-regulation performance. Therefore, the control loop design is a trade-off between PF and transient performance. The simulation result of transfer function with 50Hz ac input shows fluctuations at frequencies around 100Hz.

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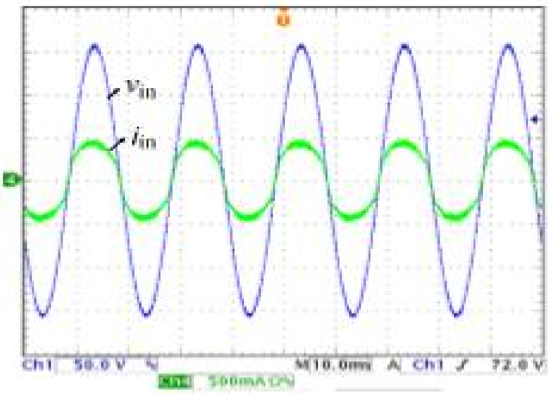


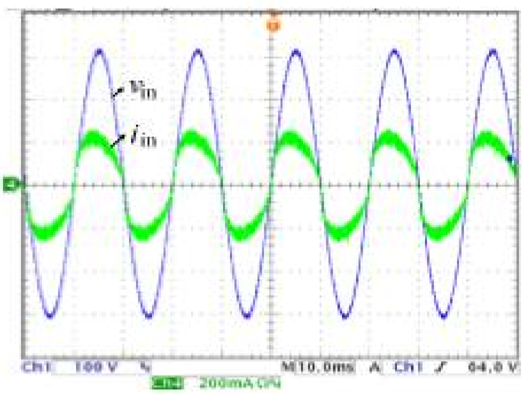
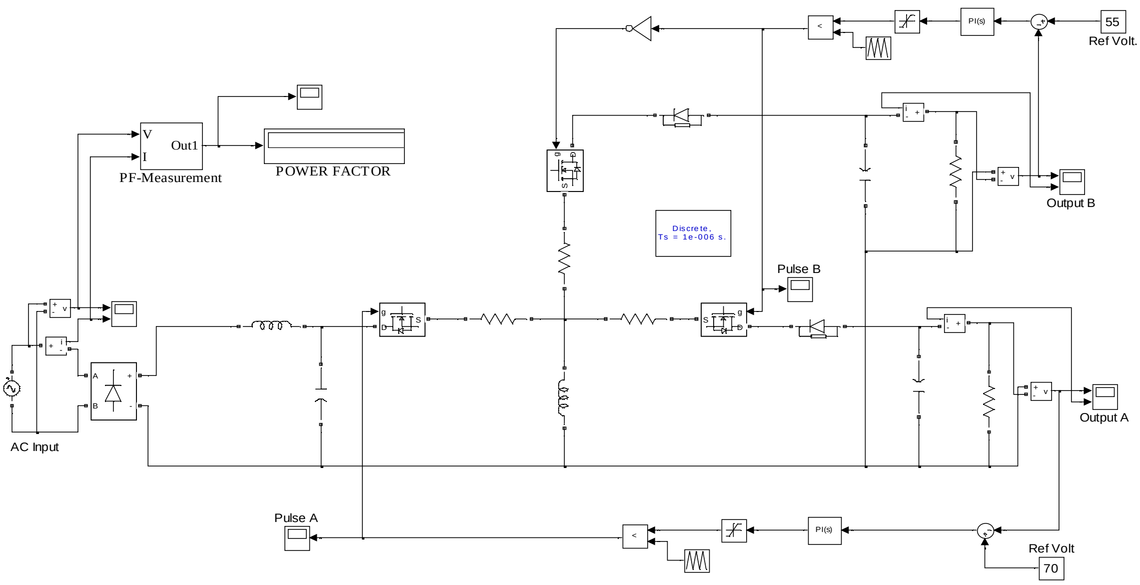


Fig.11 *v*in and *i*in waveforms of SIDO buck-boost PFC Converter at 110Vac input
Fig.12 *v*in and *i*in waveforms of SIDO buck-boost PFC Converter at 220Vac input

This fluctuation is due to the combined effects of 100Hz switching at the bridge rectifier and the 100Hz ripple in the output voltage. In order to make the design simple, the same compensation parameters are applied in two compensation network and the compensation parameters are designed as *R*e3=*R*e4=10k_, *C*e3=*C*e4=47nF considering high PF and acceptable transient performance, i.e., _=0.47ms. The steady-state input current waveforms of CRM SIDO buck-boost PFC converter at rated output power are shown in Fig.11 and Fig.12. From Fig.11 and Fig.12, it can be known that input current *i*in is in phase with input voltage *v*in. The power factor correction function is achieved.

V. SIMULINK



In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit,[1][2] and is a dimensionless number in the closed interval of -1 to 1. A power factor of less than one means that the voltage and current waveforms are not in phase, reducing the instantaneous product of the two waveforms (V x I). Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power.

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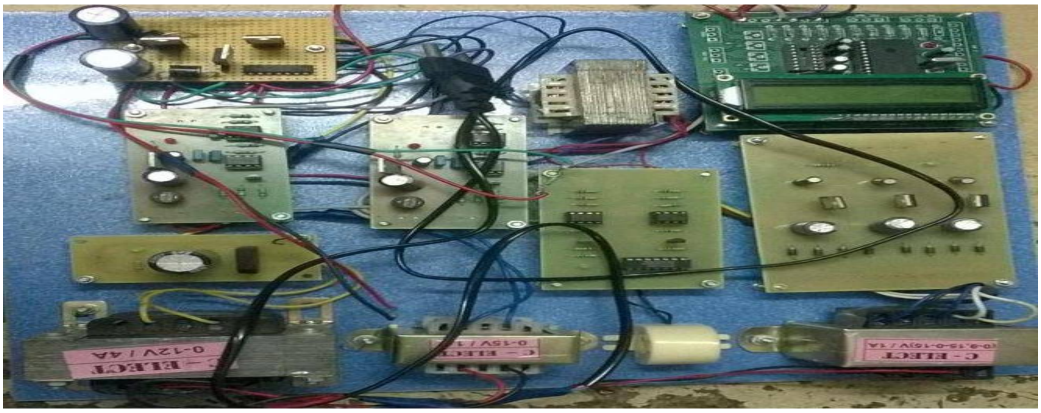
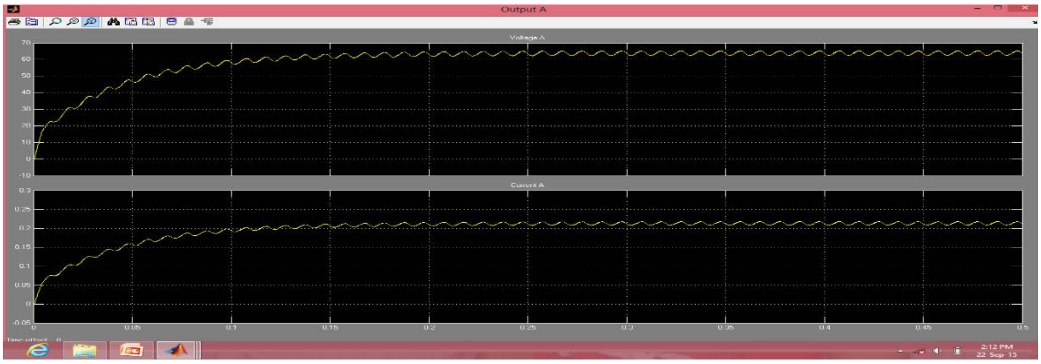
Experimental results



a) Proposed the hardware structure

Wave Form A



b) Output voltage and current 1

c)

The above diagram discussed about the wave form difference between current and voltage. the voltage and current waveforms differs only by varying the value in reference voltageThe circuit configuration of multiple output ac/dc converter shown in Fig.1 is complex and suffers from high cost, with multiple inductors and controllers are required [6],[7]. Moreover, the two-stage power conversion with PFC pre regulator and dc-to-dc converters suffer from lower efficiency and higher volume and cost. However, single-stage PFC converter can achieve high PF and output current or voltage regulation at the same time [8], [9]. Hence, it has drawn more and more attention in recent years. Flyback PFC converter with multiple secondary windings is a typical single-stage multiple outputs converter, with only one output can be well regulated. Multiple secondary windings in the transformer leads to cross-regulation due to leakage inductance, forward voltage drop of diodes, and series resistance of the windings.

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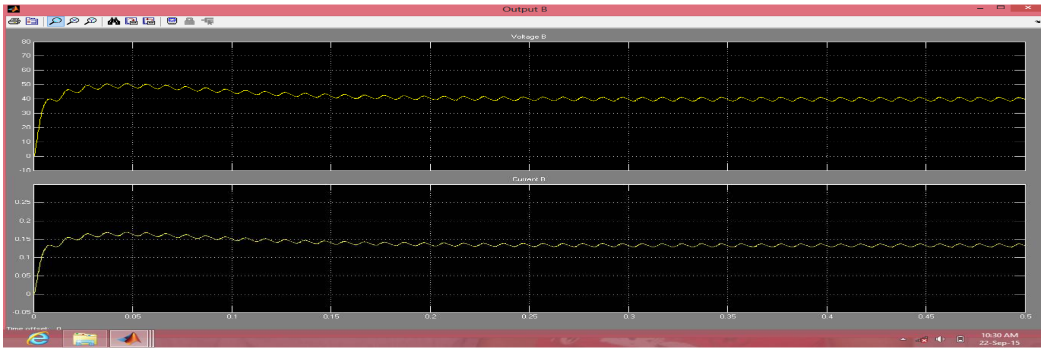
Wave Form B



C) output voltage and current 2

The above diagram discussed about the wave form difference between current and voltage. the voltage and current waveforms differs only by varying the value in reference voltage.

V. CONCLUSION

A single-inductor dual-output buck-boost PFC converter operating CRM is proposed in this paper. Detailed control strategy analysis and design considerations are presented. Each output can be regulated independently in this converter by multiplexing a single inductor. Compared with conventional two-stage multiple output ac/dc converters, the proposed single-stage multiple output ac/dc converter benefits from significant overall cost saving, small size and light weight of device. Experimental results are presented to verify the analysis results, and demonstrate the advantage of the proposed converter. Although only dual-output converter is discussed in detailed in this paper, the proposed converter can be easily extended to realize SIMO PFC converters with different topology to fulfil different system requirements.

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