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A POWER FACTOR CORRECTION USING SINGLE-INDUCTOR DUAL-OUTPUT BUCK-BOOST CONVERTOR

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ABSTRACT

A Power Factor Correction Using single- inductor dual-output buck-boost converter operating in critical conduction mode is proposed in this paper. Each output of the Single-Inductor Dual-Output buck-boost converter can be regulated independently by multiplexing a single inductor, Compared with a conventional two-stage multiple-output converter, the single- inductor dual-output buck-boost converter benefits from significant overall cost saving, small size, and light weight. Moreover, the efficiency of the SIOD buck-boost converter can be improved due to single-state power conversion. The efficiency, power factor, total harmonic distortion, and output accuracy are verified using MATLAB simulation results.

Index Terms—*Power Factor Correction (PFC), Single-inductor dual-output (SIDO),single Stage, time multiplexing (TM)*

I. INTRODUCTION

A multiple-output ac/dc converter provides a high power factor and accurately regulates the output voltages or currents. In conventional multiple-output ac/dc power converter consisting of two-stage power conversion is utilized, where the Power Factor Converter provides the DC bus V_{bus} and parallel-connected dc-to-dc regulators used to regulate the output voltage or output current from V_{bus}

This circuit configuration of the multiple-output ac/dc converter is suffers from high cost and complex with multiple inductors and controllers required. Moreover, the two-stage power conversion with power factor correction preregulator and dc-to-dc converters suffers from lower efficiency and higher volume and cost. the proposed paper have single-stage conversion can achieve high power factor and output current or voltage regulation at the same time. Hence, it has more attention in recent years.

II. PROPOSED SIDO BUCK_BOOST PFC CONVERTER

The power stage of the single inductor dual-output buck-boost is shown in Fig. 2(a). it consists of a diode bridge D_{brige} ; an input filter consisting of L_f and C_f ; three switch networks consisting 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, the converter transfers power to output A, and when Q_2 is turned off and Q_3 is turned on. The converter transfers power to output B.

The control loop of the single inductor buck-boost converter with two constant output currents. R_{s1}, R_{s2} and R_{s3} are series connected with $Q_{1,}$ $Q_{2,}$ and Q_3, respectively, and their common-connect point is set as signal ground. Thus $Q_{1,}$ $Q_{2,}$ and Q_3 can be driven as Low side with respect to this signal ground, which benefits from simple driving. As the average of the inductor freewheeling current for each sub converter in a half-line cycle is equal to the corresponding output current, it can be detected as the output current for control. V_{s1} and V_{s2} are the sense voltages across sense resistors R_{s1} and R_{s2}, produced by inductor freewheeling currents i_{Q2} and i_{Q3}. The average of V_{s1} and V_{s2} by low-pass filters is used as the output current information for each output.

A flyback PFC converter with multiple secondary windings is a typical single-stage multiple-output converter, where only one output can be well regulated. Multiple secondary windings in the transformer lead to cross-regulation due to leakage inductance, forward voltage drop of diodes, and series resistance of windings. Moreover, only voltage output regulation can be achieved, while multiple current outputs are hard to regulate independently. In order to achieve a highly accurate regulation of multiple-output converters, the magnetic amplifier post regulator approach is applied but it still requires multiple inductors and windings.

A single-inductor multiple-output converter with only one inductor benefits from significant overall cost saving, small size, and light weight, which make it as one of the multiple-output power supplies. Which make it as one of the most suitable and cost-effective solutions for multiple-output power supplies. Single-inductor multiple-output dc/dc converters in mobile application have studied on recent years. In some offline application, such as LED lighting, single-stage PFC converters are preferred. A single-stage buck-boost PFC converter has the advantage of low cost and high PF, which make it widely applied in single-output non isolated general lighting applications. In this proposed paper, a novel single-inductor dual output buck-boost PFC converter operating in critical conduction mode is proposed. Its control strategy and corresponding characteristics are analysed. Independent regulation of each output can be achieved in this converter by multiplexing a single inductor. Compared with a conventional two-stage multiple-output converter, the proposed converter benefits from 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 the single inductor multiple output buck boost converter to fulfil different system requirements.

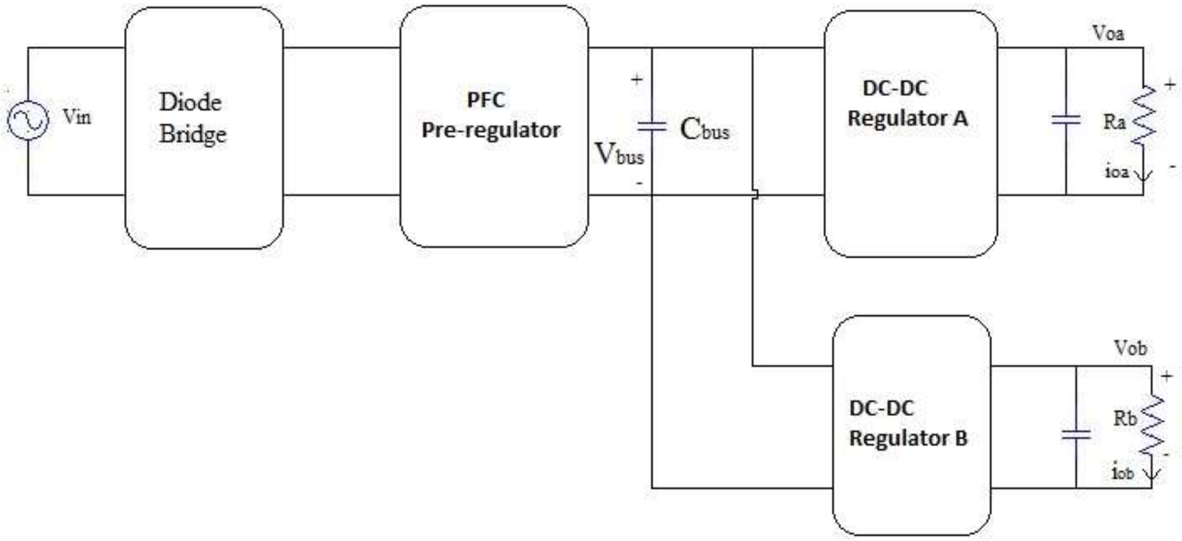

Fig. 1. Block diagram of a conventional multiple-output ac/dc power converter with a high PF.

III. DESIGN CONSIDERATIONS AND ANALYSIS

The single inductor dual output buck-boost converter operating in critical conduction mode is analysed under the following assumptions.

1) All of the components as shown in Fig.2 are ideal.
2) The switching frequency f_{sw} is much higher than the line frequency $2f_L$, i.e, $f_{sw}>>2f_L$; the input voltage can thus be considered as constant in a switching cycle.
3) The input voltage is full-wavw rectified sine wave, i.e, $V_{in\ rec}(t)=|V_{in}(t)|=V_p|\sin(\ \omega_L)|$, where Vp is the amplitude and $\omega_L=2\pi f_L$ is the angular frequency of the ac input voltage.

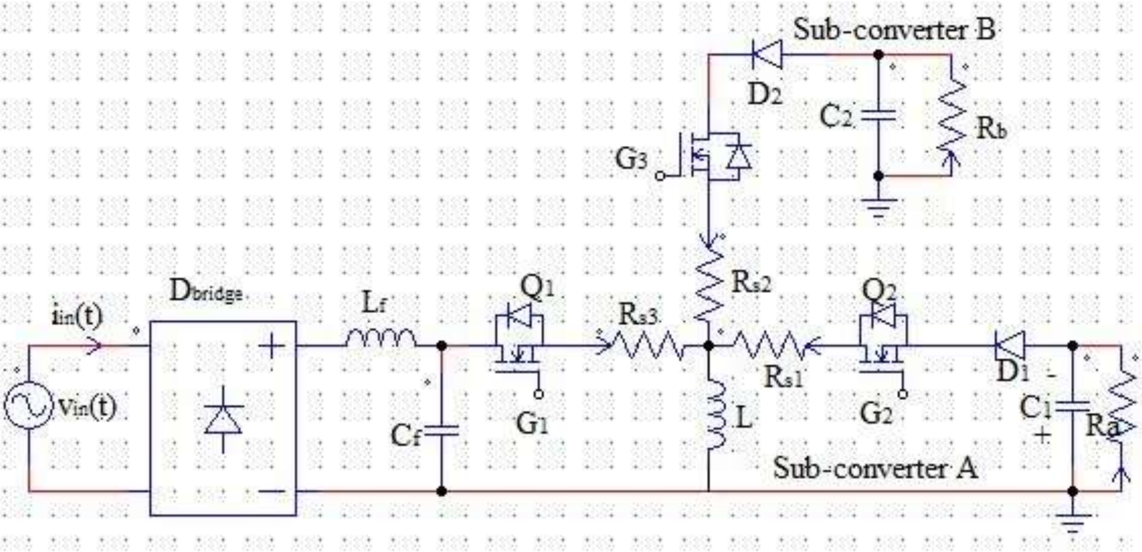

Fig. 2. Proposed SIDO buck–boost PFC converter

4) The output voltages 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 the PFC converter is usually much lower than the rectified line frequency ($2f_L$), the error voltage of each output $V_{e[i]}$(i = 1, 2) is constant within each half of a line cycle, i.e., constant on time control can be achieved by the controller.

A. Input Current and Harmonic Current Analysis

Fig. 2 shows the inductor current waveform and its control sequence within a half line cycle. The SIDO buck–boost PFC converter transfers input power to each output alternately by using a varied multiplexing time ($T_A + T_B = T_S$).

In CRM, the peak inductor current of sub converters A and B in a multiplexing cycle can be obtained as

$$i_p,A(t)=\frac{T_{on},A}{L}v_{in,rec}(t)=\frac{v_{oa}}{L}T_{off},A(t)$$
$$i_p,B(t)=\frac{T_{on},B}{L}v_{in,rec}(t)=\frac{v_{ob}}{L}T_{off},B(t)\quad(1)$$

Where $T_{on,A}$, $T_{on,B}$, $T_{off,A}$, and $T_{off,B}$ are the turn-on times and turn-off times of sub-converter A and sub-converter B, and V_{oa} and V_{ob} are the output voltages of sub-converters A and B, respectively.

From (1), the turn-off time of sub-converters A and B in a multiplexing cycle can be described by

$$\mathrm{T_{off}},\mathrm{A}(t)=\frac{\mathrm{T_{on}},\mathrm{A}}{\mathrm{v_{oa}}}\mathrm{v_{in,rec}}(t)$$
$$\mathrm{T_{off}},\mathrm{B}(t)=\frac{\mathrm{T_{on}},\mathrm{B}}{\mathrm{v_{ob}}}\mathrm{v_{in,rec}}(t)\quad(2)$$

From (1) and (2), the multiplexing cycle of the CRM SIDO buck–boost PFC converter can be given as

$$T_s(t)=T_{on,A}+T_{on,B}+\left(k_1T_{on,A}+k_2T_{on,B}\right)|sin\omega t|\quad(3)$$

Where $k_1=V_p/V_{oa}$, $k_2=V_p/V_{ob}$, and $Ts(t)=1/f_S(t)$

From (1) and (3) the average input currents of subconverters A and B multiplexing cycle are

$$i_{in,rec,A}(t)=\frac{\propto T_{on,A}V_p|sin\omega t|}{2L[1+\propto+(\propto k_1+k_2)|sin\omega t|}$$
$$i_{in,rec,B}(t)=\frac{\propto T_{on,B}V_p|sin\omega t|}{2L[1+\propto+(\propto k_1+k_2)|sin\omega t|}\quad(4)$$

Where $\propto=T_{on,A}/T_{on,B}$

From(4), the input power of subconverter A and B in a half line cycle can be obtained as

$$P_{in,A}=P_{o,A}=\frac{\int_0^{\pi}v_{in,rec}(t)\,i_{in,rec,A}(t)d(\omega t)}{\pi}=\frac{\propto\beta V_p^2T_{on,A}}{2\pi L}$$
$$P_{in,B}=P_{o,B}=\frac{\int_0^{\pi}v_{in,rec}(t)i_{in,rec,B}(t)d(\omega t)}{\pi}=\frac{\propto\beta V_p^2T_{on,B}}{2\pi L}\quad(5)$$

Where $\propto=\frac{T_{on,A}}{T_{on,B}}=\sqrt{\frac{P_{o,A}}{P_{o,B}}}\quad(6)$

$$\beta=\int_0^{\pi}\frac{sin^2\omega t}{1+\alpha+(\alpha k_1+k_2)sin\omega t}d(\omega t)$$

From (5), the turn on time of sub-converters A and B can be Expressed as

$$T_{on,A}=\frac{2\pi L\sqrt{P_{o,A}P_{o,B}}}{\beta V_p^2}$$
$$T_{on,B}=\frac{2\pi LP_{o,B}}{\beta V_p^2}\quad(7)$$

From (4), the average input current of Critical conduction mode single inductor dual output buck-boost converter in a multiplexing cycle is

$$i_{in,rec}(t)=i_{in,rec,A}(t)+i_{in,rec,B}(t)$$
$$=\frac{(\propto T_{on,A}+T_{on,B})V_p|sin\omega t|}{2L[1+\propto+(\propto k_1+k_2)|sin\omega t|}\quad(8)$$

By substituting (7) into (8), the input current of the CRM SIDO buck-Boost Converter can be expressed as

$$i_{in,rec}(t)=\frac{\pi(P_{o,A}+P_{o,B})|sin\omega t|}{V_p\int_0^{\pi}\frac{sin^2\omega t}{k+sin\omega t}d(\omega t)(k+|sin\omega t|)}\quad(9)$$

Where

$$k=\frac{1+\propto}{\propto k_1+k_2}\quad(10)$$

B. PF Analysis

The power factor of CRM SIDO buck-boost converter can be obtained as

$$PF=\frac{\sqrt{2}\int_0^{\pi}\frac{sin^2\omega t}{k+sin\omega t}d(\omega t)}{\sqrt{\pi}\sqrt{\int_0^{\pi}\frac{sin^2\omega t}{k^2+2ksin\omega t+sin^2\omega t}d(\omega t)}}\quad(11)$$

C. Current Stress Analysis

By substituting (6) and (7) into (1), the peak inductor current of sub-converters A and B can be described as

$$i_{p,A}(t)=\frac{2\pi\sqrt{P_{0,A}P_{0,B}}}{\beta V_p^2}v_{in,rec}(t)$$
$$i_{p,B}(t)=\frac{2\pi P_{0,B}}{\beta V_p^2}v_{in,rec}(t)\quad(12)$$

It can be seen from (12) that $i_{p,A}(t)$and $i_{p,B}(t)$ are sinusoidal in a half line cycle. the peak inductor current will increase to its maximum when |sinωLt|=1,

$$i_{p,A,max}=\frac{2\pi\sqrt{P_{0,A}P_{0,B}}}{\beta V_p}$$
$$i_{p,B,max}=\frac{2\pi P_{0,B}}{\beta V_p}\quad(13)$$

Equation (13) demonstrates that ip,A,max or ip,B,max is a function of the amplitude of the input voltage, output power, and β. In other words, ip,A,max and ip,B,max will be fixed if the input and output are fixed.

D. Voltage stress analysis

The maximum reverse voltage of Q_1 can be described as

$$v_{Q1,R,max} = \begin{cases} V_p + |v_{oa}|, & TMS = 1 \\ V_p + |v_{ob}|, & TMS = 0 \end{cases} \quad (14)$$

From (14), it can be known that the reverse voltage of Q1 is determined by TMS. When TMS = 1, the reverse voltage of Q1 is Vp + |voa|, and when TMS = 0, the reverse voltage of Q1 is Vp + |vob|. The reverse voltage of Q1 is the same as that of the single-output buck–boost PFC if $v_{oa} = v_{ob}$.

IV SIMULATION

A. Architecture Parameter Specification

The simulation is executed in the MATLAB R2010a version. The specifications of different parameter in the simulation circuit are described below in the table 1.simulated results are obtained from the proposed half bridge inverter circuit.

Input supply voltage	100-240V
Input frequency	50Hz
Input Filter Inductor	1mH
Input Filter Capacitor	220nf
Output Filter Capacitor	220uF

B. Simulation Results

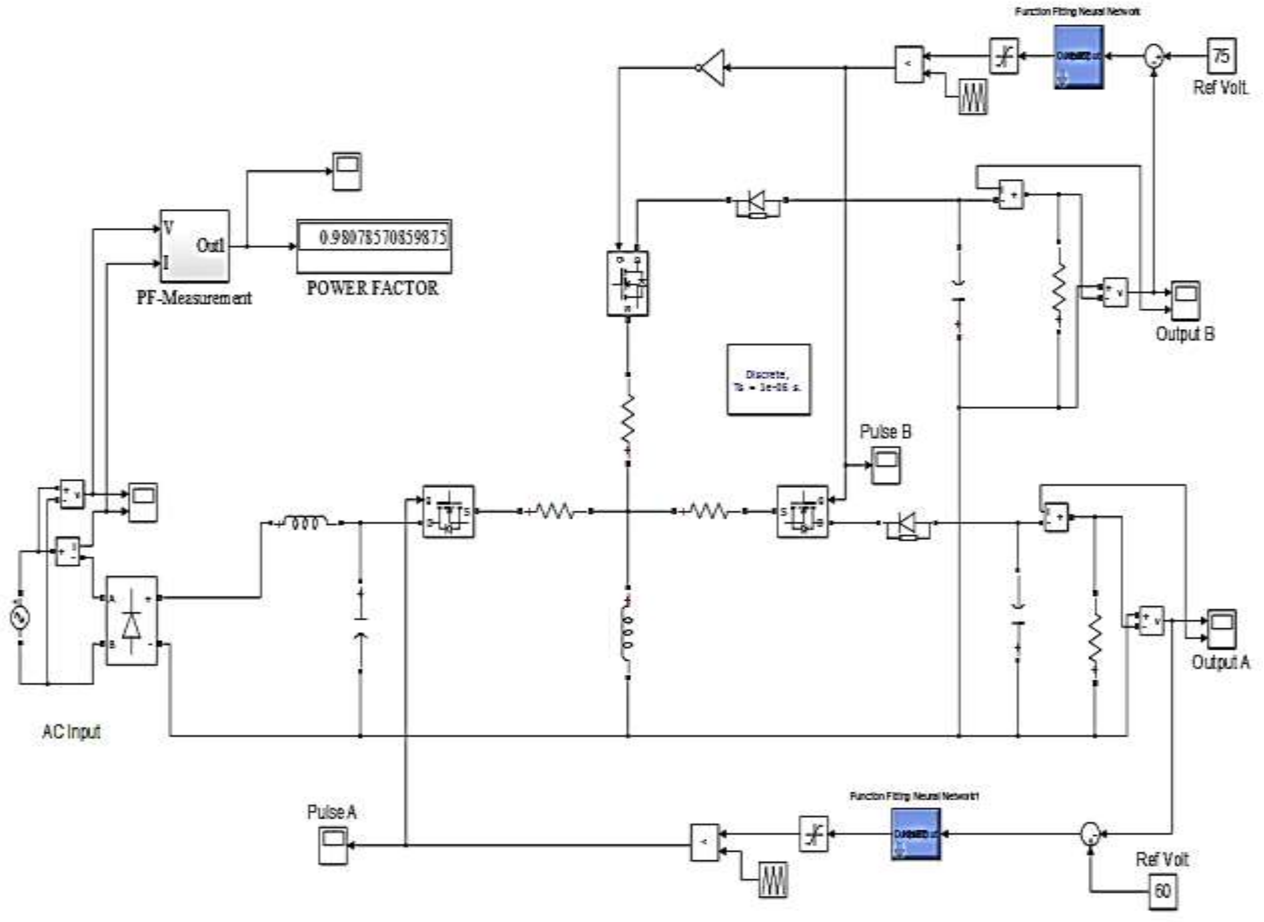

Fig. 3 Simulation circuit for proposed system

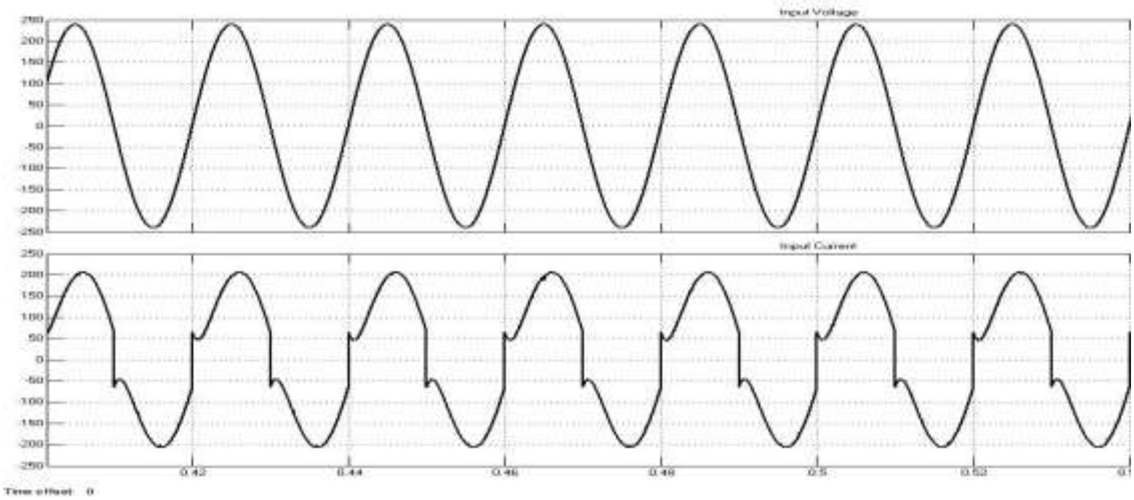

Fig. 4. Simulation Waveform of Input Voltage and Current

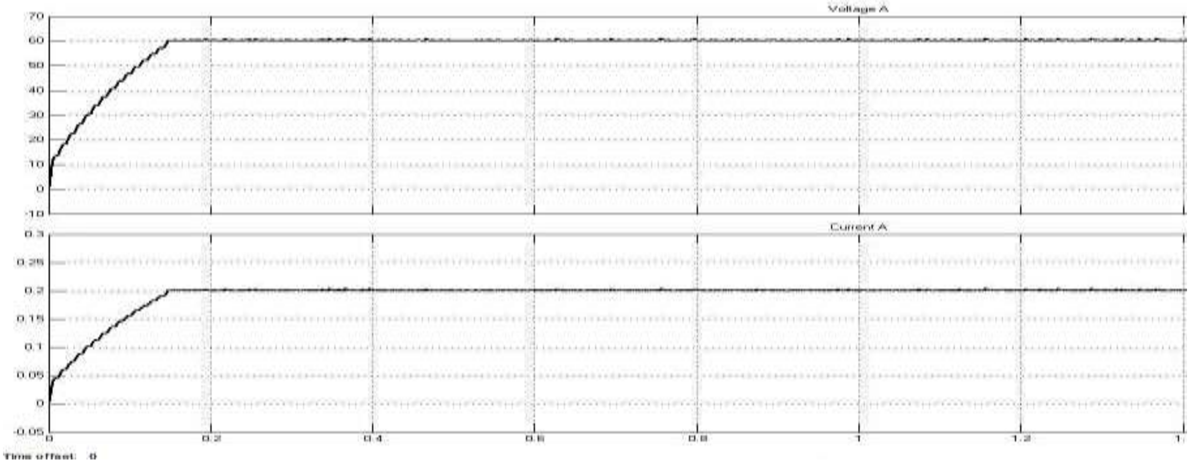

Fig. 5 Simulation waveform of Converter A Output voltage and Current

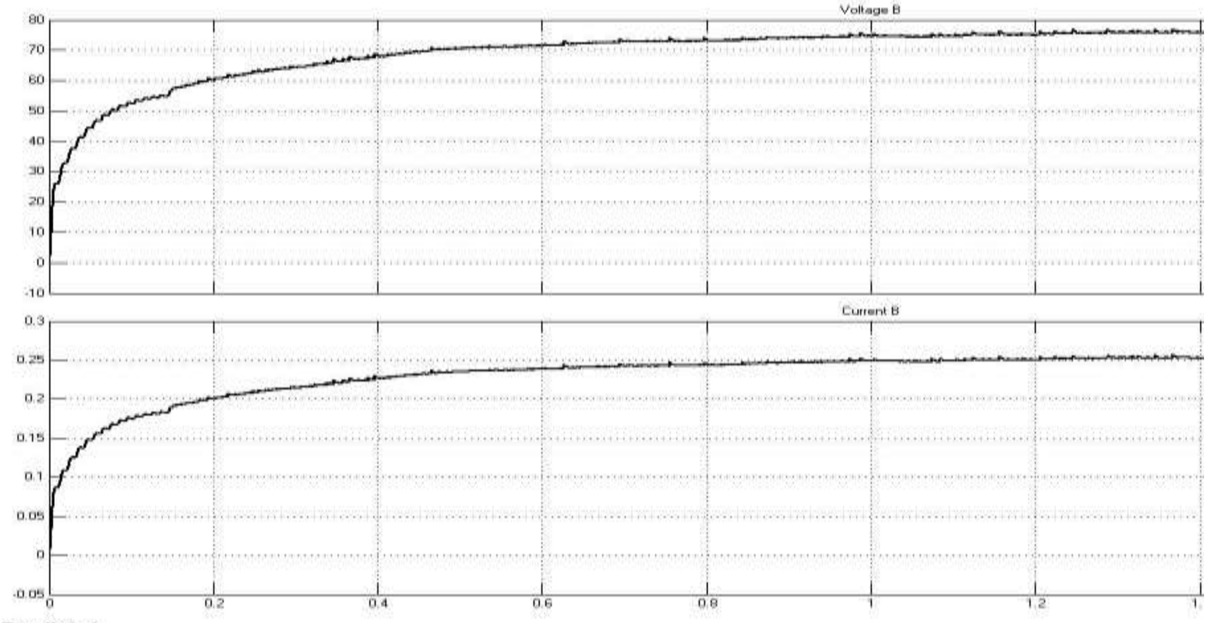

Fig.6 Simulation Waveform of Converter B Output Voltage and Current

V. CONCLUSION

A Power factor correction using buck-boost converter operating in CRM has been proposed in this paper. Detailed control strategy analysis and design consideration have been presented. each output can be regulated independently in this converter by multiplexing a single inductor. Compared with conventional two-stage. Multiple-output ac/dc converter, the proposed single-stage multiple-output ac/dc converter benefits from significant overall cost saving, small size, and light weight of the device. the proposed converter can be easily extended to realize PFC SIDO converters with different topologies to fulfil different system requirements.

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