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SINGLE STAGE SINGLE SWITCH AC-DC STEP DOWN CONVERTER WITHOUT TRANSFORMER

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ABSTRACT

This paper presents a Single Stage Single Switch AC-DC step down converter without transformer suitable for universal supply (90–270Vrms). Due to the absence of transformer number of components and cost of the converter are reduced. This topology integrates a buck-type power-factor correction cell followed by a buck–boost DC-DC cell. Hence it is called as Integrated Buck Buck Boost (IBuBuBo) converter. In which a part of the input power is directly coupled to the output after the power factor correction. By this direct power transfer concept and capacitor voltage sharing, the converter is able to achieve high power factor, efficient power conversion, low voltage stress on intermediate bus and low output voltage without a high step-down transformer. The working principles of this converter, circuit details are given and output of the circuit is obtained by using PSIM simulation software.

Index Terms**:** Direct power transfer (DPT), integrated buck– buck–boost converter (IBuBuBo), power-factor correction (PFC), single-stage (SS), transformerless, Bus voltage control, Discontinuous conduction mode (DCM)

I. INTRODUCTION

Now a days, DC source are widely used for many applications such as DC power supply for charging Laptops, mobile phones, lighting system, inverter and so on. Traditionally, the diode bridge rectifier or controlled rectifier is used for AC/DC power conversion. However, these type of rectifiers have some drawbacks such as pulsating input current, low power factor, high harmonic, high electromagnetic interference (EMI) and so on. In order to overcome these problems, some other topologies have been presented. Many boost-type PFC converters have been proposed, but the boost types converters are only used for voltage step-up applications. But it has drawbacks it cannot limit input inrush current and provide output short-circuit protection [4]. If we required to step-down the voltage, again converter has to be cascaded with another DC/DC converter. This results in system complexity and so cost will be increase. Hence, some other converter with single-stage circuits are presented for voltage step down applications, such as boost-forward type, CUK type, boost-flyback type, buck type and buck-boost type. These converters can achieve adjustable output voltage and almost unity power factor. but the DC-link voltage is higher than the peak input voltage. The total harmonic distortion of input current (THDi) is about 10–15% higher [1][5][6].

The single stage single switch ac/dc converter reduces cost, size, and complexity in the control loop by cascading a PFC cell with a post-dc/dc cell with a one common switching-control signal. It is a best solution for low power application and also in some multistage power electronics system (e.g., in data center, petrochemical industries, electrochemical and subway applications [3]) with low cost and size of converter. The principle for the SS ac/dc conversion is to force the power factor correction inductor operating in discontinuous conduction mode (DCM) to achieve high power factor without any control loop, and also the well and tight output regulation is obtain by post-dc/dc cell working in DCM or in continuous conduction mode (CCM)[7]. Therefore, only one control loop is needed for the whole circuit [2]. So an Integrated Buck–Buck-Boost (IBuBuBo) converter with low output voltage is proposed. The converter utilizes a buck converter for power factor correction which is able to reduce the bus voltage

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below the input line voltage effectively. In addition, by the voltage sharing between the intermediate bus and output capacitors, and further reduction of the bus voltage can be achieved by the dc-dc cell. Therefore, a transformer is not needed to obtain the low output voltage.

This IBuBuBo converter has the following advantages:
1) Bus voltage can be reduced by direct power transfer, adjusting inductance ratio,
2) High power factor and high efficiency;
3) Improved performance for the universal line-input range by using two frequencies low and high line respectively;
4) Lower cost and smaller circuit size due to the absence of a transformer and its side effects.
5) Lower total harmonic distortion.

II. CIRCUIT DESCRIPTION

The proposed IBuBuBo converter, which consists of the merging of a buck PFC cell and buck–boost dc/dc cell. Buck PFC cell consists of $L1$, $S1$, $D1$, Co , and CB and buck-boost cell consists of $L2$, $S1$, $D2$, $D3$, Co , and CB as given in Fig. 1. Although $L2$ is on the return path of the buck PFC cell. Thus, $L2$ is not considered as in the PFC cell. Moreover, both cells are operated in discontinuous conduction mode (DCM) so there are no currents in both inductors $L1$ and $L2$ at the beginning of each switching cycle $t0$.

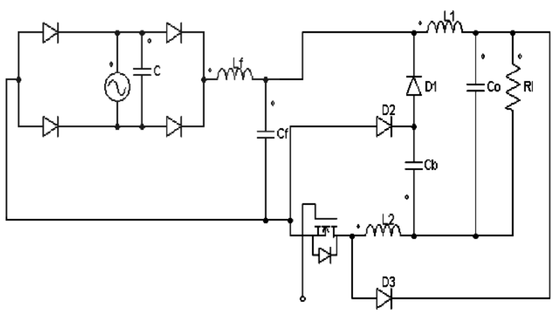

Fig. 1 Circuit diagram of IBuBuBo

III. OPERATING PRINCIPLE

Due to the characteristics of buck PFC cell, there are two operating modes in the circuit. Mode A (Vin $(\theta)\leq VB + Vo$): When the input voltage Vin (θ) is smaller than the sum of intermediate bus voltage VB , and output voltage Vo, the buck Power factor correction cell becomes inactive and it does not shape the line current around zero-crossing line voltage owing to the reverse biased of the bridge rectifier. Thus only the buck–boost dc-dc cell sustains the output power to the load. Therefore, two dead-angle zones are present in a half-line period and no input current is drawn as shown in Fig. 2. The circuit operation within a switching period can be divided into three stages and the corresponding sequence is Fig. 3(a), (b), and (c). Fig. 4(a) shows its key current waveforms.

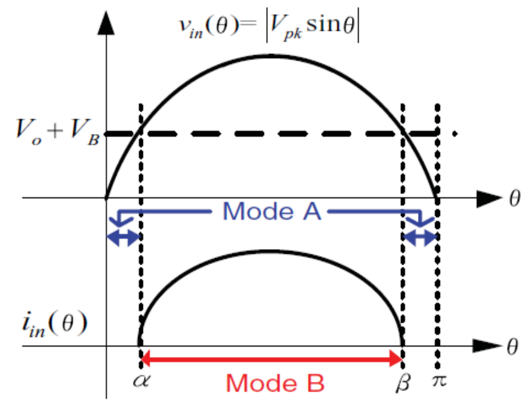

Fig. 2 Input current waveform under Mode A and Mode B

Stage 1 (period $d1Ts$ in Fig. 4) [see Fig. 3(a)]: When switch $S1$ is turned ON, inductor $L2$ is charged linearly by the bus voltage VB while diode $D2$ is conducting. Output capacitor Co delivers power to the load.

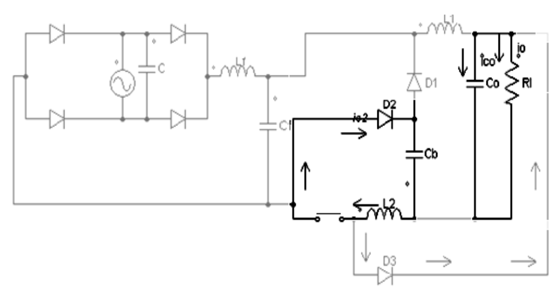

Figure 3.a

Stage 2 (period $d2Ts$ in Fig. 4) [see Fig. 3(b)]: When switch $S1$ is switched OFF, diode $D3$ becomes forward biased and energy stored in $L2$ is released to Co and the load.

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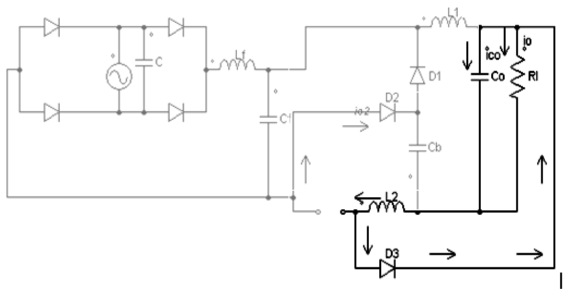

Figure 3.b

Stage 3 (period *d*3*Ts* - *d*4*Ts* in Fig. 4) [see Fig. 3(c)]: The inductor current *iL*2 is totally discharged and only *Co* sustains the load current

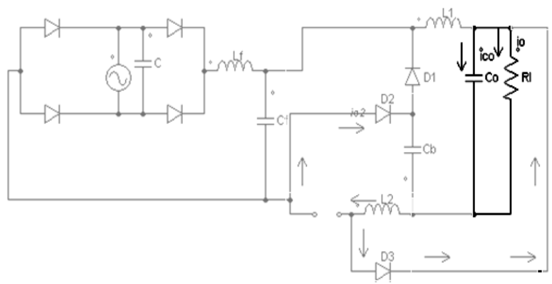

Figure 3.c

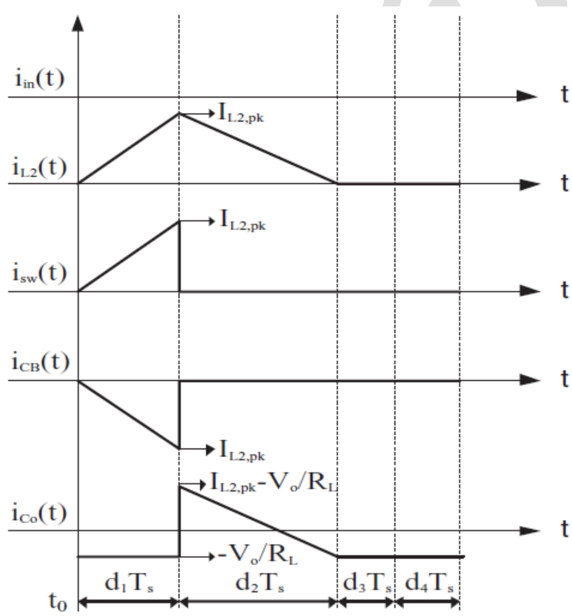

Figure 4

Mode B (*vin* (*θ*)> *VB* + *Vo*): This mode occurs when the input voltage is greater than the sum of the bus voltage and output voltage. The circuit operation over a switching period can be divided into four stages and the corresponding sequence is Fig. 3(d), (e), (f) and (c). The key waveforms are shown in Fig. 5.

Stage 1 (period *d*1*Ts* in Fig. 5) [see Fig. 3(d)]: When switch *S*1 is turned ON, both inductors *L*1 and *L*2 are charged linearly by the input voltage minus the sum of the bus voltage and output voltage (*vin* (*θ*) − *VB* − *Vo*), while diode *D*2 is conducting.

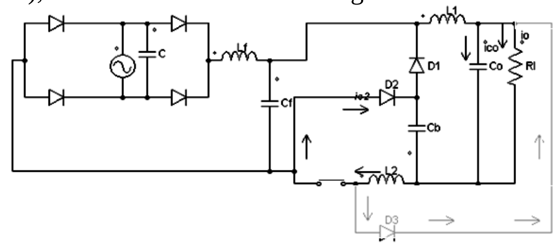

Figure 3.d

Stage 2 (period *d*2*Ts* in Fig. 5) [see Fig. 3(e)]: When switch *S*1 is switched OFF, inductor current *iL*1 decreases linearly to charge *CB* and *Co* through diode *D*1 as well as transferring part of the input power to the load directly. Meanwhile, the energy stored in *L*2 is released to *Co* and the current is supplied to the load through diode *D*3. This stage ends once inductor *L*2 is fully discharged.

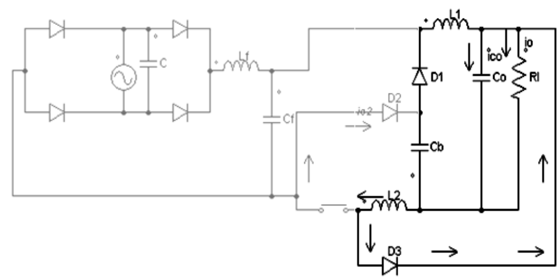

Figure 3.e

Stage 3 (period *d*3*Ts* in Fig. 5) [see Fig. 3(f)]: Inductor *L*1 continues to deliver current to *Co* and the load until its current reaches zero.

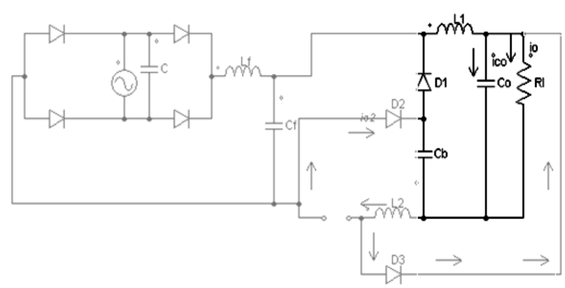

Figure 3.f

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Stage 4 (period *d4Ts* in Fig. 5) [see Fig. 3(c)]: Only *Co* delivers all the output power

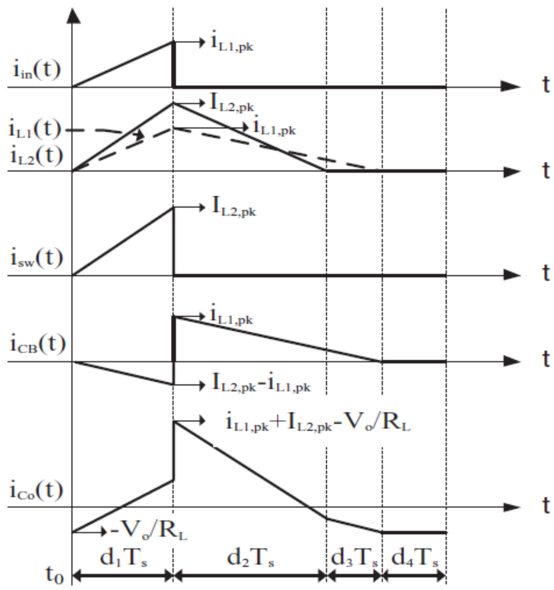

Figure 5

IV. SIMULATION RESULTS

The performance of the proposed circuit is verified by simulation using PSIM software. Circuit diagram of simulation circuit is shown in following figure 6.

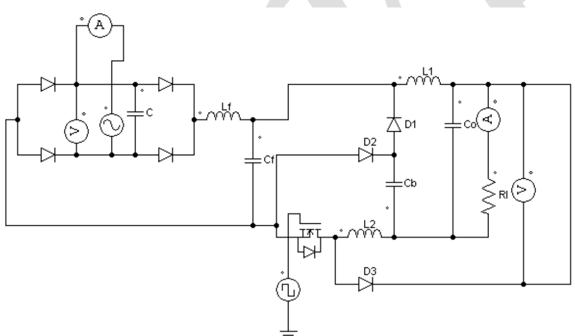

Figure 6

To ensure the converter working properly with constant output voltage, a constant voltage source is supplied. Taking the performance of the converter on bus voltage, power factor, and efficiency into account, the inductance ratio around M = 0.4 is selected. Table I given below depicts all the components used in the circuit,

Table I

Circuit components	
Input filter capacitor	*Cf* 2 μF
Input filter inductor *Lf*	2 mH
Inductor *L*1	106 μH
Inductor *L*2	46 μH
Inductance Ratio (M = *L*2/*L*1)	0.434
CB	5 mF
Co	5 mF

and its specification is stated as follows:
1) Output power: 145 W;
2) Output voltage: 40Vdc;
3) Power factor:0.973
4) Intermediate bus voltage: < 150V;
5) Line input voltage: 90Vrms/50 Hz;
6) Switching frequency (*fs*): 20 kHz.
Fig. 7a and 7b shows the waveforms of the line-input voltage along with its current under full load condition at 90 Vrms respectively. Figure 8 shows the output voltage waveform, In addition the input voltage and current with power factor is showed in figure 9

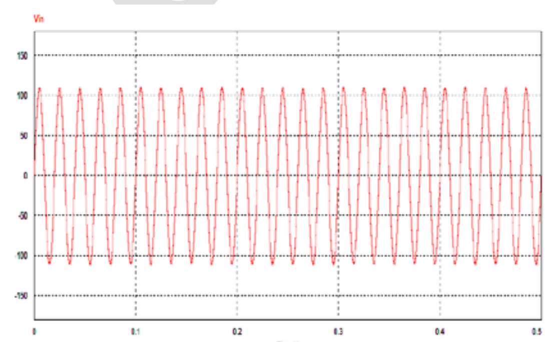

Figure 7.a

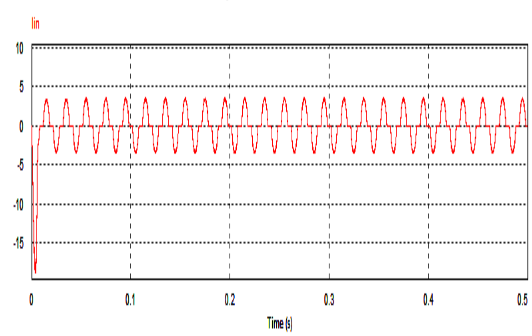

Figure 7.b

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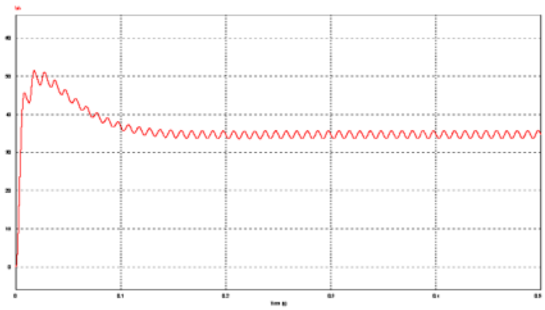

Figure 8

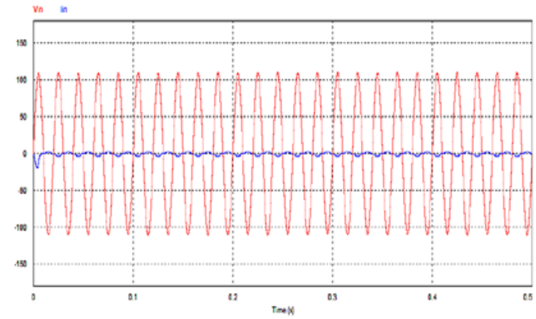

Figure 9

Table II

	Diode	Capacitor	Inductor	Control Switch	Intermediate Bus Voltage V_B	Input Voltage Vrms	Output
[1]	3	2	3	2	≤209 V	85-265 Vrms	-48 V/111.52 W
[2]	3	2	2	1	≤400 V	90-270 Vrms	100 V/100 W
[7]	2	2	1	2	≤36 V	187-265 Vrms	56 V/100 W
[8]	6	3	3	1	V_{B1}= 70 V, V_{B2}=30 V	85 Vrms	-5V/20 W
[9]	2	2	2	1	N/A	90-240 Vrms	19V/100W
Proposed	**3**	**2**	**2**	**1**	**≤130 V**	**90-270 Vrms**	**40 V/140 W**

V. DISCUSSION

According to [2], the direct power transfer ratio under this type of capacitive coupling is *Vo/VT* . It can shows the portion of direct power transfer from input to output which decreases when the bus voltage, *VB* becomes larger resulting in increase of *VT* . In [1] and [18], the converters employs a buck–boost PFC cell resulting in negative polarity at the output terminal. In addition, the topology in [18] process power at least twice resulting in low power efficiency. Moreover, the reported converters in [17] consist of two active switches leading to more complicated gate control. The Table II as following compares the proposed converter with other topologies with number of components used and also with the performance.

VI. CONCLUSION

The proposed IBuBuBo single-stage ac/dc converter without transformer has been Verified by simulation, and the results have shown with the predicted values. The intermediate bus voltage of the circuit is able to keep below150Vat all input and output conditions. Thus, the lower voltage rating of capacitor can be used. Moreover, the topology is able to obtain low output voltage without high step-down transformer. Owing to the absence of transformer, the demagnetizing circuit, the associated circuit dealing with leakage inductance, and the cost of the proposed circuit are reduced compared with the isolated counterparts. In addition, both input surge current and output short-circuit are protection. Thus a dc-dc converter with high power factor of 0.975 is designed with a single switch control.

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