Controlled Transformerless Step-Down Single Stage AC/ DC Converter

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***Abstract*—This paper presents a controlled transformerless step down single stage ac dc converter suitable for universal line applications (90-270V$_{rms}$). The topology consists of a buck type power factor correction (PFC) and a buck boost dc/dc cell. A part of input is transferred to output directly after first power processing due to which the converter is able to achieve high power conversion efficiency, high power factor, low intermediate bus voltage and low output voltage without a step-down transformer. The topology includes a control circuit to maintain constant output voltage under varying input voltage conditions. Detailed analysis of proposed circuit are given and verified through simulation.**

Keywords - Direct power transfer (DPT); Integrated buck buck boost converter (IBuBuBo); power factor correction (PFC); single stage (SS).

I. INTRODUCTION

Single-stageac/dc converters have become increasingly important because of its simplicity and cost effectiveness. SS ac/dc conversion works on the principle that PFC cell inductor is operating in discontinuous conduction mode to achieve high power factor automatically without any control loop. Conventional SS converter topologies consists of a boost type power factor correction cell and a dc/dc cell. For high voltage applications, the intermediate voltage which is obtained at the output of PFC cell will be very high [2]-[8]. Intermediate bus voltage usually exceeds 450V, which may lead to high voltage stress on dc/dc cell.

For low output voltage applications, high intermediate voltage leads to poor power conversion efficiency [10], [11]. In order to avoid this, a high step down transformer is to be used. Inclusion of transformer causes increase in component increase in component count and lower power conversion efficiency due to transformer leakage inductance that results in high spikes on active switches [14]. Apart from that boost based PFC is inefficient to provide output short circuit protection and to limit input inrush current. In order to overcome these disadvantages intermediate bus voltage has to be reduced by using a buck based PFC.

Different PFC cells were used in converters [10], [11], [16]-[19] to reduce intermediate bus voltage. Leakage inductance cannot be avoided in converters [10] and [16] as it uses transformers. Power conversion efficiency is low in converter [19] and [11] as it processes the power twice. Converter [17] and [18] has complicated gate control as it consists of two active switches.

Resonant technique is used in converter [20] to increase the step down ratio and to eliminate intermediate storage capacitor. In the absence of intermediate storage converter cannot provide hold up time which leads to output voltage ripple. Converter [1] is an integrated buck-buck-boost converter with low output voltage. The converter utilizes a buck based PFC cell and provides a low intermediate voltage. However its output voltage cannot be maintained at constant value under varying input voltage conditions.

In this paper, a controlled integrated buck-buck-boost converter (IBuBuBo) is proposed. The converter integrates comprises of a buck based PFC cell and a buck boost dc/dc cell. The converter also integrates a control circuit which controls the duty ratio of the pulses provided to active switch in the circuit and maintains output voltage constant under varying input voltage. There is no need of a step down transformer to get a low output voltage in the proposed topology. Moreover the topology maintains constant output voltage. The converter is simple and can provide:

i. High input power factor.
ii. High power conversion efficiency.
iii. Protection against input surge current.
iv. Low intermediate bus voltage.
v. Constant output voltage under varying input voltage.
vi. Low cost and small size.

This paper intends to verify the performance of controlled transformer-less single stage ac/dc converter for operation in universal line input conditions. Operation principle of proposed system is depicted in section II. Simulation result is given in section III. Finally, conclusion is stated in section IV.

II. CIRCUIT OPERATION

The proposed converter, which integrates
a) buck based PFC (L_1, S_1,D_1,C_0 and C_B)
b) buck boost dc/dc cell (L_2, S_1, D_2, D_3, C_0 and C_B)
is illustratedinFig1.

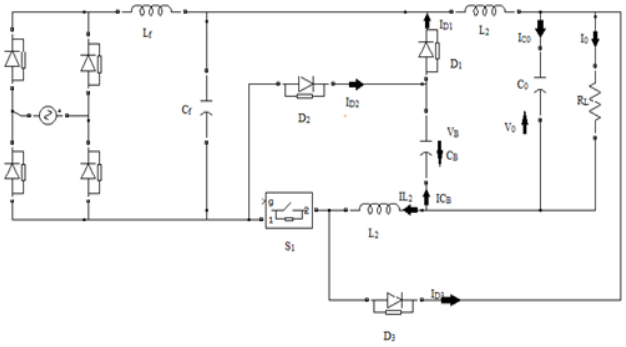


Fig. 1.IBuBuBo SS ac/dc converter.

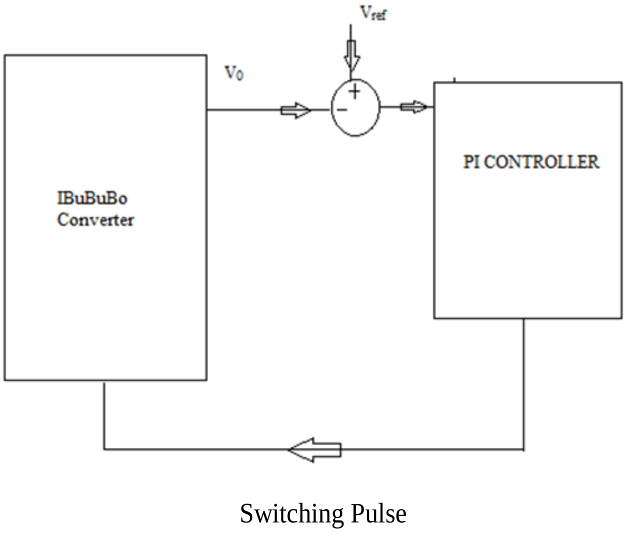


Fig. 2 Proposed Topology.

Operation of converter is divided into two modes mode A and mode B. Modes are determined by comparing the instantaneous value of input voltage and sum of intermediate voltage and output voltage as shown in Fig 3.

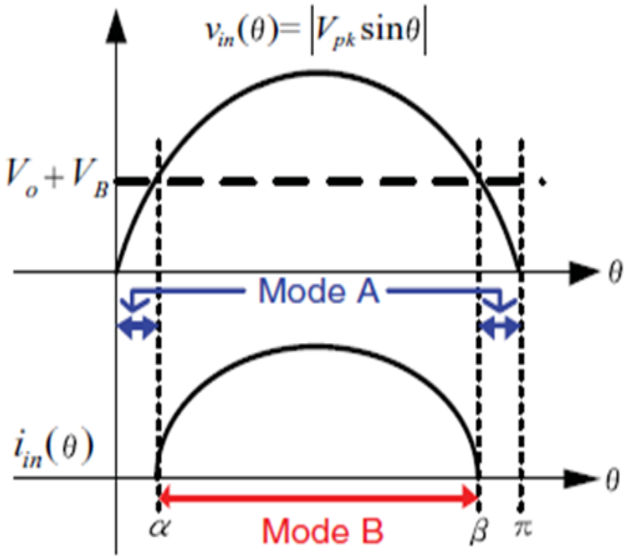


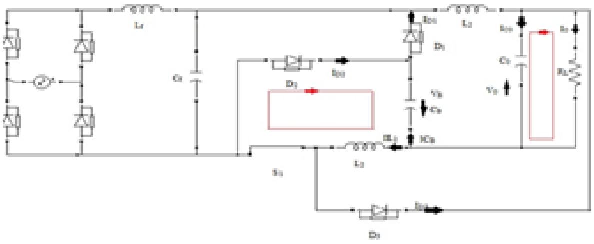
Fig. 3 Input voltage and current waveform

Converter operates in mode A when instantaneous input voltage is smaller than sum of output voltage and intermediate voltage. PFC cell is inactive in mode A. Converter operates in mode B when instantaneous input voltage is greater than sum of output voltage and intermediate voltage. Mode A operation can be divided into three stages which are represented by Fig4 (a), (b) and (c).Fig5 shows its key waveforms.

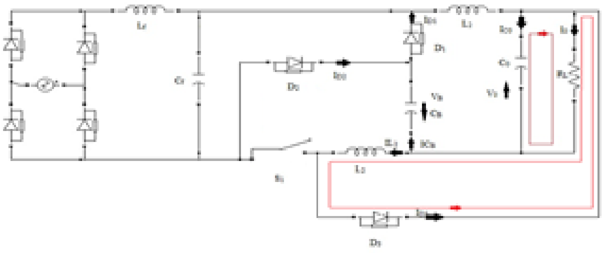
Stage 1: Switch S1 is closed, C_B discharges to charge L_2 through D_2.[see Fig 4(a)]

Stage 2: Switch S1 is opened, diode D_3becomes forward biased and energy stored in L_2 is released to C_o and the load.[see Fig 4(b)]

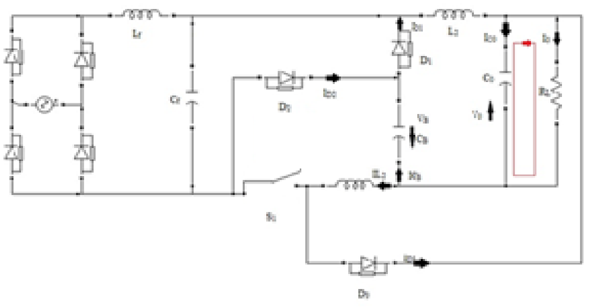
Stage 3: The inductor current i_{L2} is totally discharged and only C_o sustains the load current.[see Fig 4(c)]



(a)



(b)



(c)

Fig. 4 Mode A operation stages

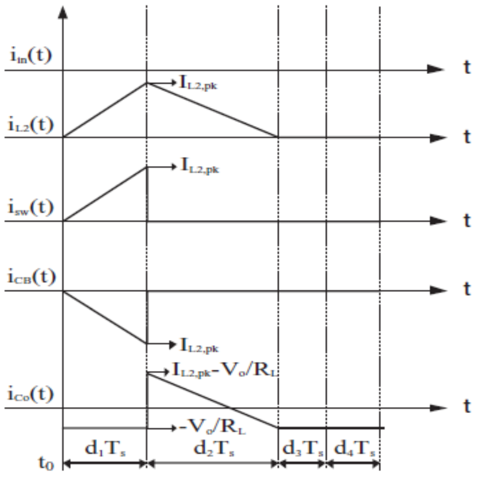


Fig. 5 Mode A key waveforms

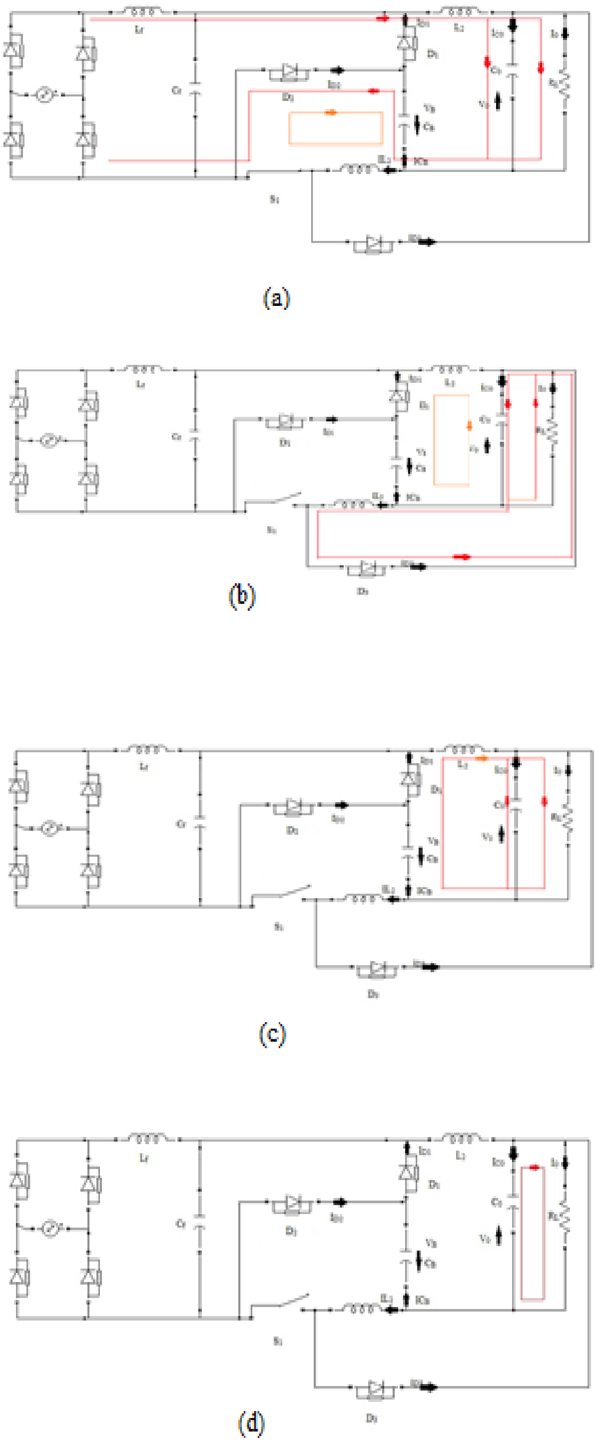
Mode B operation can be divided into four stages which are represented by Fig6 (a),(b), (c) and (d).Fig7 shows its key waveforms.

Stage 1: Switch $S_1$is turned ON, both inductors $L_1$and L_2arecharged linearly by the input voltage minus the sum of the bus voltage and output voltage .diode D_2 is conducting.[see Fig 6(a)]

Stage 2: switch S_1 is switched OFF, inductor current i_{L1} decreases linearly to charge C_B and C_o through diode D_1. Direct power transfer occurs. Meanwhile, the energy stored in L_2 is released to C_o. This stage lasts until inductor L_2 is fully discharged.[see Fig 6(b)]

Stage 3: Inductor L_1 discharges to deliver current to load and capacitor C_0.[see Fig 6(c)]

Stage 4: C_0 sustains the load.[see Fig 6(d)]



(a)

(b)

(c)

(d)

Fig. 6 Mode B operation stages

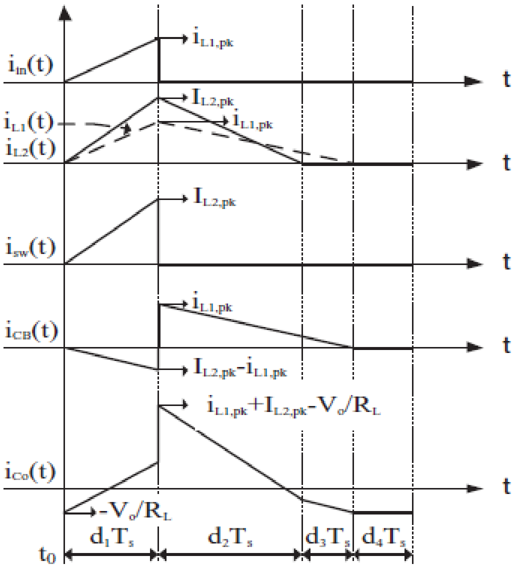


Fig. 7 Mode B key waveforms

From Fig (3), dead time α and β are expressed as follows

$$\alpha = \arcsin\left(\frac{V_T}{V_{PK}}\right) \tag{1}$$

$$\beta = \pi - \alpha = \pi - \arcsin\left(\frac{V_T}{V_{PK}}\right) \tag{2}$$

$$\gamma = \beta - \alpha = \pi - 2\arcsin\left(\frac{V_T}{V_{PK}}\right) \tag{3}$$

By applying volt second balance on L_1 and L_2, duty ratio relationships are given by

$$d_2+d_3 = \begin{cases} \frac{v_{in}(\theta)-V_T}{V_T} d_1, & \alpha < \theta < \beta \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

$$d_2 = \frac{V_B}{V_0} d_1 (5)$$

From [1], the intermediate voltage and power factor are given by:

$$V_B = \frac{MV_{pk}^2}{2\pi(V_B+V_0)} \times \left[\frac{\pi - 2\arcsin\left(\frac{V_T}{V_{PK}}\right)}{V_{pk}} - 2\,\frac{(V_B+V_0)\sqrt{(V_{pk}+V_B+V_0)(V_{pk}-V_B-V_0}}{V_{pk}^2}\right. \tag{6}$$

$$PF = \sqrt{\frac{2}{\pi}}\,\frac{V_{pk}\left(\frac{\gamma}{2}+\frac{A}{4}\right)-V_T B}{\sqrt{V_{pk}^2\left(\frac{\gamma}{2}+\frac{A}{4}\right)-2V_{pk}V_T B+\gamma V_T^2}} \tag{7}$$

Where A and B are constants given by

$$A = \sin 2\alpha - \cos 2\beta \tag{8}$$

$$B = \cos\alpha - \cos\beta \tag{9}$$

In the controller section the reference voltage is compared with the output voltage of the converter. The error signal generated is given to a PI controller. The PI controller generates a control signal which is compared with a triangular signal to generate the pulses given to the switch. Integrator section of the controller reduces the steady state error. Thus the controller section maintains the output voltage constant.

III. SIMULATION RESULTS

The performance of the proposed topology is verified using simulink model. The inductance ratio was chosen to be M = 0.4.Values of the components used in the circuit are as given in [1] and are depicted in table I. Specification of the circuit is stated as follows:

1) Output power:100w
2) Output voltage:19V_{dc}
3) Power factor >98%
4) Intermediate bus voltage:<100V
5) Switching frequency:20KHz
6) Input voltage:90-270Vrms, 50Hz

TABLE I : CIRCUIT COMPONENTS

Parameters	Values
Input filter inductor L_f	2 mH
Input filter capacitor C_f	2 μF
InductorL_1	106 μH
InductorL_2	46 μH
Diode D_1	MUR3040PT
DiodeD_2	MUR3040PT
DiodeD_3	MUR3040PT
Capacitor C_B	5 mH
CapacitorC_0	5 mH

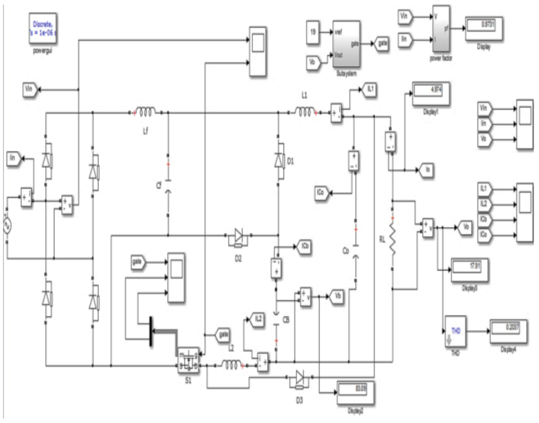


Fig. 8 Simulink model for feedback controlled transformerless single stage ac/dc converter.

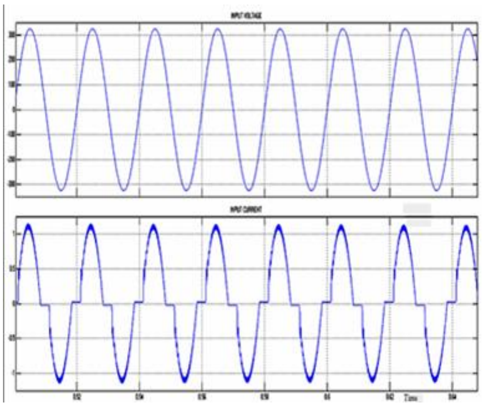


Fig. 9 Input characteristics of the converter

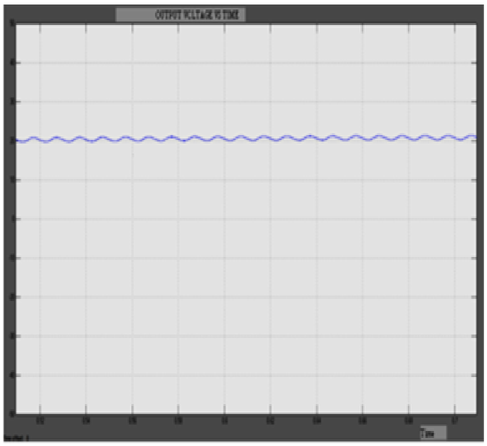


Fig. 10 Output voltage of the converter

The performance of converter [1] and proposed topology under varying input line conditions were verified. Table II depicts comparison result.

TABLE II :COMPARISON OF CONVERTER PERFORMANCE

Converter	V_{in}	V_{out}	V_B	Pf
IBuBuBo converter	230 100	20 8.84	99.4 99.43	.987 .97
Controlled IBuBuBo converter	230 100	19 19	95.5 39.36	.98 .997

It is found that the portion of direct power transfer from input to output increases with decrease in V_B which in turn increases the power conversion efficiency. The proposed topology is able to achieve constant output voltage under varying input voltage conditions. Decrease of V_B extends conduction angle and there by power factor can be improved.

As the input line voltage value is decreased, the controlled converter provides low intermediate bus voltage and high power factor along with maintaining constant output voltage. Switching and conduction losses are very less in converter as it consists of a single switch.

IV. CONCLUSION

The proposed feedback controlled IBuBuBo converter has been verified using MATLAB. The intermediate bus voltage is able to be kept below 100V under various input line conditions. Thus the topology facilitates the use of low voltage rating capacitors. Moreover the topology is able to obtain constant low output voltage under various input conditions without the use of a step down transformer. The absence of transformer makes the circuit cost effective and efficient. In addition to that the proposed converter is able to limit the input surge current and to provide output short circuit protection.

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