

A High Efficient Non-Isolated Single Stage AC/DC Converter for DC Motor Applications

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Abstract— A single stage single switch AC/DC converter is an integration of input current shaper and a DC/DC cell with a shared controller and one active switch. The converter is applicable for digital input power supply with high input power factor and tight output voltage regulation. An ac to dc converter is an integral part of any power supply unit used in the all electronic equipments. In recent years, single-phase switch-mode AC/DC power converters have been increasingly used in the industrial, commercial, residential, aerospace, and military environment due to advantages of high efficiency, smaller size and weight. However, the proliferation of the power converters draw pulsating input current from the utility line, this not only reduce the input power factor of the converters but also injects a significant amount of harmonic current into the utility line. To improve the power quality, various PFC schemes have been proposed. In this project a buck type power factor correction (PFC) circuit with a buck boost DC/DC circuit is presented. The main switch of the boost type PFC circuit converter handles the peak inductor current of DC/DC circuit rather than the super position of both the inductor currents. In this project the circuit is designed and simulated by using Matlab/Simulink software. The proposed converter can be applied for DC motor.

Index Terms— DC motor, Direct power transfer (DPT), integrated buck–buck–boost converter (IBuBuBo), power-factor correction (PFC), single-stage (SS), transformer less.

I. INTRODUCTION

The use of rectifiers in industrial applications started at the era of mercury converters with the electromechanical contact converter. DC machines are common in day to day use. But the supply that we get from power companies is AC. To use those machines AC supply has to be turned into DC supply by the use of a rectifier. A rectifier is an electrical device that converts the incoming AC (alternating current) from a transformer or any other ac power source to pulsating DC (direct current). Rectifier may be made of diodes, solid states, vacuum tube, mercury arc valves and other components. All rectifier circuits may be classified into one of two categories, i) half wave rectifiers and ii) full wave rectifier. Rectifiers are also used for 3-phase inputs. Rectifiers can further be classified into two categories i. e. Controlled and uncontrolled rectifier. The dc output

always remain constant if ac input voltage is constant in an uncontrolled rectifier whereas the output voltage can be controlled in a controlled rectifier. Rectifiers are widely used in non linear loads which are connected with distribution systems which plays an important role in power system network (ex: UPS, discharge lamp, television, computer, fax machines, ferromagnetic devices, arc furnaces, energy savers etc).

A further application of the rectifier is driving a DC motor. Speed control in DC motor is an important issue. With time the need of flexible speed control for motor is becoming essential. One way to control the speed of the motor is by varying its input voltage. Thus this project aims on designing a rectifier circuit that can supply a voltage as required and can be adjusted if necessary even after the operation starts. An integrated buck–buck–boost (IBuBuBo) converter with low output voltage is proposed. The converter utilizes a buck converter as a PFC cell. It is able to reduce the bus voltage below the line input voltage effectively. In addition, by sharing voltages between the intermediate bus and output capacitors, further reduction of the bus voltage can be achieved.

Therefore, a transformer is not needed to obtain the low output voltage. To sum up, the converter is able to achieve:

- 1) Low intermediate bus and output voltages in the absence of transformer;
- 2) Simple control structure with a single-switch;
- 3) Positive output voltage;
- 4) High conversion efficiency due to part of input power is processed once and
- 5) Input surge current protection because of series connection of input source and switch.

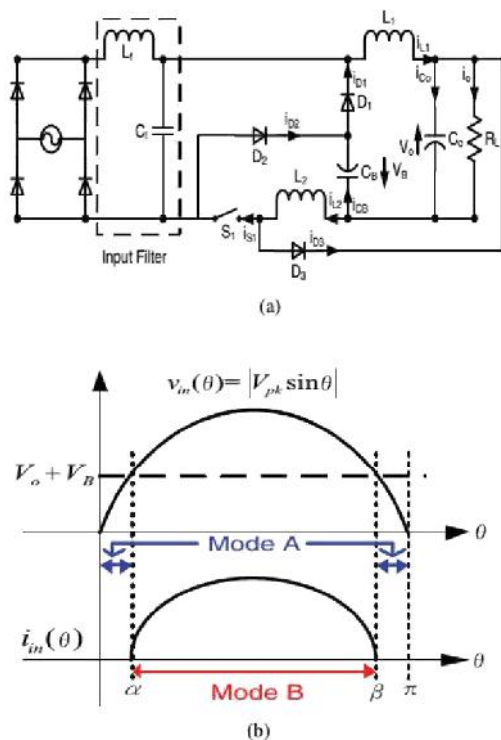


Fig. 1. (a) Proposed IBuBuBo SS ac/dc converter. (b) Input voltage and current waveforms

II. PROPOSED CIRCUIT AND ITS OPERATING PRINCIPLE

The proposed IBuBuBo converter, which consists of the merging of a buck PFC cell (L_1 , S_1 , D_1 , C_o , and C_B) and a buck–boost dc/dc cell (L_2 , S_1 , D_2 , D_3 , C_o , and C_B) is illustrated in Fig. 1(a). Although L_2 is on the return path of the buck PFC cell, it will be shown later in Section III-A that it does not contribute to the cell electrically. Thus, L 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 L_1 and L_2 at the beginning of each switching cycle t_0 . Due to the characteristic of buck PFC cell, there are two operating modes in the circuit.

Mode A ($V_{in}(\theta) \leq V_B + V_o$): When the input voltage $V_{in}(\theta)$ is smaller than the sum of intermediate bus voltage V_B , and output voltage V_o , the buck PFC cell becomes inactive and does not shape the line current around zero-crossing line voltage [20], owing to the reverse biased of the bridge rectifier. Only the buck–boost dc/dc cell sustains all 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. 1(b). The circuit operation within a

switching period can be divided into three stages and the corresponding sequence is Fig.

2(a),(b), and (f). Fig. 3(a) shows its key current waveforms.

1) Stage 1 (period $d_1 T_s$ in Fig. 3) [see Fig. 2(a)]: When switch S_1 is turned ON, inductor L_2 is charged linearly by the bus voltage V_B while diode D_2 is conducting. Output capacitor C_o delivers power to the load.

2) Stage 2 (period $d_2 T_s$ in Fig. 3) [see Fig. 2(b)]: When switch S_1 is switched OFF, diode D_3 becomes forward biased and energy stored in L_2 is released to C_o and the load.

3) Stage 3 (period $d_3 T_s - d_4 T_s$ in Fig. 3) [see Fig. 2(f)]: The inductor current i_{L2} is totally discharged and only C_o sustains the load current.

Mode B ($V_{in}(\theta) > V_B + V_o$): 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. 2(c), (d), (e), and (f). The key waveforms are shown in Fig. 3(b).

1) Stage 1 (period $d_1 T_s$ in Fig. 3) [see Fig. 2(c)]: 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 ($v_{in}(\theta) - V_B - V_o$), while diode D_2 is conducting.

2) Stage 2 (period $d_2 T_s$ in Fig. 3) [see Fig. 2(d)]: When switch S_1 is switched OFF, inductor current i_{L1} decreases linearly to charge C_B and C_o 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 C_o and the current is supplied to the load through diode D_3 . This stage ends once inductor L_2 is fully discharged.

3) Stage 3 (period $d_3 T_s$ in Fig. 3) [see Fig. 2(e)]: Inductor L_1 continues to deliver current to C_o and the load until its current reaches zero.

4) Stage 4 (period $d_4 T_s$ in Fig. 3) [see Fig. 2(f)]: Only C_o delivers all the output power.

III. DESIGN CONSIDERATIONS

To simplify the circuit analysis, some assumptions are made as follows:

- 1) All components are ideal;
- 2) Line input source is pure sinusoidal, i.e. $V_{in}(\theta) = V_{pk} \sin(\theta)$ where V_{pk} and θ are denoted as its peak voltage and phase angle, respectively;

3) Both capacitors CB and Co are sufficiently large such that they can be treated as constant DC voltage sources without any ripples;

(8)

4) The switching frequency fs is much higher than the line frequency such that the rectified line input voltage |Vin(θ)| is constant within a switching period.

Where the constants A and B are

$$A = \sin(2\alpha) - \sin(2\beta)$$

(9)

$$B = \cos(\alpha) - \cos(\beta)$$

(10) Putting (8) to zero due to the steady-state operation, this leads to

$$V_B = \frac{MV_{pk}^2}{2\pi(V_B + V_o)} \times \left[\pi - 2\arcsin\left(\frac{V_B + V_o}{V_{pk}}\right) - \frac{2(V_B + V_o)\sqrt{(V_{pk} + V_B + V_o)(V_{pk} - V_B - V_o)}}{V_{pk}^2} \right]$$

(11)

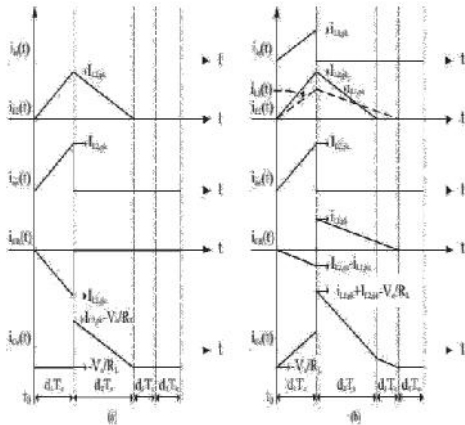


Fig.3.Key waveforms of the proposed circuit.

In addition, by considering volt-second balance of the L1 and L2, respectively, the important duty ratio relationships can be expressed as follows:

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

(5)

$$d_2 = \frac{V_B}{V_o} d_1$$

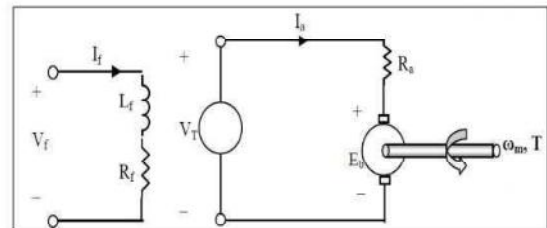
(6) By applying charge balance of CB over a half-line period, the bus voltage VB can be determined. From Fig. 3, the average current of CB over a switching and half-line periods are expressed as follows:

$$\begin{aligned} \langle i_{CB} \rangle_{sw} &= \frac{1}{2} (i_{L1-pk}(d_1 + d_2 + d_3) - I_{L2-pk}d_1) \\ &= \frac{d_1^2 T_s}{2} \left[\frac{(v_{in}(\theta) - V_T)v_{in}(\theta)}{L_1 V_T} - \frac{V_B}{L_2} \right] \end{aligned}$$

(7)

$$\begin{aligned} \langle i_{CB} \rangle_{\pi} &= \frac{1}{\pi} \int_0^{\pi} \langle i_{CB} \rangle_{sw} d\theta \\ &= \frac{d_1^2 T_s}{2\pi} \left[\frac{V_{pk}}{L_1} \left(V_{pk} V_T \left(\frac{\gamma}{2} + \frac{A}{4} \right) - B \right) - \frac{\pi V_B}{L_2} \right] \end{aligned}$$

Where M is the inductance ratio L2/L1



IV. DC motor

In DC drives (or in other type of electrical drives), it is normally necessary to control the motor current since it is, in most of the cases, proportional to the developed motor torque. This is especially true for a DC motor. The reference current (or reference torque) is compared with actual current and the error is fed to the current controller to generate the control signal Vc. The firing circuit is responsible in generating the pulses used to trigger the SCRs so that the desired average voltage is produced at the output of the converter. As we have seen before, the relation between a and the average voltage Va is non-linear due to the cosine term present in the expression. If the relationship between Vc and a is linear, obviously the relationship between Vc and Va will be non-linear. While it is true that we can linearized (1) for the purpose of

designing the controller, this however only valid for a small perturbation around an operating point of the delay angle. On the other hand, if we can establish an inverse cosine relation between v_c and a , then the relation between V_c and V_a will become linear.

V.SIMULATION RESULTS

Here the simulation is carried out by three different cases

- 1) proposed ac/dc converter with 90 Vrms condition
- 2) proposed ac/dc converter with 270 Vrms condition
- 3) proposed converter with DC motor condition

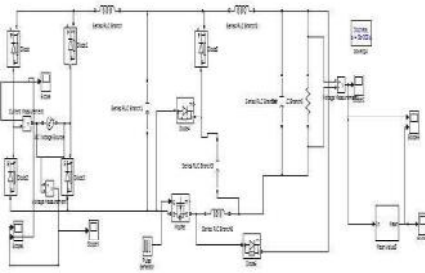


Fig.5 Matlab/simulink model of ac/dc converter with 90 Vrms

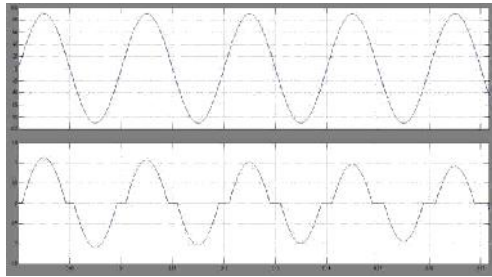


Fig.6 Measured input characteristic of the converter at 90 Vrms and

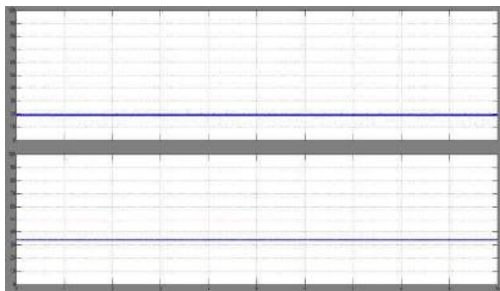


Fig. 7 Measured output voltage and intermediate bus voltage at 90 Vrms

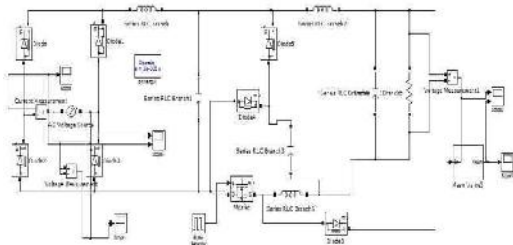


Fig.8 Matlab/simulink model of ac/dc converter with 270 Vrms

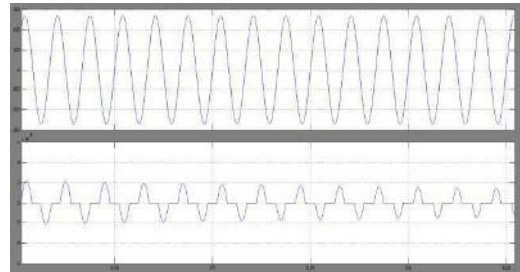


Fig.9 Measured input characteristic of the converter at 270 Vrms under 100-W condition

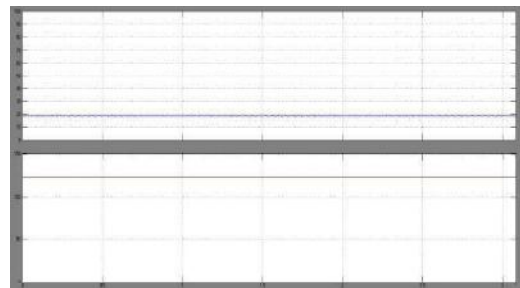


Fig.10 Measured output voltage and intermediate bus voltage at 270 Vrms under full load condition

VI. CONCLUSION

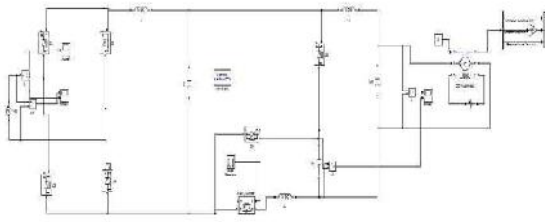


Fig.11. Simulink model of the Dc Motor with the proposed PFC ac/dc converter.

The proposed I_{Bu}B_uB_o single-stage ac/dc converter with DC motor has been verified by using simulation analysis, and the results have shown good agreements with the predicted values. The intermediate bus voltage of the circuit is able to keep below 150V at all input and output conditions, and is lower than that of the most reported converters. 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. It is analyzed that voltage magnitude variation done by using proposed converter under normal loads, input power factor and voltage variation also done under Dc motor loading conditions.



Fig.12. Simulated output wave form of Motor Current, Speed and torque.

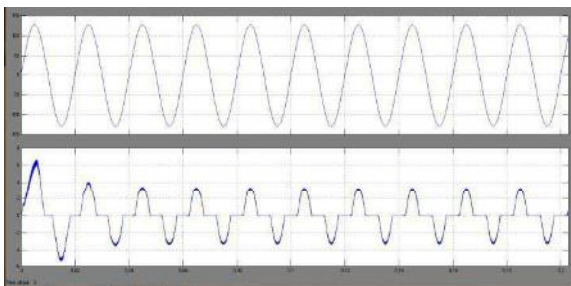


Fig.13. Source voltage and current with Dc motor

