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A NOVEL DUAL-INPUT DC–DC CONVERTER COMBINING A BOOST-HALF-BRIDGE CELL AND A VOLTAGE-FED FULL-BRIDGE CELL

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ABSTRACT

This letter presents a new zero-voltage-switching (ZVS) isolated dc–dc converter which combines a boost half-bridge (BHB) cell and a full-bridge (FB) cell, so that two different type of power sources, i.e., both current fed and voltage fed, can be coupled effectively by the proposed converter for various applications, such as fuel cell and supercapacitor hybrid energy system. By fully using two high- frequency transformers and a shared leg of switches, number of the power devices and associated gate driver circuits can be reduced. With phase-shift control, the converter can achieve ZVS turn-on of active switches and zero-current switching (ZCS) turn-off of diodes. In this letter, derivation, analysis, and design of the proposed converter are presented. Finally, a 25–50 V input, 300–400 V output prototype with a 600 W nominal power rating is built up and tested to demonstrate the effectiveness of the proposed converter topology.

***Key Words*:** Boost half-bridge (BHB), dc–dc converter, dual-input, phase-shift, soft switching and hybrid.

I. INTRODUCTION

The unregulated dc output voltage, the low dynamics, and the discontinuity of renewable energy sources, like solar energy and fuel cell, generally, it is well known that not only a front-end dc–dc converter as an interface circuit is required, but also an auxiliary power supply is needed to compensate or regulate output power seamlessly at different load conditions [1]–[3]. Therefore, an efficient hybrid renew-able power conversion system has become an interesting topic. In terms of the applications with a galvanic isolation, various system configurations have been investigated in the last decade, and usually they can be divided into three categories, i.e., direct hybridization, multiple-stage conversion and multiple-port con-version

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[4]–[9]. With different specifications and requirements, the adequate converter and/or configuration can be adopted. This letter proposes a new step-up isolated dc–dc converter with dual-input ports by combining a current-fed BHB cell [10], [11] and a voltage-fed FB cell, and the proposed converter can be used in applications such as hybrid electric vehicles, photovoltaic power generation systems, and fuel cell systems [8]. Based on the cir-cuit topology, the derivation process of the proposed converter is introduced. The steady-state operating principles and features are explained so as to demonstrate the merits of the converter. Design considerations on some critical parameters are studied. Finally, representative experimental results from a 600-W proto-type are provided to validate the proposed concept. The salient advantages of the proposed converter can be summarized as follows:

- Ability of dual-input connection;
- Reduced number of power devices and their associated gate driver components;
- ZVS turn-on of the main switches;
- ZCS turn-off of the diodes without reverse recovery issue.

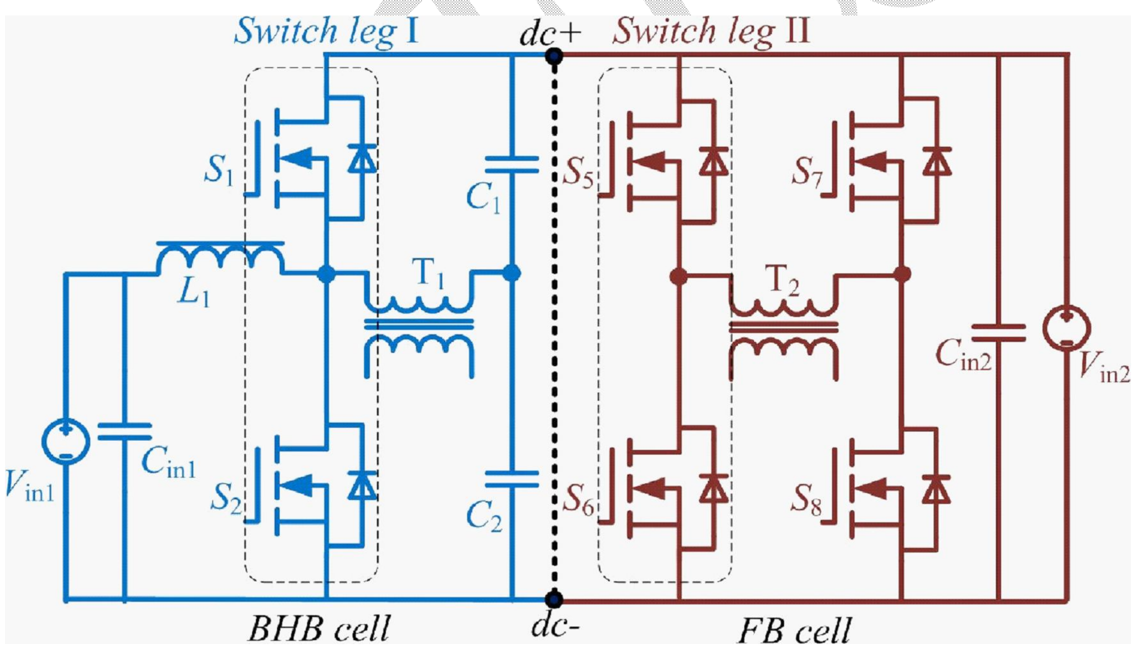

Fig.1.Schematic of a dual-input converter with BHB and FB cells.

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II. PROPOSED SOFT-SWITCHED DC–DC CONVERTER

In order to hybridize the two inputs, i.e., V_{in1} and V_{in2} , a BHB cell can be paralleled with an FB cell by adopting

a mutual low voltage dc bus as shown in Fig. 1. Because of the similarity of the pulse width modulation pattern of BHB and FB cells, the switch legs I and II can be merged as a common bridge. Hereby, a new topology with full function but a simpler connection com-pared to the previous discrete cells is derived and illustrated in Fig. 2. The proposed converter consists of a current-fed port and a voltage-fed port, which provides a larger flexibility in practical applications with different type of power sources. Transformers T_1 and T_2 which have the turn ratios as $n_1 : n_2 = 2{:}1$ in this study are connected in a special way: the dotted terminals of the primary windings are connected in the conjunction point A, while two secondary windings are connected in series (it is also possible to connect them in parallel depending on different requirements).

A voltage doubler circuit is employed on the secondary side and the voltage ringing over the diodes can inherently be clamped by the output capacitor C_3 or C_4 . L_2 is essentially the sum of the transformer leakage inductance and an extra inductance. A dc blocking capacitor C_b is added in series with the primary winding of T_2 in order to avoid trans-former saturation caused by any asymmetrical operation in the FB circuit. Same as the dual active bridge (DAB) converters [12], the pro-posed converter can be viewed as a voltage source v_p interfaced to another voltage source v_s through the energy interfacing element L_2 as shown in Fig. 3. In steady state, the timing diagram and the key waveforms of the proposed converter controlled by phase-shift angle between the switch pairs, S_1 , S_2 and S_3 , S_4 , are presented in Fig. 4, where $V_L = n_1 \cdot V_{\text{in1}}$, $V_H = \frac{1}{2} \cdot V_o$, and T_s is the switching period. In this letter, only the symmetrical operation condition, i.e., the switching duty cycle D is 50%, is discussed, so that S_1 and S_2 as well as S_3 and S_4 have the complementary driving signals that gives $V_{\text{in2}} = 2V_{\text{in1}}$.

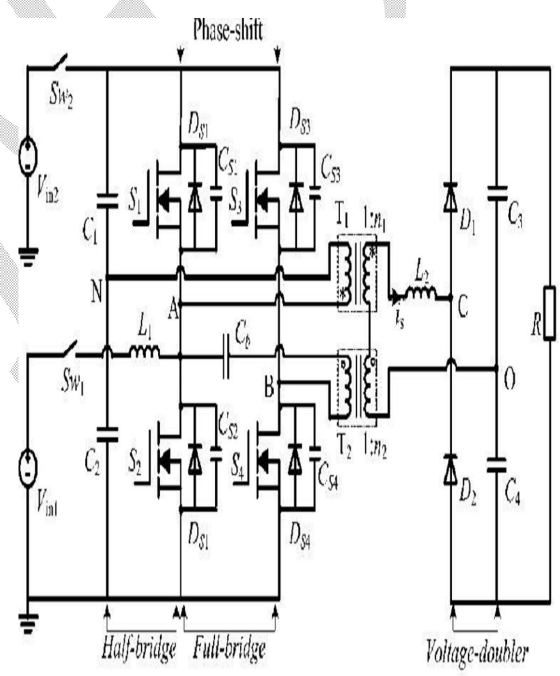

Fig.2.Topology of the proposed hybrid dc-dc converter.

Accordingly output voltage and power transferred can only be regulated by the phase-shift angle α of the two poles of

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the input bridge. The power factor of the high frequency ac loop can be evaluated by the angle which represents the phase delay between the secondary voltage and current. In order to avoid high reactive power in the converter, the regulated phase-shift angle will be limited in the range: $0 \leq \alpha \leq \pi$, in the practical applications [13]. Since the output diode rectifier is current driven, the following constrains must be satisfied: 1) when i_s is positive, v_s must be positive; and 2) when i_s is negative, v_s must be negative, and thereby based on the waveforms shown in the Fig. 4(a), the operation principle of the converter can be explained as follows.

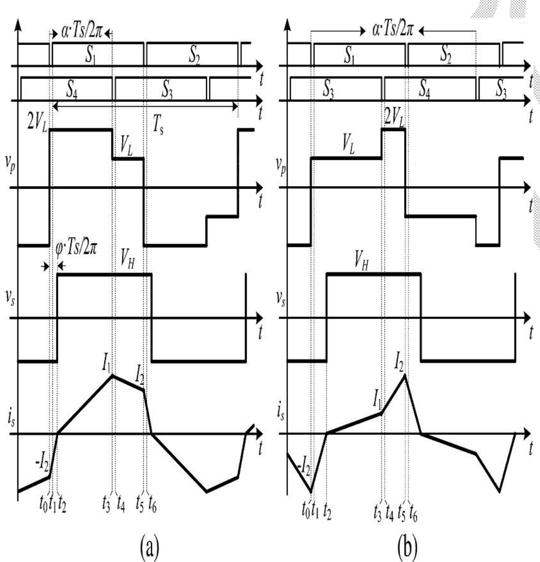

Fig. 3 Timing diagram and typical waveforms

III. MODES OF OPERATION

During [t_0 , t_2], as shown in Fig. 5(a), the body diodes of S_1 and S_4 conduct and v_p is clamped to a voltage of $2V_L$ until i_s decreases with a slope $(2V_L + V_H)/L_2$ to zero at t_2 . At t_0 , S_1 turns ON under ZVS. During [t_2 , t_3], when i_s becomes positive and flows through D_1 , S_1 and S_4 will conduct and i_s increases with a slope $(2V_L - V_H)/L_2$, as shown in Fig. 5(b).

During [t_3 , t_5], when S_4 turns OFF at t_3 , $C_{S\,3}$ and $C_{S\,4}$ start to resonate with L_2 until $V_{C\,S\,3} = 0$, and then S_3 can turn ON under ZVS. Current in the primary side flows through S_1 and $D_{S\,3}$ that makes v_p equal to V_L , and i_s decreases with a slope $(V_H - V_L)/L_2$.

The equivalent circuit is given in Fig. 5(c). After t_5 the second half switching cycle starts. Obviously, the diodes on the secondary side will always turn OFF under ZCS in the whole operation range.

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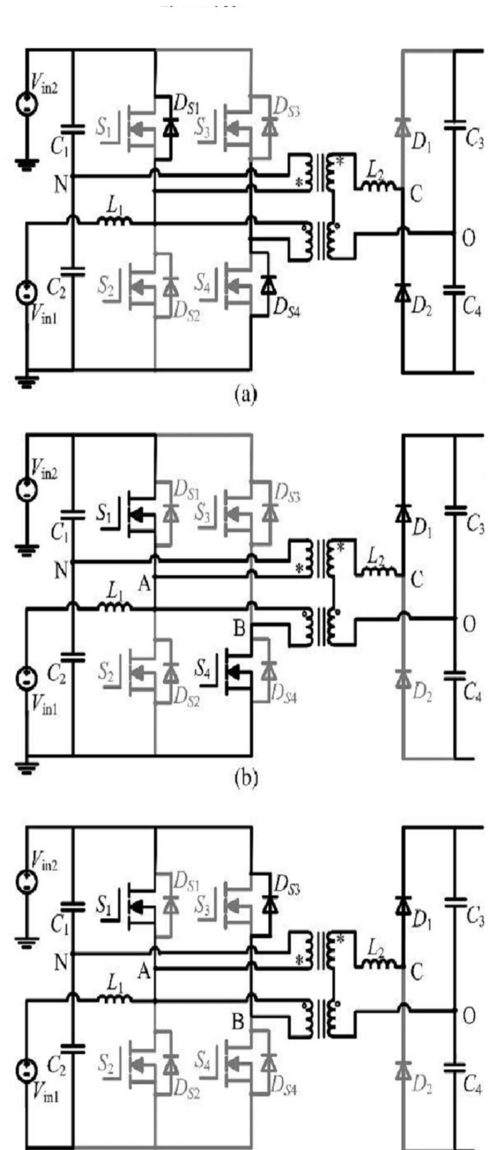

IV.DESIGN CONSIDERATIONS

Generally, ZVS can be deduced on the precondition that the anti parallel diode of switch must conduct before the switch is triggered. In other words, the main devices are turned OFF with a positive current flowing and then the current diverts to the opposite diode which allows the in-coming MOSFET to be switched on under zero voltage. Therefore, ZVS constraints depend on the magnitude of primary side currents, i.e., (n1 + n2)*, and , and have the relationships at driving instant

$$\begin{cases} -(n_1+n_2)\cdot i_s(t_1) - i_{L1}(t_1) < 0, & \text{for } S_1 \\ (n_1+n_2)\cdot i_s(t_5) - i_{L1}(t_5) > 0, & \text{for } S_2 \\ n_2 \cdot i_s(t_3) > 0, & \text{for } S_3, S_4 \end{cases}$$

In fact, the condition for S1, S3, and S4 can be easily satisfied, so ZVS can achieve over the whole load range and is independent on the converter's parameters. While to ensure the ZVS turn-on of S2, the following function of the circuit parameters and the control variables must be satisfied:

$$(n_1+n_2)I_2 - \frac{V_o^2}{V_{in1}R} + \frac{V_{in1}}{2L_1 f_s} > 0 \Rightarrow \frac{(n_1+n_2)(4n_1+G_V)\varphi}{2\omega L_2} + \frac{1}{2L_1 f_s} > \frac{G_V^2}{R}.$$

For converters with low input voltage and high current, turnoff loss of the switches on the low voltage side is the predominating factor of the switching loss [2], which cannot be ignored and is closely related to the stress of switch-off current. Moreover, during converter design, it is also necessary to compute the root mean square (rms) values of the switch current to estimate conduction loss as for choosing MOSFETs, especially for the power devices located in the high current path. As an

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example, when input voltage is 30 V, Fig. 9 plots the values of transient turn-off current and rms current of the devices on the primary side as a function of α. It can be seen that the current stress is not distributed equally and among the switches, $S2$ will have to handle highest current stress and also high conduction loss owing to the BHB structure [14]. Both the turn-off transient current and the rms current of $S2$ are approximately proportional to the phase-shift angle that means for same output power, if α decreases, switching and conduction losses of $S2$ will become less, so as a result the system efficiency can be improved. Regarding to this fact as well as the ZVS operation, an optimal design and trade off between switching loss and conduction loss may be considered for the future research.

IV. SIMULATION RESULTS

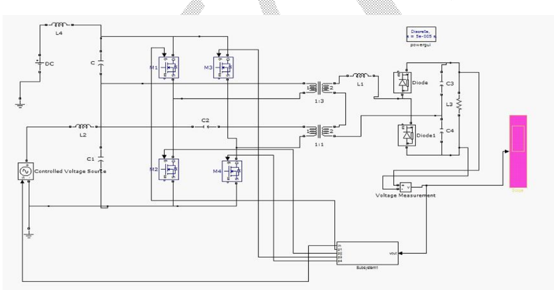

Fig.5. Simulation diagram of proposed system

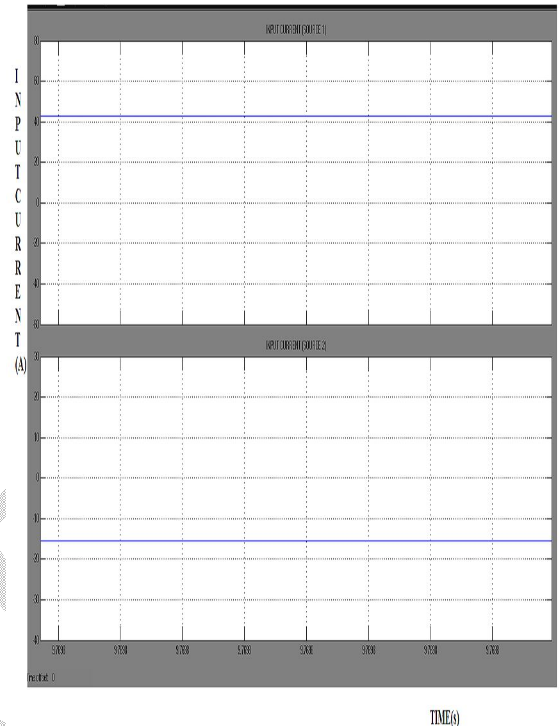

Fig.6.Input Current

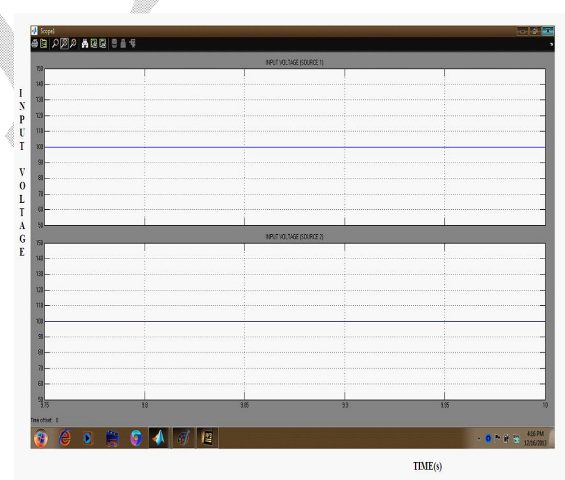

Fig.7.Input Voltage

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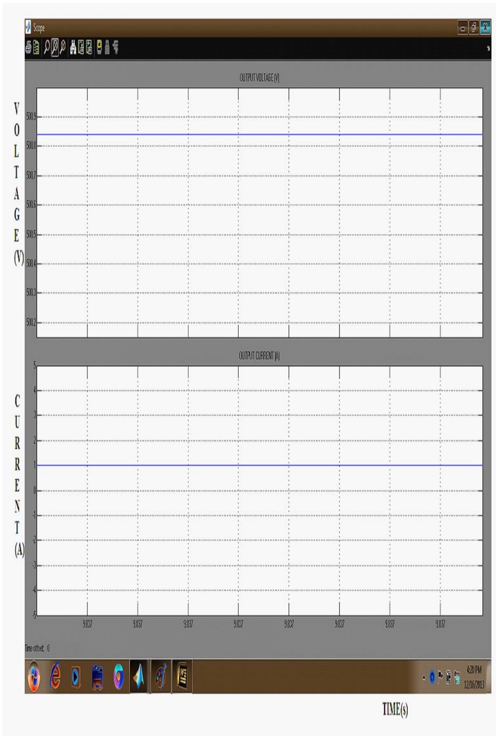

Fig.8.Output Voltage and Current

V. CONCLUSIONS

This project, proposed an improved switching method for a dual input DC- DC converter combining a boost half bridge cell and a voltage fed full bridge cell for high step-up applications. This circuit structure helps for mitigating without the need for current sensors and the current imbalance problems in existing system. The half bridge and full bridge cells combining DC- DC converter achieves ZVS turn ON of switches and ZCS turn OFF of diodes. The new technique of combining half bridge and full bridge inverters gives an efficient result. A soft-switched isolated dc–dc converter with the ability of handling two independent inputs is derived, investigated, and designed.

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