A Bridge Type DC-DC Converter with Dual Input for Hybrid Energy System

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Abstract

A proper power electronic circuit is critical in the hybridization of various sources of energy as their relevance is reached a milestone in the area of hybrid energy application. A dual input bridge type DC-DC converter to incorporate various energy sources is introduced in this paper. The proposed converter is better suited for all the basic modes of operations like buck, buck-boost etc. In this paper experimental and simulation validation of the converter is performed for buck-boost operation. Performance evaluation with other reported topologies is done based on the various aspects such as efficiency, component count etc. It clearly reveals that the given converter holds large voltage conversion ratio, fewer number of components and a good efficiency profile.

Keywords. Hybrid energy integration, multi input DC-DC converters, DIBC converter.

1. INTRODUCTION

Due to increasing demand of non-conventional sources in the power generation scenario, the hybridization of various energy sources has gained more attention. Hybrid Energy System (HES) is a key answer intended for the problems associated with the power generation from the individual energy sources. These renewable sources and storages like a battery are greatly utilised to structure an HES [1-2]. In conventional method, multiple numbers of DC-DC converters with single input are coupled in parallel manner and it marks in high intricacy in controller part, high cost, and reduction in the compactness and low efficiency profile. To surpass these drawbacks, the perception of multi input DC-DC converters (MICs) is discussed. Major attractive features of MICs are reduced complexity, cost and good efficiency profile [4-6]. Since MICs have several advantages compared to single input converters, their application is radically increased in the recent HES applications. Many MICs are previously reported in the literature [4-14], where they classified in to isolated and non-isolated MICs. In isolated topologies, the existence of transformers with multiple winding to provide isolation enhances the cost of the system and also enhances the complexity. A

MIC with flux additivity feature is discussed in [7]. Various MICs and their identification methods are described in [8-10]. A two input converter is introduced for distinct sources addition in [11]. A new MIC that can be applied for renewable applications is introduced in [12].

The converters discussed in the literature can be used for a variety of applications. But some of the converter [3], [12] are restricted for the simultaneous power supply from the input sources. Even though some MICs [4] are well suited for both individual and simultaneous power supply, large number of components present in these converters increases the complexity and reduces the efficiency. Many of the reported MICs are only capable for unidirectional operation; hence they are not appropriate for specific applications such as electric vehicle where bi-directional operation is an essential criterion. Thus, in this paper, an effort is done to propose a Dual input Bridge type DC-DC (DIBC) converter that is skilful of parallel and series energy supply capacity from input sources without any compromise in efficiency and cost. The operating principle and functioning states of DIBC converter are described in subsequent sections.

2. DUAL INPUT BRIDGE TYPE DC-DC (DIBC) CONVERTER

The idea of DIBC converter is conceived from the concept of normal DC-DC converter. The structure of DIBC converter topology is displayed in Figure 1. The circuit has diodes (D_1&D_2) and power switches (S_1-S_m) along with the inductor and capacitor. With the proper control of S_1, S_2 and S_3, the individual, concurrent operation of the inputs can be realized. The conduction of diodes and S_m decides the possible operating modes. With respect to switching scheme opted, four working states are present in buck-boost mode as revealed in Figure 2 (a-d).Four functioning states of DIBC converter are mentioned below:

***State 1*:** Figure 2a shows the equivalent circuit of state 1. Here S_1 and S_m are ON, where the other devices are non-conducting. Thus V_1 energizes the inductor and energy to the load is provided by the capacitor.

***State 2*:** Figure 2b shows the equivalent circuit of state 1. Here, the ON devices are S_2 and S_m and all other devices are turned OFF. Here, energy to the load is given by the capacitor, source V_2 charges the inductor.

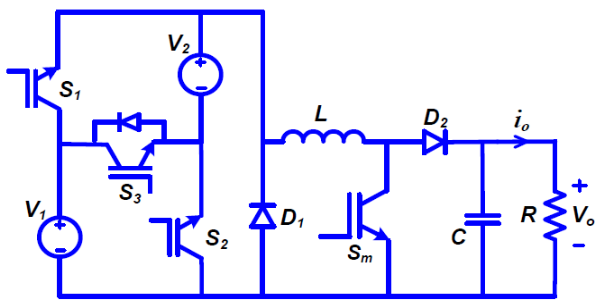


Figure 1. Basic circuit of DIBC converter.

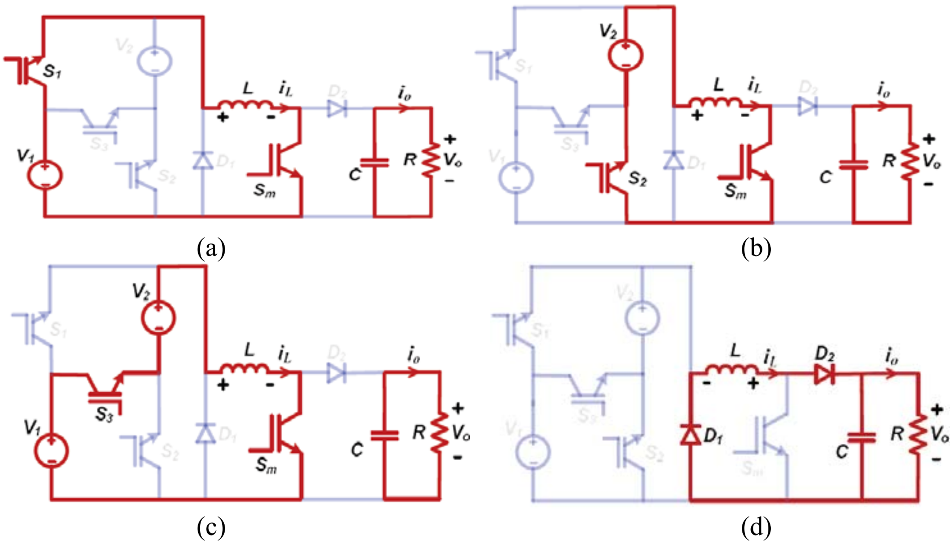


Figure 2.States of DIBC converter (a) V_1 is delivering the power (b)V_2 is delivering the power (c) V_1 and V_2 simultaneously supplies the power (d) Freewheeling state.

***State 3*:** Figure 2c displays, the converter circuit in state 3. The conducting devices are S_3 and S_m, and all other devices are in non-conducting state. S_3conduction supports to realize the series supply of inputs. Here, the inductor is energized simultaneously by both input sources.

***State 4*:** Figure 2d shows the structure of the converter in state 4. Only diodes are conducting in this state and the inductor energy is freewheeled through D_1 and D_2.

2.1. DIBC Converter Analysis

The Detailed converter analysis is conducted in CCM of the inductor for buck-boost operation. Based on the concept of volt-second balance, a DC-DC converter should have zero average inductor voltage which can be expressed as

$$V_1 d_1 + V_2 d_2 + (V_1 + V_2) d_3 - V_0 (1 - d_1 - d_2 - d_3) = 0 \quad (1)$$

Hence the expression for the output voltage is

$$V_0 = \frac{V_1 d_1 + V_2 d_2 + (V_1 + V_2) d_3}{(1 - d_1 - d_2 - d_3)} \quad (2)$$

The value of the inductor can be determined from the below expression;

$$L = \frac{V_0 (1 - (d_1 + d_2 + d_3)}{\Delta i_L f} \quad (3)$$

Similarly, the capacitor value can be determined as

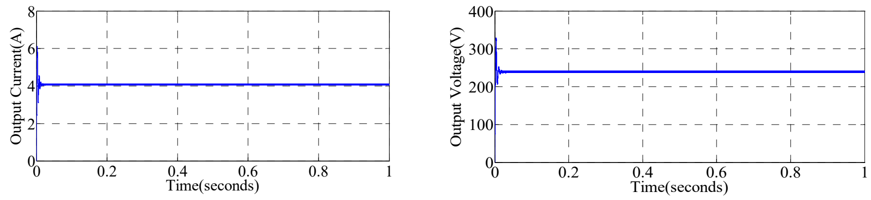
$$C = \frac{V_o (d_1 + d_2 + d_3)}{R \Delta V_o f} \quad (4)$$

3. SIMULATION ANALYSIS AND DISCUSSION

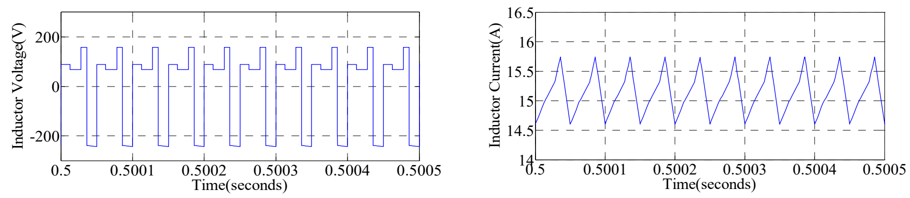
The converter simulation is performed in MATLAB/Simulink platform. The specifications chosen are revealed in Table 1. Waveforms of DIBC converter in buck-boost state for a total duty ratio of greater than 0.5 are depicted in Figure 3. From Figure 3(b), it is observed that the inductor is energized with a voltage of 90 V and 70 V for first two working states. Then it is energized with 160 V (V_1+V_2) for d_3 and is de-energized with -240 V (-Vo).

Table 1. Simulation parameters of DIBC converter.

Input 1 (V)	**Input 2 (V)**	**L (mH)**	**C (µF)**	**F (kHz)**	**Vo (V) Buck-boost**
90	70	5	470	20	240/80

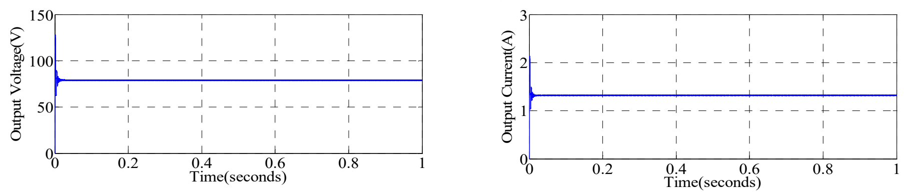


(a)

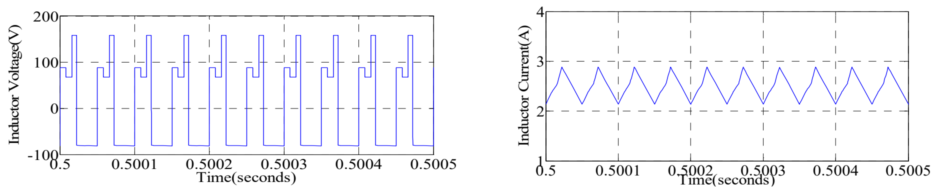


(b)

Figure 3. Simulation wave form: (a) output voltage, current (b) inductor voltage, current (d > 0.5).



(a)



(b)

Figure 4. Simulation wave forms: (a) Load voltage, current (b) voltage, current of inductor (d < 0.5).

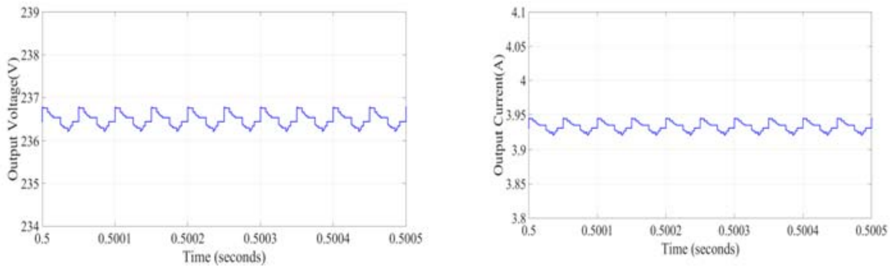
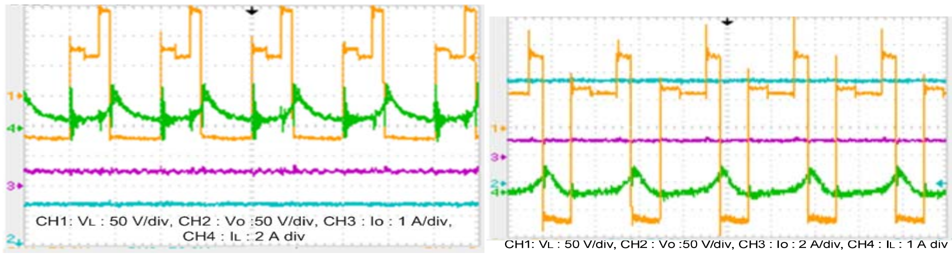


Figure 5. Ripple content in load voltage and current in steady state condition.

Simulation waveforms of the converter for a total duty ratio of less than 0.5 in buck-boost mode are illustrated in Figure 4. The inductor is charged by 90 V, 70 V and 160 V for d_1, d_2 and d_3 correspondingly. Finally, it is de-energized by V (-Vo). The simulation of DIBC converter is done with ideal components, due to which the results are so closer to theoretical investigation of the converter. Figure 5 shows the ripple contents presents in the output current and voltage. From the analysis it is verified that the amount of ripple contents are within the permissible limit.

4. Experimental Results

To verify the practicability of DIBC converter in real time condition, a hardware prototype is built. Using LabVIEW 2013 software, gate pulses are generated by a frequency of 20 kHz. The switches of DIBC converter are realised with IRFP 460 MOSET and MUR 860 diodes are also used. The specifications considered for the analysis are already tabulated in Table 1. Various waveforms such as output voltage, inductor voltage etc., are recorded and are illustrated in Figure 6 (a-b). For a duty ratio lesser than 0.5, the voltage obtained at the output is 77 V (Figure 6(a)), and for a duty ratio of greater than 0.5, the measured output voltage is 200 V (Figure 6(b)). Here the experimental and simulation results are well matched each other. From these results it is inferred that, the DIBC converter is well appropriate for the hybrid energy source incorporation and is competent to deliver energy to the load in individual and simultaneous manner. The efficiency values are plotted with respect to the power variation as given in Figure 7. From the figure, it can be summarised that the efficiency range of DIBC converter is good. Quantitative comparison of the DIBC converter with other converters is conducted based on the parameters like, efficiency, count of switching devices etc., and are described in Table 2.



(a) (b)

Figure 6. Hardware waveforms of voltage, current of the inductor, output voltage and current (a) for duty ratio less than 0.5(b) for duty ratio greater than 0.5.

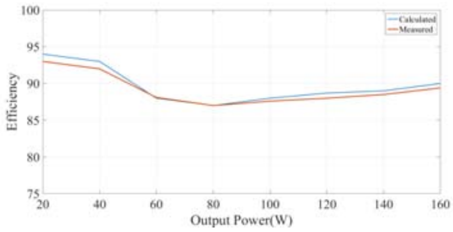


Figure 7. Efficiency analysis of DIBC converter.

Table 2. Comparison of DIBC converter and other reported MICs.

Converter proposed	Switching Devices	Inductor	Capacitor	Voltage stress	Efficiency (%)
Converter in [4]	2n	n	1	V_o	78-91
Converter in [6]	n+4	1	1	V_n	80-92
DIBC converter	n+4	1	1	V_n	88-93

n: Number of inputs

5. CONCLUSION

A two input bridge type DC-DC converter is proposed in this article to include two input sources. Complete converter analysis is performed for buck-boost operation. The hardware evaluation of DIBC converter is conducted to confirm the correctness of simulation outcomes. From the analyses, the converter operation is found acceptable. The efficiency analysis of the DIBC converter is conducted to confirm the superior performance DIBC converter. From the overall analysis, it is noticed that the DIBC converter has certain merits such as optimized structure, low voltage stresses and lower component count due to which the converter efficiency is good. These merits definitely boost up the significance of DIBC converter in the specific applications such as renewable energy incorporation, microgrid, and hybrid electric vehicle.

6. REFERENCES

[1] Cao and A. Emadi, ‘A New Battery/UltraCapacitor Hybrid Energy Storage System for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles’, in IEEE Transactions on Power Electronics, vol. 27, no. 1, pp. 122-132, Jan. 2012.

[2] S. Kumar and H. P. Ikkurti, ‘Design and control of novel power electronics interface for battery-ultracapacitor Hybrid Energy Storage System’, International Conference on Sustainable Energy and Intelligent Systems (SEISCON 2011), pp. 236-241, 2011.

[3] A. Khaligh, J. Cao and Y. Lee, ‘A Multiple-Input DC–DC Converter Topology’, in IEEE Transactions on Power Electronics, vol. 24, no. 3, pp. 862-868, March 2009.

[4] Kumar, L and Jain, S., ‘Multiple-input DC/DC converter topology for hybrid energy system’, in IET Power Electronics, vol.6, no.8, pp.1483-1501, September 2013.

[5] Y. Li, X. Ruan, D. Yang, F. Liu and C. K. Tse, ‘Synthesis of Multiple-Input DC/DC Converters’, in IEEE Transactions on Power Electronics, vol. 25, no. 9, pp. 2372-2385, Sept. 2010.

[6] Y. Liu and Y. Chen, ‘A Systematic Approach to Synthesizing Multi-Input DC/DC Converters’, 2007 IEEE Power Electronics Specialists Conference, pp. 2626-2632, 2007.

[7] Yaow-Ming Chen, Yuan-Chuan Liu and Feng-Yu Wu, ‘Multi-input DC/DC converter based on the multiwinding transformer for renewable energy applications’, in IEEE Transactions on Industry Applications, vol. 38, no. 4, pp. 1096-1104, July-Aug. 2002.

[8] A. Kwasinski, ‘Identification of Feasible Topologies for Multiple-Input DC–DC Converters’, in IEEE Transactions on Power Electronics, vol. 24, no. 3, pp. 856-861, March 2009.

[9] S. Athikkal and K. M. R. Eswar, ‘A Three Input Dual Output Boost Type Non Isolated DC-DC Converter’, 2021 International Conference on Intelligent Technologies (CONIT), pp. 1-6, 2021.

[10] G. Guru Kumar, K. Sundaramoorthy, S. Athikkal and V. Karthikeyan, ‘Dual input super boost DC-DC converter for solar powered electric vehicle’, in IET Power Electronics, vol. 12, no. 9, pp. 2276-2284, 2019.

[11] Athikkal, S., Sundaramoorthy, K., Sankar, A, ‘Development and performance analysis of dual-input DC–DC converters for DC microgrid application’, IEEJ Trans. Electr. Electron. Eng., 2018, 13, (7), pp. 1034–1043.

[12] S. Athikkal, ‘Performance Evaluation of A Positive Output Voltage Dual Input DC-DC Converter’, 2021 2nd International Conference for Emerging Technology (INCET), pp. 1-5, 2021.