IMPROVED MULTI-INPUT CONVERTER CONFIGURATION (IMCC) TO OVERCOME CIRCULATING CURRENT

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Abstract – In this paper, improved multi input DC/DC converter configuration (IMCC) topology is introduced for integrating two input energy sources. The topology is an improved version of the former one. The proposed converter has the capability to simultaneously deliver power to the load from the input energy sources. The major advantage of the improved converter is capable to stop the severe flow of circulating current in the topology proposed in prior work. Hence, the detailed software simulation of the improved converter has been performed using MATLAB/Simulink platform. Different analyses have been conducted by considering the parameters, such as the equivalent series resistance of the passive elements in the converter and efficiency of the converter, for better validation of the converter performance. The proposed converters have certain merits like less component count, compact structure, and efficient energy utilization, compared with existing converter topologies, which are already reported in the literature.

Keywords: *multi-port dc/dc converter, renewable energy sources, bidirectional dc-dc converters.*

I. INTRODUCTION

In Hybrid Energy System (HES) Conventionally single input DC-DC converters has been used to integrate multiple numbers of input sources .Multiple Input DC-DC Converter (MIC) has been developed to nullify the complexity, high cost, lower efficiency and dropping of compactness in high system[1-2]. The concept of Multiple Input DC-DC Converter (MIC) has been developed to nullify these demerits. Comparatively simple and compact structure, lower part counts and higher efficiency are the potential merits of multiple input DC-DC converters (MICs). The isolated and non-isolated types of MIC are widely reported. In isolated topologies, the presence of multi-winding transformers provides electrical isolation but increases the system complexity and cost compared to non-isolated topologies [3-4]. Hence the use of non-isolated MIC is favoured in the applications where efficiency and cost of the system are significant concerns. A non-isolated MIC for solar-PV application has drawback that it delivers power from one energy source at a time, and simultaneous power delivery from the input sources are not possible [5-6].

A high step-up DC-DC converter and a multiple input voltage summation converter are reported in [7] and [8]. For n-input mode, the above converters require `n' number of switches and inductors due to which the system becomes complex and expensive. The idea of MICs to manage the power flow from the input supply sources for electric vehicle application is discussed in [9-10]. A bidirectional MIC for fuel cell/EV application was developed in [11]. But due to the discontinuous input current, this converter is unsuitable for solar-PV or other renewable energy applications. An extendable multi input step-up DC-DC converter for the efficient integration of non-conventional energy sources is proposed in [12]. So, a large number of DC-DC converters are reported in the literature. The converters reported in the literature can be effectively used for hybridization of different energy sources for various applications. Some of them have limitations for simultaneous power delivery from the input energy sources; while others require sophisticated control strategies even though they are capable of individual and simultaneous power supply [13-14].

In this paper, the proposed topologies can be named as improved multi input DC/DC converter configuration (IMCC). Actually, IMCC converter is derived from IBDC converter to eliminate high circulating current flow in the IBDC. The proposed IMCC converter is capable of performing the basic operations of a DC-DC converter such as buck, boost and buck-boost. This converter is also capable of supplying power from the input sources individually and simultaneously. Detailed study of the IBDC converter has been carried out for validating the converter performance.

II. STUCTURE OF IMCC

The basic circuit of IMCC is shown in Fig.1. The proposed structure of IMCC overcome the major drawbacks (Whenever switch S_3 will conduct, it will short-circuit both the sources. Hence huge short/circulating circuit current will flow in the circuit and damages the switches) reported in the work proposed in [1].The IMCC converter contains four power switches (S_{1b}, S_{2b}, S_3 and S_m, where S_{1b}, S_{2b} are bidirectional power switches) and two diodes (D_1 and D_2). If the IMCC converter needs to operate in the bidirectional mode, the diodes D_2 must be replaced by the power switches with an anti-parallel diode. By doing this, it is possible to operate the IMCC converter in the bidirectional mode which is an essential feature for the electric vehicular application etc. The individual and simultaneous operation of the input energy sources of the converter is accomplished by controlling the bidirectional power switches S_{1b}, S_{2b}, and S_3. The possible operating modes of the IMCC converter in boost, buck-boost and buck are decided by the conduction of the power switch S_m, and the two diodes available in the converter. The IMCC converter has four working states in under buck, buck-boost and boost mode of operation and details are mentioned in Table 1. For the simple representation of the circuits in different operating states, the power switches in Fig.1 have been represented as single pole single through switches (SPST) in all the three modes of operation.

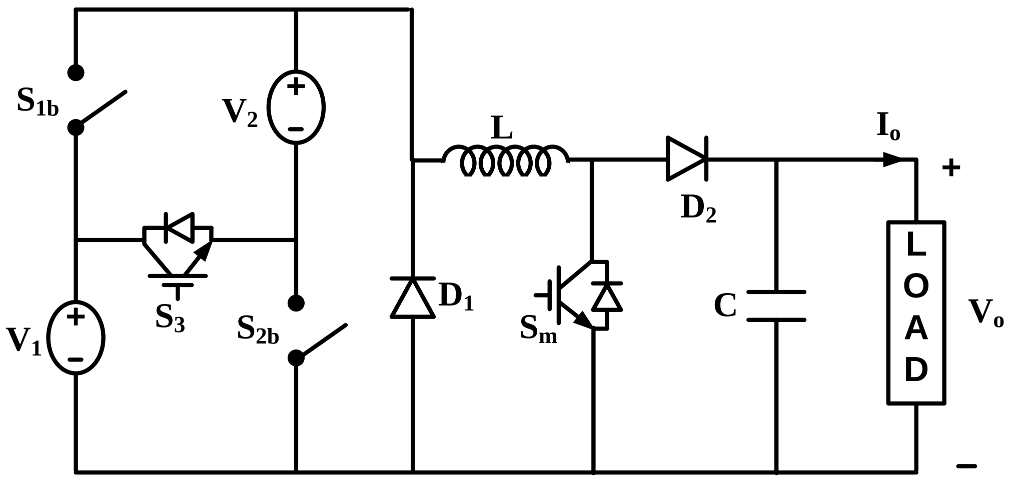


Fig.1 Topological structure of proposed IMCC

Table 1. Various working states of proposed buck-boost converter.

Working state	ON State Switch	Input Source	Inductor Voltage	Inductor status
State-1	S_{1b},S_m	V_1	V_1	Charging
State-2	S_{2b},S_m	V_2	V_2	Charging
State-3	S_3, S_m	V_1+V_2	V_1+V_2	Charging
State-4	D_1, D_2	None	-V_o	Discharging

The energy flow between the input sources and the load is controlled by regulating the duty ratios of power switches (S_{1b}, S_{2b} and S_3) existing in the converter. The theoretical analysis and corresponding waveforms of the proposed IMCC converters in steady state condition are given in Fig. 2.

III. OPERATING MODE OF THE PROPOSED CONVERTER

The proposed IMCC converter is capable of buck and buck-boost and boost mode of operation operations. These operations can be achieved by a proper control of different semiconductor switches available in the IMCC converter. The converter operating states under buck operation is illustrated in Fig. 3(a-d).

State 1: During state 1, the switch S_{1b} and diode D_2 are in conduction, while all other switches are non-conducting. So, the inductor is charged by the source V_1.

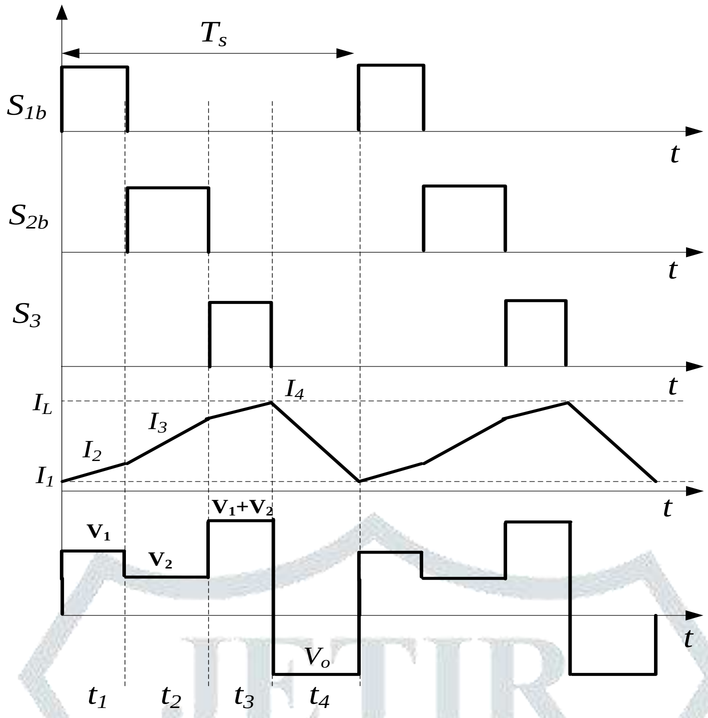


Fig.2. Theoretical analysis waveforms of switching signal, inductor current and voltage for proposed IMCC converters

State 2: Here only the switch S_{2b} and diode D_2 are in conduction. So, the source V_2 charges the inductor.

State 3: In this state, the inductor is charged by both the input sources (V_1+V_2), which are connected in series. The power switches S_3 is in conduction to make the input sources in series.

State 4: This state is similar to that of the freewheeling state of buck-boost operation of the converter. Here, the stored energy in the inductor is delivered to the load through diodes D_1 and D_2.

A. BUCK MODE OF OPERATION

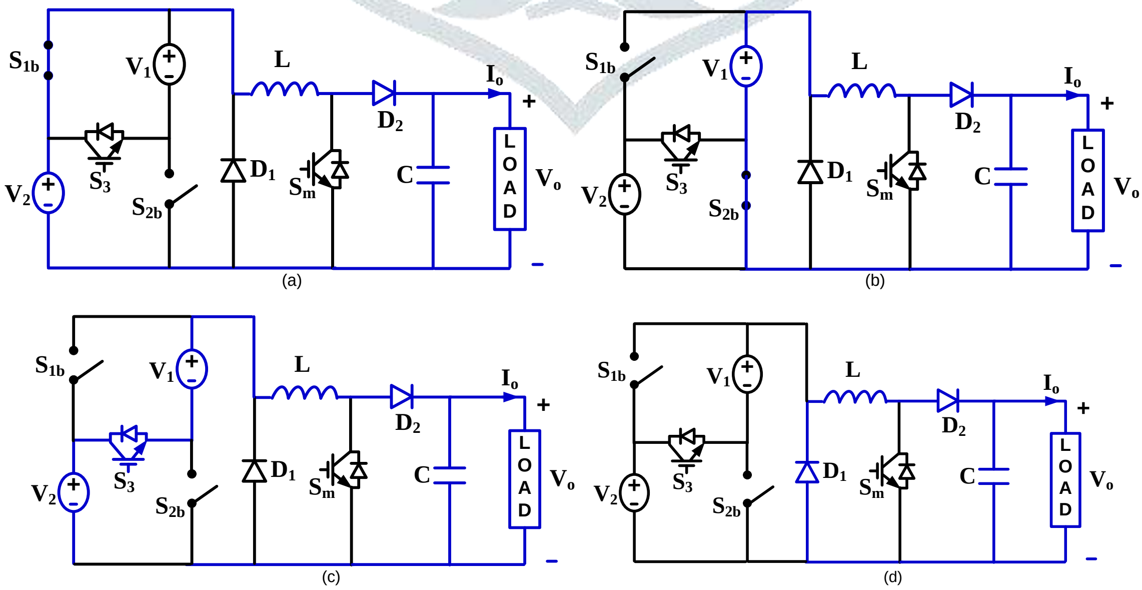


Fig.3 Various working states of IMCC converter during buck operation. (a) Source V_1 charges the inductor and supplies the load. (b) Source V_2 charges the inductor and supplies the load. (c) Source V_1& V_2 together charge the inductor and supply the load. (d) Freewheeling period.

TABLE 2 DIFFERENT WORKING STATES IN BUCK MODE OF OPERATION

Working state	Switching Interval	ON Switches	Inductor Status	V_L	I_c
State-1	t_1	S_{1b},D_2	Charging	V_1-V_o	$i_L - I_0$
State-3	t_2	S_{2b},D_2	Charging	V_2-V_o	$i_L - I_0$
State-2	t_3	S_{1b},S_{2b},D_2	Charging	V_1+V_2-V_o	$i_L - I_0$
State-4	t_4	D_1,D_2	Discharging	-V_o	$I_0 - i_L$

The different working states of dual input converter in buck mode of operation for is shown in Fig. 3. In buck mode of operation, for time interval t_1, t_2 and t_3, input voltage V_1, V_2 and V_1 +V_2 are applied across the inductor respectively. For time interval t_4 negative voltage –V_0 appears across the inductor. The detailed analysis of Buck mode of operation is summarized in Table 2.

The similar analysis for buck-boost and boost mode of operation can be performed. Different configuration for buck-boost and boost mode of operation is given in Fig 4 and 5 respectively.

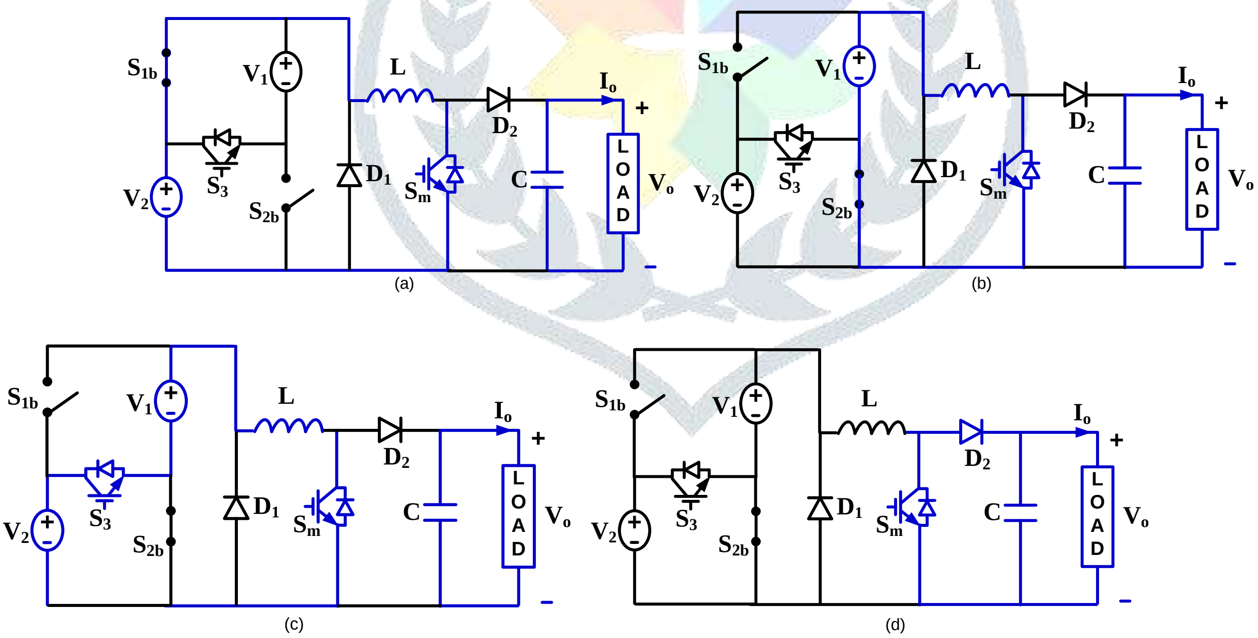


Fig.4 Various working states of IMCC converter during buck-boost operation (a) Contribution from source V_1. (b) Contribution from source V_2. (c) Contribution from both sources V_1 and V_2 together. (d) Freewheeling period.

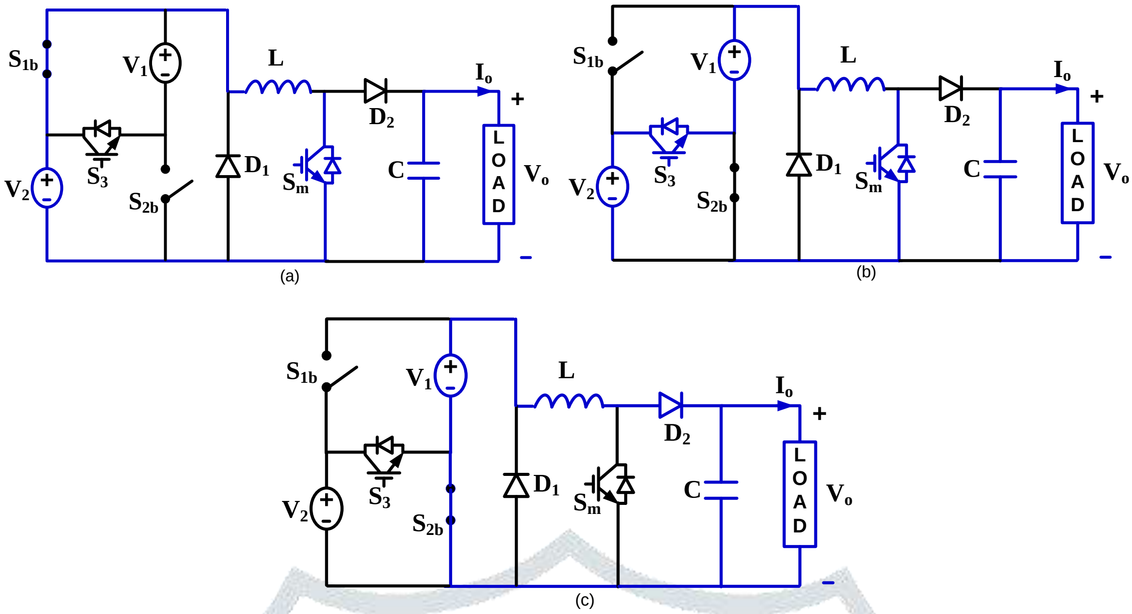


Fig.5 Various working states of IBDC converter during Boost operation. (a) Source V_1 charges the inductor. (b) Source V_1& V_2 together charge the inductor. (c) Source V_2 charges the inductor and supplies the load.

IV. SIMULATION RESULTS

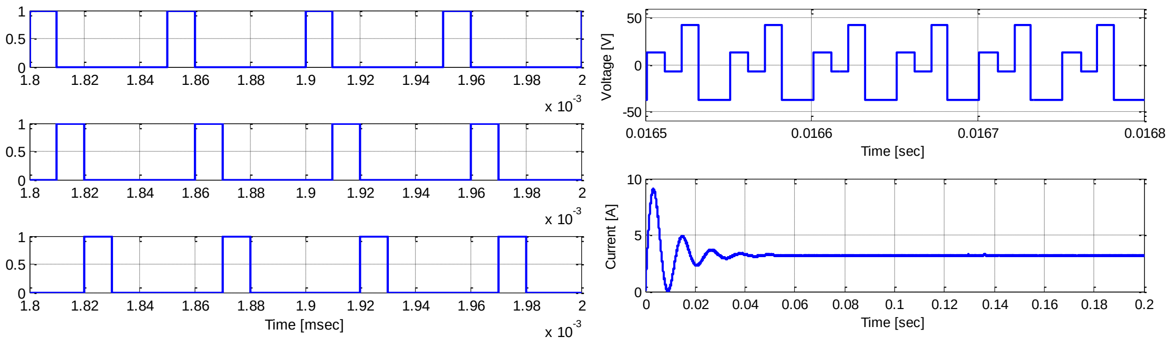
The simulation of the IMCC converter is performed using MATLAB/ Simulink platform. The parameters considered for the simulation and experimental purpose of IMCC converter are given in Table 3. The results of IMCC converter obtained from the simulation studies for buck, buck-boost and boost operation are shown in Fig. 6, Fig.7 and Fig 8 respectively. The simulation results for buck operation are illustrated in Fig. 6 (a-f). From the figure, it is evident that the charging voltages of the inductor are 18 V (i.e., V_1-V_o) for duty ratio d_1,-2 V (i.e., V_2-V_o) for duty ratio d_2 and 28 V (i.e., V_1+V_2-V_o) for duty ratio d_3. Finally, the discharging voltage of inductor is -48V (i.e., -V_o) for the remaining period.

Similarly, the performance of the IMCC converter under boost operation is depicted in Fig. 7 (a-c). Initially, the inductor is charged by a voltage of 50 V (i.e., V_1) for a duty ratio d_1, and then it is charged by a voltage of 30 V (i.e., V_2) till the switch S_m is turned OFF. Finally, the energy stored in the inductor is delivered to the load with a discharging voltage of -70 V (i.e., V_2-V_o).

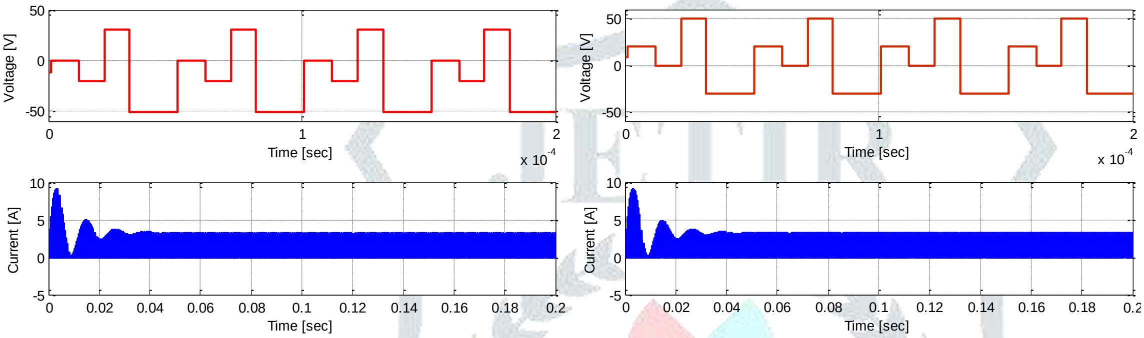
The results of the IMCC converter for buck-boost operation are shown in Fig. 8 (a-c) for the duty ratio greater than 0.5 (i.e. dm=0.66). In both cases, the inductor is charged by a voltage of 50 V (i.e., V_1), 30 V (i.e., V_2) and 80 V (i.e., V_1+V2) for duty ratios d_1, d_2 and d_3 respectively. Then the stored energy in the inductor is discharged with the voltages of -100 V for the operation of the IMCC converter with duty ratio (i.e., d_1+d_2+d_3) greater than 0.5 respectively.

Table.3 Simulation Parameter

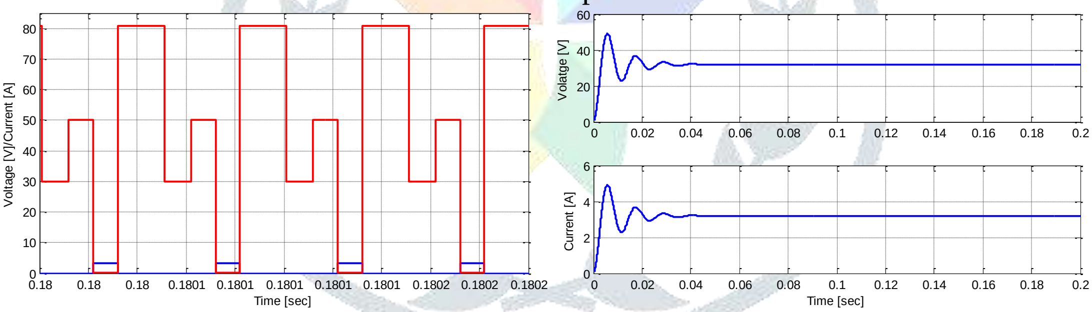
Source (V_1)	Source (V_2)	Inductor (L)	Capacitor (C)	Switching Frequency (f_s)	Out Voltage (V_o)		
					Buck	Buck-Boost	Boost
50	30	7 mH	470µF	20 kHz	32	30/100	100



6(a) Switching signals of switch S_1, S_2,S_3 in buck mode of operation, (b) Inductor voltage and current in buck mode of operation

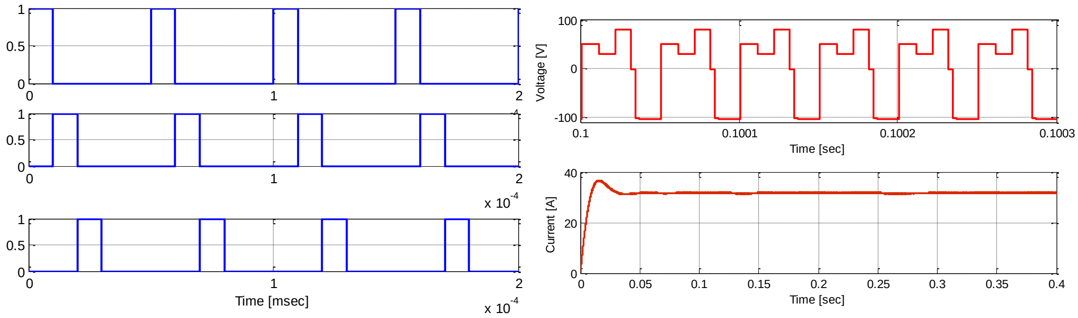


6(c) Voltage and current across S_1 in buck mode of operation, (d) Voltage and current across S_2 in buck mode of operation



6(e) Voltage and current across S_3 in buck mode of operation,(f) Output voltage and current in buck mode of operation

Fig.6 (a-f) various waveforms for buck mode of operation for V_1 = 50 V, V_2 = 30 V, d_1 = 0.2, d_2 = 0.2, d_3 =0.2



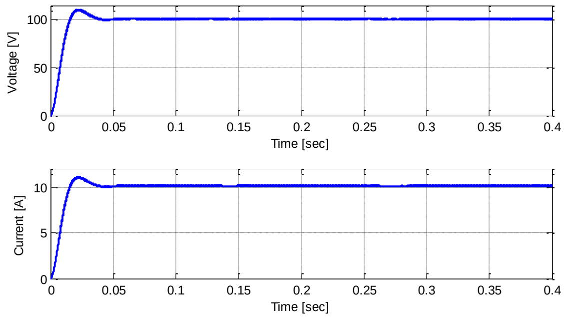
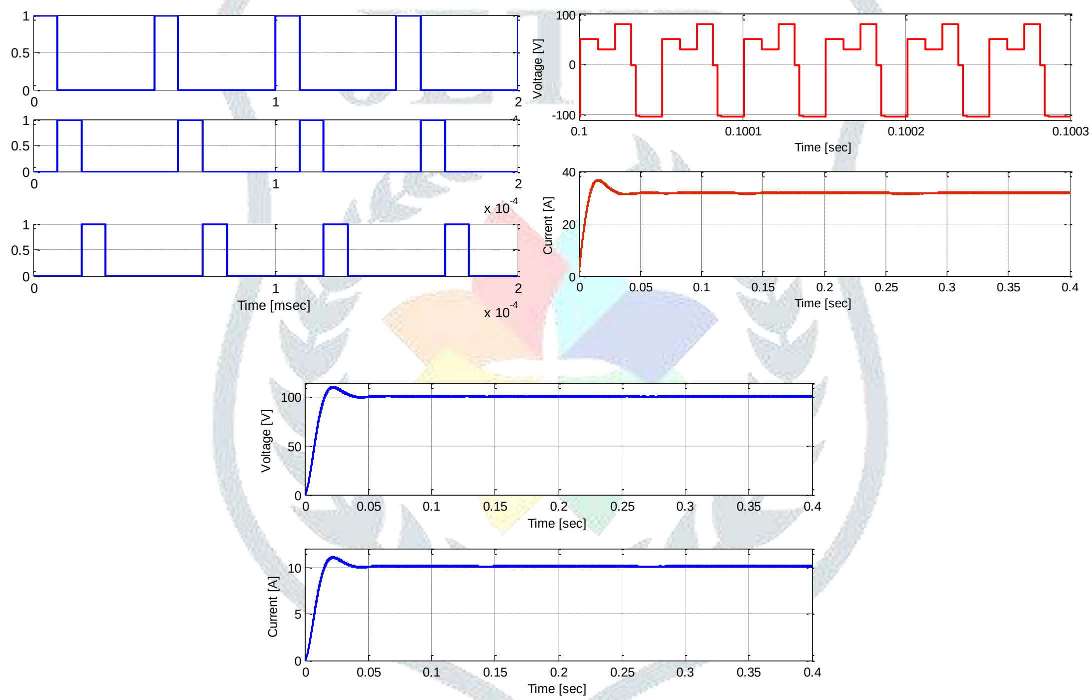


Fig.7 (a) Switching signals of switch S_1, S_2,S_3 in buck-boost mode of operation**,** (b) Inductor voltage and current in buck-boost mode of operation (c) Output voltage and current in buck-boost mode of operation **(**Various waveforms for buck-boost mode of operation for $V_1 = 50$ V, $V_2 = 30$ V, $d_1 = 0.2$, $d_2 = 0.26$, $d_3 = 0.2$ and dm=0.66)



8(a) Switching signals of switch S_1, S_2, S_3 in boost mode of operation, (b) Inductor voltage and current in boost mode of operation (c) Output voltage and current in boost mode of operation

Fig.8 (a-c) various waveforms for boost mode of operation for $V_1 = 50$ V, $V_2 = 30$ V, $d_1 = 0.2$, $d_2 = 0.26$, $d_3 = 0.2$ and dm=0.66

V. CONCLUSION

In this paper IMCC has been proposed. Complete analysis of the proposed converter for dual input sources has been studied for different working states under buck, buck-boost and boost mode of operation. Theoretical analysis and mathematical formulation has been derived for input-output voltage, inductor current ripple and capacitor voltage ripple. The proposed converter has also been explored and found that the proposed converter offers higher degree of reliability, flexibility and source availability. A detailed simulation study has been carried out for the proposed IMCC in buck, buck-boost and boost mode of operation in steady state condition. It is observed that steady state response of the converter is satisfactory. The proposed converter is proficient for energy diversification from different energy sources. The proposed converter has found application in the fields of electric vehicular application, integration of renewable energy sources, distributed generation and micro DC grid where hybridization of energy systems are essential.

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