

ANN Based Closed loop control scheme for transformer less DC – DC Converter

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Abstract.

A bidirectional DC-DC Converter by using sliding mode controller is designed and simulated in this paper. The proposed converter employs a coupled inductor with same winding turns in primary and secondary sides. In step-up mode, to achieve high step-up voltage gain, the primary and secondary windings of the coupled inductor are charged in parallel and discharged in series. In step-down mode, to achieve high step-down voltage gain, the primary and secondary windings of the coupled inductor are charged in series and discharged in parallel. The structure of the proposed converter is very simple. Thus, the proposed converter has higher step-up and step-down voltage gains than the conventional bidirectional boost/buck converter. The operating principle and efficiency analysis are discussed in detail. Finally, a 14/42-V circuit in closed loop mode is designed and simulated to verify the performance for the automobile battery system.

Keywords

Bidirectional dc-dc converter; Sliding Mode Controller; coupled inductor

1. Introduction

Bidirectional dc-dc converters allows the transfer of power between two dc sources in either direction. These bidirectional dc-dc converters are increasingly needed in applications, such as hybrid electric vehicle energy systems, dc uninterrupted power supplies, fuel cell hybrid power systems, photovoltaic hybrid power systems and battery chargers. The bidirectional dc-dc flyback converters, a very simple structure [2], but the active switch suffer a high voltage stresses due to the leakage inductance of the transformer. The coupled inductor [3] type converters can provide solutions to achieve high step-up and step-down voltage gains but its circuit configuration in more complicated. The multilevel type[4] is a magnetic less converter which requires more switches to achieve high step-up and step-down voltage gains. The circuit becomes more complicated. The conventional bidirectional dc-dc boost/buck converter which is simple in structure and easy to control as shown inFig.1.

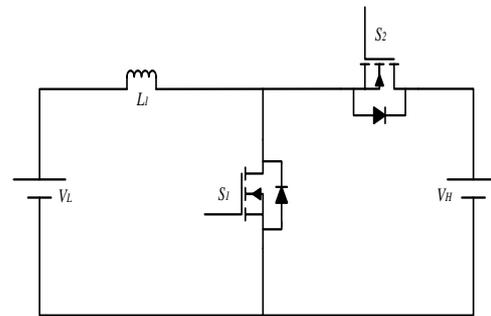


Fig.1.Conventional Bidirectional DC-DC Converter

However, the step-up and step-down voltage gains of the conventional bidirectional dc-dc converter are low due the effect of power switches. To achieve the high step-up and step-down voltage gains, a novel bidirectional dc-dc converter is proposed as shown in Fig.2

The proposed bidirectional dc-dc converter employs a coupled inductor with same windings turns in the primary and secondary sides.

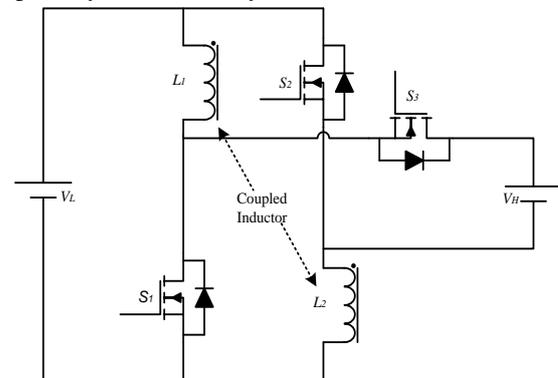


Fig.2.Proposed Converter

The organisation of the paper is as follows, Sec-2 describes the operation of the proposed converter. In Sec-3, the voltage mode control of the proposed converter is described. In Sec-4, MATLAB/Simulink models and Results are discussed. Sec-5 concludes the dynamic response of the proposed converter in open loop and closed loop mode.

2. Operation

2.1. Step-Up Mode

The proposed converter in step-up mode, the primary and secondary windings of the coupled inductor are operated in parallel charge and series discharge. The proposed converter in step-up mode in shown in Fig.3(a). The pulse width modulation technique is used to control the switches.

The voltages across the coupled inductor can be expressed as follows

$$v_{L1} = L_1 \frac{di_{L1}}{dt} + M \frac{di_{L2}}{dt} = L \frac{di_{L1}}{dt} + kL \frac{di_{L2}}{dt} \quad (1)$$

$$v_{L2} = M \frac{di_{L1}}{dt} + L_2 \frac{di_{L2}}{dt} = kL \frac{di_{L1}}{dt} + L \frac{di_{L2}}{dt} \quad (2)$$

Mode 1: The Fig.3(b). Shows the current flow path of the proposed converter in step-up mode, *Mode 1* operation. During this mode, the switches S_1 and S_2 are turned on and S_3 is turned off. The primary and secondary windings of the coupled inductor are in parallel.

Thus voltages across inductors L_1 and L_2 is obtained as

$$v_{L1} = v_{L2} = V_L \quad (3)$$

Substituting Eq's(1&2) in Eq(3), we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_L}{(1+k)L}, \quad t_0 \leq t \leq t_1 \quad (4)$$

Mode 2: During this mode of operation, the switch S_1 and S_2 are turned off and switch S_3 of the proposed converter is turned on. The Fig.3(c). Shows the current flow path of the proposed converter in step-up mode, *Mode 2* operation. Thus the inductor currents through the primary and secondary windings of the coupled inductor and the voltages across the inductor L_1 and L_2 are obtained as follows

$$i_{L1} = i_{L2} \quad (5)$$

$$v_{L1} + v_{L2} = V_L - V_H \quad (6)$$

Substituting Eq's(1,2 and 5) in Eq(6), we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_L - V_H}{2(1+k)L}, \quad t_1 \leq t \leq t_2 \quad (7)$$

By using the state-space averaging method, the following equation is derived from Eq(4) and Eq(7)

$$\frac{DV_L}{(1+k)L} + \frac{(1-D)(V_L - V_H)}{2(1+k)L} = 0 \quad (8)$$

Simplifying (8), the voltage gain is given as

$$G_{(step-up)} = \frac{V_H}{V_L} = \frac{1+D}{1-D} \quad (9)$$

2.2. Step-down Mode

The proposed converter in step-down mode, the primary and secondary windings of the coupled are operated in series charge and parallel discharge. The proposed converter in step-down mode is shown in Fig.4(a). The Pulse width modulation technique is used to control the switch S_3 Meanwhile; the switches S_1 and S_2 are the synchronous rectifiers.

Mode 1: During this mode of operation, the switches S_1 and S_2 are turned off and switch S_3 is turned on. Fig.4(b). shows the current flow path of the proposed converter in step-down *Mode 1* operation. The current flowing through the inductors and the voltages across the primary and secondary windings of the coupled inductor are expressed as follows

$$i_{L1} = i_{L2} \quad (10)$$

$$v_{L1} + v_{L2} = V_H - V_L \quad (11)$$

On substituting Eq's (1,2&10) in Eq(11), we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_H - V_L}{2(1+k)L}, \quad t_0 \leq t \leq t_1 \quad (12)$$

Mode 2: The current flow path of the proposed converter in step-down *Mode 2* operation is shown in Fig.4(c). During this, mode of operation, switches S_1 and S_2 are turned on and switch S_3 is turned off. Therefore the voltages across the inductors L_1 and L_2 are expressed as

$$v_{L1} = v_{L2} = -V_L \quad (13)$$

On substituting Eq(1),(2) in Eq(13), we get

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = -\frac{V_L}{(1+k)L}, \quad t_1 \leq t \leq t_2 \quad (14)$$

The following equation is obtained from Eq's(12&14), by using the state space averaging method

$$\frac{D(V_H - V_L)}{2(1+k)L} - \frac{(1-D)V_L}{(1+k)L} = 0 \quad (15)$$

Finally, on simplifying Eq(15), the voltage gain of the proposed converter in step-down mode operation is obtained as

$$G_{(step-down)} = \frac{V_L}{V_H} = \frac{D}{2-D} \quad (16)$$

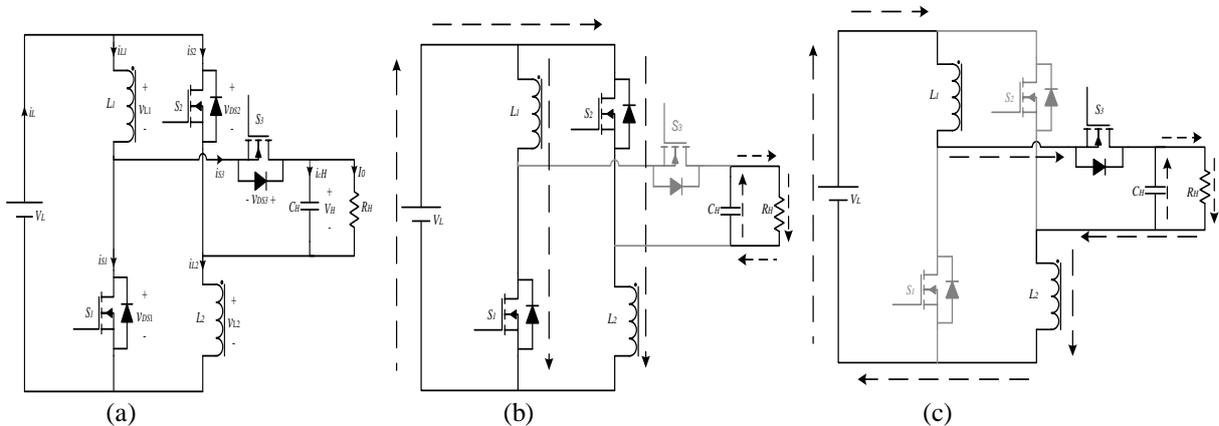


Fig.3. (a) Proposed Converter in step-up mode, Current flow paths of the proposed converter (b) Mode1, (c) Mode2.

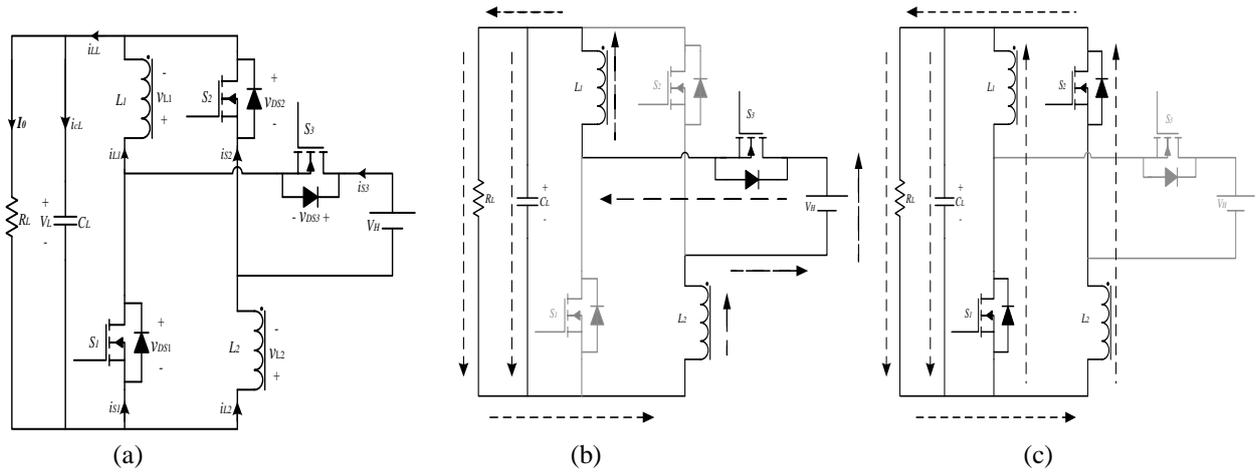


Fig.4. (a) Proposed Converter in step-down mode, Current flow paths of the proposed converter (b) Mode1, (c) Mode2.

3. Voltage Mode Control of the proposed converter

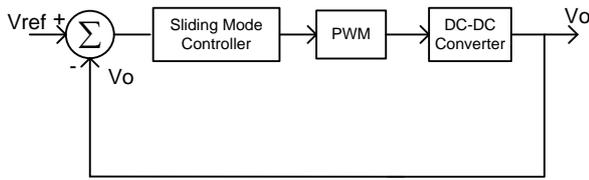


Fig.5.Basic Block diagram of the proposed converter.

The block diagram of the proposed converter by using Sliding mode controller is shown in Fig.5.

4. MATLAB/Simulink Models and Results

The design parameters, MATLAB/Simulink Models of the proposed converter and the MATLAB program for calculating the efficiency of the proposed converter are discussed in this section

4.1 Design Parameters

The design parameters of the proposed converter are shown in Table.1.

Table .1. Tabular form indicating the Design Parameters of the proposed converter.

Mode of Operation	Step-up	Step-down
Input	14v	42v
Output	42v	14v
Frequency	50KHz	50KHz
Power	200W	200W
Inductance	15.5μH	15.5μH
Capacitance	330 μF	330 μF

4.2 MATLAB/Simulink Models and Results of proposed converter in open loop

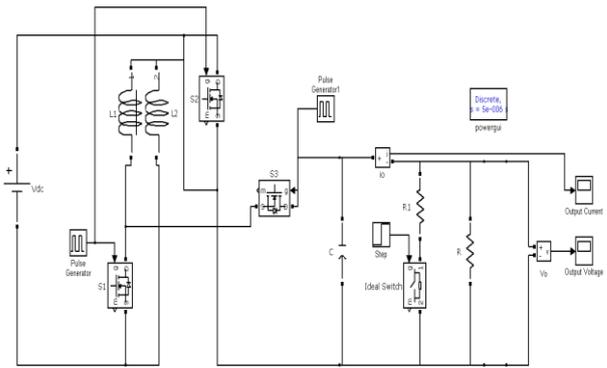


Fig.5.Simulink Model of the Proposed Converter when step change in power from 0.47A to 5.2A.

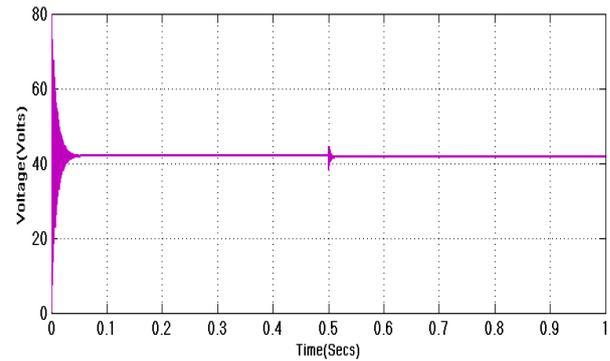


Fig.8.Output Voltage Waveform of the proposed converter when a step change in load from 0.47A to 5.2A at t=0.5sec.

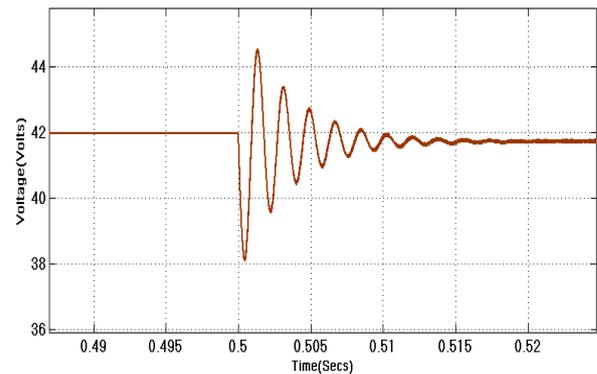


Fig.9.Transient Voltage Deviation (Output Voltage waveform enlarged) of the proposed converter at t=0.5sec.

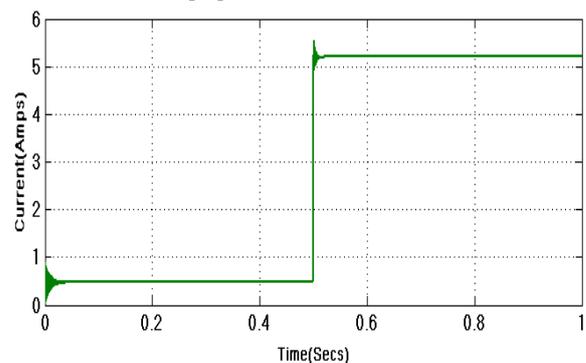


Fig.10.Output Current Waveform of the proposed converter when a step change in load from 0.47A to 5.2A at t=0.5sec.

The MATLAB/Simulink model of the proposed converter in open loop is shown in Fig.7. The output voltage shown in Fig.8, undergoes a transient voltage deviation of 8.3% at $t=0.5$ sec is shown in Fig.9. The output current waveform is shown in Fig.10.

4.3. MATLAB/Simulink Models and Results of proposed converter by using Sliding Mode Controller

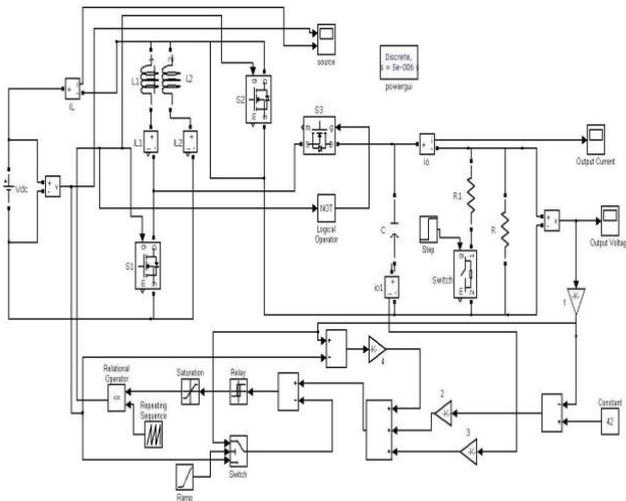


Fig.11.Simulink Model of the Proposed Converter when a step change in load from 0.47A to 5.2A at $t=0.5$ sec

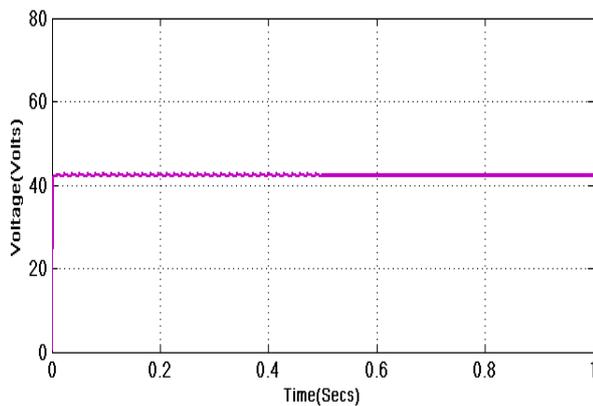


Fig.12.Output Voltage Waveform of the proposed converter when a step change in load from 0.47A to 5.2A at $t=0.5$ sec.

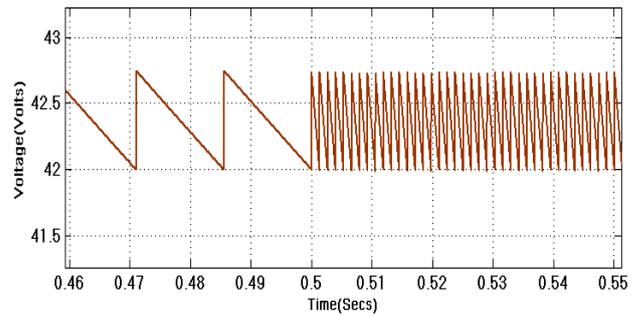


Fig.13.Transient Voltage Deviation (Output Voltage waveform enlarged) of the proposed converter at $t=0.5$ sec.

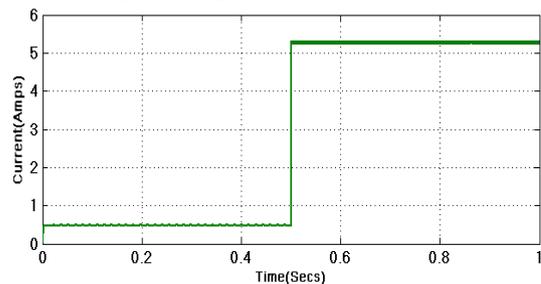


Fig.14.Output Current Waveform of the proposed converter when a step change in load from 0.47A to 5.2A at $t=0.5$ sec.

The MATLAB/Simulink model of the proposed converter by using Sliding Mode controller is shown in Fig.11.

The output voltage shown in Fig.12, undergoes a transient voltage deviation of 0% at $t=0.5$ sec is shown in Fig.13. The output current waveform is shown in Fig.14.

4.4 Table for Comparison

The comparison of the proposed converter in open loop and closed loop mode is tabulated in Table.2.

Mode	Voltage Dip	Settling Time (at $t=0.5$ secs)
Open loop	8.33%	0.015secs
Sliding Mode Controller	0%	0 secs

Table No.2.Tabular form for comparison of proposed converter in open loop and closed loop.

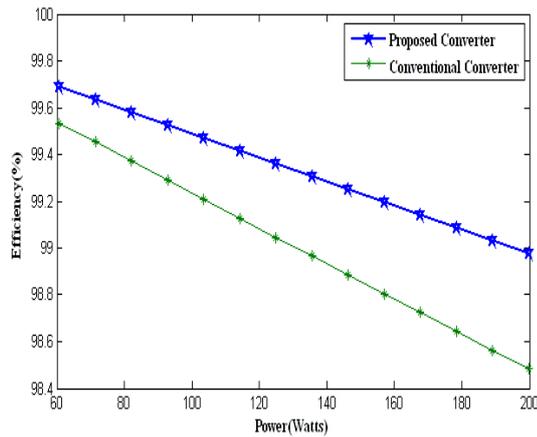


Fig.15. efficiency plot of the proposed and conventional converter in step-up mode.

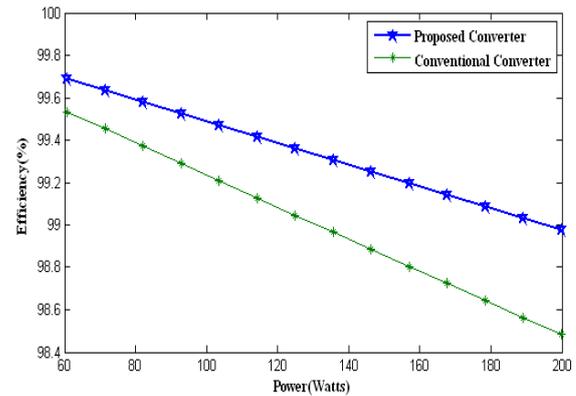


Fig.16. efficiency plot of the proposed and conventional converter in step-down mode.

6. Conclusion

A bidirectional dc-dc converter is designed and simulated in this paper. The dynamic performance of the proposed converter by using Sliding Mode controller is better than the open loop performance and also the proposed converter achieves the higher step-up and step-down voltage gains than conventional converter. The efficiency of the proposed converter in step-up mode is 99.2% and in step-down mode is 88.5% at full load condition.

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