International Journal of Engineering Research And Management (IJERM)
ISSN : 2349- 2058, Volume-01, Issue-06, September 2014

Analysis, Design and Simulation of A Sliding Mode Controlled Bidirectional Dc-Dc Converter

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***Abstract*— This paper describes a bidirectional DC-DC Converter, an advanced DC-DC Converter. The structure of the proposed converter is very simple and employs a coupled inductor with same winding turns on both 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. 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. In this project a 14/42-V circuit is designed for automobile battery system. The simulation is done in MATLAB/Simulink with Sliding Mode Controller using voltage mode control strategy. The simulation results are compared with the open loop mode for verifying steady state as well as dynamic performance of the converter.**

I. INTRODUCTION

The Bidirectional DC-DC Converters are used to transfer the power between two DC-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. Most of the existing bidirectional dc-dc converters fall into the generic circuit structure illustrated in Figure 1, which is characterized by a current fed or voltage fed on one side. Based on the placement of the auxiliary energy storage, the bidirectional dc-dc converter can be categorized into buck and boost type. The buck type is to have energy storage placed on the high voltage side, and the boost type is to have it placed on the low voltage side.

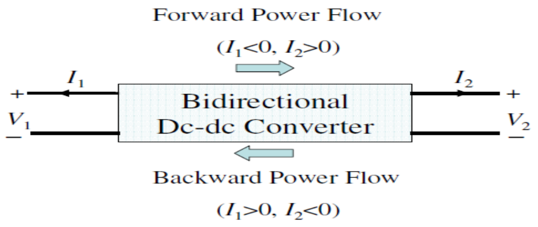

Fig.1 Illustration of Bidirectional Power flow

Manuscript received Sep 03, 2014

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To realize the double sided power flow in bidirectional dc-dc converters, the switch cell should carry the current on both directions. It is usually implemented with a unidirectional semiconductor power switch such as power MOSFET (Metal-Oxide-Semiconductor-Field-Effect-Transistor) or IGBT (Insulated Gate Bipolar Transistor) in parallel with a diode; because the double sided current flow power switch is not available.

II. PROPOSED CONVERTER

The proposed converter employs the coupled inductor with same winding turns in the primary and secondary sides. The Fig.2 shows the circuit diagram of the proposed bidirectional DC-DC converter.

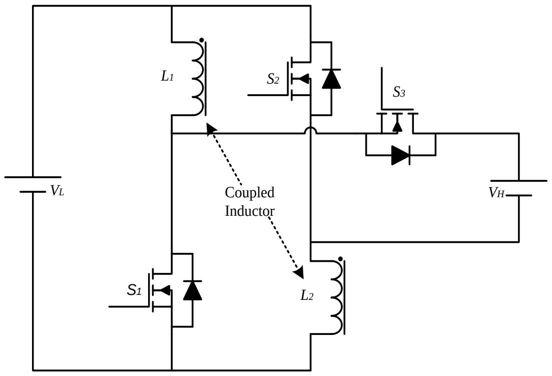


Fig.2.Proposed bidirectional DC-DC converter

This circuit utilizes three switches which are nothing but MOSFET's. The pulse width modulation technique is used to control the switches.

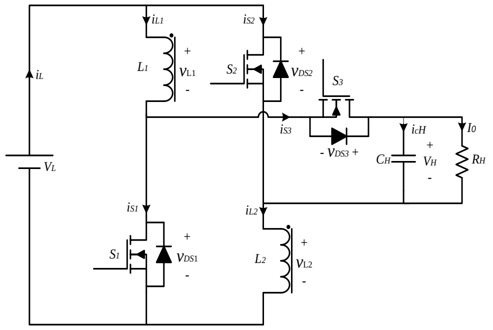
A. Modes of Operation

The proposed bidirectional DC-DC converter operates in two modes

1.Step-up mode
2.Step-down mode

B.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. The pulse width modulation technique is used to control the switches.



Since the primary and secondary windings of the coupled inductor are same, the inductance can be expressed as

$$L_1 = L_2 = L \tag{1}$$

Where L_1 and L_2 are the inductances of the primary and secondary sides of the coupled inductor.

Thus, the mutual inductance M of the coupled inducer can be expressed as

$$M = k\sqrt{L_1L_2} = kL \tag{2}$$

Where k is the coupling coefficient.

The voltages across the coupled inductor can be expressed as follows

$$v_{L1} = L_1\frac{di_{L1}}{dt} + M\frac{di_{L2}}{dt} = L\frac{di_{L1}}{dt} + kL\frac{di_{L2}}{dt} \tag{3}$$

C.Efficiency Analysis

The Equivalent Circuits of the proposed converter in step-up mode is shown below. The equivalent circuit when the switches S_1 and S_2 are turned on and switch $S3$ is turned off is shown in Fig.4. Where r_{L1} and r_{L2} represents the equivalent series resistor of the coupled inductor.r_{S1}, r_{S2} and r_{S3} represents the ON-state resistance of the switches S_1, S_2 and S_3 respectively.

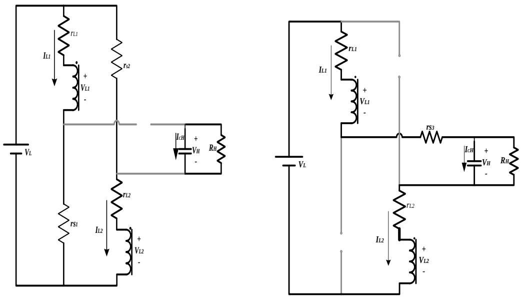


Fig.4. Equivalent circuit of the proposed converter in step-up mode,

$$\eta = \frac{P_o}{P_{in}} = \frac{(1-D)^2R_H}{(1-D)^2R_H + 2D(r_{L1} + r_{S1}) + (1-D)(r_{L1} + r_{L2} + r_{S3})} \tag{4}$$

III. CONTROL STRATEGIES

In control theory, sliding mode control, or SMC, is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position in the state space. Hence, sliding mode control is a variable structure control method. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. Instead, it will slide along the boundaries of the control structures. The motion of the system as it slides along these boundaries is called a sliding mode and the geometrical locus consisting of the boundaries is called the sliding (hyper) surface. In the context of modern control theory, any variable structure system, like a system under the SMC, may be viewed as a special case of a hybrid dynamical system as the system both flows through a continuous state space but also moves through different discrete control modes. The basic block diagram of the proposed converter is shown on Fig.5.

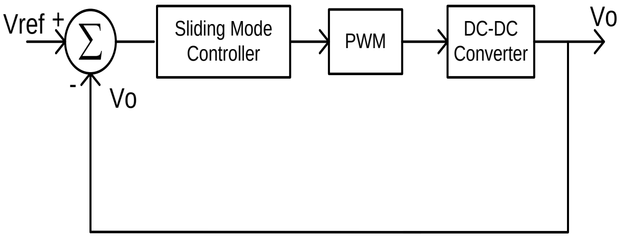


Fig.5. Basic block diagram of the Proposed Converter using Sliding Mode Controller

IV. SIMULATION AND RESULTS

The simulink model of the proposed converter is developed using the key parameters that are tabulated in Tab.1.

Parameter	Step-up	Step-down
Input Voltage V_{in}	14v	42v
Output Voltage V_o	42v	14v
Switching Frequency f_s	50KHz	50KHz
Power P_o	200W	200W
Mutual Inductance L_1,L_2	15.5µH	15.5µH
Capacitance C_L,C_H	330 µF	330 µF

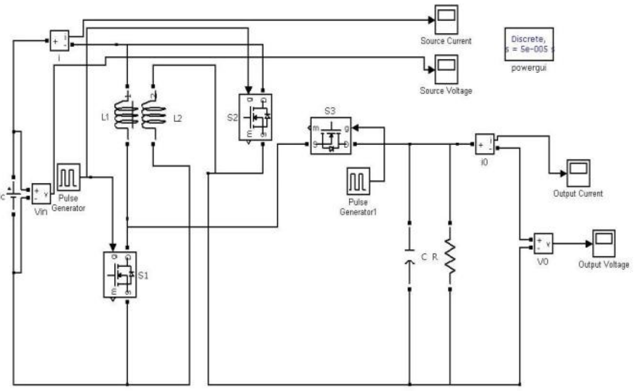


Fig.6.Simulink model in step-up mode

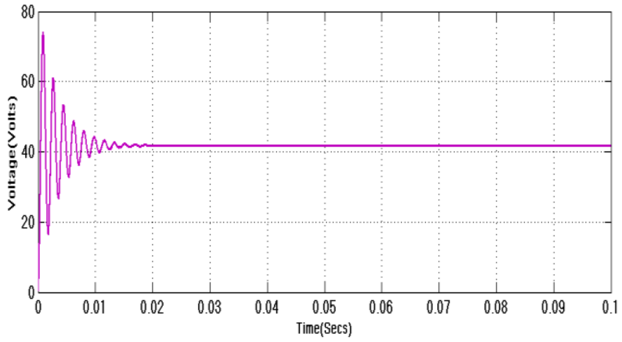


Fig.7 .Output voltage in step-up mode

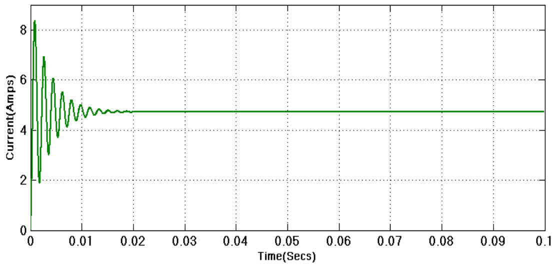


Fig.8.Output current in step-up mode

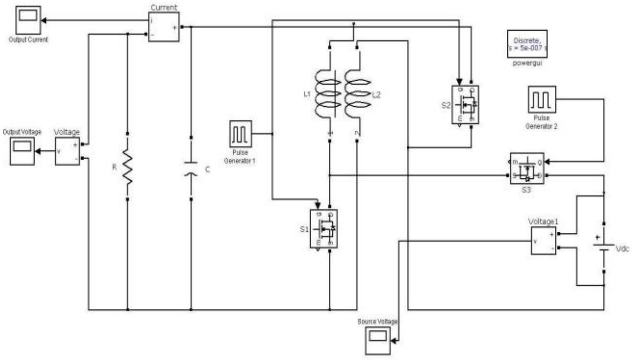


Fig.9.Simulink model in step-down mode

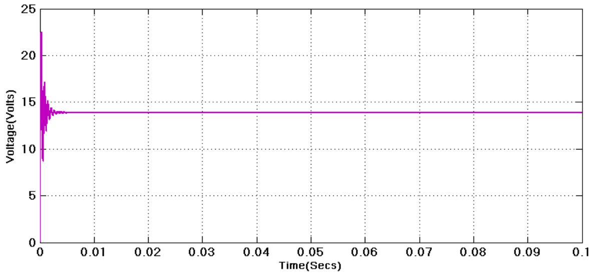


Fig.10.Output voltage in step-down mode

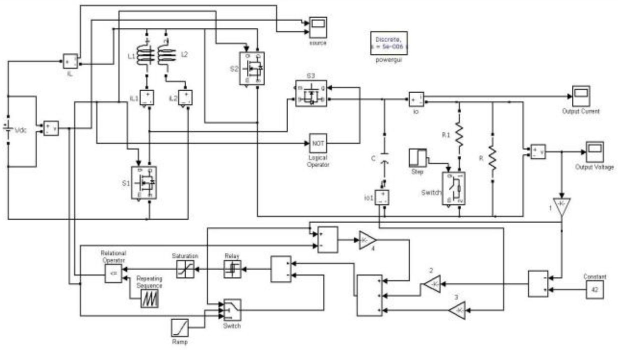


Fig.11.Simulink model for a step change in load from 0.47 to 5.2A at time t=0.5sec with sliding mode controller

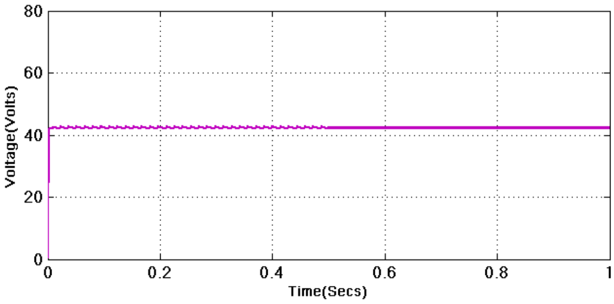


Fig.12.Output voltage for a step change in load from 0.47A to 5.2A at time t=0.5sec

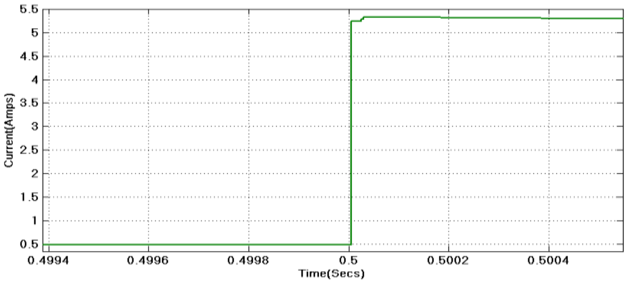


Fig.13.Output current for a step change in load from 0.47A to 5.2A at time t=0.5sec

The steady state and dynamic performance comparison for the proposed converter in open loop and closed loop modes in terms of steady state voltage ripple, transient voltage deviation and transient settling time are tabulated in Table.2

Mode	Transient settling time for a step change in load	Voltage Ripple
Open loop	0.015sec	2.6%
Sliding Mode Controller	0 sec	2.6%

A.Efficiency Analysis

The efficiency plots of the proposed converter and conventional bidirectional DC-DC converter for both step-up and step down modes under the full load condition is shown in the figures 14 and 15.

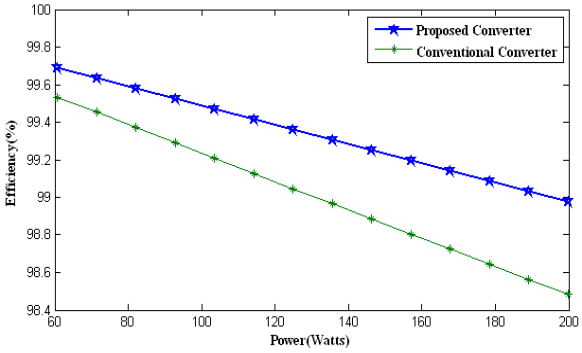


Fig.14.Efficiency plot of the proposed converter in step –up mode

.The efficiency of the proposed converter in step-up mode at full load condition (200W) is 99.1% and in conventional converter it is 98.5%.Thus, the proposed converter in step-up mode achieves the better efficiency than the conventional converter under the full load condition.

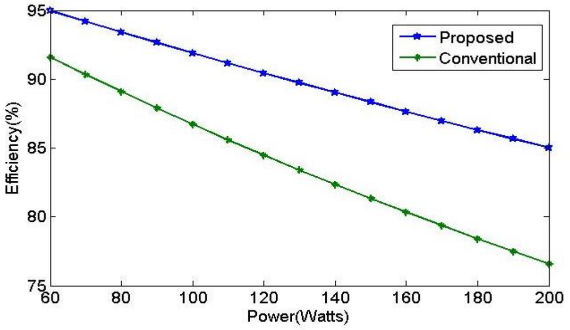


Fig.15Efficiency plot of the proposed converter in step –down mode.

.The efficiency of the proposed converter in step-down mode under full load condition (200W) is 86.5% % and in conventional converter it is 77.5%.Thus, the proposed converter in step-down mode achieves the better efficiency than the conventional converter under the full load condition.

CONCLUSION

In this project the bidirectional DC-DC converter is designed and simulated in Closed Loop Mode with Sliding Mode Controllers. The Fuzzy Logic controller gives better steady state as well as dynamic performance compared to the Sliding Mode Controller. Also, the proposed converter achieves higher step-up and step-down voltage gains than conventional bidirectional boost/buck converter. The theoretical efficiency of the proposed converter in step-up mode is 99.2% and in step-down mode is 88.5% at full load condition, which is higher than the conventional converter.

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