An Isolated Bi-Directional Buck Boost Converter with Fly Back Snubber

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Abstract

In renewable DC systems bi-directional DC-DC converters are used for high voltage and high power applications. One such isolated bi-directional full bridge buck boost converter with a flyback snubber that has significant voltage spike clamping capability is proposed in this project.. An isolated bidirectional full-bridge dc–dc converter with high conversion ratio, high output power, and soft start-up capability is also proposed. The use of a capacitor, a diode and a flyback converter can clamp the voltage spike caused by the current difference between the current-fed inductor and leakage inductance of the isolation transformer and can reduce the current flowing through the active switches at the current-fed side. The simulated model of the conventional converter without flyback snubber,proposed converter with flyback snubber as well as modification of the proposed method with RCD snubber is developed in MATLAB software for both buck and boost modes.

Keywords: Buck Boost, Flyback Snubber

I. INTRODUCTION

Over the past decade buck-boost converters have become an important research topic with major focus on voltage spike reduction. The major concerns of these studies include reducing switching loss, reducing voltage and current stresses, and reducing conduction loss due to circulation current. A more severe issue is due to leakage inductance of the isolation transformer, which will result in high voltage spike during switching transition.

Additionally, the current freewheeling due to the leakage inductance will increase conduction loss and reduce effective duty cycle. Several approaches have been suggested to alleviate voltage spike few are stated below, Pre-charging leakage inductance, Active clamp circuit etc.

T. Reimann and G. Berger(2008) has proposed a novel control principle of bi-directional DC-DC power conversion is an alternative approach to pre-charge the leakage inductance to raise its current level up to that of the current-fed inductor, which can reduce their current difference and, in turn, reduce voltage spike has been proposed. However, since the current level varies with load condition, it is hard to tune the switching timing diagram to match these two currents.

S.Yujin and P.N. Enjeti(2009) has proposed a newsoft switching technique for bi-directional power flow full-bridge DC-DC converter is that an active commutation principle to control the current of leakage inductance. however, clamping circuits are additionally required. Passive and active clamping circuits have been proposed to suppress the voltage spikes due to the current difference between the current-fed inductor and leakage inductance of the isolation transformer. An active clamping circuit has been proposed to suppress voltage spike due to the current difference by controlling the current of leakage inductance. But its resonant current increases the current stress on switches.

Hua Bai and Chris Mi(2008) has described reactive power elimination and increase system efficiency of isolated bidirectional dual-active bridge dc-dc converters using novel dual-phase-shift control states that a novel dual-phase-shift (DPS) control strategy for a dual-active-bridge isolated bidirectional dc–dc converter.

This DPS control consists of a phase shift between the primary and secondary voltages of the isolation transformer, and a phase shift between the gate signals of the diagonal switches of each H-bridge. It shows that the DPS control has excellent dynamic and static performance compared to traditional phase-shift control (single phase shift). In this paper, the concept of reactive power is defined and the corresponding equations are derived for isolated bidirectional dc–dc converters.

It is shown that the reactive power in traditional phase-shift control is inherent, and is the main factor contributing to large peak current and large system loss.The DPS control can eliminate reactive power in isolated bidirectional dc–dc converters. In addition, the DPS control can decrease the peak inrush current and steady-state current, improve system efficiency, increase system power capability (by 33%), and minimize the output capacitance as compared to the traditional phase-shift control.
The soft-switching range and the influence of short-time-scale factors, such as deadband and system-level safe operation area, are also discussed in detail. Under certain operation conditions, deadband compensation can be implemented easily in the DPS control without a current sensor.

Hua Bai and S. Gargies(2008) has described the short-time-scale transient processes in high-voltage and high-power isolated bidirectional DC-DC converters is that the effect of deadband and the influence of phase-shift error. It also discusses the energy flow during the deadband and introducesa definition of energy deadband to describe the condition during steady state and transients where no energy flows from source to load or load to source, but only from the leakage inductance to load and sources. Chuanhong Zhao and Simon D. Round(2008) has proposed an isolated three-port bidirectional DC-DC converter with decoupled power flow management is that the minimum overall system losses, managing the power flow between the ports, utilization of the duty cycle control for optimizing the system behavior combined with the phase-shift control between the high-frequency ac voltages generated by the full-bridge cells.

Controlling the power flow independently is implemented through the use of a decoupling network.This converter is suitable for multiple voltage electrical systems where a storage element is required such as in renewable energy generation systems powered by solar and fuel cells.

R. Huang and S. K. Mazumder(2008) has described a soft-switching scheme for an isolated DC/DC converter with pulsating DC output for a three-phase high frequency-link PWM converter is a detailed analysis of soft-switching mechanism based on zero-voltage-zero-current-switching (ZVZCS) principle for the front-end isolated dc/dc converter of an isolated three-phase rectifier-type high-frequency-link bidirectional power converter.

H. Xiao and S. Xie(2008) has designed a ZVS bidirectional dc-dc converter with phase-shift plus PWM control scheme is presents a current-voltage-fed bidirectional dc–dc converter, which refers to a current-fed inverter at low voltage side and a voltage-fed inverter at high voltage side, can realize zero voltage switching (ZVS) for the switches with the use of phase-shift (PS) technology.

W. Qu and Y. Liu(2009) has described a zero-voltage-switching bidirectional DC-DC converter with state analysis and soft-switching-oriented design consideration is that the converter achieved zero-voltage switching (ZVS) for the entire main switches and zero-current switching for the rectifier diodes in the large-load range. These features reduce switching loss, voltage and current stresses, and diode reverse-recovery effect.

K. Wang and C. Y. Lin(1998) has described bi-directional DC to DC Converters for Fuel Cell Systems is that the need of a bi-directional dc to dc converter for a fuel cell system. Various combinations of current-fed and voltage-fed converters are explored for the application of different voltage levels. With a preliminary study, putting current-fed on low-voltage side and voltage-fed on high-voltage side indicated higher efficiency than the other way around. Two low-side circuit topologies were then selected for hardware implementation.

One is the L-type half-bridge current-fed converter and the other is full-bridge current-fed converter. The high-side circuit topology is fixed with a full bridge voltage-fed converter. Two systems were built and tested to full power. The results indicate that the combination with the full-bridge converter on the low-voltage side is more efficient than the combination with the L-type half-bridge converter on the low-voltage side for both charging and discharging modes.The main drawback is L-type converter under discharging is inefficient due to passive clamp circuit and relatively high device conduction drop.

A. Circuit Configuration

The proposed isolated bidirectional full-bridge dc–dc converter with a fly back snubber is shown in Fig.3.2. The converter is operated with two modes: buck mode and boost mode. It consists of a current-fed switch bridge, a fly back snubber at the low-voltage side, and a voltage-fed bridge at the high-voltage side. Inductor L_m performs output filtering when power flows from the high-voltage side to the batteries, which is denoted as a buck mode.

On the other hand, it works in boost mode when power is transferred from the batteries to the high-voltage side. Furthermore, clamp branch capacitor C_C and diode D_C are used to absorb the current difference between current-fed inductor L_m and leakage inductance L_{ll} and L_{lh} of isolation transformer T_x during switching commutation.

The fly back snubber can be independently controlled to regulate V_c to the desired value, which is just slightly higher than V_{AB} .

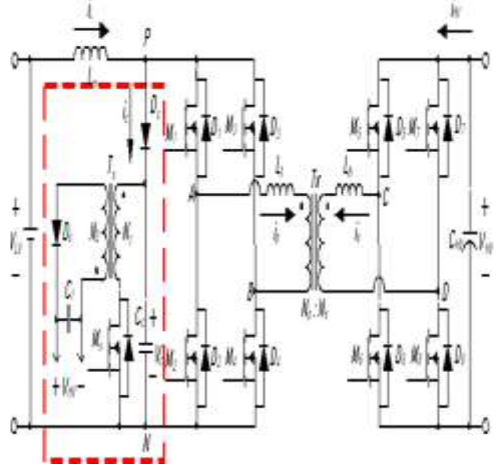

Fig. 1: Proposed circuit diagram

Thus, the voltage stress of switches $M1$–$M4$ can be limited to a low level. The major merits of the proposed converter configuration include no spike current circulating through the power switches and clamping the voltage across switches $M1$–$M4$, improving system reliability significantly. Note that high spike current can result in charge migration, over current density, and extra magnetic force, which will deteriorate in MOSFET carrier density, channel width, and wire bonding and, in turn, increase its conduction resistance.

II. CIRCUIT OPERATION

A bidirectional dc–dc converter has two types of conversions: step-up conversion (boost mode) and step-down conversion (buck mode). In boost mode, switches $M1$–$M4$ are controlled, and the body diodes of switches $M5$–$M8$ are used as a rectifier. In buck mode, switches $M5$–$M8$ are controlled, and the body diodes of switches $M1$–$M4$ operate as a rectifier. To simplify the steady-state analysis, several assumptions are made, which are as follows.

1) All components are ideal. The transformer is treated as an ideal transformer associated with leakage inductance.
2) Inductor L_m is large enough to keep current i_L constant over a switching period.
3) Clamping capacitor CC is much larger than parasitic capacitance of switches $M1$–$M8$.

In boost mode, switches $M1$–$M4$ are operated like a boost converter, where switch pairs ($M1$, $M2$) and ($M3$, $M4$) are turned ON to store energy in L_m. At the high-voltage side, the body diodes of switches $M5$–$M8$ will conduct to transfer power to V_{HV} . When switch pair ($M1$, $M2$) or ($M3$, $M4$) is switched to ($M1$, $M4$) or ($M2$, $M3$), the current difference i_C (= $i_L - i_P$) will charge capacitor C_C, and then, raise i_p up to i_l .

The clamp branch is mainly used to limit the transient voltage imposed on the current-fed side switches. Moreover, the fly back converter can be controlled to charge the high-voltage-side capacitor to avoid over current. The clamp branch and the fly back snubber are activated during both start-up and regular boost operation modes.

A non phase-shift PWM is used to control the circuit to achieve smooth transition from start-up to regular boost operation mode. A detailed description of a half-switching cycle operation is shown as follows.

Mode 1 [$t_0 \leq t < t_1$]

In this mode, all of the four switches $M1$–$M4$ are turned ON. Inductor L_m is charged by V_{LV}, inductor current i_L increases linearly at a slope of V_{LV} /L_m, and the primary winding of the transformer is short-circuited. The equivalent circuit is shown in Fig.3.3.

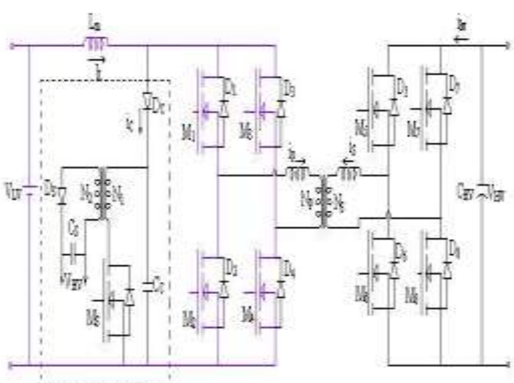

Fig. 2: Mode 1 (M_1-M_4 ON and L_m charged)

Mode 2 [$t_1 \leq t < t_2$]

At t_1, $M1$ and $M4$ remain conducting, while $M2$ and $M3$ are turned OFF. Clamping diode D_C conducts until the current difference (i_L ($t2$) – i_P ($t2$)) drops to zero at $t = t_2$. Moreover, the body diodes of switch pair ($M5$, $M8$) are conducting to transfer power. During this interval, the current difference (i_L (t) − ip (t)) flows into clamping capacitor C_C . The equivalent circuit is shown in Fig.3.4.

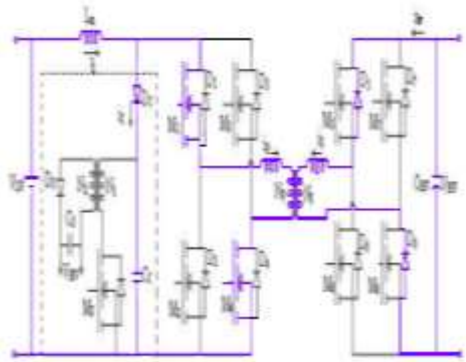

Fig. 3: Mode 2 (M_2 -M_3 -OFF,D_5-D_8 Power transfer and D_c conducts)

Mode 3 [$t_2 \leq t < t_3$]

At t_2 , clamping diode D_c stops conducting, and the flyback snubber starts to operate. At this time, clamping capacitor C_c is discharging, and flyback inductor is storing energy. Switches *M*1 and *M*4 still stay in the ON state, while *M*2 and *M*3 remain OFF. The body diodes of switch pair (*M*5, *M*8) remain ON to transfer power. The equivalent circuit is shown in Fig.3.5.

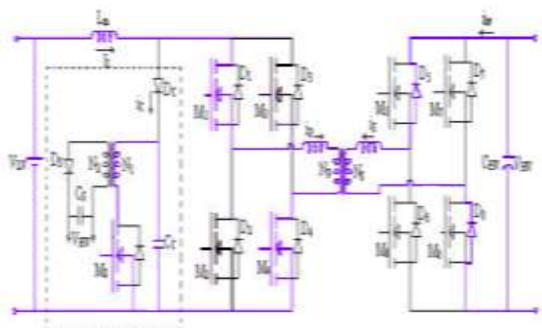

Fig. 4: Mode 3(D_c OFF, C_c discharges and flyback stores energy)

Mode 4 [$t_3 \leq t < t_4$]

At t_3 , the energy stored in flyback inductor is transferred to the high-voltage side. Over this interval, the flyback snubber will operate independently to regulate V_C to V_C (*R*) . On the other hand, switches *M*1 and *M*4 and diodes *D*5 and *D*8 are still conducting to transfer power from V_{LV} to V_{HV} .The equivalent circuit is shown in Fig.3.6.

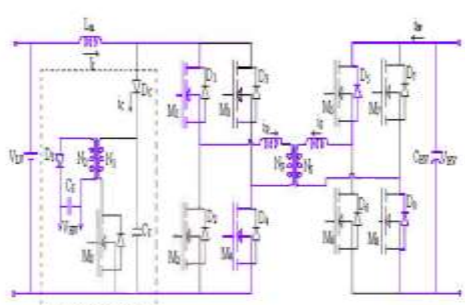

Fig. 5: Mode 4(flyback transfer energy to HV side)

Mode 5 [$t_4 \leq t < t_5$ **]**

At t_4, capacitor voltage V_C has been regulated to V_C (*R*) , and the snubber is idle. Over this interval, the main power stage is still transferring power from V_{LV} to V_{HV} . It stops at t_5 and completes a half-switching cycle operation. The equivalent circuit is shown in Fig.3.7.

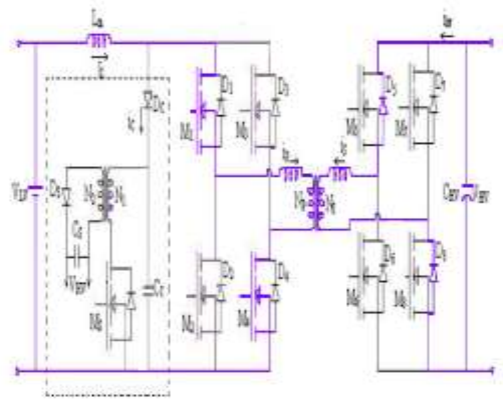

Fig. 6: Mode 5 (V_c regulated and snubber becomes idle)

The operation waveforms of step-up conversion are shown in Fig.3.8.

III. SIMULATION RESULTS AND DISCUSSION

The simulation is done for both buck and boost modes of operation for the proposed circuit,hardware prototype as well as for the modification of proposed circuit . MATLAB version 7.11 is used for the simulation.

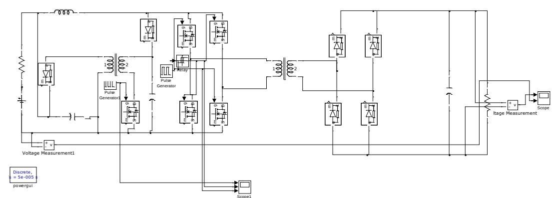

Fig. 7: Proposed circuit simulation diagram diagram

In boost mode, switches $M1$–$M4$ are operated like a boost converter, where switch pairs ($M1$, $M2$) and ($M3$, $M4$) are turned ON to store energy in L_m. At the high-voltage side, the body diodes of switches $M5$–$M8$ will conduct to transfer power to V_{HV} . When switch pair ($M1$, $M2$) or ($M3$, $M4$) is switched to ($M1$, $M4$) or ($M2$, $M3$), the current difference i_C (= $i_L - i_P$) will charge capacitor C_C, and then, raise i_p up to i_l .

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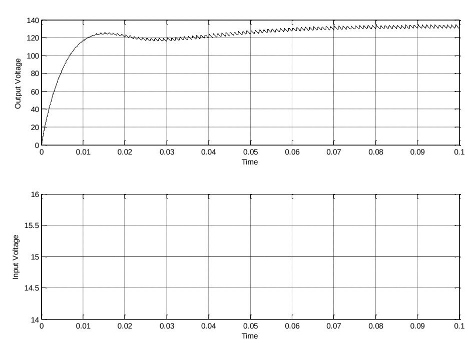

Fig. 8: Input and Output waveforms

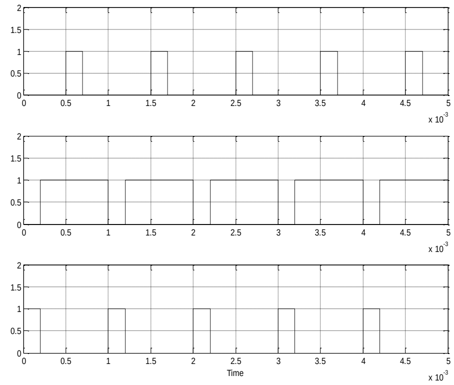

Fig. 9: Switching pulse waveforms

IV. CONCLUSIONS

This project has presented an isolated bidirectional full-bridge buck–boost converter with a flyback snubber for high-power applications. The flyback snubber can alleviate the voltage spike caused by the current difference between the current-fed inductor and leakage inductance of the isolation transformer, and can reduce the current flowing through the active switches at the current-fed side. Since the current does not circulate through the full-bridge switches, their current stresses can be reduced dramatically under heavy-load condition, thus improving system reliability significantly.

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