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# Isolated bidirectional full-bridge dc–dc converter with fly back snubber for high-power applications

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*GJRE-F Classification : FOR Code: 090604,090699*

ISOLATEDBIDIRECTIONALFULL-BRIDGEDCDCCONVERTERWITHFLYBACKSNUBBERFORHIGH-POWERAPPLICATIONS

*Strictly as per the compliance and regulations of:*

# Isolated bidirectional full-bridge dc–dc converter with fly back snubber for high-power applications

K.Banu priya [α], JBV Subrahmanyam [σ], Ch.Srikanth [ρ] PK Sahoo [Ѡ] & Bandana [¥]

*Abstract -* This paper introduces a flyback snubber to recycle the absorbed energy in the clamping capacitor. The flyback snubber can be operated independently to regulate the voltage of the clamping capacitor; therefore, it can clamp the voltage to a desired level just slightly higher than the voltage across the low-side transformer winding. 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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## I. Introduction

Power electronic converters are used extensively in personal electronics, power systems, hybrid electric vehicles (HEVs), and many other applications to provide dc voltage sources and manage power flow by switching actions .To obtain high power quality, switching control strategies that can achieve high performances are attracting more and more attention .[1]

Many advanced control strategies, such as fuzzy-neural control or sliding-mode control, have been proposed to enhance the steady-state and dynamic performance of power electronic systems. Although these control strategies are predicted to be promising in more complex-structured converters, such as dual-active-bridge (DAB) and dc–dc converters. Most of the present applications are still confined to simple structured circuits, such as buck, boost, and half-bridge converters.[1]

Compared to traditional dc–dc converter circuits, isolated bidirectional DAB dc–dc converters have many advantages, such as electrical isolation, high reliability, ease of realizing soft-switching control, and bidirectional energy flow.[1]

A double-phase-shift control for a unidirectional three-level converter is proposed in. The phase shift is implemented on the primary side. A start-up circuit to suppress the inrush current with a set of auxiliary circuits is proposed.[2]

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The dc–dc converter is a key component in hybrid electric vehicles (HEVs) to manage power flow and maintain battery health. Electrical isolation may be required to provide safe operation for the equipment operated on the hybrid battery, such as in military applications. State-of-the-art isolated dc–dc converters are generally based on single-phase full-bridge topologies with isolation transformers. An isolated bidirectional dc–dc converter, which consists of dual H-bridges located on the primary and secondary sides of an isolated transformer, respectively.[3]

The primary bridge consists of four switches, Q1, Q2, Q3 and Q4, which are commonly insulated gate bipolar transistors (IGBTs) for high-power applications. The second H-bridge also consists of four switches, Q5, Q6, Q7, and Q8, which are connected to the secondary winding of the transformer. With a phase-shift control algorithm, the first H-bridge provides a square wave with duty ratio of 50% to the primary winding of the high-frequency transformer.[3]

In traditional unidirectional dc–dc converters, the power ratings are generally low, and the switching frequency is relatively high (for MOSFET or Si C, turning on and off processes are both in the nanosecond level). Therefore, there is, generally, no need to deal with dead band effect. However, in high-voltage and high-power isolated bidirectional dc–dc converters, the dead band and phase-shift error will greatly affect the operation of the converter, both in steady-state and transient processes. These issues generally deteriorate the operational performance, or even damage the system under some specific switching conditions because of large unexpected current and voltage spikes.[4]

A few integrated multi-port dc-dc converter topologies are found in the literature. There are two categories for the integrated isolated multi-port converter. One type of converter involves a transformer in which there is a separate winding for each port, therefore all ports are fully electrically isolated. The other type has a reduced parts count where some windings are absent, if the system allows the corresponding ports to share a common ground.[4]

A dual active full bridge dc-dc converter was proposed for high power BDC , which employs two voltage-fed inverters to drive each sides of a transformer. Its symmetric structure enables the bidirectional power flow and ZVS for all switches. A dual active half bridge current-voltage-fed soft-switching bidirectional dc-dc converter was proposed with reduced power components however, the current-fed half bridge suffers from a high voltage spike because of the leakage inductance of the transformer. When the voltage amplitude of the two sides of the transformer is not matched, the current stresses and circulating conduction losses become higher.[5]

In addition, these converters cannot achieve ZVS in low-load condition. These disadvantages make it not suitable for large variation of input or output voltage condition. An asymmetry bidirectional dc-dc converter with Phase shift plus PWM (PSP) control was proposed in, the circulating conduction loss is reduced. The converter with an active clamping branch avoids the voltage spike, achieves Zero Voltage Switching and restrains the start-inrush current.[6]

The demands of a bidirectional dc/dc converter are high frequency, high power density, high efficiency and high reliability. Nevertheless, the conventional bidirectional dc/dc converters still have some drawbacks: Electric insulation and soft switching is difficult to realize, and the reverse-recovery effect of the rectifier diode restricts the switching speed. These defects limit the high-frequency power conversion applied in a bidirectional dc/dc converter. Therefore, an isolated bidirectional dc/dc converter with soft switching is the best way to meet the previously mentioned demands.[7]

## II. Configuration & Operation

The proposed isolated bidirectional full-bridge dc–dc converter with a fly back snubber is shown in Fig.1 The converter is operated in two modes: buck mode and boost mode. Fig.1 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 $Lm$ 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 $CC$ and diode $DC$ are used to absorb the current difference between current-fed inductor $Lm$ and leakage inductance $Ll l$ and $Llh$ of isolation transformer $Tx$ during switching commutation. The fly back snubber can be independently controlled to regulate $VC$ to the desired value, which is just slightly higher than $V_{AB}$. 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. 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 $Lm$ is large enough to keep current $iL$ constant over a switching period.
3. Clamping capacitor $CC$ is much larger than parasitic capacitance of switches $M1$–$M8$ [7]

## III. Step-up Conversion

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 $Lm$. At the high-voltage side, the body diodes of switches $M5$–$M8$ will conduct to transfer power to $VHV$ . When switch pair ($M1$ , $M2$) or ($M3$ , $M4$ ) is switched to ($M1$ , $M4$) or ($M2$ , $M3$ ), the current difference $iC$ (= $iL$ − $ip$ ) will charge capacitor $CC$ , and then, raise $ip$ up to $iL$ . 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. Referring to Fig, the average power $PC$ transferred to $CC$ can be determined as follows:

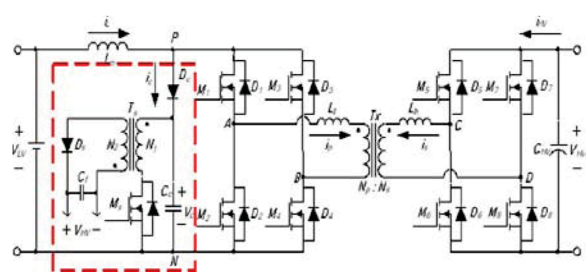

*Fig.1 :* Isolated bidirectional full-bridge dc–dc converter with a fly back snubber

$$P_C = \frac{1}{2} C_C [(i_L Z_o)^2 + 2 i_L Z_o V_{C(R)}] f_s \qquad (1)$$

where

$$Z_o = \sqrt{\frac{L_{eq}}{C_C}}$$

$$L_{eq} = L_{ll} + L_{lh} \frac{N_P^2}{N_S^2}$$

*VC* (*R*) stands for a regulated *VC* voltage, which is close to (*VHV* (*NP* /*NS* )), *fs* is the switching frequency, and *Lm* _*L*eq. Power *PC* will be transferred to the high-side voltage source through the fly back snubber, and the snubber will regulate clamping capacitor voltage *VC* to *VC* (*R*) within one switching cycle *Ts* (=1/*fs* ). Note that the fly back snubber does not operate over the interval of inductance current *ip* increasing toward *iL*. The processed power *PC* by the fly back snubber is typically around 5% of the full-load power for low-voltage applications. With the fly back snubber, the energy absorbed in *CC* will not flow through switches *M*1–*M*4, which can reduce their current stress dramatically when *L*eq is significant. Theoretically, it can reduce the current stress from 2*iL* to *iL* . The peak voltage *VC* (*P*) of *VC* will impose on *M*1–*M*4 and it can be determined as follows:

$$V_{C(P)} = i_{L(M)} Z_o + V_{HV} \frac{N_p}{N_s} \qquad (2)$$

Where *iL* (*M*) is the maximum inductor current of *iL*, which is related to the maximum load condition. Additionally, for reducing conduction loss, the high-side switches *M*5–*M*8 are operated with synchronous switching. Reliable operation and high efficiency of the proposed converter are verified on a prototype designed for alternative energy applications. The operation waveforms of step-up conversion are shown in Fig.6 A detailed description of a half-switching cycle operation is shown in fig.2

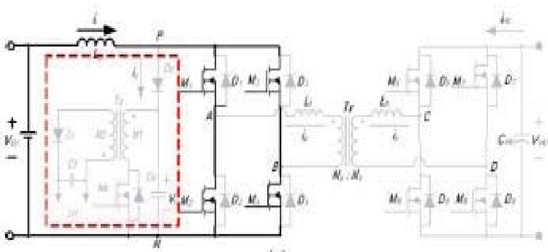

*Fig.2 :* Boost modes 1and 2

Mode 1 [t0≤ t < t1 ]: Mode 2 [t1≤ t < t2 ]:

In these modes, all of the four switches M1–M4 are turned ON. Inductor Lm is charged by VLV, inductor current iL increases linearly at a slope of VLV /Lm, and the primary winding of the transformer is short-circuited. The equivalent circuit is shown in Fig.2

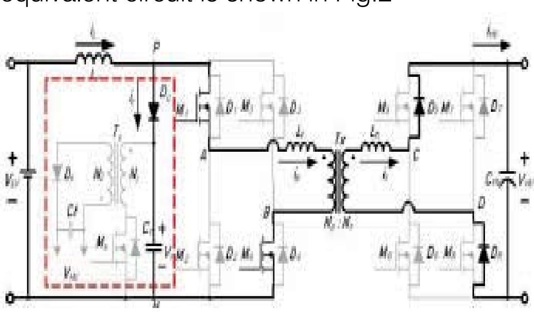

*Fig.3 :* Boost mode 3 [t2<t<t3]

Mode 3 [t2 ≤ t < t3 ]:

At t2, clamping diode Dc stops conducting, and the fly back snubber starts to operate. At this time, clamping capacitor Cc is discharging, and fly back inductor is storing energy. Switches M1 and M4 still stay in the ON state, while M2 and M3 remain OFF. The body diodes of switch pair (M5 , M8 ) remain ON to transfer power. The equivalent circuit is shown in Fig.3

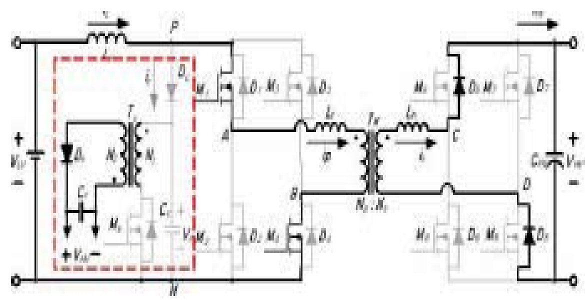

*FIG 4 :* BOOST MODE 4 [t3<t<t4]

Mode 4 [t3 ≤t<t4 ]:

At t3, the energy stored in fly back inductor is transferred to the high-voltage side. Over this interval, the fly back snubber will operate independently to regulate VC to VC (R). On the other hand, switches M1 and M4 and diodes D5and D8 are still conducting to transfer power from VLV to VHV .The equivalent circuit is shown in Fig.4

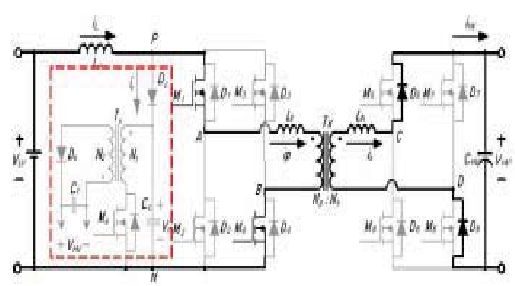

*FIG 5 :* BOOST MODE 5 [t4<t<t5]

Mode 5 [t4 ≤ t < t5]:

At t4, capacitor voltage VC has been regulated to VC (R) , and the snubber is idle. Over this interval, the main power stage is still transferring power from VLV to VHV. It stops at t5 and completes a half-switching cycle operation.[7]The equivalent circuit is shown in Fig.5

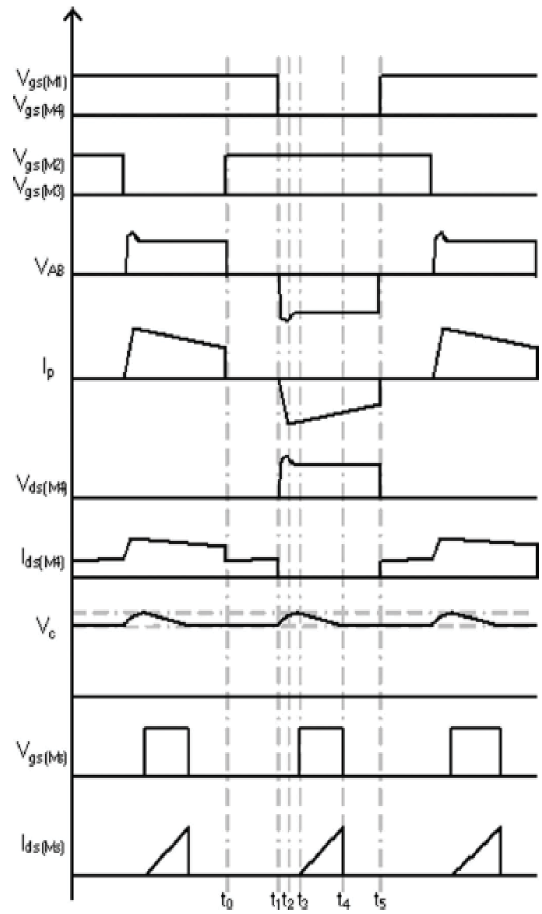


*Fig.6 :* Operation waveforms of step-up conversion.

## IV. Step-Down Conversion

In the analysis, leakage inductance of the transformer at the low-voltage side is reflected to the high-voltage side, as shown in Fig. 4, in which equivalent inductance *Leq* equals(*Llh* + *Lll* (*N2p_N2 s* )). This circuit is known as a phase-shift full-bridge converter. In the step-down conversion, switches *M5*–*M8* are operated like a buck converter, in which switch pairs (*M5* , *M8* ) and (*M6* , *M7* ) are alternately turned ON to transfer power from *VHV* to *VLV*. Switches *M1*–*M4* are operated with synchronous switching to reduce conduction loss. For alleviating leakage inductance effect on voltage spike, switches *M5*–*M8* are operated with phase-shift manner. Although, there is no need to absorb the current difference between *iL* and *ip* , capacitor *CC* can help to clamp the voltage ringing due to *Leq* equals (*Lll* + *Llh* (*N2p_N2s* )) and parasitic capacitance of *M1*–*M4* .The operation waveforms of step-down conversion are shown in Fig.12. A detailed description of a half-switching cycle operation is shown as follows.

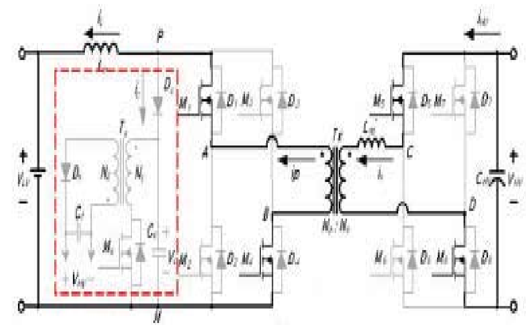

*Fig.7 :* Buck mode 1

Mode 1 [t0 ≤ t < t1 ]:

In this mode, M5 and M8 are turned ON, while M6 and M7 are in the OFF state. The high-side voltage VHV is immediately exerted on the transformer, and the whole voltage, in fact, is exerted on the equivalent inductance L*eq and causes the current to rise with the slope of VHV /L*eq. With the transformer current increasing linearly toward the load current level at t1 , the switch pair (M1 , M4 ) are conducting to transfer power, and the voltage across the transformer terminals on the current-fed side changes immediately to reflect the voltage from the voltage-fed side, i.e., (VHV (Np /Ns )). The equivalent circuit is shown in Fig.7

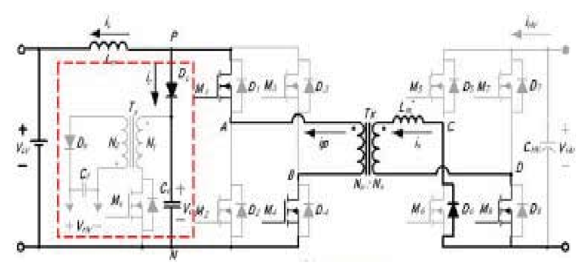

*Fig.8 :* Buck mode 2

Mode 2 [t1 ≤t<t2 ]:

At t1,M8 remains conducting, whileM5 is turned OFF. The body diode of M6 then starts to conduct the freewheeling leakage current. The transformer current reaches the load-current level at t1 , and VAB rise to the reflected voltage (VHV (Np /Ns )). Clamping diode Dc starts to conduct the resonant current of Leq and the clamp capacitor CC . This process ends at t2 when the resonance goes through a half resonant cycle and is blocked by the clamping diode Dc. The equivalent circuit is shown in Fig.8

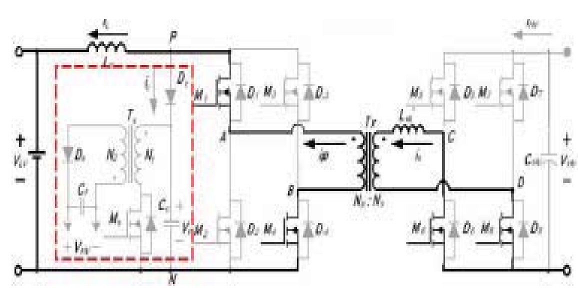

*FIG. 9 :* Buck Mode 3

Mode 3 [t2 ≤ t < t3 ]:

At t2 , with the body diode of switchM6 conducting, M6 can be turned ON with zero-voltage switching (ZVS). The equivalent circuit is shown in Fig.9

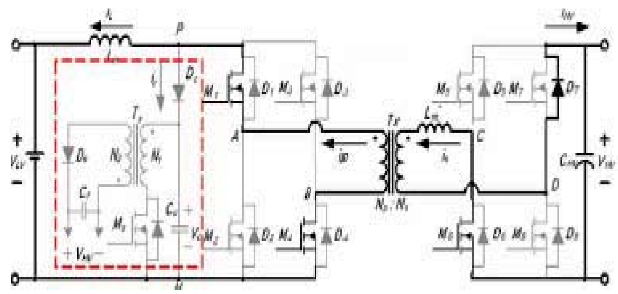

*FIG.10 :* Buck Mode 4

Mode 4 [t3 ≤t<t4 ]:

At t3 ,M6 remains conducting, whileM8 is turned OFF. The body diode of M7 then starts to conduct the freewheeling leakage current. The equivalent circuit is shown in Fig.10

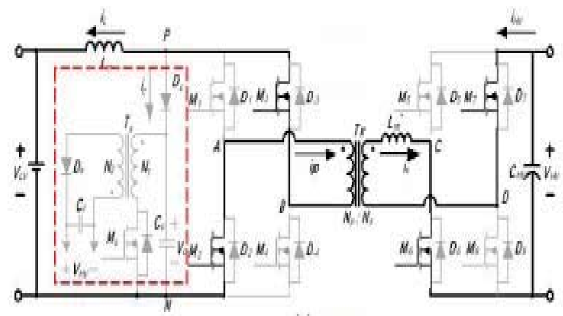

*Fig.11 :* Buck Mode 5

Mode 5 [t4 ≤ t < t5 ]:

At t4 , with the body diode of switch M7 conducting, M7 can be turned ON with ZVS. Over this interval, the active switches change to the other pair of diagonal switches, and the voltage on the transformer reverses its polarity to balance flux. It stops at t5 and completes a half-switching cycle operation. [7]
The equivalent circuit is shown in Fig.11

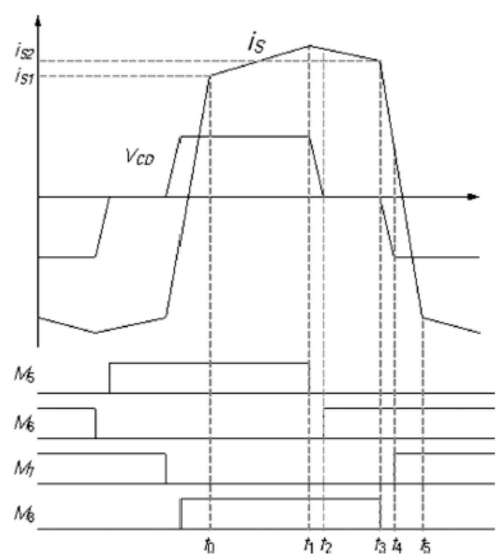


*Fig. 12 :* Operation waveforms of step-down conversion

*a) Practical Consideration*

i. *Low-Voltage Side*

Switch pairs (M1,M4) and (M2,M3) are turned ON alternately under any load condition. Its minimum conduction time is

$$T_{C(\min)} = \frac{L_{\text{eq}} i_L}{V_{AB}}. \qquad (3)$$

ii. *Clamping Capacitor*

For absorbing the energy stored in the leakage inductance and to limit the capacitor voltage to a specified minimal value Vc, l, capacitance Cc has to satisfy the following inequality

$$C_c \geq \frac{L_{\text{eq}}(i_L - i_P)^2}{V_{C,l}^2}. \qquad (4)$$

iii. *Fly back Converter*

In the interval of t1 ≤ t ≤ t2 , the high transient voltage occurs inevitably in boost mode, which could be suppressed by the clamp branch (Dc , Cc ). The energy stored in capacitor Cc is transferred to the high-voltage side via a fly back converter. The regulated voltage level of the fly back converter is set between 110%–120% of the steady-state voltage at the low-voltage side. Power rating of the fly back converter can be expressed as follows:

$$P_{FB} = 0.5C_c(V_{c,h}^2 - V_{c,l}^2)f_s \qquad (5)$$

where Vc,h is the maximum voltage of Vc , Vc,l is the minimum voltage of Vc , and fs is the switching frequency.[7]

## V. Simulation Results

*Fig.17 :* Illustrates the simulated circuit

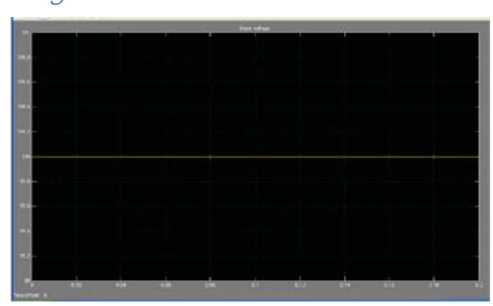

*Fig.13 :* Input voltage

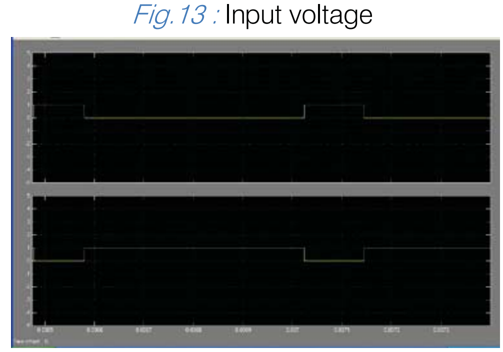

*Fig.14 :* Pulse waveform

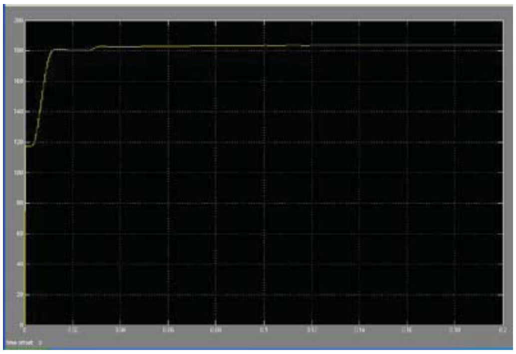

*Fig.15 :* Capacitor voltage

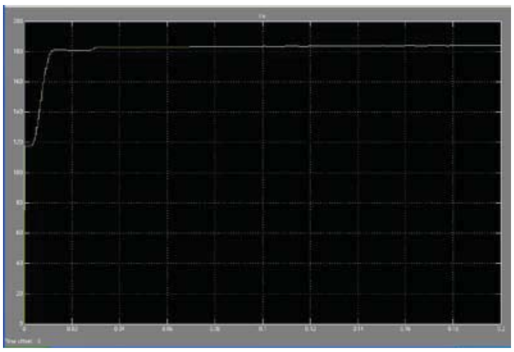

*Fig.16 :* Output voltage

Fig.13 to 16 confirm the applicability of the proposed method

## VI. Conclusion

This paper presents an isolated bidirectional full-bridge dc–dc converter with a fly back snubber for high-power applications. The fly back 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 by 50%. 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. The fly back snubber can also be controlled to achieve a soft start-up feature. It has been successful in suppressing inrush current which is usually found in a boost-mode start-up transition.

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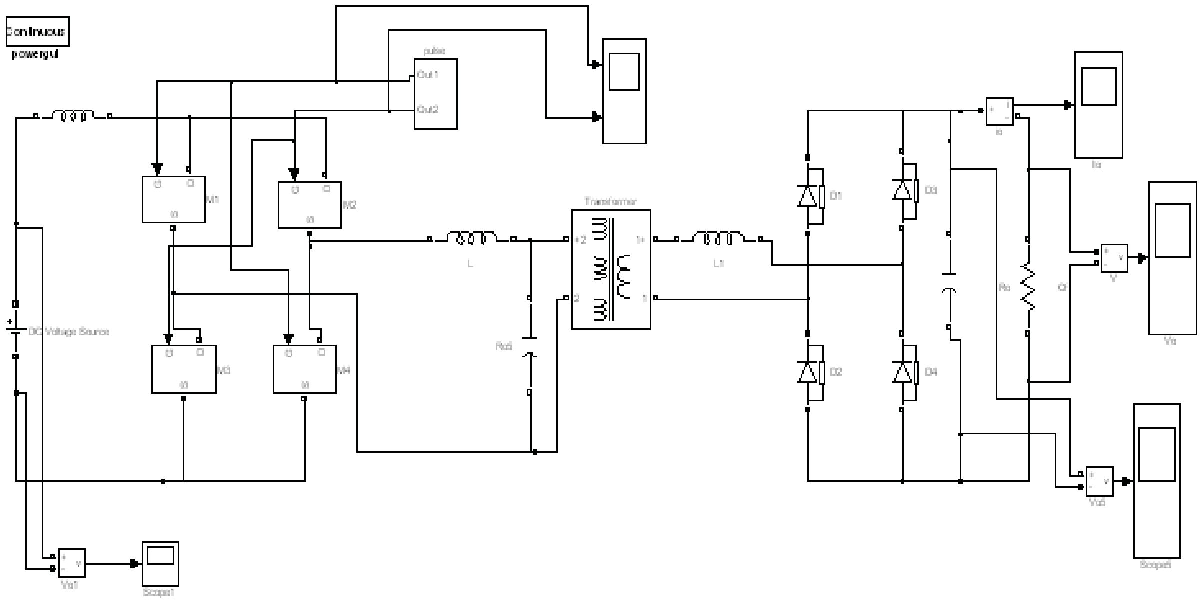


*Fig.17 :* Simulated circuit