Research Article

Embedded Controlled Isolated Bidirectional Full-Bridge DC-DC Converter with Flyback Snubber

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An isolated bidirectional full-bridge DC-DC converter with flyback snubber for supplying a resistive load is simulated and experimentally verified. The DC-DC converter for high conversion ratio, high output power, and soft start-up capability is presented in this paper. The circuit consists of a capacitor, a diode, and a flyback converter. These components help to clamp the voltage spikes caused by the current difference between the current fed inductor and leakage inductance of the isolation transformer. The switches are operated by soft-switching technology. The suppression of inrush current which is usually found in the boost mode start-up transition is presented here. The simulated and experimental results for output voltage, output current, and power for both buck and boost modes are presented.

1. Introduction

A DC-DC converter converts a source of direct current (DC) from one voltage level to another. These converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. The ordinary circuit of a DC-DC converter for high power applications typically includes a bidirectional full-bridge DC-DC converter [1–3]. The current difference between the inductor and isolation transformer does not ensure a well-defined output voltage and is characterized by less reliability and efficiency. The output voltage contains voltage spikes. An active commutation can be used to control the current in the leakage inductance [4]. But it requires an additional clamping circuit to suppress the voltage spikes. An RCD passive snubber can be used to clamp the voltage. A buck converter was employed to replace RCD snubber. But it still needed complex clamping circuit [5, 6]. Active clamping increases the current stress on switches. Soft-switching capability can be used, but it is not suitable for step-down operation.

In this scheme of DC-DC converter with flyback snubber (Figure 1), the snubber recycles the absorbed energy in the

clamping capacitor. The voltage of the clamping capacitor can be regulated by operating the flyback snubber independently. The current does not circulate through the full-bridge switches, and hence the current stress can be reduced, improving the system reliability significantly.

2. Configuration and Operation

The operating principle of the circuit consists of two modes:

- (i) step-up conversion,
- (ii) step-down conversion.

The modes of operation of boost mode are shown in Figure 2 and of buck mode in Figure 4. The theoretical waveform for boost and buck modes is shown in Figures 3 and 5, respectively. Initially all components are assumed to be ideal, and the transformer is treated as an ideal transformer associated with leakage inductance.

2.1. Step-Up Conversion

Interval 1: $t_0 \leq t < t_1$. The equivalent circuit is shown in Figure 3(a). All the four switches M_1 and M_4 are turned ON.

FIGURE 1: Isolated bidirectional full-bridge Dc-Dc converter with flyback snubber.

FIGURE 2: Operational waveform of step-up conversion.

In this interval, the inductor L_m is charged by V_{LV} and the current i_L increases linearly. The primary windings of the transformer are short circuited.

Interval 2: $t_1 \leq t < t_2$. The equivalent circuit is shown in Figure 3(b). At t_1 , M_1 and M_4 are conducting while M_2 and M_3 are turned OFF. Clamping diode D_c conducts until the current difference $(i_L(t_2) - i_p(t_2))$ drops to zero. D_5 and D_8 conduct to transfer power. The current difference $(i_L(t) - i_p(t))$ flows into clamping capacitor C_c .

Interval 3: $t_2 \leq t < t_3$. The equivalent circuit is shown in Figure 3(c). At t_2 , D_c stops conducting and flyback snubber

starts to operate. Clamping capacitor C_c is discharging and flyback conductor stores energy. M_1 and M_4 in ON state and D_5 and D_8 remain ON to transfer power.

Interval 4: $t_3 \leq t < t_4$. The equivalent circuit is shown in Figure 3(d). At t_3 , the energy stored in flyback conductor is transferred to high-voltage side. The flyback snubber operates to regulate V_{LV} to V_c to $V_{c(R)}$ same switches operates to transfer power from V_{LV} to V_{HV} .

Interval 5: $t_4 \leq t < t_5$. The equivalent circuit is shown in Figure 3(e). At t_4 , we obtain a regulated voltage $V_{c(R)}$. The main power stage

FIGURE 3: Continued.

(a) Mode I ($t_0 - t_1$) (b) Mode II ($t_1 - t_2$) (c) Mode III ($t_2 - t_3$)

FIGURE 5: Continued.

FIGURE 5: Equivalent circuit for step-down conversion.

is still transferring power from V_{LV} to V_{HV} . It stops at t_5 and a half switching cycle operation is completed.

2.2. Step-Down Conversion

Interval 1: $t_0 \leq t < t_1$. The equivalent circuit is shown in Figure 5(a). At t_0 , M_5 and M_8 are turned ON. The V_{HV} is immediately excited on the transformer and the whole voltage is exerted on L_m . The transformer current increases linearly towards the load current at t_1 . M_1 and M_4 conduct to transfer power.

Interval 2: $t_1 \leq t < t_2$. The equivalent circuit is shown in Figure 5(b). At t_1 , M_8 remains conducting while M_5 is turned OFF. D_6 conducts the freewheeling leakage current.

The transformer current reaches the load current level at t_1 . DC conducts the resonant L_m and the clamping capacitor C_c .

Interval 3: $t_2 \leq t < t_3$. The equivalent circuit is shown in Figure 5(c). At t_2 , with diode D_6 conducting, M_6 is turned ON with zero voltage switching.

Interval 4: $t_3 \leq t < t_4$. The equivalent circuit is shown in Figure 5(d). At t_3 , M_6 remains conducting while M_8 is turned OFF. The diode D_7 starts to conduct the freewheeling leakage current.

Interval 5: $t_4 \leq t < t_5$. The equivalent circuit is shown in Figure 5(d). At t_4 , with D_7 conducting, M_7 is turned ON with ZVS. Over this interval, the active switches change to

FIGURE 6: Simulation circuit and results. (a) Input voltage for boost mode. (b) Driving pulse for switches M_1 and M_2 . (c) Output voltage for boost mode.

FIGURE 7: Simulation circuit and results. (a) Input voltage for buck mode. (b) Driving pulse for switches M_1 and M_2 . (c) Output voltage for buck mode.

FIGURE 8: Hardware layout and results. (a) Photograph of the prototype converter. (b) Switching pulse of switch, S1. (c) Transformer primary side voltage. (d) Transformer secondary side voltage. (e) Converter with buck output. (f) Plot of efficiency in step-up mode.

the other pair of diagonal switches, and the voltage and the transformer reverse its polarity. It stops at t_5 and it completes a half switching cycle operation.

3. Simulation

The full-bridge DC-DC converter with flyback snubber is simulated using the Matlab Simulink results presented here. The Simulation parameters are shown in Table 1. Scopes are

connected to measure I/P voltage, driving pulses, and O/P voltage. Switching pulses are shown in Figure 6(b). This is the switching pulse given to the MOSFET switches. The output voltage is shown in Figure 6(c).

For the buck mode with resistor as the load, switching pulses are shown in Figure 7(b). Input and the output voltage are shown in Figures 7(a) and 7(c), respectively.

FIGURE 9: (a) PIC-based control circuit. (b) Flow chart.

TABLE 1: Simulation parameters.

Input voltage	V_{in}	15 (V)
Output voltage	V_o	33 (V)
Switching frequency	F_s	8 (kHz)
Filter capacitor	C_1	2200 (μ F)
Flyback capacitor	C_2	100 (μ F)
Main inductor	L_1	20 (μ H)
Filter inductor	L_2	5 (μ H)

The PIC 16F876S microcontroller can be used to generate the driving pulse for MOSFET switches. Thus the PIC circuit acts as the control circuit.

4. Experimental Results

The input 230 V is stepped down to 15 V using a step-down transformer and it is rectified to DC by the bridge rectifier. In boost mode, the output of the rectifier is boosted by a

step-up transformer of ratio 1 : 2. The output is converted into ac by an inverter. The load used is a resistive load of rating 1 K, 10 W. The output of the flyback converter is fed to the load through a series connection. The output in boost mode is 35 V. In buck mode, the input 15 V is stepped down to 8 V. Figure 8(a) shows the photograph of the prototype converter with boosted output. The switching frequency is 20 KHz and the switching pulse of switch, S1, is shown in Figure 8(b). The primary side voltage of the transformer is measured to be 15 V. In the boost mode it is boosted to 30 V and it is shown in Figure 8(c). The output of the buck mode is shown in Figure 8(e). The output is measured using a multimeter and it is 8.5 V. Figure 8(f) shows the plot of conversion efficiency of the bidirectional converter with various snubbers operated in the step-up mode.

It can be observed that the conversion efficiency of the proposed converter is around 90–92%, which is higher than the other types.

The PIC 16X7X-based control circuit is shown in Figure 9(a). The microcontroller is used to generate driving

pulses for the MOSFET switches. They are amplified using the driver IC IR2110. The gate signal is connected to port pin P1.0. Various steps involved in the firing pulse generation are shown in Figure 9(b).

5. Conclusion

An isolated bidirectional full-bridge DC-DC converter transformer converter had voltage spikes due to the current difference between the current fed inductor and leakage inductance of the isolation transformer. This voltage spike has been alleviated by the flyback snubber. The flyback snubber can be controlled to attain a soft start-up feature. The current stress is reduced under heavy load conditions. This converter has also the advantage of increased reliability and efficiency. The simulation demonstrates the actual converter capability to alleviate voltage spikes and to improve the efficiency.

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