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Designing Of Bidirectional Dc-Dc Converter For High Power Application With Current Ripple Reduction Technique

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Abstract----- This paper presents the design of bidirectional dc/dc converter with three bridges. In this configuration, only a single bridge is used for bidirectional control and two bridges are used for electrical isolation and for a gain of constant. RMS currents in the source and link capacitor can be improved by capacitor division and paralleling the operation of both stages. This simple arrangement provides the better control scheme and eliminates the snubber circuitry, so the switching frequency and efficiency of the system can be obtained.

Key Words---- Bidirectional converter, dc/dc converter.

I. INTRODUCTION

Fuel cell has a slow dynamic response, so the power supply from the fuel cell cannot cope with the power demand during a transient load. Thus, a secondary power source is required to compensate the power difference between the fuel cell and the load, and a battery is generally used to supply a transient power. The power flow between the fuel cell and the battery is managed by a bidirectional dc/dc converter. Conventional isolated/bidirectional dc/dc converters for high-power applications have a voltage-fed full-bridge (FB) (VF-FB) scheme in the high-voltage (HV) side and various current-fed (CF) schemes in the low-voltage (LV) side in general because voltage-fed half-bridge (HB) and voltage-fed push–pull (PP) schemes have disadvantages of high current stress and/or high voltage stress. According to which schemes are used in the LV side, they have several variations such as VF-FB + two-inductor CF-HB, VF-FB + CF-FB, and VF-FB + CF-PP with six or eight switches. These converters suffer from efficiency decrease at a light-load condition and low efficiency at boost-mode operation due to switching loss. Also, they require a snubber circuit such as an active-clamp circuit to alleviate turn-off voltage spikes in the LV side, which increases the switch number by one or two as a result.

In this paper, a two-stage isolated/bidirectional dc/dc converter adopting a current ripple reduction technique is proposed. The resonant converter with two bridges takes in charge of electrical isolation and constant gain, and the bidirectional control is accomplished using only the second stage with a single bridge. To reduce rms currents in the HV source and link capacitor, capacitor division and synchronizing operation of two stages are adopted. A 2-kW prototype converter has been designed and verified based on design guidelines that are derived from the circuit analysis.

II. PROPOSED CONVERTER

A. Explanation of t he Proposed Converter

Figs. 1 and 3 shows the proposed converter with input waveforms, and its operational mode diagrams are shown in Fig.2.The resonant converter with a fixed frequency automatically forms bidirectional power flow according to input/output conditions, and the bidirectional control is accomplished using only M_5 and M_6. The bulk capacitors

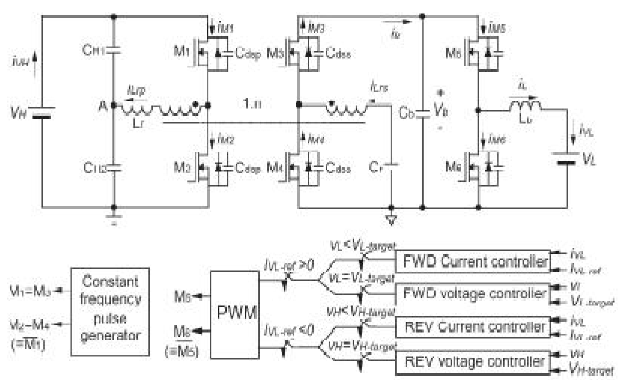


Fig.1 Schematic of the proposed bidirectional converter

C_{H1} and C_{H2} provide resonant current paths to alleviate the current ripple from the HV source. The voltage-doubler structure in the LV side reduces the rms current of the link capacitor C_b by compensating the discharge current, which helps to reduce the link capacitor size. Before explanation, C_{H1} and C_{H2} have the same value, and the resonant frequency f_r is equal to the switching frequency f_s. Also, the second stage is modeled by a pulse current source with the switching frequency synchronized with that of the first stage. Because the resonant converter has a symmetric structure, buck and boost modes have identical operation, and we will explain the operation only with buck mode. When $M_1$and M_3 are turned on at t_0, M_1 has zero-voltage switching (ZVS), and the secondary resonant current i_{Lrs} begins to flow through the channel of M_3, the link capacitor C_b, and the resonant capacitor C_r. After the primary resonant current i_{Lrp} crosses zero at t_1, it flows through the channel of M_1 and the resonant inductor L_r. Because the impedances seen from node A to C_{H1} and C_{H2} are identical, i_{Lrp} is divided into half and each half current flows through the two capacitors. When v_{gs1} is decreased to the Miller plateau voltage $V_{gs,\ Miller}$ at t_2, the drain–source voltage of M_{1vds1} is linearly increased, and i_{Lrs} flows through the body diode of M_3. The discharge current of the drain–source capacitance of M_2C_{dsp}

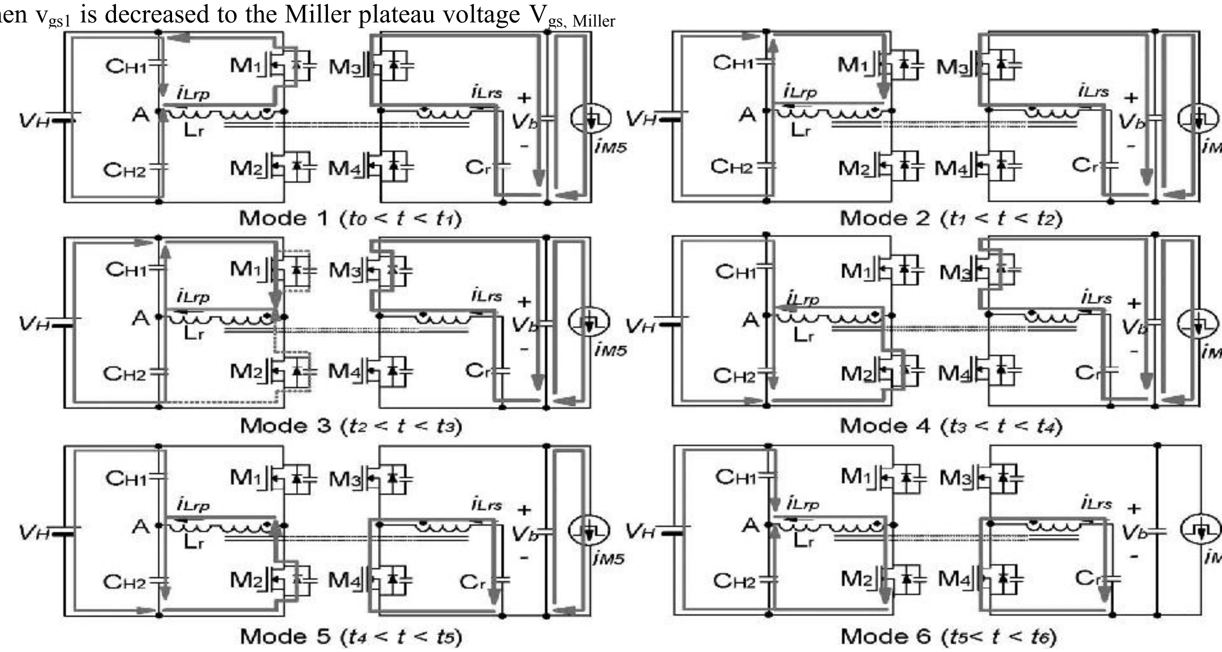


Fig.2.Operational mode diagram

can be written as $i_{M2} = -C_{dsp}V_H/T_{off}$, where T_{off} is the turn-off time of M_1. Thus, the HV-side current i_{VH} becomes $i_{Lrp}/2 - C_{dsp}V_H/T_{off}$.

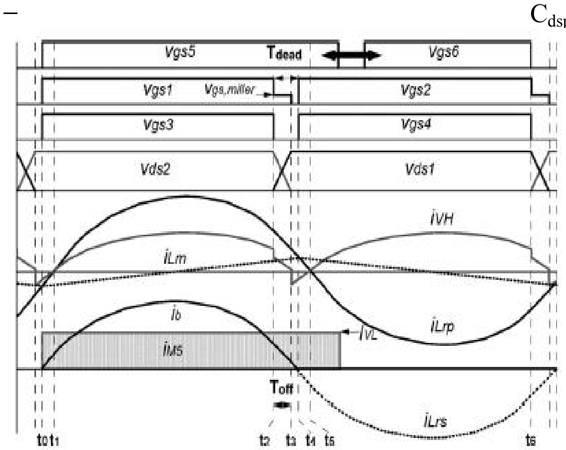


Figure 3. operational waveforms of the proposed converter

After M_1 is completely turned off at t_3, i_{Lrp} starts to flow through the body diode of M_2, and the ON state of the body diode of M_3 is maintained to provide the current path of i_{Lrs}. When M_2 and M_4 are turned on at t_4, ZVS of M_2 is accomplished, and i_{Lrs} flows through the channel of M_4 and C_r. After t_5, i_{Lrp} changes its direction, flowing through C_{H1} and C_{H2} similar to mode 2. Thus, i_{VH} also has $i_{Lrp}/2$. Referring to the key waveforms, the current ripple in the HV source is like that of the FB structure, and the charge and discharge currents of C_b happen at the same time. The current cancellation helps to reduce the rms current of C_b that suffers from the heavy current stress. In steady state, the average discharge current of C_b, which is equal to the average LV-side current I_{VL}, is balanced with the average charge current so that i_{Lrs} can be written as

$i_{Lrs} = \pi D I_{VL} \sin(2\pi f_r t)$, where D is the duty ratio of M_5. Because the magnetizing current i_{Lm} is circulated in the primary side, the effective current supplied from the HV source is equal to half the rectified current i_{Lrs} reflected to the primary side, i.e., $i_{VH} = |n\pi D I_{VL} \sin(2\pi f_r t)/2|$. By averaging this equation, the current gain becomes $I_{VH} = nDI_{VL}$, and it follows that the voltage gain is derived as $V_L = nDV_H$. Thus, the bidirectional power flow is controlled only with D.

B. Structural comparisons between the proposed converter and conventional converters

Table1 shows the structural comparisons between the proposed converter and conventional bidirectional converters. The switch block of the proposed converter has a number of advantages over those of basic conventional converters. Considering additional active-clamp circuits to absorb the voltage spikes in conventional converters, the proposed converter has an advantage in the switch block because it does not require any snubber circuitry. The number of magnetic elements in the proposed converter is equal to or less than those of conventional converters. However, the proposed converter has drawbacks in capacitor blocks and diode blocks due to the cascaded structure of two converters. Synthesizing the comparisons, the structure of the proposed converter is not inferior to the conventional converters despite the two-stage structure.

Table 1

	Conventional converters						
HV side	VF-FB			VF-HB			Proposed converter
LV side	CF-HB	CF-FB	CF-PP	CF-HB	CF-FB	CF-PP	
Switch (With active clamp circuit)	6 (8)	8 (9)	6 (8)	4 (6)	6 (7)	4 (6)	6 (6)
Capacitor	1	1	1	1	1	1	2
Inductor	2	1	1	2	1	1	1

III. DESIGN STRATEGY

To accomplish the ZVS condition, the peak magnetizing current should be large enough to discharge the drain–source capacitances of MOSFETs during dead time T_{dead}. From this condition, the primary magnetizing inductance L_m to meet ZVS both buck and boost modes can be driven as

$$\text{buck mode} : L_{\mathrm{mF}} \le T_{\mathrm{sL}} T_{\mathrm{dead}}/16C_{\mathrm{dsp}} \qquad (1)$$

$$\text{boost mode} : L_{\mathrm{mR}} \le T_{\mathrm{sL}} T_{\mathrm{dead}}/16n^2C_{\mathrm{dss}}. \qquad (2)$$

Thus, L_m can be selected as

$$L_m = \min(L_{\mathrm{mF}}, L_{\mathrm{mR}}) \qquad (3)$$

where C_{dss} is the drain–source capacitance of M_3, M_4. In this inequality, the first term is the maximum L_m for ZVS in buck mode, and the second term is that in boost mode. With the expression of i_{Lrs} and the operational waveforms, the rms current of C_b, $I_{c,\mathrm{rms}}$, can be calculated as

$$I_{c,\mathrm{rms}}/I_{\mathrm{VL}} = [(0.5\pi D)^2 + D\cos(2\pi D)]^{1/2}, \quad D \le 0.5$$

$$I_{c,\mathrm{rms}}/I_{\mathrm{VL}} = [(0.5\pi D)^2 - D]^{1/2}, \quad D > 0.5$$

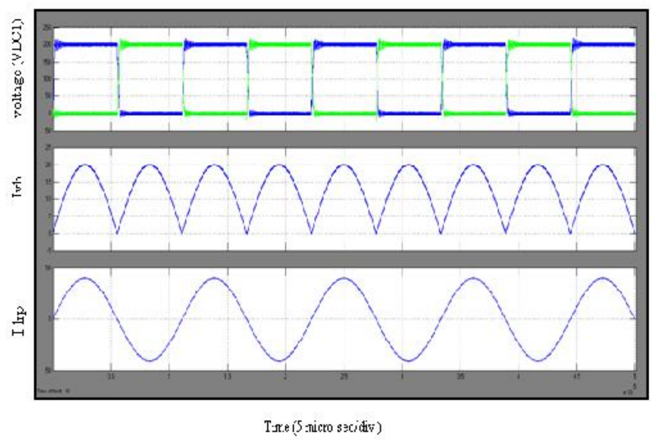
Using (1), the normalized rms current is shown in Fig., and the minimum value can be obtained at $D_{\mathrm{ripple}} = 0.45$. Thus, n can be calculated with $I_{\mathrm{VH,max}}/D_{\mathrm{ripple}}I_{\mathrm{VL,max}}$. $V_{b,\min}$ should be larger than $V_{L,\max}$ for buck-mode control. In boost-mode control, the second stage should be able to boost $V_{L,\min}$ to $V_{b,\max}$, but the maximum voltage gain k between them is not recommended higher than five that is the limit gain in general boost converters. Accordingly, the selection range of n becomes

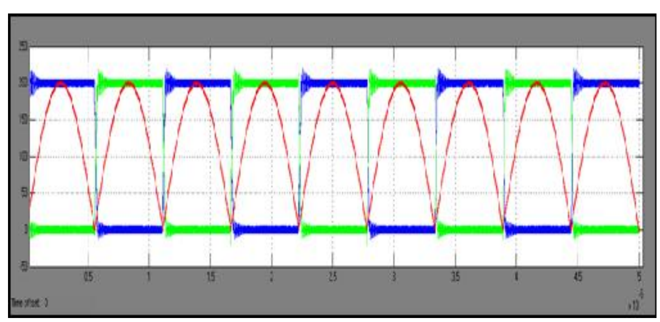
$$V_{L,\max}/V_{H,\min} < n < kV_{L,\min}/V_{H,\max} \qquad (4)$$

If the calculated n does not meet this condition, some adjustment should be performed.

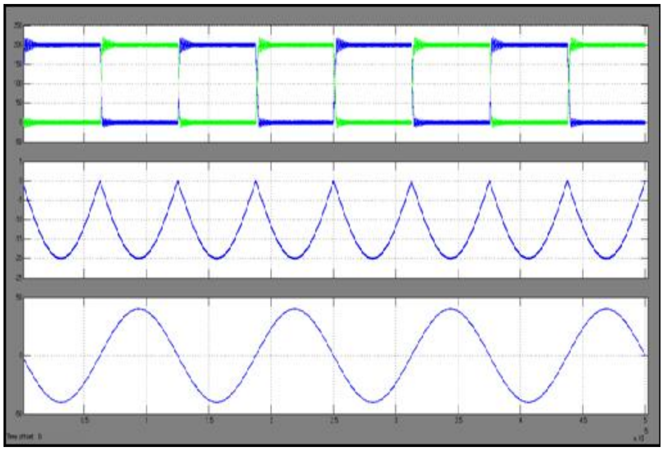
IV. SIMULATION RESULTS

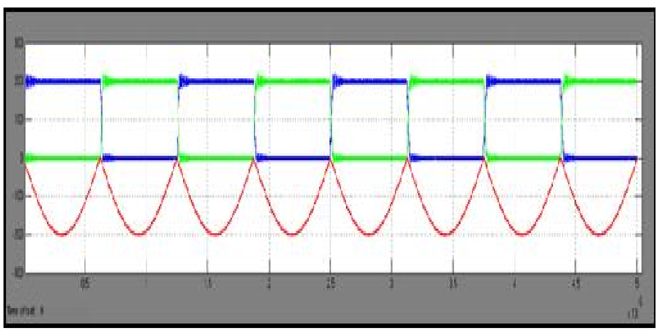
(a) DC to DC Buck Converter





(b) DC to DC Boost Converter





(C) Efficiency Plot

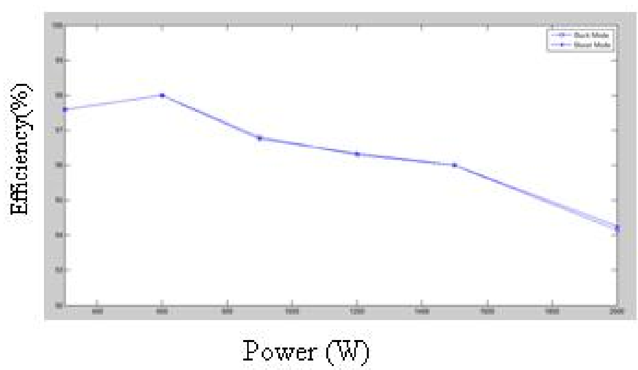


Fig.4.Measured waveforms and efficiency

V.CONCLUSIONS

A Designing of bidirectional dc/dc converter with three bridges has been proposed and analyzed. The input-to-output relationships derived through analysis have shown that the converter has a simple bidirectional control scheme. Also, methods to reduce the rms currents in the HV source and link capacitor have been suggested. To verify the performance, a 2-kW prototype converter with 90-kHz switching frequency has been implemented with design guidelines derived based on rms current reduction. The experimental results show that above 94.1% of efficiency has been obtained irrespective of the power flow direction. Therefore, it may be suitable for isolated/ bidirectional converters with a high voltage gain.

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