A Static Characteristic Analysis of Proposed Bi-Directional Dual Active Bridge DC-DC Converter

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Abstract- **Recently, the power supply network with energy storage devices such as battery has been focused. This network topology uses bi-directional isolated DC-DC converter of low or medium capacity is required for the diversification of power supply network. The dual active bridge (DAB) DC-DC converter is one of the effective bi-directional isolated DC-DC converters. However, the circuit has some instinct problems such as degradation of power efficiency and the occurrence of the surge in light-load operation. In this paper, we have been done a static characteristic analysis and highly power-efficient technique for DAB DC-DC Converter at light load. Also the analysis results and the proposed technique are verified with some experimental results.**

I. INTRODUCTION

Recently, the bidirectional dc-dc converter has been focused on because of the huge demand for diversification of power supply network including battery. The DAB dc-dc converter is one of the most popular circuits for bidirectional applications because of its simple structure. Some examples are for UPS [1], for automotive [2]-[4] and for energy storage system [5]. The one of the feature is achieving zero volt switching (ZVS) in natural operation. However, hard switching and/or power efficiency at light load condition is the intrinsic problem [6]. Some research have been done to solve the problem, for instance, use of resonant type converter with snubber circuit [7], silicon carbide (SiC) power device and new magnetic materials [8], and Quasi-ZCS operation with LC filter [9]. Furthermore by applying switching modulation, DAB converter works in wide range of input voltage and load condition [10]-[12]. These objectives of switching modulation controls are to regulate voltage and satisfy load variation [10], to expand soft switching region [11], and minimize the total power losses [12]. However, the problem of switching surges reduction was not addressed. In [13], the novel switching surge reduction technique is proposed and confirmed with some analysis and experimental results. And also, the results of power efficiency improvement of the light load were described.

In this paper, the detailed analysis of the technique is described and confirmed with some experiments.

II. CONVENTIONAL OPERATION OF A DAB DC-DC CONVERTER

Fig. 1 shows the circuit schematic of the basic DAB dc-dc

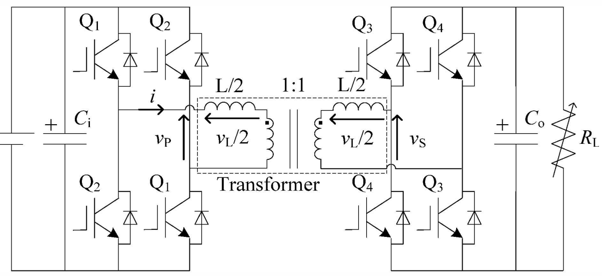

Fig. 1. The circuit schematic of DAB dc-dc converter.

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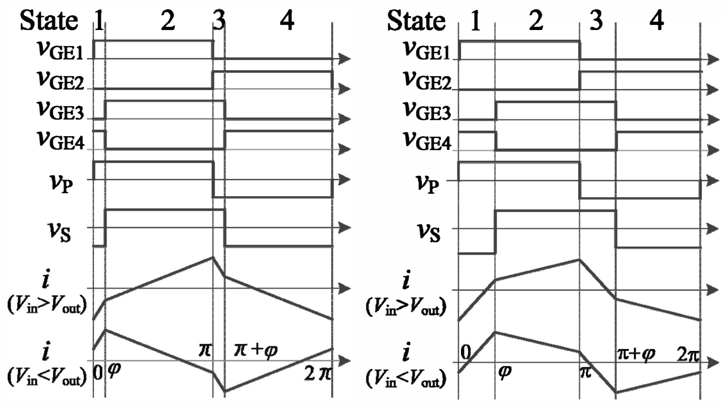
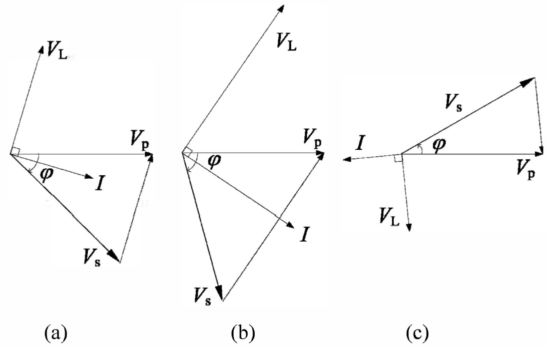


(a) Light load (b) Heavy load

Fig. 2. Conventional operating waveform.



(a) (b) (c)

Fig. 3. Phasor diagram [13]: (a) Forward power flow mode (light load); (b) Forward power flow mode (heavy load); (c) Reverse power flow mode.

converter. Fig. 2 shows the operating waveforms with the conventional operation [14]. In the conventional operation, the output power is operated by the phase-shift shown as φ between the primary voltage v_P and secondary voltage v_S of transformer. Fig. 3 shows the phasor diagram. V_P, V_S, V_L, and I are phasor symbols for v_P, v_S, v_L, i, respectively. When V_S is lagging V_P in forward power flow mode (Fig. 3 (a) and (b)), and when V_S is leading V_P, it is operated in reverse power flow mode (Fig. 3 (c)).

The output power P_o can be obtained as

$$P_o = \frac{V_{in}V_{out}}{\omega L}\varphi\left(1-\frac{\varphi}{\pi}\right). \tag{1}$$

The output power can be controlled with the phase difference φ. The waveform of the current i is changed by the load condition. In this paper, current i crossed the zero line in the state 2 is defined as a light load, and current i crossed the zero line in the state 1 is defined as a heavy load as shown in Fig. 2.

III. Intrinsic Surges Problem of a DAB DC-DC Converter

As mentioned in above, well known problem of a DAB DC-DC converter is hard switching in the light condition. However, previous researches haven't been addressed about the switching surges problem. It is caused by the reverse recovery effect of the diode. Fig. 4 shows φ - P_o. The switching surges occur at light load range of this figure.

Fig. 5 shows the generation mechanism of switching surges when $V_{in} > V_{out}$. The surges voltage occurs in the transition from State 1 (3) to State 2 (4), repeatedly. C_d is the parasitic capacitance of diode which is connected in parallel with the ideal diode, and L_{wire} is parasitic reactance. At the light load condition, the diodes D_4 is conducting in state 1. Then the switches Q_3 is turned on when state changes from State 1 to State 2. At this instantaneous moment, the diode D_4 is switched from a forward bias condition to a reverse bias condition, immediately. And the switching surges are

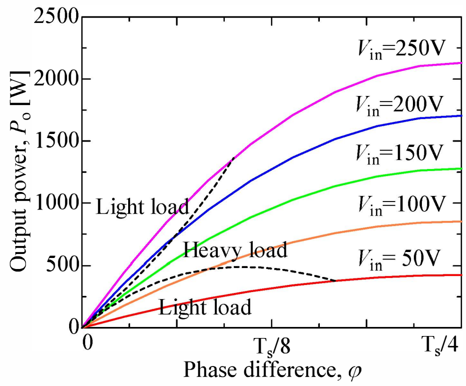
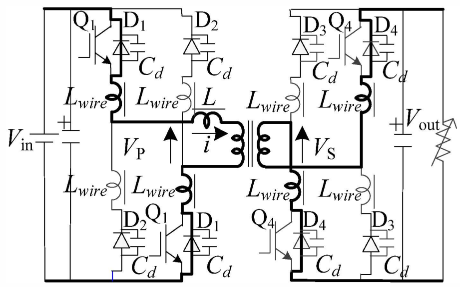
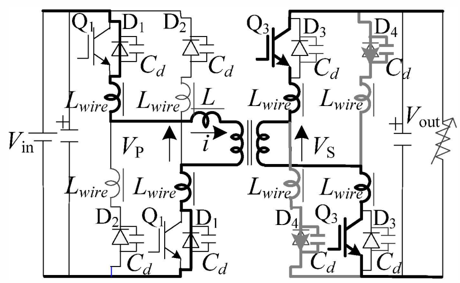


Fig. 4. φ - P_o (V_{in}=150V) [13].



(a) State 1



(b) State 2

Fig. 5. The generation mechanism of switching surge ($V_{in} > V_{out}$).