Bidirectional Dual Active Half-Bridge Converter Integrated High Power Factor Correction

AnhTuan Ngo, Kwanghee Nam
Electronics and Electrical Engineering Department, POSTECH, Pohang, Korea

Abstract

Abstract—A bidirectional dual active converter with the power factor control capability is proposed as a battery charger. The source side half-bridge acts as a PWM converter that maintains the unity power factor. The battery side half-bridge converter acts as a dual active bridge (DAB) together shares the same DC link voltage with PWM converter. The imbalance voltage phenomenon is eliminated by employing asymmetric duty cycle technique. Simulation results are included to verify theoretical analysis.

Index Terms—Bidirectional half-bridge converter, battery charger, power factor correction, asymmetric duty ratio.

I. INTRODUCTION

Due to air pollution and exhaustion of fossil fuels, nowadays, an AC-DC converter is an attractive solution for many applications. Conventionally, the front-end is an active single-phase or three-phase pulse-width modulation (PWM) rectifier to obtain power factor correction [2], [12], [14]. In [11], several topologies for both bidirectional and unidirectional converters have been reviewed.

In this work, a new bidirectional single-phase based on half-bridge converter is proposed for battery charger applications. The input current waveform can shape source voltage while energy transferred to battery package. The unbalanced-voltage problem is solved by utilizing asymmetric duty control technique [6], [5]. A 300 W converter was simulated to support the study. The introduced converter is very promising for low-power applications, especially bidirectional battery charger.

II. OPERATION PRINCIPLE OF PROPOSED CONVERTER

Fig. 1 shows the single-phase circuit of proposed converter. A PWM rectifier connects to 60 Hz source voltage and maintain nearly unity power factor. This rectifier shares the same DC link voltage with a DAB converter which is constituted by two half-bridge converters laid back-to-back through a transformer. The converter can transfer energy in a bidirectional manner: from the source to load and inversely from the load to the source.

For better understanding, the operations of PWM converter and dual active half-bridge converter are explained separately.

A. PWM Converter for Power Factor Correction

To achieve unity power factor, two switches $S_1$, $S_2$ are turned-on and -off complimentarily. Voltages across capacitors $V_{C1}$ and $V_{C2}$ are larger than the peak value of source voltage $v_s$. Due to the symmetric, the operating principle in positive half-line cycle is presented with $D$ defined as duty ratio of $S_1$.

Stage 1 ($\omega t_0 < \omega t < \omega t_1$): at $\omega t_0$, $S_1$ is turned off and $S_2$ is turned on. The current flows through $D_1$ and $D_6$, the antiparallel diodes of $S_1$ and $S_2$, respectively. In this stage, both capacitors $C_1$ and $C_2$ are charged by stored energy in $L_a$. The current $i_s$ is denoted by

$$i_s(t) = i_s(0) + \frac{v_s + V_{C2}}{L_m} t$$

This interval duration is $DT_1$.

When $S_1$ is on: input current decreases linearly from its peak value due to negative voltage on inductor. The stored energy is released to capacitor and the load. Boost current is given by

$$i_s(t) = i_s(DT_1) + \frac{-v_s + V_{C1}}{L_m} (t - DT_1)$$

From the volt-sec balance condition, duty cycle $D$ is determined

$$v_s = V_{C1} - D(V_{C1} + V_{C2})$$

To obtain unity power factor, the duty $D$ is modulated by hysteresis current control (HCC) [12] or sinusoidal PWM (SPWM) [2], [4].

The main drawback of single-phase based on half-bridge converter is the unbalanced-voltage between $v_{C1}$ and $v_{C2}$. This causes input current distortions and harmonics. Several methods to eliminate this fluctuation phenomenon have been reported [2], [4], [12], [13]. In this paper, asymmetric duty technique is employed and thoroughly discussed later.

B. Dual Active Half-Bridge Converter with Asymmetric Duty Control

All the parameters are referred to secondary side of transformer. The gating-pulse signals, voltages in both sides of transformer and leakage current of DAHB are drawn in Fig.2.

One more variable, $\theta$, is added to the control scheme to feature asymmetric duty control. Then on-time duration of the primary side switches are $T_{S3} = \pi + \theta$ and $T_{S4} = \pi - \theta$ while in secondary side $T_{S5} = T_{S6} = \pi$. The equivalent circuits of DAHB with asymmetric duty technique shown in Fig.3 are divided in six detailed stages for determining the charging and discharging intervals of capacitors. The operating principle is presented as follow.

Fig. 2 Key waveforms of DAHB converter with asymmetric duty cycle: (a) $\theta$ is negative, (b) $\theta$ is positive.

Stage 1 ($\omega t_0 < \omega t < \omega t_1$): At $\omega t_0$, $S_1$ is turned off and $S_2$ is turned on. The current flows through $D_1$ and $D_6$, the antiparallel diodes of $S_1$ and $S_2$. Boost inductor $L_a$ is energized and stores energy from the source. Current $i_s$ is given by

$$i_s(\omega t) = \frac{v_s + V_o}{2\omega L_m} \omega t + i_s(\omega t_0)$$
Stage 2 \((\text{ot}_1 + \text{ot}_4)\): the i_s current changes its direction from negative to positive value and discharges both capacitors \(C_1\) and \(C_2\). This stage is ended when \(i_s\) is turned on. The current \(i_s\) flows through \(S_1\) and \(S_2\). During this interval, \(i_s\) is charged and discharges \(C_1\) and \(C_2\), respectively. Voltage applied on inductor \(L_s\) is \(V_{vc} V_{dc}/2\) and \(i_s\) is denoted by

\[ i_s(\omega t) = \frac{V_{vc} - V_{dc}/2}{\omega L_s} (\omega t - \phi) + i_s(\omega t_4) \]  

Note that the amount of current discharges \(C_1\) can be controlled by regulating the period of this stage.

Stage 3 \((\text{ot}_4 + \text{ot}_5)\): \(i_s\) flows through \(S_1\) and \(S_2\) due to ON state of \(S_4\) and \(S_5\). During this interval, \(i_s\) is increasing in negative direction and decreases due to voltage applied on leakage \(L_k\). This stage is terminated when \(i_s\) equals zero at \(\omega t\).

Stage 4 \((\text{ot}_5 + \text{ot}_6)\): This stage start from the time when \(S_1\) is turned off and \(S_2\) is turned on. The current \(i_s\) flows through two body parallel diodes \(D_1\) and \(D_2\) as shown in Fig.3(d). This period is ended when \(i_s\) reaches its negative peak value.

Stage 5 \((\text{ot}_6 + \text{ot}_7)\): \(i_s\) increases from zero in negative direction through \(S_4\) and \(S_5\). The current \(i_s\) discharges for energy input to \(C_2\) and \(C_3\). In this interval, \(i_s\) is calculated as

\[ i_s(\omega t) = -\frac{V_{vc} - V_{dc}/2}{\omega L_s} (\omega t - \pi - \phi) + i_s(\omega t_5) \]  

This stage is terminated when \(i_s\) equals zero at \(\text{ot}_7\).

Stage 6 \((\text{ot}_7 + \text{ot}_8)\): This stage is terminated when \(i_s\) equals zero at \(\text{ot}_8\).

In the steady state, \(V_{vc} = V_{cc} = n V_{dc}/2\). The output power is rewritten as

\[ p_o = p_1 + p_2 = \frac{V_{dc}^2}{4 n \omega L_s} (\pi - \phi) + \frac{V_{dc}^2}{8 n \omega L_s} (4 \phi - \theta - 2 \phi) \]  

It should be noted from (11) that the output power \(p_o\) constitutes of two parts: \(p_1\), caused by conventional phase-shift control [3], [9], [7], [6] and \(p_2\), due to asymmetric duty cycle.

The control block diagram of whole system is shown as following in Fig.4.

The conventional control for power factor correction requires two proportional-integral (PI) controllers: one for inner current loop and the other for DC link voltage loop. Traditional PI is employed to adjust output power. The angle \(\theta\) is used for curbing imbalance voltage. A PI controller can be adopted to that controller because \(\theta\) increases linearly with the voltage difference \(\Delta v\). The decoupling term between two-later PI controllers is derived as same technique as in [6].

III. SIMULATION AND EXPERIMENT RESULTS

A 300 W, 90 V input voltage converter was simulated in ANSOFT SIMPLORER 6.0. The simulation results are shown in Fig.6. Compared to Fig.5 where the unbalanced-voltages across capacitors are in range of 0 to 25 V, the differences of two those capacitors with proposed method are very small, in range of \(-0.25 + 0.25\) V while input current shaping input voltage.

Experiments are now conducting to support the theoretical analysis and will be reported later.

IV. CONCLUSION

A new battery charger for low-power applications based on half-bridge converter has been introduced in this paper. The converter can operate near unity power factor while imbalance voltage phenomenon is eliminated by employing asymmetric duty technique. The effectiveness of proposed converter was verified by simulation results.
REFERENCES