An IGBT-Based ZCS Buck Converter for High Efficiency

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***Abstract*-- In this paper, a new ZCS buck converter with IGBT is proposed. The proposed converter can use IGBT as a main switch thanks to ZCS turn-off operation. It is possible to operate the system at a high switching frequency by reducing the large turn-off loss that occurs in the conventional IGBT buck converter. This paper deals with the concept, operational principles, and analysis of the proposed converter. The experimental results are verified with a prototype of a 200W ZCS buck converter. Since both the main switch Q_M and the auxiliary switch Q_A can be operated with soft-switching operation, the proposed converter can achieve high efficiency even with high switching frequency.**

***Index Terms*—IGBT based buck converter, soft-switching capability, zero-current switching(ZCS), and high-efficiency**

I. INTRODUCTION

Recently, the demand for weight reduction and miniaturization of a power supply has been actively increased. Passive components such as inductor and capacitor occupy a large volume in a power supply. In order to miniaturize and lighten these passive components, power supply is necessary to operate with high switching frequency. However, as the switching frequency increases, the switching loss increases accordingly. Thus, many studies have been conducted to apply various soft-switching cells to non-isolated DC-DC converters [1]-[2]. However, the resonant current by soft-switching cell can be overlapped in the main switch with large current stress in [1]-[2].

Meanwhile, the insulated gate bipolar transistor (IGBT) is a preferable device in non-isolated DC-DC converters. IGBT has been widely used in high-power industrial applications. This is because the IGBT can have large power capacity, low conduction loss, and low cost. However, IGBT has high turn-off loss due to its tail current. These excessive turn-off loss by tail current makes it difficult to operate the converter with high switching frequency. Therefore, in this paper, a new zero current switching (ZCS) buck converter with IGBT is proposed as shown in the Fig. 1. The proposed converter uses a simple soft-switching cell. It is possible to operate the converter with high switching frequency by reducing the large turn-off loss. This paper deals with concept of the proposed converter, operational principles, and loss analysis of the proposed converter. In addition, the experimental verification is verified with a prototype of a 200W output with 50kHz switching frequency.

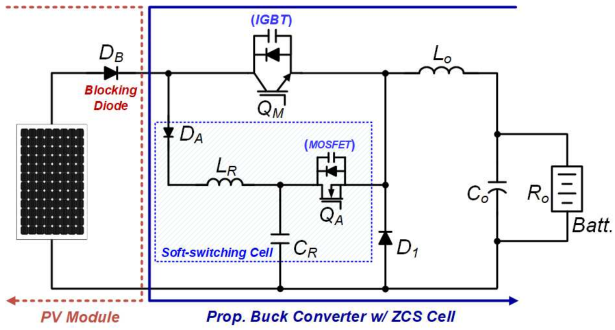

Fig. 1. Circuit diagram of proposed ZCS buck converter with IGBT.

II. ANALYSIS OF THE PROPOSED CONVERTER

A. Concepts of the proposed converter

The Fig. 1 shows the circuit diagram of the proposed converter. The proposed converter consists of a general buck converter and a new simple soft-switching cell. The new simple soft-switching cell consists of a resonant inductor L_R, a resonant capacitor C_R, an additional diode D_A, and auxiliary switch Q_A. Here, the main switch Q_M utilizes IGBT with large current capacity. Auxiliary switch Q_A uses MOSFET with a lower current capacity than the main switch Q_M. This is because a very small current flows through the auxiliary switch Q_A compared with the main switch Q_M.

B. The operational principles of the proposed converter

In this section, the operational principles of the proposed converter are going to be analyzed in detail based on the Fig. 2 and Fig. 3. To describe the operational principle of the proposed converter, The Fig. 2 shows the key waveforms of the proposed converter. Also, The Fig. 3 describes the conduction path of the current during each mode. To simplify the analysis, it is assumed that the proposed converter operates in the steady state.

Mode 1 [t_0~t_1]: This mode starts when the main switch Q_M is turned on. At this time, the voltage across the output inductor L_O is the difference between the input voltage V_S and the output voltage V_O. At the same time, the output inductor current i_{LO} increases linearly. The soft-switching cell does not operate in this interval. the resonant capacitor C_R has an initial value of $2V_S$, which is twice the input voltage. Also, no current flows through the resonant inductor L_R.

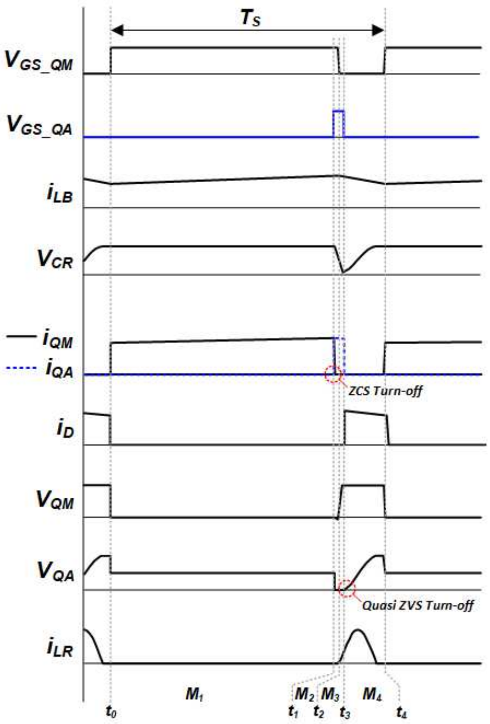

Fig. 2. Key waveforms of the proposed converter

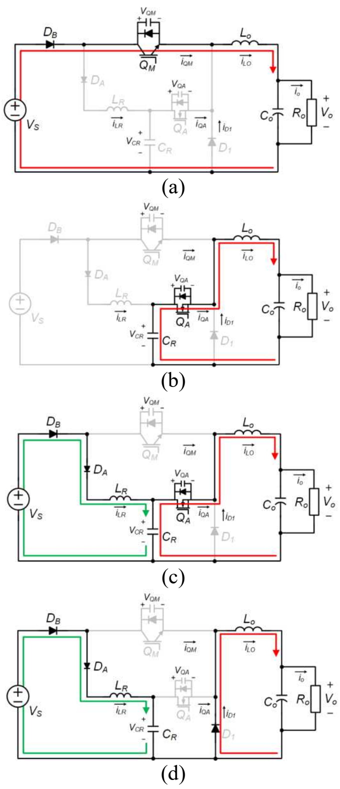

Fig. 3. Operational modes of the proposed converter (a) Mode 1 [t_0–t_1] (b) Mode 2 [t_1–t_2] (c) Mode 3 [t_2–t_3] (d) Mode 4 [t_3–t_4]

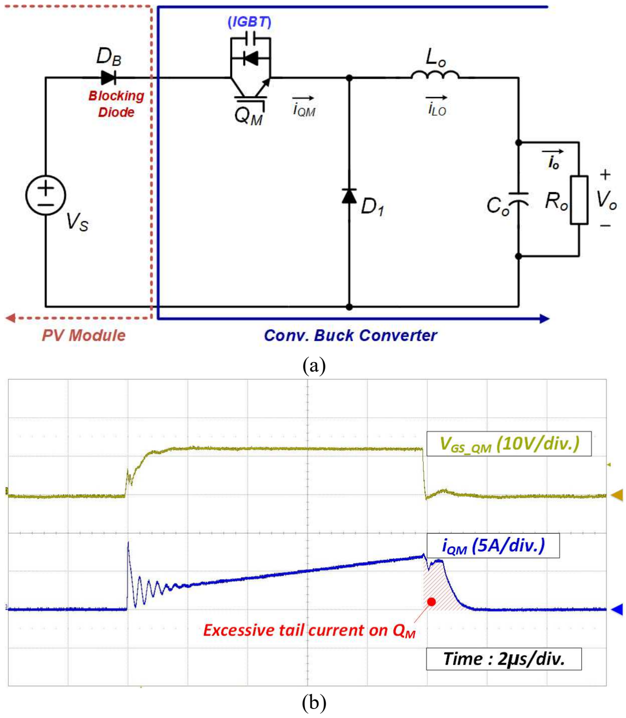

Fig. 4. Conventional buck converter (a) Circuit diagram (b) Experimental result

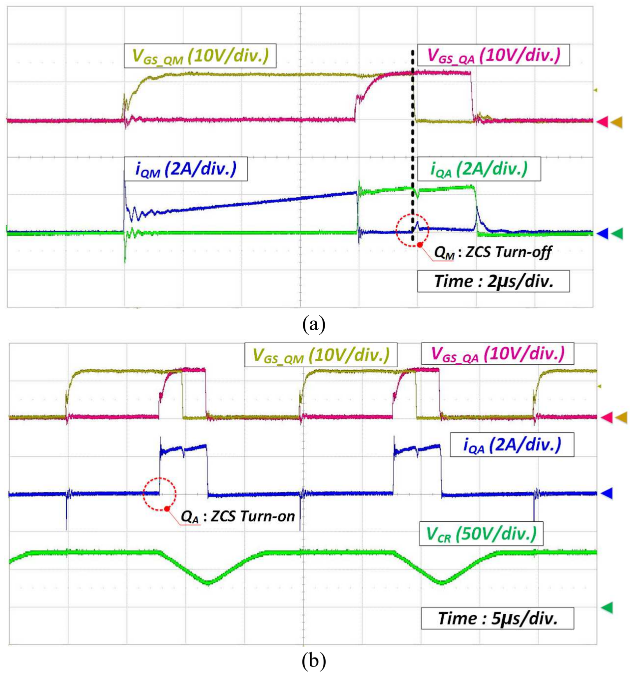

Fig. 5. Experimental results of the proposed ZCS buck converter (a) Experimental result 1 (b) Experimental result 2

Mode 2 [t_1~t_2]: When the auxiliary switch Q_A is turned on, this mode starts. In this interval, the i_{QM} becomes zero because the V_{CR} operates as an input source. Also, since the V_{CR}-V_O is applied to the output inductor L_O, output inductor current i_{LO} increases continuously in this interval. In addition, the voltage of the V_{CR} decreases linearly.

Mode 3 [t_2~t_3]: The next mode starts when the main switch Q_M is turned off. When the voltage V_{CR} of the resonance capacitor C_R becomes smaller than the input voltage V_S, then the diode D_A conducts. The voltage across the output inductor L_O is V_{CR}-V_O and the output inductor current i_{LO} increases linearly.

Mode 4 [t_3~t_4]: At the time t_3, the next mode starts when the auxiliary switch Q_A is turned off. The output voltage -V_O is applied to the output inductor L_O so that the output inductor current i_{LO} decreases linearly. Since the diode D_A is still conducting, the resonance current i_{LR} flowing through the resonant inductor L_R and the resonant capacitor C_R is charged up to the twice value of the input voltage V_S.

III. EXPERIMENT RESULTS

Based on the former analysis, the feasibility of the proposed converter has been verified by experimental results with prototype under 200W output and 35V input. In order to highlight the advantages of the proposed converter, the switching frequency is 50kHz by considering that the main switch Q_M is an IGBT(IKW20N60T). The Fig. 4(b) shows the current flowing through the main switch Q_M under the rated condition of the conventional buck converter. When the main switch Q_M is used as an IGBT, an excessive tail current flows through the main switch Q_M as shown in Fig. 4(b) during turn-off operation. Such excessive tail current leads to large turn-off loss on the IGBT, and it is difficult to secure high efficiency with high switching frequency. On the other hand, the Fig. 1 shows the proposed ZCS buck converter with IGBT. The main switch Q_M is an IGBT(IKW20N60T) and the auxiliary switch Q_A is small capacity MOSFET(IRFI1310NPbF). And the L_R is 20μH and the C_R has 10nF. In the proposed converter, if the auxiliary switch Q_A is turned on before the main switch Q_M is turned off as shown in the Fig 5(a), the output inductor current i_{LO} is supplied through the auxiliary switch MOSFET Q_A. Through this operation, an excessive tail current is not generated in the main switch IGBT Q_M, so that the large turn-off loss can be eliminated.

Since this large turn-off loss can be eliminated, the proposed converter can operate with high switching frequency and high efficiency. In the auxiliary switch Q_A, the quasi ZVS turn-off is performed as shown in Fig. 5(b). And a small RMS current flows through the auxiliary switch Q_A, so no large loss occurs in the soft-switching cell.

IV. CONCLUSIONS

In this paper, a new ZCS buck converter with IGBT is proposed. The proposed converter can use IGBT as a main switch with ZCS turn-off operation. It is possible to operate the system at a high switching frequency by reducing the large turn-off loss that occurs in the conventional IGBT buck converter. This paper deals with the concept, operational principles, and analysis of the proposed converter. The experimental results are verified with a prototype of a 200W ZCS buck converter. Since both the main switch Q_M and the auxiliary switch Q_A can be operated with soft-switching operation, the proposed converter can achieve high efficiency even with high switching frequency.

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