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# 동기 스위치 제어를 통한 영전압 동작 고효율 능동 클램프 포워드 컨버터

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# High Efficiency Active Clamp Forward Converter with Synchronous Switch Controlled ZVS Operation

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ABSTRACT

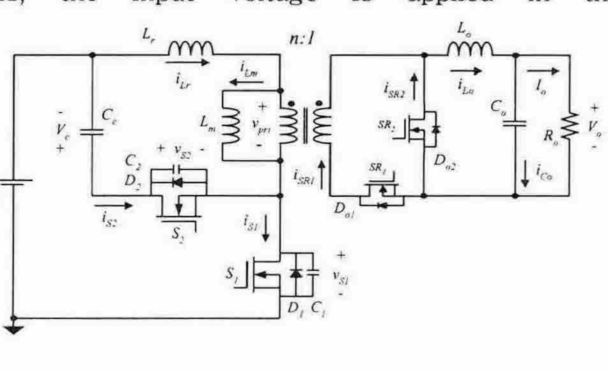
A new synchronous switch controlled transient current build-up zero voltage switching (TCB-ZVS) forward converter is proposed. The proposed converter is suitable for the low-voltage and high-current applications. The features of the proposed converter are low conduction loss of magnetizing current, no additional circuit for the ZVS operation, high efficiency, high power density and low EMI noise throughout all load conditions.

## 1. Introduction

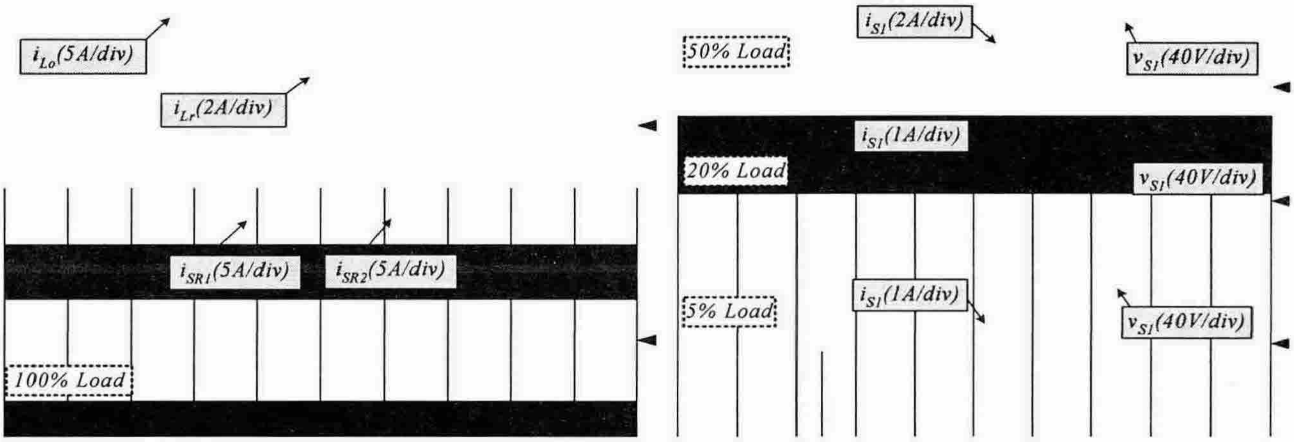
In general, the hard switching operation of the power switch results in a high switching loss, high EMI noise and high voltage stress of switches. Therefore, many soft switching DC/DC converters have been proposed to achieve the high efficiency and high power density. Among them the activeclamp forward converter is attractive due to simple structure and good ZVS performance [1-2]. However, to achieve the ZVS operation of main power switch, large magnetizing current or additional ZVS circuits are required. Therefore, its structure is complicated or conduction loss is increased. In order to solve all these drawbacks, a new ZVS PWM converter using the control of secondary synchronous switch is presented. It is suitable for the low-voltage and high-current application, which is using the synchronous switch to reduce the Schottky diode's conduction losses. Since it controls the synchronous switch to build up the current for the ZVS operation in a very short period of time, the ZVS operation is easily achieved without any additional conduction losses in the transformer and clamp circuit. Furthermore, there are no additional circuits required for the ZVS operation. As a result, the proposed converter can achieve the high efficiency, high power density and the low EMI noise resulting from the simple soft switching technique regardless of load variations.

## 2. Proposed Converter

Fig. 1 shows the circuit diagram and operational waveforms of the proposed TCB-ZVS forward converter. Since the ZVS operation of clamp switch is easily achieved by the large reflected load current or the magnetizing current after the end of secondary inductor's freewheeling, the current build-up is only accomplished for the ZVS operation of main switch. The operational principle of the proposed converter can be explained as follows. In mode M1, the input voltage is applied in the

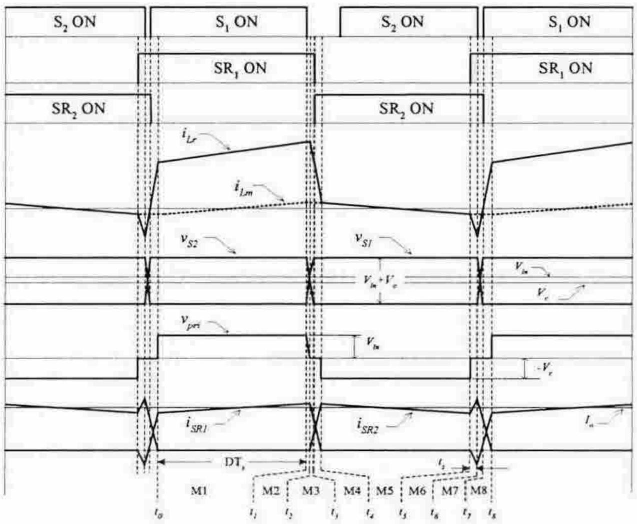



(a) Circuit diagram




(a) Waveforms at full load condition (b) ZVS waveforms of S1

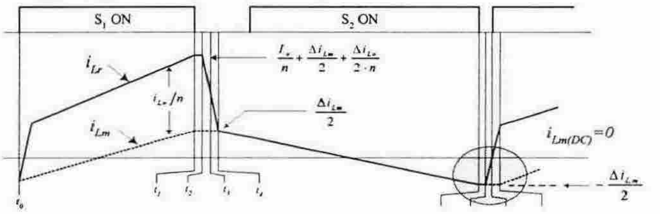
Fig. 3 Experimental waveforms



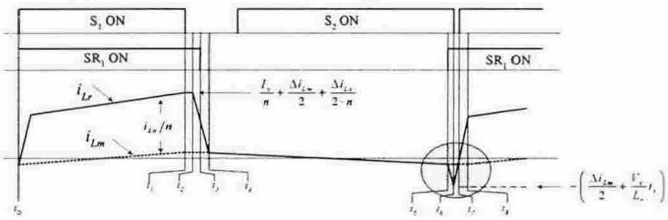

(b) Operational waveforms

Fig. 1 Proposed TCB-ZVS forward converter

primary side of transformer, and $V_{in}/n-V_o$is applied to output inductor. Therefore the power is transferred form source to output. In mode M2, the output capacitor of $S_2$ is discharged by the magnetizing inductor. In mode M3, secondary diode's commutation begins and the output capacitor of $S_2$ is discharged to zero by the leakage inductor and the zero voltage across the clamp switch is maintained. In mode M4, the commutation is accomplished form $SR_1$ to $SR_2$. In mode M5, the output inductor current flows to $C_o$ through $SR_2$, and the magnetizing current and leakage inductor current flow to $S_2$ and clamp capacitor. In mode M6, synchronous switch $SR_1$ is turned on with $S_2$ is on state. Then, the transformer secondary and primary voltage become zero and $-V_c$ is all applied to $L_r$.




(a) Conventional active clamp forward converter




(b) Proposed Converter

Fig. 2 Analysis of the ZVS operations

Therefore, leakage inductor current rapidly increases in a negative direction during the very short period and this build-up current is used for the ZVS of $S_1$ in the next mode. When clamp switch is turned off, the output capacitor of $S_1$is discharged by the build-up leakage inductor current of mode M6. Fig. 2 shows the different ZVS operations of active clamp forward converter and proposed converter, respectively. In the conventional active clamp forward converter, since the leakage inductorhas small inductance value, the large inductor current is required to achieve the ZVS operation of $S_1$. This large current can only be achieved by the large magnetizing current. Therefore, the conventional active clamp forward converter requires the large magnetizing current and transformer conduction loss is inevitable for the ZVS operation of $S_1$. However, in the proposed converter, since the ZVS current is built up in a very short period of

$t_5$~$t_6$, the large magnetizing current is not required and the transformer conduction loss can be reduced significantly. In mode M8, the output inductor current finishes its commutation form $SR_2$ to $SR_1$.

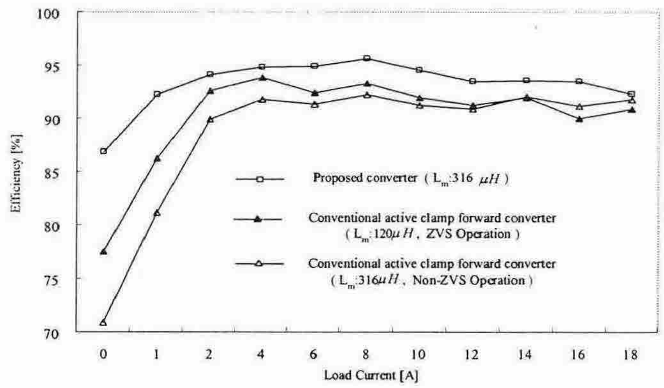



Fig. 4 Efficiency comparison

## 3. Experimental Results

A prototype of a 5V, 100W converter operated at 100kHz with 48V input has been built for the application of the distributed power system of the server and telecommunication with following components switch $S_1$ and $S_2$: IRF3315, synchronous switches: IRF3703, blocking capacitor $C_b$: $2.2\mu F$, output capacitor $C_o$: $1000\mu F/35V$, magnetizing inductor $L_m$: $316\mu H$, leakage inductor $L_r$: $3\mu H$, output inductor $L_o$: $5.6\mu H$, transformer turns: 12 turns of primary and 3 turns of secondary and current build-up time for the ZVS of $S_1$: 120ns. Fig. 3 shows the key experimental waveforms in the full load condition and the ZVS operations of $S_1$with the load variations. It is noted that the ZVS operation of main switch can be easily achieved by the build-up current even with the very small magnetizing current. Fig. 4 shows the comparative efficiency curves of the proposed converterand conventional active clamp forward converter according to the load variations. In addition, the proposed current build-up concept can be easily extended to other topologies such as forward/flyback converter and asymmetrical operated half-bridge converter [1]. By applying the proposed concept, all of these converters can achieve the ZVS operation regardless of load variation and no additional circuit is required.

## 4. Conclusion

The proposed converter shows good ZVS operation regardless of load variation and there are no additional components required. It also significantly reduces the magnetizing current conduction loss, which is essential for the ZVS operation of conventional forward converters. Therefore, it is suitable for sever and telecommunication equipment that require high efficiency, high power density and low EMI noise with 48V bus voltage. Furthermore, the proposed concept can be extended to other topologies.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## 참 고 문 헌


[1] F. D. Tan, " The Forward Converter: from the classic to the contemporary ", IEEE APEC 2002, Vol. 2, 10-14 March 2002, pp. 857-863

[2] A. Acik and I. Cadirci, " Active clamped ZVS forward converter with soft-switched synchronous rectifier for high efficiency, low output voltage applications", Electric Power Application, IEE Proceedings, Vol. 150, Issue 2, March 2003, pp. 165-174.