# A Soft-switching Active-Clamp Scheme for Isolated Full-Bridge Boost Converter

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*Abstract*— **In this paper, the isolated full-bridge boost converter with active clamp is described and a new active-clamping algorithm to improve the efficiency is suggested. In the proposed method, the resonance between the clamp capacitor and the leakage inductor is utilized to reduce switching losses. The loss analysis is performed by simulation and the improved performance is confirmed by experimental results.**

***Keywords-component; an active clamp, a full bridge boost converer***

## I. INTRODUCTION

In the high-power bi-directional dc/dc converter, the isolated full-bridge boost converter with an active clamp has been a good choice due to its effectiveness to limit the overshoot of bridge switch's turn off voltage and to enable the energy stored in the transformer leakage inductance to be used for zero voltage switching [2]. Effectiveness of this circuit topology has been demonstrated in the applications of the alternative energy systems, or the hybrid vehicle systems [3]. However, the loss analysis of the converter in section 2.1 shows that the turn-off loss in the clamp switch contributes a significant portion to the total loss. In order to minimize this loss, a soft-switching active clamp scheme utilizing the resonance between the clamp capacitor and the leakage inductor is proposed. Design considerations are given. The simulation results are presented to compare the loss between the conventional and the proposed method. For the overall efficiency comparison, the experimental results, taken from a 5kW prototype converter, are presented.

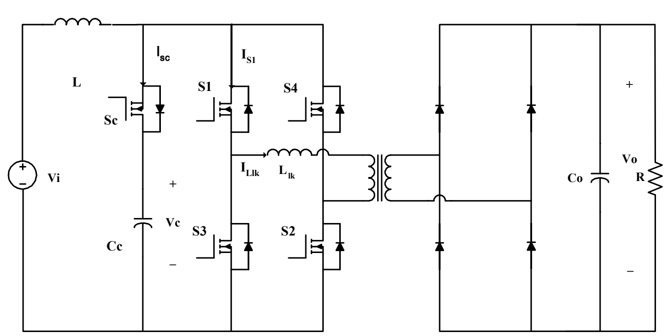


Figure 1. Full-bridge isolated converter with active clamp.

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## II. CIRCUIT DESCRIPTION

Fig. 1 shows the full-bridge isolated current fed converter with an active clamp. Fig. 2 shows the timing diagram and the key waveforms of the converter. When the converter is operating in the steady state, the bridge switch pairs in diagonal positions conduct with the duty cycle larger than 0.5. The boost inductor is charged during the overlapping interval when all four of the bridge switches are on ($T_1 - T_4$), and discharged when one diagonal switch pair is switched off and the clamp switch is turned on ($T_5 - T_7$). At $T_4$, $S_C$ turns on in zero voltage switching condition because $I_{SC}$ goes through the diode of $S_C$ first. During the time interval from $T_5$ to $T_7$, the voltage

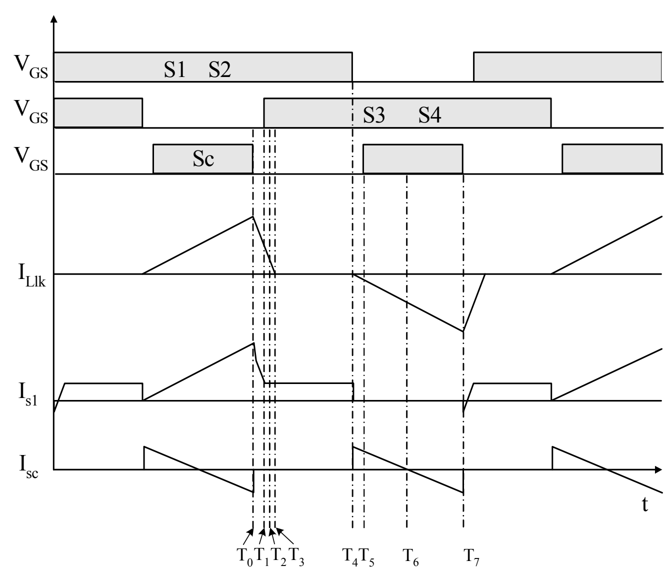


Figure 2. Key waveforms of the converter.

difference between the clamp capacitor and the reflected output voltage is exerted on the leakage inductor of the transformer. Thus, the transformer current increases at a rate of $-(Vc-Vo)/L_{lk}$. From $T_5$ to $T_6$, the surplus inductor current runs into the clamp branch, and from $T_6$ to $T_7$, the clamp capacitor supplies the deficient current to the transformer leakage current.

### *A. Design of Cc in the conventional scheme*

The design is based on the resonant tank formed by $C_c$ and $L_k$. The resonance happens during the off stage of boost mode operation. So its maximum span must exceed about T/2. The criterion is to select $C_c$ such that the resonant period is larger than T/2, or

$$C_c \geq (T_s / 4\pi)^2 / L_k \tag{1}$$

where $L_k$ : $L_{lk}/n^2$, the transformer leakage inductance reflected to the current-fed side,
$T_s$ : the period of the driving signal for each bridge switch.

From Eq. (1), the value of Cc can be obtained. In this case, it is assumed that $L_{lk}$ is 3.5uH and $L_k$ is 285nH in n=3.5. The value of Cc is designed 35uF.

### *B. Loss analysis*

A 5 kW converter is designed and built to assess the loss breakdown in the system. Because all of the switches are turned on with ZVS, the switch turn-on loss can be neglected. The switch off loss is calculated by measurement. Also, the conduction loss is estimated by using the datasheet of the switch.

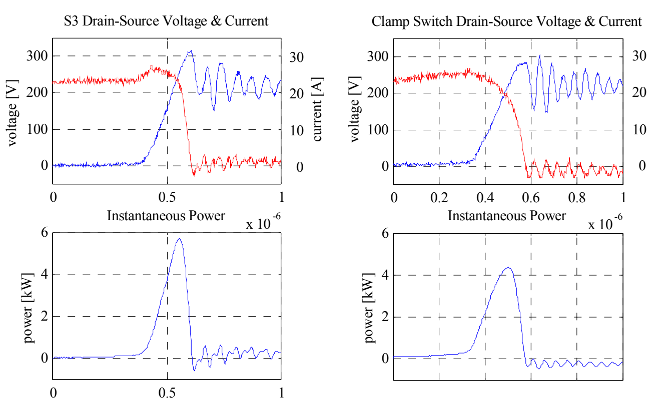


Figure 3. the measured switch turn off loss

Fig 3 shows that in one switching cycle, the off loss energy of the clamp switch is more or less the same amount compared to that of the bridge switch. However, because the frequency of the clamp switch is twice as high as that of the bridge switches, the switching loss of the clamp switch is twice as high as that of the bridge switches. So by reducing the switching turn-off loss of the clamp switch, we can improve the efficiency of the converter. The losses of the bridge switch and the clamp switch, indicating the conduction loss and the switching loss, respectively, are summarized in TABLE I.

TABLE I. LOSS ANALYSIS IN THE CONVENTIONAL SCHEME

| Switch | Bridge switch | Clamp switch |
|---|---|---|
| **Conduction loss** | 47.6 W | 27.4 W |
| **Switching loss** | 35.0 W | 70.0 W |
| **Total loss** | 82.6 W/unit | 97.4 W |

## III. PROPOSSED ACTIVE CLAMP SCHEME

From the above analysis, the efficiency of the converter can be improved by reducing the turn-off loss of the clamp switch. When the clamp branch is conducting in [$T_4$– $T_7$], the clamp capacitor and the leakage inductance resonate. By properly designing the resonant period, the clamp switch can be turned off at the nearly zero current switching condition. To achieve this, the design criterion of the clamp capacitor must be different from the previously proposed criterion in Eq(1)[1,4].

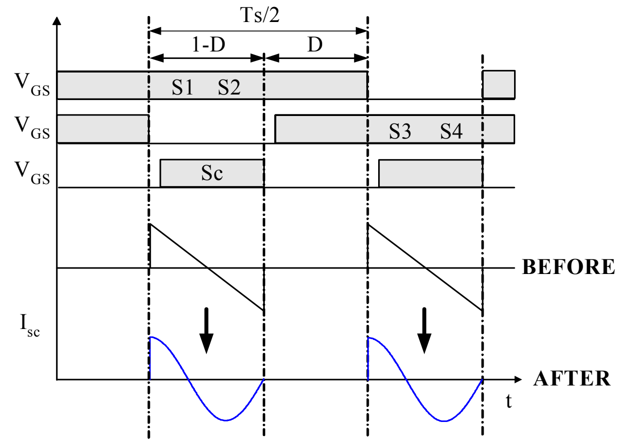


Figure 4. ZCS turn-off of the clamp switch current

Once the effective duty ratio, D, is determined, the clamp switch on-time is made to be close to three-fourths of the resonance period by the following design criterion in Eq(2). Fig. 4 shows the ZCS turn-off condition meeting the proposed criterion.

$$C_c \geq \left[\frac{(1-D)T_s}{3\pi}\right]^2 / L_{lk} \tag{2}$$

where $C_c$ is the clamp capacitance
$L_{lk}$ is the leakage inductance
D is the effective duty
$T_s$ is the switching period

The effective duty D is determined by voltage gain and load. The voltage gain, M, is like the following equation :

$$M = \frac{f(T_2) - \sqrt{f(T_2)^2 - \frac{g(T_1)}{\tau}}}{\frac{g(T_1)}{\tau}} \tag{3}$$

where $D = 1 - 2 \cdot [\frac{T_1}{T_s} - \frac{\sin(\omega_r T_1)}{\omega_r T_s}]$,

$$T_2 = T_1 - \frac{L_{lk}}{V_o'} \cdot I_L \cdot [1 - \cos(\omega_r T_1)],$$

$$f(t) = \frac{t}{T_s} - \frac{\sin(\omega_r t)}{\omega_r T_s},$$

$$g(t) = [1 - \cos(\omega_r t)]$$

From Eq. (3), the minimum effective duty, D, is 0.285. When $L_{lk}$ is 3.5uH and Ts is 1/36kHz, Cc is designed 1uF. The circuit is simulated by PSIM tool in order to verify the result. The clamp switch turns off in nearly ZCS condition as shown in Fig. 5.

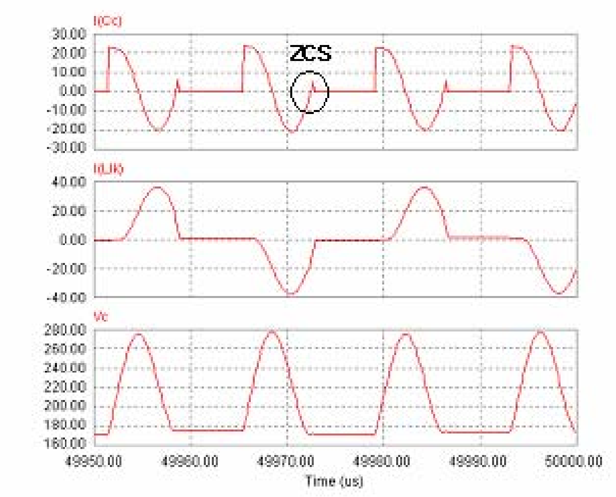


Figure 5. The simulation of $Ic_c$ , $I_{lk}$ and Vc

The loss of the clamp switch decreases according to the adequate clamp capacitance value. Also, the bridge switch turn-off loss is reduced because of the reduced drain-source voltage, $V_C$, of the full-bridge switches when they turn off, which makes the total efficiency of the overall converter higher.

TABLE II shows the analysis of the loss according to the clamp capacitors designed by the conventional scheme and the proposed scheme.

TABLE II. LOSS COMPARISON OF THE CLAMP SWITCH AND FULL BRIDGE SWITCH ACCORDIING TO CLAMP CAPACITANCE

| **Capacitance (uF)** | **Clamp switch (W)** | **Bridge switch (W)** | **Total switching loss (W)** | **Comment** |
|---|---|---|---|---|
| 1 | 26.1 | 18.434 | 99.7 | **The proposed scheme** |
| 35 | 70 | 35.34 | 210 | **The conventional scheme** |

## IV. EXPERIMENTAL RESULTS

The proposed converter is used for the UPQC (Unified Power Quality Controller) in which the energy is stored in the ultra capacitor bank and is supplied to the DC link capacitor when it is needed during an interrupt. For a charger and discharger for the ultra capacitor bank, the proposed bi-directional dc/dc converter is placed between the capacitor bank and the dc link capacitor. In this experiment, the discharge mode (boost mode) is set up to verify the results. A 5 kW proto-type converter is built. The performance of the conventional scheme and the proposed soft-switching active clamp scheme is compared. The converter specifications and components are listed below:

- input voltage : 120 ~ 135 VDC
- output voltage : 700 VDC
- ouput power : 5 kW maximum
- switching frequency : 36 kHz
- MOSFET IXFN130N30
- Transformer turn ratio : 12T : 35T

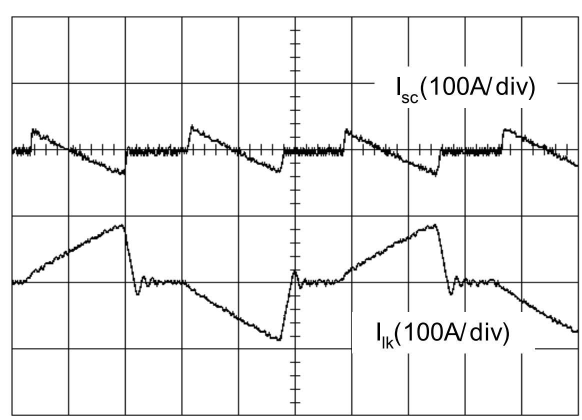


Figure 6. Clamp switch current and transformer secondary current when Cc = 35uF in the conventional scheme.

Experimental Results show that the clamp switch turns off hard in the conventional scheme when Cc = 35uF and turns off soft in the proposed scheme when Cc = 1uF. The experiment in the conventional scheme is Fig. 6. The top trace is a clamp switch current and the bottom trace is a transformer secondary current.

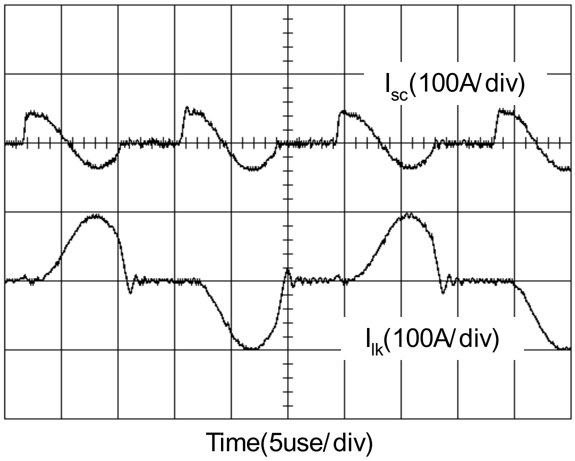


Figure 7. Clamp switch current and transformer secondary current when Cc = 1uF in the proposed scheme

As can be seen in Fig 7, the clamp switch turns off at nearly zero current. There are slight increases in the peak current in the clamp switch and the bridge switches, which increase the conduction loss. However the increase of the conduction loss is much smaller than the loss reduction in the switch turn-off loss. Fig. 8 shows the measured overall efficiency of the conventional scheme and the proposed scheme. It shows about a 2% increase in the overall efficiency, and the loss reduction in clamp switch simplifies its thermal design.

## V. CONCLUSION

A soft-switching active clamp scheme for the high power isolated full-bridge converter is proposed. Using the resonance between the transformer leakage inductor and the clamp capacitor during the operation of the clamp branch, the switch turn-off loss is minimized, and the efficiency is improved. These results also lead to a significant simplification of the thermal design of the clamp switch. A 5kW prototype converter is built to verify the results.

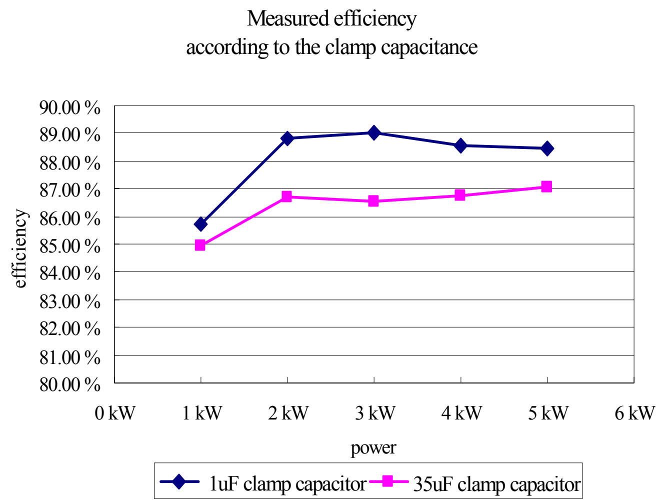


Figure 8. measured efficiency according to the clamp capacitor

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