Reduction of Power Loss of Zero Current Switching Converter by Optimizing Power Devices

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1. Introduction

A high power switching for power applications has been achieved by the power semiconductor devices, such as IGBT. Since turn-off loss due to current tail of IGBT degrades the converter efficiency, a Zero Current Switching (ZCS) has been proposed for high frequency operation. Improvement of the ZCS circuit has mainly been performed by changing the circuit configuration and control method [1]. Although some groups have investigated from the viewpoint of the internal dynamics of power switching devices during soft switching [2-3], a reduction of the power loss by these devices has not yet been achieved.

This paper reports on a reduction of the power loss of the ZCS converter by the power switching devices, the main and auxiliary switch (Si-IGBT), for the first time. We found that an improvement of the loss reduction rate to the Hard Switching (HS) can be realized by adjusting each device for an optimal combination of characteristics.

2. Experiments

Figure 1 shows the ZCS boost converter circuit and the switching sequence. This circuit has an additional resonant network which consists of an inductor (L), a capacitor (C), and an auxiliary switch. Commercial 1.2kV/200A Si-IGBT modules of the low conduction and high speed type are used for the main and auxiliary switch, respectively. Since the auxiliary switch partially overlaps with the main switch turn-off, the resonant current flows into the LeC circuit and ZCS can be realized. The detailed circuit parameters and measurement conditions are also shown in Figure 1.

3. Results and Discussion

Figure 2 shows the measured switching waveforms under the ZCS condition. An overlapping of the current and voltage curves can be reduced during the turn-on of the auxiliary switch. However, a rapid current spike occurs at the end of the resonant period with an increase in the collector to emitter voltage [Fig.2 (a)]. This undesirable behavior causes an increase in the turn-off loss of ZCS.

To clarify the origin of the current spike, the internal carrier dynamics of the main switch during the turn-off was investigated by device simulation (Synopsys Sentaurus Device) as shown in Figure 3. This current spike is similar to the mechanism reported previously [4], and originated from the sweep out of the excess carrier in the drift layer. These results indicate that the dynamics of the ZCS turn-off shows the same mechanism with that of the HS. Therefore, this current spike can be reduced by reducing the concentration of p+collector of the main switch and shortening the turn-off time.

Figure 4 shows the dependency on the main switch turn-off time (tm) of the switching loss reduction rate to the HS. The turn-off time is defined as the time from 90% to 10% of the rated current with the inductive load. As expected, the turn-off loss reduction rate is improved by shortening the tm due to reducing the current spike in the inset of Figure 4. At this time, it is necessary to note that the turn-on loss of the ZCS becomes substantially higher compared to the HS, because the anti-resonant current from the resonant circuit is added to the main switch when turned-on [see Fig. 2 (b)]. Since the turn-on loss rate becomes larger for the total switching loss as the tm becomes shorter, the maximum value of a certain turn-off time (tm_max) is taken for the reduction rate of the total switching loss. Figure 5 shows the dependency on the tm of the switching loss reduction rate to the HS as a parameter of the turn-off time of the auxiliary switch (ta). The tm_max is also shifted by changing the ta. This is due to the variation in the impedance of the device caused by adjustment of the ta in which the resonant current fluctuates. As a result, it becomes clear that there is a strong correlation between the two switches as shown in the inset of Figure 5.

These results indicate that there is an optimal combination of characteristics of the switching devices suitable for the ZCS. Figure 6 shows the simulated results of the comparison of the total loss of the main switch including the conduction loss, before and after the device optimization. Because of the selection of an auxiliary switch with longer turn-off time from the results of Figure 5, the turn-off loss was effectively reduced. It was confirmed that the power loss of the ZCS was improved by 18% by power device optimization.

4. Conclusions

In summary, a reduction of the power loss of the ZCS converter by the power switching devices was demonstrated. An improvement of the switching loss reduction rate to the HS can be realized by selecting an optimal turn-off time of the main switch. In addition, the optimal turn-off time has a strong correlation with the turn-off time of the auxiliary switch. It became clear that there is an optimal combination in the characteristics of the switching devices of the ZCS. From this optimization, the power loss of the ZCS was improved to 18%.
References

Fig. 1 (a) ZCS circuit, (b) Switching sequence.

Fig. 2 Measured switching waveforms (a) Turn-off, (b) Turn-on.

Fig. 3 The internal carrier dynamics during turn-off by the HS and ZCS.

Fig. 4 Simulated turn-off time dependence of the switching loss reduction rate to HS.

Fig. 5 Relationship between turn-off time of main and auxiliary switches to maximize switching loss reduction rate to HS.

Fig. 6 Comparison of total loss of the main switch before and after device optimization.