Adaptive Synchronous Rectification Control Method for High Efficiency Resonant Converter

Joohoon Kim, Sangcheol Moon, Jintae Kim
ON Semiconductor

ABSTRACT

New adaptive SR (synchronous rectification) control method is proposed offering high efficiency in entire load conditions for resonant converters, in this paper.

Unlike the conventional SR control method where turn-on time of the MOSFETs is varied depending on load conditions due to the stray inductance induced by a lead frame of MOSFET or PCB patterns, the proposed method automatically maintains a time interval between turn-off instance of a MOSFET and zero current instance of a body diode of the MOSFET as a predetermined time, in each switching cycle. Therefore, optimized turn-on time of the MOSFET can be achieved regardless of the leakage inductance.

In this paper, the operational principle of proposed control method has been discussed. It has been tested on LLC resonant converter with 240 W to verify the proposed control method.

1. Introduction

As increasing demands of high power density and efficiency in an LC or LLC resonant converter, SR (synchronous rectification) drivers at the secondary side draws lots attentions. It can reduce conduction loss by letting a current flow the channel of MOSFET instead of the body diode. Thus, various types of SR control method have been proposed and realized in a silicon-based.

At SR control methods for the LLC resonant converter, a turn-off method for SR MOSFETs is important features. If proper turn-off instance cannot be achieved, efficiency may be worse or a reverse current may flow from the drain to source of the MOSFET. One of the conventional SR control method compares an instantaneous drain voltage with a fixed threshold voltage and turns off an SR MOSFET. This method is widely employed due to easy realization, however, it usually has shown premature turn-off due to parasitic stray inductances caused by PCB pattern and lead frame of SR MOSFET. The stray inductances induce positive offset voltage across drain-to-source voltage when SR current decreases. Accordingly, the SR controller detects abnormal turn-off instance and may turn off prematurely as shown in Fig. In addition, turn-off time can be changed depending on load variation.

To overcome the late or premature turn-off observed at the conventional SR methods while maintaining advantages of the both methods, new SR control method is proposed in this

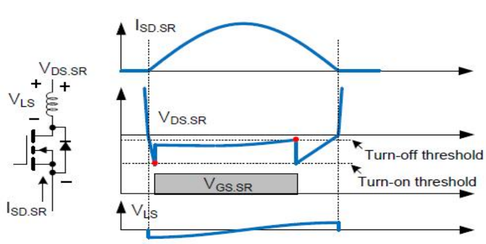

Fig 1. SR MOSFET with stray inductance and premature turn-off operating waveforms.

paper and realized as FAN6248. In the proposed method, turn-on method is same as the conventional methods, but the instantaneous drain voltage is compared with an adaptive threshold voltage to turn off SR gate. The proposed controller adjusts an adaptive turn-off threshold voltage to maintain time interval between turn-off instance of a MOSFET and zero current instance of the body diode of a MOSFET as a predetermined time in each switching cycle.

In this paper, the operational principle of proposed control method has been discussed. It has been tested on LLC resonant converter with 240 W to verify the proposed control method.

2. Principle of SR Control Method

This section explains the proposed SR control method able to avoid premature or late turn-off of the SR MOSFET, which results in improvement of efficiency and EMI.

A. Turn-on method in normal

Fig 2 shows operating waveforms of the proposed SR control method. The proposed control method turns on the SR MOSFET when V_{DS_SR} is lower than V_{TH_ON}. In practice, severe voltage oscillation may occur at the drain-to-source of the SR MOSFET after turn-on. It causes that the SR MOSFET turns on and off abnormally during the oscillation.

The proposed control method offers an adaptive minimum turn-on time t_{ON_MIN}. During t_{ON_MIN}, the SR MOSFET continues to be turned on even if V_{DS_SR} is higher V_{TH_OFF} due to the oscillation. t_{ON_MIN} is determined as 50% of a current conduction time interval of SR MOSFET t_{SR_COND}, that is measured in previous cycle.

B. Turn-on method at light load condition

At the light load condition, a current to the SR body diode is delayed and conducted after the magnetizing inductor voltage builds up to the reflected output voltage. At the conventional

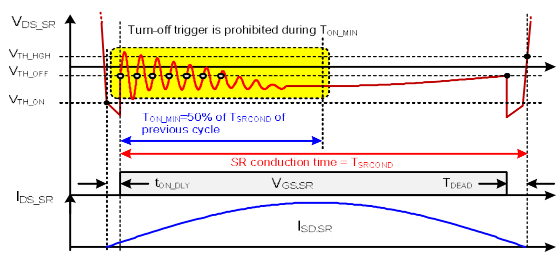

Fig 2. Turn-on and off of the proposed SR control method.

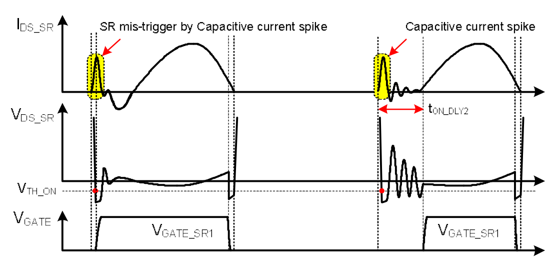

Fig 3. Capacitive current spike at light load condition.

SR control method, the SR MOSFET abnormally can be turned on repeatedly without waiting the delayed conduction time because the capacitive current spike is misrecognized as normal current conduction. To prevent the abnormal operation, the proposed control method detects the current spike voltage and increases turn-on delay time from t_{ON_DLY} to t_{ON_DLY2} at the next cycle. Thus, the SR MOSFET can be turned on after t_{ON_DLY2}. when V_{DS_SR} is higher than V_{TH_OFF}, as shown in Fig. 3

C. Turn-off method

The proposed SR control method employs an adaptive dead time control method in order to prevent premature turn-off of the SR MOSFET due to the stray inductance of the lead frame of SR MOSEFT and PCB patterns. The adaptive dead time controller maintains time interval between turn-off instance of a MOSFET and zero current instance of the body diode of a MOSFET as a predetermined time in each switching cycle. Accordingly, optimized turn-on time can be maintained regardless of load conditions.

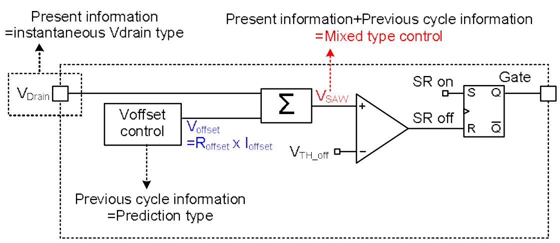

Fig 4. Adaptive dead time control circuit.

3. Experiment

To verify the proposed SR control method, it was implemented in an LLC resonant converter with 240 W where the output winding configuration is the center-tap method. Table I shows the electrical specifications of the LLC resonant converter.

Table I. Electrical specifications of the converter

Parameter	Value	Parameter	Value
Input voltage	390 V	Output voltage	12 V
Output current	20 A	Resonant frequency	120kHz
Parasitic Inductance at SR MOSFET1	1.9uH	Parasitic Inductance at SR MOSFET2	1.87uH

Fig 5 shows the operating waveforms of two SR MOSFETs at the full load condition, which is controlled by the proposed control method. Since different parasitic inductance is induced in each SR MOSFETs, the different resonant waveforms are observed during the turn-off intervals.

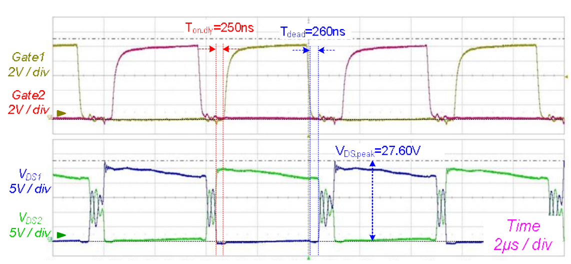

Fig 5. Operating waveforms of two SR MOSFETs

Fig 6 shows the operating waveforms of two SR MOSFETs at the 10% load condition No inversion current is not because an instance of SR MOSFET turn-on is delayed by the turn-on delay control method.

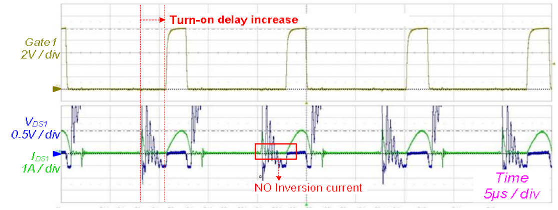

Fig 6. SR inversion current detection at light load

Fig. 7 shows the measured efficiencies of the conventional SR control method and the proposed control method depending on load conditions. In overall load condition, efficiency of the proposed control method resulted in improved efficiency of around 0.5% compared to the conventional one.

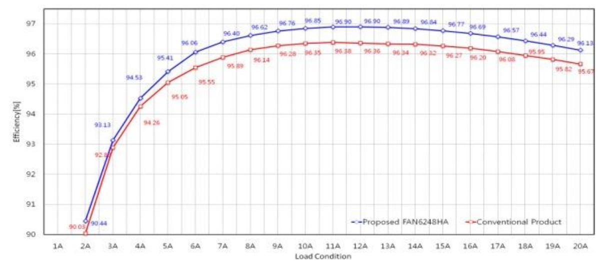

Fig 7. Efficiency depending on load conditions

Conclusion

The paper proposed new SR control method comprising of the adaptive minimum turn-on time and adaptive dead time control method. These methods offer stable turn-on at the light load condition and optimized turn-off regardless of conditions of load and parasitic inductances. The proposed SR control method was verified with 240 W LLC resonant converter, whose efficiency resulted in 96.13%. Typically, 0.55% of efficiency was improved. This control method can be a good candidate for high efficiency and high density resonant converters.

References

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