연속전류모드를 위한 새로운 순회복 게이트 드라이브

김 학성, 정 용채, 조 규형

A NEW SOFT RECOVERY DRIVE FOR CONTINUOUS CONDUCTION MODE

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Abstract

New soft recovery drive which can alleviate the loss due to reverse recovery of diode is proposed. By using this drive, the reverse current of the diode is minimized and stabilized because there is inner local feedback loop between the turn-on current of the power MOSFET and the reverse recovery current of the diode. The loss and EMI noise can be considerably reduced in this way. Brief operational principle and experimental results are included to verify the usefulness.

I. Introduction

One of the major problems in the high frequency power conversion is the reverse recovery current of the diode. This reverse current of the diode gives rise to unwanted EMI noise and increases additional switching losses of semiconductor devices, and sometimes brings forth the destruction of the devices in the worst case of excessive peak recovery loss.

To moderate this problem, we can improve gate drive circuit or use resonant switching method. Resonant switching method can reduce the reverse current, however the voltage or/and current stresses of devices is increased significantly, resulting in larger device conduction losses. In some circuits such as boost converter, even soft switching is not possible using single device. In the hard switching method, some improvement is possible by modifying gate drive circuits such as two step driving method for MOSFET[1]. But it does not effectively cope with the load current because it dose not utilize the previous load current information.

Usually, active power factor correction(PFC) circuit is design with hard switched boost converter. The PFC converter can be designed to be operated either in the continuous conduction mode(CCM) or discontinuous conduction mode(DCM). The CCM is better for higher power applications. However, this mode of operation has a serious problem due to reverse recovery current of the diode. In order to reduce the reverse recovery loss, a discontinuous operation mode is usually used for small power applications. In this case the peak device and inductor current becomes as large as twice or more than that of the continuous operation mode. In order to minimize the peak current, the controlled on time zero current switching method is adopted[2]. However, the another drawback of this approach is that it must operate on variable frequency mode.

In this paper, a new simple soft recovery power MOSFET drive is presented. It can moderate the reverse recovery loss and EMI noise, and can be used to continuous as well as discontinuous conduction mode operation.

II. SOFT RECOVERY DRIVE

For better understanding of the reverse recovery of the diode, the boost regulator and the waveforms are considered in combination with the power MOSFET assuming linear current rise and fall during switching transient as shown in dotted lines of Fig. 1.

The peak reverse recovery current I_{RM} is proportional to the rising slope of the device current. These current spikes are due to reverse recovery of diode produce unwanted ringing and EMI noise in the circuit. One of the methods to minimize the recovery current spikes in the hard switching converter is to extend the current rise time of the power MOSFET longer than the reverse recovery time of the rectifying diode. Another method, proposed in this paper, is to use the direct feedback of the reverse recovery current in the gate driver circuit. By doing so, the reverse recovery current can be controlled within a predetermined level. To do this operation, a new circuit named as soft recovery drive is presented in this paper.

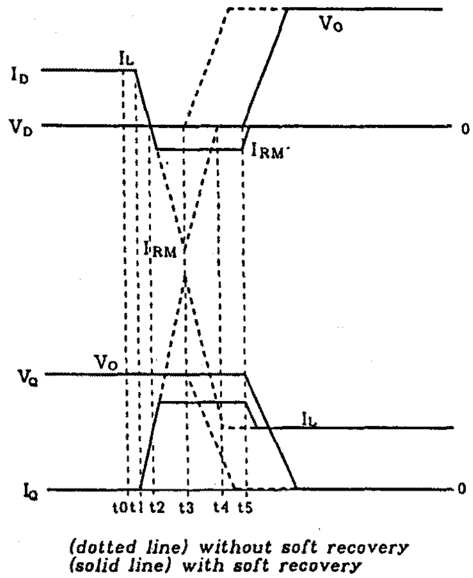

Fig. 1 Turn-on transient waveform of boost converter.

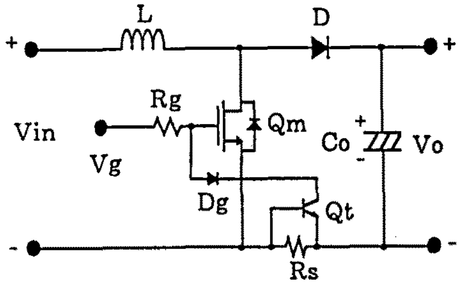

Fig. 2 Boost converter with soft recovery driver.

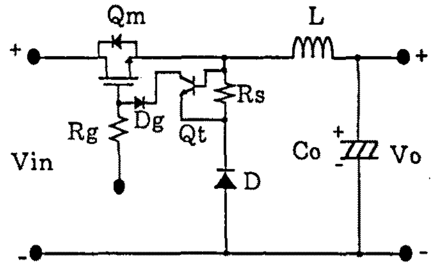

Fig. 3 Buck converter with soft recovery driver.

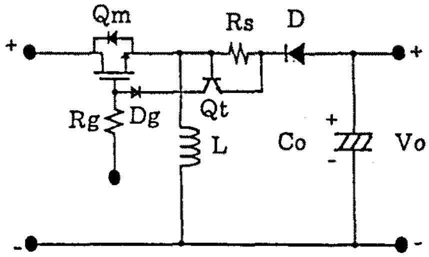

Fig. 4 Buck-boost converter with soft recovery driver.

The soft recovery drive circuit is composed of diode D_g, transistor Q_T and small valued sensing resistor R_s as shown in Fig. 2. This circuit operates only during reverse recovery period of the diode.

If the diode current flows forward through R_s, the gate circuit is not affected because the transistor Q_T is off state because of the reverse bias between base and emitter. On the other hand, if the diode reverse current flows reverse direction through the sensing resistor R_s by turning on the MOSFET, the Q_T is activated. Solid lines of Fig. 1 show the related waveforms of the suggested soft recovery driver circuit. Brief description of the operation is as follows.

The gate voltage starts to build up at t_0 toward the gate threshold voltage. At t_1 the MOSFET current starts to rise and as a result the diode current starts to decrease due to constant inductor current. During t_2 and t_3, the MOSFET is fully conducting and flowing all the inductor current and the diode reverse current. In this interval only the reverse current of the diode flows through the R_s, hence the Q_T is activated. By this operation, the reverse current value can be limited to a certain level because the negative feedback loop is formed the power MOSFET and transistor Q_T. The limited current level can be set to any value much lower than that of the hard recovery driver circuit.

The control of reverse current value is done by sensing resistor R_s, that is, the larger the R_s, the lower the reverse current. On the contrary, there exists a power loss which is proportional to R_s value. To reduce loss due to R_s, we can consider a circuit with pre-bias voltage of transistor as shown in Fig. 3. But this circuit may be weak to noise immunity. Another circuit with saturable reactor is presented as shown in Fig. 4, this circuit can be used for higher load current applications.

The concept of soft recovery drive as in the boost converter can be extended to any converter. Fig. 5 and 6 show buck and buck-boost converter with soft recovery drive circuit.

III. Experimental results

Experiments are performed using 100[W] prototype boost converter. The peak reverse recovery current I_{RM} of the suggested soft recovery driver is considerably reduced, whereas the reverse recovery time, T_{rr} is somewhat increased compared with the hard recovery driver circuit as shown in Fig. 7 and 8. The I_{RM} and T_{rr} are fully dependent on the sensing resistance value as shown in Fig. 9. Therefore, some trade-off is required between switching time and I_{RM} for optimizing the efficiency and EMI noise.

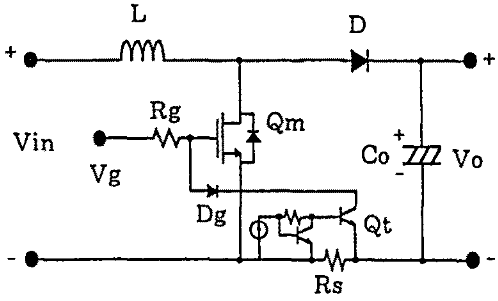

Fig. 5 Soft recovery driver circuit with pre-bias.

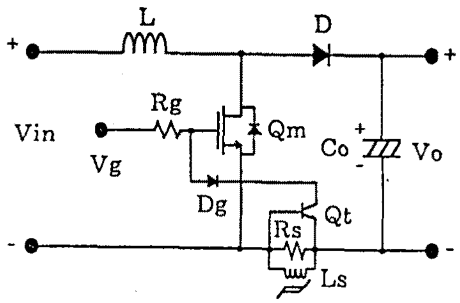

Fig. 6 Soft recovery driver with saturable reactor.

IV. Conclusions

A new soft recovery driver which can alleviate the loss and EMI noise due to reverse recovery of diode is proposed and verified by experiment. The proposed soft recovery driver can be adopted for any type of both continuous and discontinuous conduction mode hard switched converters. It is especially advantageous for high voltage boost converter scheme such as front-end converter for power factor correction.

Reference

[1] D. Y. Huh, H. H. Seong and G. H. Cho, "I Comparative Study of Electronic Transformers Using Resonant and Nonresonant Switching Converters", IEEE PESC Rec., pp. 1433-1440, 1992

[2] Unitrode Seminar Manual, 1991

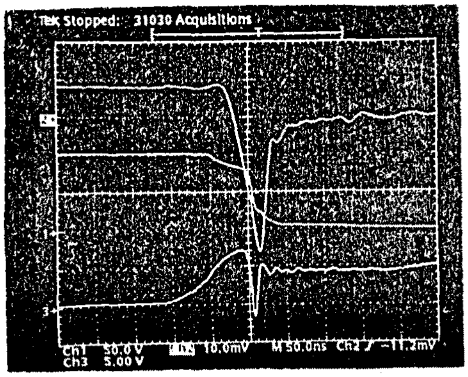

Fig. 7 Experimental waveforms of hard recovery driver.
upper trace : diode current, 1[A/div]
middle trace : drain-source voltage, 50[V/div]
lower trace : gate voltage, 5[V/div]

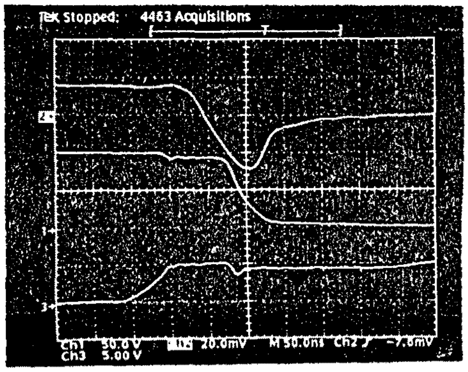

Fig. 8 Experimental waveforms of soft recovery driver.
upper trace : diode current, 1[A/div]
middle trace : drain-source voltage, 50[V/div]
lower trace : gate voltage, 5[V/div]

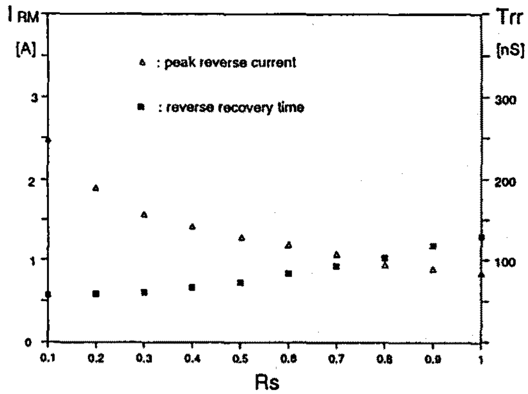

Fig. 9 Comparison of peak reverse current and reverse recovery time.