第31卷第1期
2003年 1月

华南理工大学学报(自然科学版)
Journal of South China University of Technology
(Natural Science Edition)

Vol.31 No.1
January 2003

**Article ID**:1000-565X(2003)01-0060-05

# Synchronous Rectifier Analysis of Forward Converter under the Condition of Light Load

*Xie Yun-xiang* *Wang Hao*

(College of Electrical Power, South China Univ. of Tech., Guangzhou 510640, China)

**Abstract**: While the converter works at light load, the output filter inductor current will go negative through MOSFET in synchronous rectifier and the circulating current will be formed. In order to solve this problem, the detection method of light load condition of converter used by UC3842 is proposed in this paper, meanwhile, the technique has also been studied which is used to make the inductor current cannot be flow negatively by switching off the MOSFET while converter works at light load. The theory analysis and experiment have proved that the proposed method is effect, the converter efficiency has also been improved a lot at light load.

**Key words**: forward converter; synchronous rectifier; switching mode power supply

**CLC number**: TM 92 **Document code**: C

With the quick development of the electronics and the widely use of microprocessors, ICs and digital signal processors, research of low-voltage high-current output converters comes to be an important project. As an absolutely necessary approach to improve the efficiencies of low-voltage high-current output converters, synchronous rectifier technique receives much recognition of the researchers and some kinds of synchronous rectifiers appear in succession[1~4]. Because of the unilateral conduction of diode, converter works at DCM (Discontinued Current Mode) while it works at light load. However, when the converter uses synchronous rectifier, because of the bi-directional conduction of MOSFET, output filter inductance current would reach zero and then go negative if the MOSFET $M_2$ is switching on, the negative current is flowing as Fig.1, so the circulating current is formed, which will make a larger conduction loss and a lower light-load efficiency of the converter. At the same time, the circulating current has increased the current stress on the switching MOSFET $M_2$, which is a disadvantage to the conduction condition of the MOSFET. With the development of power supplies technique and the higher demands to the electronic equipment power supplies, it asks the converters to keep a high efficiency during a wide range load. So how to solve the low light-load efficiency problem on synchronous rectifier technique is very urgent and necessary. In this paper a detection method of converter light-load used by UC3842 is proposed, which makes the inductor current work at DCM mode by switching off the MOSFET $M_2$ while converter works at light load, and then can increase the transformation efficiency.

## 1 Synchronous Rectifier Analysis of Forward Converter

Forward converter is generally used in the low-voltage high-current output switch mode power supplies. It has a low ripple current and is suitable to be used in low voltage, high current

**Received date**: March 10, 2002

**Biography**: Xie Yun-xiang(born in 1965), male, Ph.D., professor, mainly researches on power electronics.

and larger output power situations, which makes forward converter to be a main object of researching and utilizing synchronous rectifier technique. The main circuit of the forward converter with synchronous rectifier is shown in Fig. 1. It has used two MOSFET $M_1$ and $M_2$ to replace the conventional output rectifier's diodes. $Q_1$ is main switch MOSFET which turns on or off alternately, when $Q_1$ is switching on, the $M_1$ is also switching on and $M_2$ is switching off at the same time, the energy is transferred to load through the high frequency transformer. If $Q_1$ is switching off, $M_1$ is switching off and $M_2$ is switching on meanwhile, the current of the output filter inductor L will flow through $M_2$, C and R. The inductor current cannot reach zero because the $Q_1$ duty cycle is large under the heavy load condition, so the current has only one direction. However, if the $Q_1$ duty cycle is small under the light load condition, this current will go negative after it reaches zero because C can discharge through L and $M_2$, so the circulating current is formed, which will make a larger conduction loss and a lower light-load efficiency of the converter.

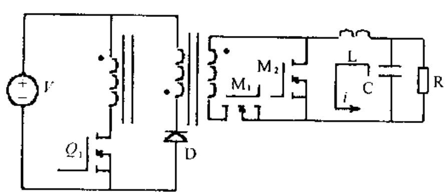


Fig. 1 Forward converter with synchronous rectifier

The PWM signal of the MOSFET $Q_1$, $M_1$ and $M_2$ is generated by UC3825, the peripheral circuit is shown in Fig. 2. The RC between the pin 5 and pin 6 of the UC3825 is the resistant-capacitor network to decide the operating frequency of the PWM signal and with the parameters in Fig. 2, the operating frequency of the PWM signal is 100 kHz. Two complemental PWM signals are output from pin 11 and pin 14 and the maximum duty cycle is 43%. The feedback signal of the output voltage is input from the inverse terminal of the internal error amplifier. A RC compensation network is added between pin 3 and pin 1. A voltage reference is added at pins 7 and RC compensation network is added between pin 7 and 6, which can increase the dynamic response speed. Current feedback signal is input from pin 9, which can limit the current. When the voltage of pin 9 is larger than 1.4 V, UC3825 disables the PWM output signal.

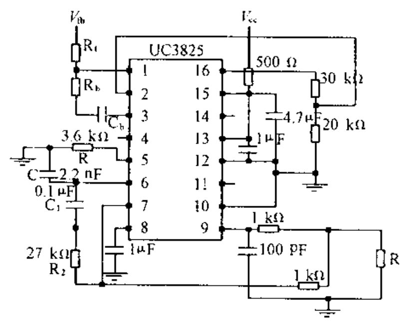


Fig. 2 Peripheral circuit of UC3825

## 2 The Detection and Control While the Forward Convert Works at Light-load

Because the load is changing continually, converter must adjust the operating mode and control method with the load change situation, which ensures that the converter can get a good performance at heavy load and light load conditions. To prevent the inductance current reverse flowing through the synchronous rectifier and forming a circulating current at light load condition, in this paper, converter disables the flywheel MOSFET when it judges that the converter is working at light load condition, which avoids forming the circulating current. The detection principle of light load condition of converter is shown in figure 3.

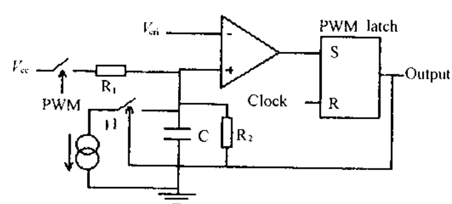


Fig. 3 Detection principle of light load condition of converter

Voltage source $V_{cc}$ charges the capacitor C through a PWM controlled switch and resistor $R_1$. While the duty cycle of the PWM signal is large enough, the voltage of C can reach or exceed the critical value $V_{cri}$, and then the output of comparator turns to a high level. And this output signal sets the PWM latch and the output of the PWM latch keeps a high level during this cycle. At the same time, this output signal turns on the switch of the current source and the capacitor C is discharged. While the duty cycle of the PWM signal is small, the voltage of the capacitor C is less than the critical value $V_{cri}$ and the output of the PWM latch keeps a low level. Capacitor C is discharged through resistor $R_2$ during the off time of the PWM control switch. In a new cycle of the PWM signal, the clock signal of the main topology will reset the PWM latch, which can ensure that the output of the detection circuit has the same frequency as the main topology.

Associating with the main switch's PWM control, we can use different control schemes at heavy load or light load condition in the following control method. While the converter works at heavy load, the duty cycle of the PWM signal is large and the detection circuit outputs a high level, which allows the driving signal of the fly-wheel MOSFET to work and the fly-wheel MOSFET can be turned on by the driving signal's control. While the converter works at light load, for the small duty cycle PWM signal, detection circuit outputs a low level, which locks the driving signal of the fly-wheel MOSFET and disables the fly-wheel MOSFET. Then the converter uses a Schottky diode to continue the load current and the light-load efficiency of the converter increases.

## 3 Light-load Condition Detect Circuit With UC3842

UC3842 is a conventional bargain PWM control chip. Its internal circuit has all the necessary components of the light-load detection circuit shown in Fig. 3, which includes comparator, RS tripper, internal current source, switch and it also has voltage reference, PWM latch and totem pole output. So we can just use a UC3842 and a small amount of peripheral components to realize the light-load condition detection. And the concrete circuit is shown in Fig. 4.

The inverse terminal of the internal error amplifier and the current sense terminal of the UC3842 are led to ground, which makes the current sense comparator output a low level. So the PWM latch cannot get the reset signal and output a high level. Then the output of the UC3842 is decided by the output of the internal oscillator (clock signal). While the clock is a high level, UC3842 outputs a low level; while the clock is a low level, UC3842 outputs a high level. Voltage reference source charges the capacitor C through resistor $R_3$, switch $Q_1$ and resistor $R_1$. Capacitor C is connected with the input terminal of the internal oscillator of the UC3842 (pin 4). The voltage of capacitor C is compared with the three comparators in the oscillator. If the turn-on time of the switch $Q_1$ is long enough, which depends on the duty cycle of the main topology, the clock will turn to a high level when the voltage of capacitor C reaches 2.7 V and the output of UC3842 will turn to a low level. The internal current source in the oscillator will discharge the capacitor C. When the voltage of C reaches 1 V, RS tripper is reset and the clock turns to a low level. Then the output of UC3842 turns to a high level and the capacitor C is charged again. If the turn-on time is short, the voltage of C cannot reaches 2.7 V, the clock keeps a low level and the output of UC3842 keeps a high level. The capacitor C is discharged through resistor $R_2$ during the turn-off time of the switch $Q_1$. Experiment proves that this detection circuit can realize the light-load condition detection.

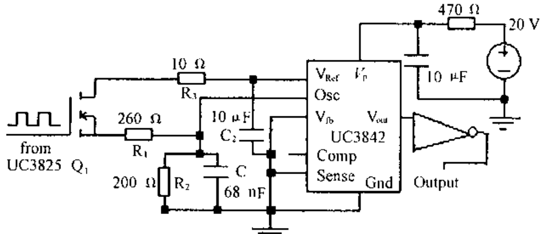


Fig. 4 Detection circuit of light load condition of converter used by UC3842

## 4 Critical Duty Cycle Define

In respond to the former discussions, the light-load condition detection is actually realized by detecting the duty cycle of the driving signal. While the duty cycle is less than a critical value, it judges the converter to work at light load condition. While the duty cycle is larger than the critical value, it judges to be a heavy load condition. The converter has a critical duty cycle that can make the output filter inductance current work at the critical mode between the CCM and DCM. And how to get this critical duty cycle is the problem that must be solved when the control circuit defines the threshold value of the detect circuit. Because of the non-linearity of the converter, it is difficult to get an accurate critical duty cycle value in theory. Normally, we can get a rough critical duty cycle by estimation in theory, and modify this value with experimental measures. And then an optimal critical duty cycle value can be got. In the low-voltage high-current output forward converter, the rough estimation formula of the critical duty cycle is:

$$D_{cri} = \frac{V_o + I_{cri} \cdot R_{on}}{V_{in}/N} \quad (1)$$

In which, $D_{cri}$ is the critical duty cycle, $I_{cri}$ is the load current value when the converter turns to light-load condition, $V_o$ is the output voltage of the converter, $V_{in}$ is the input voltage of the converter, $R_{on}$ is the MOSFET's equivalent on-resistance and $N$ is the winding ratio of the transformer.

## 5 Experimental Result Analysis

According to the former principle, this paper has designed a forward converter experimental power supply with synchronous rectifier, which is shown in figure 5. Its input voltage is 48 V, output current is 0~20 A, maximum PWM duty cycle is 43% and has an operating frequency of 100 kHz.

The experimental result indicates that it can effectively eliminate the reverse circulating current by using the proposed method in this paper. It is shown in Figure. 6. Figure. 6(a) is the inductance current waveform of the converter that doesn't use a light-load detection control method. We can see that the inductance current comes down to zero and goes negative when the converter works at light load.

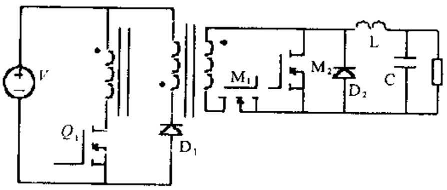


Fig. 5 Experimental forward converter

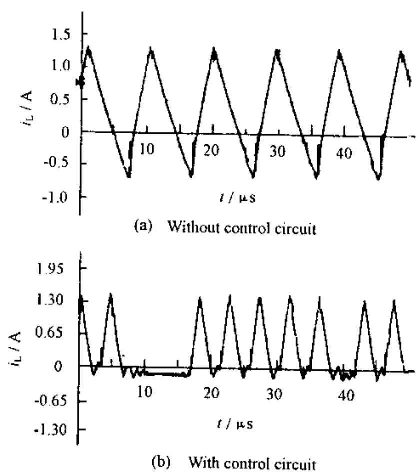


Fig. 6 Output inductance current waveform comparison under the light-load condition

This means with control circuit a reverse current appeared. figure. 6(b) is the inductance current waveform of the converter that uses the light-load detection and control method. In this figure, the current is discontinued, but the current value is effectively inhibited to about zero. So it is no reverse inductance current. Experiment also indicates that the output voltage of the experimental converter is stable not only at light load but also at heavy load. The experiment data of light-load efficiencies are shown in Table 1. For the converter has used the light-load detect and control method, the reverse circulating inductance current is eliminated and the light-load efficiencies increase.

Table 1 Efficiency comparison between the light-load control circuit exists or not

| $I_o$/A | Efficiency/% | |
|---|---|---|
| | Without control circuit | With control circuit |
| 0.01 | 0.9 | 20.8 |
| 0.1 | 8.2 | 54.1 |
| 0.2 | 15.2 | 58.3 |
| 0.3 | 21.1 | 58.4 |
| 0.4 | 26.0 | 58.9 |
| 0.5 | 30.6 | 60.7 |
| 0.6 | 34.7 | 60.8 |
| 0.7 | 37.9 | 61.7 |
| 0.8 | 41.2 | 55.7 |
| 0.9 | 44.1 | 56.7 |

## 6 Conclusion

In this paper, authors have propose a method, which is used to detect and control the light-load condition of the forward converter with synchronous rectifier technique. The former analysis and experiment indicate that this proposed method is feasible. This method can markedly increase the transformation efficiency at light-load condition. At the same time, it is unnecessary to change the control method at the heavy load operating. So this method is practical.

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# 正激式变换器轻载条件下的同步整流分析


**谢运祥 王 浩**

(华南理工大学 电力学院,广东 广州 510640)



**摘 要**:针对具有同步整流的正激变换电路在轻载条件下,因输出滤波电感电流经同步整流 MOSFET 管反向流动而形成环流的现象,提出了利用 UC3842 检测轻载条件,并通过禁止续流 MOSFET 导通来阻止电感反向电流的技术方案,理论分析和实验研究证明该方法是可行的,并且能明显提高变换器轻载运行时的变换效率.



**关键词**:正激变换器;同步整流;开关电源

**中图分类号**:TM 92 **文献标识码**:A

**文章编号**:1000-565X(2003)01-0060-05

收稿日期:2002-03-10

作者简介:谢运祥(1965-),男,博士,教授,主要从事电力电子技术的研究.