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Power Supplies with Synchronous Rectification for Computer and Communication Systems

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Due to their higher working frequencies, modern day computer and communication systems require higher and higher voltage and power of the power source, and because of this the main parameters of the power supply converters need to be improved, most of all the energy efficiency and the total costs, but also the compactness and the reliability. These requirements are to best extent achieved by the converters with synchronous rectification.

At first, synchronous rectification was only applied in the most complicated and expensive devices. However, the development of accessible production technologies of appropriate MOSFET-transistors and specialized integrated circuits for their control made it possible to apply synchronous rectification in the more commonly used and cheaper power supplies.

Power supply converters with synchronous rectification have been mainly used in Notebook-computers, High-end-Desktop computers and other devices, used in wideband communication networks. The main reason for this is the need of modern devices with increasingly lower values of the output (below 1.3-1.5 V) and increasingly higher values of the output current (above 20A in the Notebook computers and above 100 A in the servers).

There are three types of converters, which are most commonly applied and which are referred to the below-mentioned appendices [1]:

- Single-phase buck converters for Notebook-PC;
- Multi-phase buck converters for servers and High-End Desktop Computers, which are actually comprised of several single-phase buck converters, connected parallelly.
- Single-phase forward converters for wideband networks, usually with a single transistor on the primary side. The application of the expensive forward converters in the telecommunications equipments is required because of the need of

converting the higher primary supply voltage (attachment to 48 V – Bus-Systems) into a lower secondary voltage (below 1.5 V), and also because of the need of galvanic isolation of the two voltages.

The expedience of the use of converters with synchronous rectification, on the place of traditional converters with Schottky diodes depends of the specific requirements, which the power supply is expected to achieve and is determined by the comparative estimation of the cost expenses of the two types of converters.

The difference is that in the buck converters with synchronous rectification the reverse Schottky diode at the exit of the converter is replaced with a MOSFET-transistor in a switching mode. The successful application of the synchronous rectification is due on one hand to the rapid decrease in the market price of the MOSFET-transistors and to the significant decrease of the On-Resistance of these transistors in conduction mode $R_{DS(on)}$ on the other.

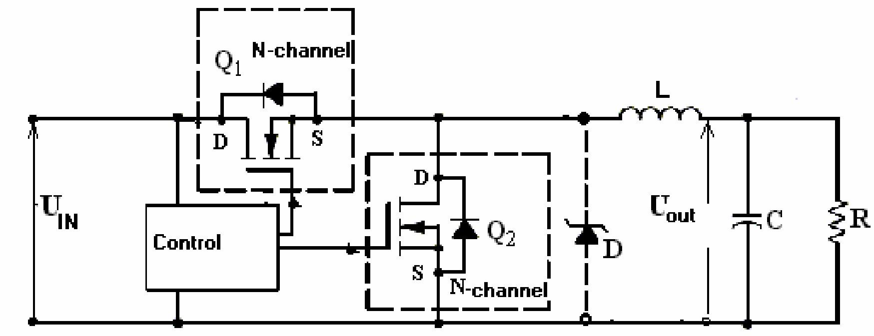

Fig. 1. Typical buck converter employing synchronous rectification

Here follows a comparative estimation between synchronous rectification and rectification with Schottky diodes regarding converters, realized via the commonly used in the computer technologies circuit of a buck converter. Fig. 1 illustrates a typical buck converter employing synchronous rectification. When a buck converter employing a Schottky-rectifier is used, the Schottky diode D, given with dotted line, replaces the synchronous transistor Q_2 .

The structure of the synchronous MOSFET-transistor contains a parasite (outer) diode, which has to be inserted in the same direction like in the case with the Schottky diode. That is why the synchronous MOSFET-transistor N-channel has to work in the third quadrant, i.e. in negative voltages and currents. This turns out to be easy, because the characteristics of the MOSFET-transistor permit work in the third quadrant, while keeping the $R_{DS(on)}$ values low.

In this presentation it is assumed that the impulses, supplying the key elements are square and pulse-width modulated.

To simplify the modulations in the typical scheme the Schottky diode (D) is replaced by an emf source (V_f), and the synchronous transistor Q_2 is replaced by a linear transistor with value – $R_{DS(on)}$.

Furthermore, the only costs taken into account are the costs produced during working of the key elements, due to the fact that these costs comprise the main part of all the costs. The analysis, regarding the expedience of replacing the Schottky-diode with a MOSFET-transistor, is based on a simple statistical design of these elements, without taking into account the commutation processes. Because of this, the conclusions, which have been drawn are valid for a relatively low-frequency converters with a commutation frequency up to 250 kHz.

The losses of the Schottky-diode are calculated by the following formula

$$P_D = V_f I_{Dav},$$

where

$$I_{D_{av}} = \frac{1}{T}\int_{\delta T}^{T} I_0 dt = I_0(1-\delta).$$

Then

(1) $$P_D = V_f I_0 (1-\delta).$$

The total losses of the synchronous transistor Q_2 are calculated by the following formula:

$$P_{Q_2} = R_{DS(on)} I_{ef}^2, \text{ where } I_{ef} = \sqrt{\frac{1}{T}\int_{\delta T}^{T} I_0^2 dt} = I_0\sqrt{1-\delta}.$$

Then:

(2) $$P_{Q_2} = R_{DS(on)} I_0^2 (1-\delta).$$

The following symbols are used in the formulae above:

I_0 – converter's output current;

T – the period of the clock impulse;

δ – the filling coefficient of the impulses of the main transistor Q_1.

The equation between the two appliances is used to determine the border current I_{DIV}. The synchronous rectifier proved to be the better one below the border current, and the Schottky-diode rectifier proved to be better at currents, higher than the border current:

(3) $$I_{DIV} = \frac{V_f}{R_{DS(on)}}.$$

With the parameters of the MOSFET-transistor getting better and better, the border current constantly increases and has reached values above 100 A.

A comparative estimate has been done in the statement, regarding the total costs for the realization of a typical buck converter, using either synchronous rectifier or a rectifier with Schottky diode with the following parameters:

(4) $$U_{in} = 12 \text{ V}; \; U_{out} = 3.3 \text{ V}; \; I_0 = 20 \text{ A}.$$

The comparison is only valid for the part of the realization of the scheme, when the two designs are different from one another. The difference of the two realizations of the scheme is that in the scheme applying Schottky-rectifier a Schottky-diode D has been used and in the scheme, applying synchronous rectification a synchronous transistor Q_2 and an integral control scheme has been used, instead of a Schottky diode.

The actual realization of the two compared rectifiers is based on elements with parameters, corresponding to the up-to-date developments of the world's leading companies. IRF6618, manufactured by the International Rectifier company [2] is adopted as a synchronous transistor, and STPS40L15CT, manufactured by the ST Microelectronics company or the International Rectifier company [3] is used as a Schottky-diode transistor. The control is carried out by an integral controller for control of a buck converter LM2746, manufactured by the National Semiconductor company [4]. The main transistor (Q_1) is the same for both types of converters and because of this it is not included in the comparison.

The MOSFET-transistor IRF6618 is an "ideal" device in its role as a synchronous transistor in the output rectifier of highly-effective DC-DC converters. This transistor is a combination of International Rectifiers's newest technologies for MOSFET-transistors with very high density of the HEXFET Power MOSFET and for the structure of the DirectFET packaging. The result is that very high values of the main parameters have been achieved:

(5) $$R_{DS(on)max} = 2.2\ \text{m}\Omega \ \text{ when } I_{drain}=30\ \text{A},\ T_J = 25\ °\text{C}$$

$$\text{and equal to } 2.75\ \text{m}\Omega \ \text{ when } I_{drain} = 30\ \text{A},\ T_J = 100\ °\text{C}.$$

(6) $$R_{thJA,max}= 45\ °\text{C per 1W}$$

(thermal resistance ratio between the transition and the surrounding air in a surface installation of the transistor).

STPS40L15CT is a "Low drop OR-ing Schottky Diode" with a very low voltage decrease in a forward direction:

(7) $$V_{f,max} = 0.5\ \text{V (when } I_D = 20\ \text{A).}$$

Thermal resistance ratio between the transition and the corpus and between the corpus (TO220) and the heatsinks are the following:

(8) $$R_{thJC} = 1.5\ °\text{C per 1W and } R_{thCS} = 0.5\ °\text{C per 1 W.}$$

The duty cycle ration of the main transistor is determined, according to (4), by the equation

$$\delta = U_{out} / U_{in} = 3.3\ \text{V} / 12\ \text{V} = 0.275.$$

Then:

(9) $$1 - \delta = 0.725.$$

For facility's sake the pulsations of the output current are neglected and it is accepted that the current through Q_2 and D (Fig. 1) in a conductive mode is equal to I_0.

The losses of the Schottky-diode D and the synchronous transistor Q_2 are determined respectively by (1) and (2), when the value of V_f is taken from (7), the values of $R_{DS(on)}$ from (5), the value of I_0 from (4) and the values of 1– δ – from (9). Then:

(10) $$P_D = V_f I_0 (1-\delta) = 0.5\times20\times0.725 = 7.25 \text{ W};$$

(11) $$P_{Q_2} = R_{DS(on)}.\ I_0^2\ (1-\delta) = 2.75\times10^{-3}\times20^2\times0.725 = 0.8 \text{ W}.$$

To conduct the losses of the Schottky diode, at T_J =115 °C and T_A =50 °C and R_{thJC} and R_{thCS} values, according to (9) a cooling radiator with thermal resistance (between the radiator and the ambient) is required:

(12) $$R_{thSA} = \frac{T_J - T_A}{P_D} - R_{thSC} - R_{thJC} = \frac{115-50}{7.25} - 1.5 - 0.5 \approx 7 \text{ °C per 1 W}.$$

An appropriate device for this purpose is the standard SK 409 38,1 radiator, with the following dimensions: 45×38.1×12.7 mm and R_{thSA} = 7 °C per 1 W.

When a synchronous transistor is applied, a cooling radiator is not needed to conduct the losses at T_A = 50 °C, and $R_{thJA,max}$ and P_{Q_2} according to (6) and (11), because the transition temperature is significantly lower than the maximum admissible:

(13) $$T_J = T_A + P_{Q_2} R_{thJA} = 50 + 0.8\times45 = 86 \text{ °C}.$$

On the basis of the losses of D and Q_2 , Table 1 shows the total costs in the application of the two compared elements – a IRF6618 MOSFET-transistor or a STPS40L15CT Schottky diode. The total costs are determined by the formula

$$\sum = C_{invest} + E_{loss}C_{el.},$$

where

C_{invest} is the price of the compared elements in BGN;

E_{loss} – electric power, measured in kWh, which is lost in the synchronous transistor and in the Schottky diode for a definite period of time (for 3 years, 24 hours a day – 8000 kWh per 1 year or 8 hours per 1 day – 2000 kWh per 1 year),

C_{el} – the price of the electric energy in BGN per 1 kWh.

At the end, the following could be summarized. The results from Table 1 show that the electric power losses are 9 times higher when using a Schottky-diode than when using a synchronous transistor, the ultimate result of which is a decrease in the total costs when using a converter with synchronous rectification.

Apart from the lower total costs, the smaller losses when using synchronous rectification give the opportunity to increase the compactness (reducing the need of cooling devices) and the reliability (lower working temperatures of the transition of the synchronous transistor).

Table 1

Compared elements	Types of Converters			
	Using synchronous rectification		Using Schottky diode rectification	
	IRF6618	LM2746	STPS40L15	SK409 38.1
Price, BGN	2.25	2.15	1.51	1.66
Investments, BGN	4.40		3.17	
Losses, W	0.8		7.25	
Energy lost, kWh for 8000 h per 1 year for 3 years	19.2		174	
Price BGN at 0.145 BGN per 1 kWh	2.78		25.23	
Energy lost, kWh For 2000 h per 1 year for 3 years	4.8		43,5	
Price, BGN at 0.145 BGN per 1 kWh	0.70		6.31	
Total costs BGN For 8000 h per 1 year for 3 years	4.40 + 2.78 = 7.18		3.17 + 25.23 = 28.40	
Total costs BGN For 2000 h per 1 year for 3 years	4.40 + 0.70 = 5.10		3.17 + 6.31 = 9.48	
Savings, BGN For 8000 h per 1 year for 3 years	28.40 – 7.18 = 21.22			
Savings, BGN For 2000 h per 1 year for 3 years	9.48 – 5.10 = 4.38			

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4. National Semiconductor Corporation. Application Note 1385-LM2746 Evaluation Board, May 2005.

Источники питания с синхронным выпрямлением для компьютерных и коммуникационных систем

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(Р е з ю м е)

В работе потвердена целесообразность применения преобразователей с синхронным выпрямлением на месте традиционных преобразователей с Шотки-диодами в источниках питания с ниским напряжением и большим током на выходе. Сделана сравнительная оценка суммарных расходов конкретной схемной реализации преобразователя с синхронным транзистором и с Шотки-диодом с напряжением 3.3 V и током 20 A на выходе.