고효율, 고전력밀도 아답터를 위한 도통밴드 제어 AC-DC 벅 컨버터

문상철, 정봉근, 구관본
온세미컨덕터

A Conduction Band Control AC-DC Buck Converter for a High Efficiency and High Power Density Adapter

SangCheol Moon, Bonggeun Chung, Gwanbon Koo
ON Semiconductor

ABSTRACT

This paper proposes a new control method for an AC-DC Buck converter which is utilized as a front-end converter of a 2-stage high power density adapter. In the conventional adapter applications, 2-stage configuration shows higher power transfer efficiency and higher power density than those of the single stage flyback converter. In the 2-stage AC-DC converter, the boost converter is widely used as a front-end converter. However, an efficiency variation between high AC line and low AC line is large. On the other hand, the proposed conduction band control method for a buck front-end converter has an advantage of small efficiency variation. In the proposed control method, switching operation is determined by a band control voltage which represents output load condition, and an AC line voltage. If the output load increases in low AC line, the switching operation range is expanded in half of line cycle. On the contrary, in light load and high line condition, the switching operation is narrowed. Thus, the proposed control method reduces switching loss under high AC line and light load condition. A 60W prototype which is configured the buck and LLC converter with the proposed control method is experimented on to verify the validity of the proposed system. The prototype shows 92.16% of AC-DC overall efficiency and 20.19 W/in^3 of power density.

1. Introduction

Recently, weight and size are very important considerations in selecting portable devices. For charging systems, small size adapters are also preferred by customers. Thus, a high efficiency and a high power density are highly required to realize the small size adapters.

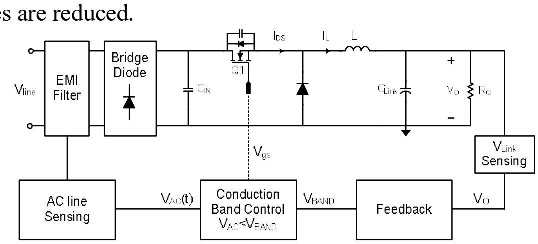
In conventional adapter applications, 2-stage configuration shows higher power transfer efficiency and higher power density than those of the single stage flyback converter because the flyback converter needs a relatively huge size transformer. In the 2-stage AC-DC converter, the boost converter is widely used as a front-end converter. It provides continuous input current and power factor correction. However, typically the boost PFC front-end converter shows 2%-3% lower efficiency at a low AC line when compared to that at a high AC line. So, the power density is limited by the low AC line.

Since the power factor correction is not essential for a low power adapter application less than 75W, the buck front-end converter may overcome the disadvantages of the boost front-end converter. Although this buck front-end converter shows higher efficiency at a low AC line and small efficiency variation between the low AC line and the high AC line, the lower efficiencies at high AC line and light load condition caused by the switching losses may not comply with the regulations such as CoC version5 and DoE level6. To achieve higher efficiency at the high AC line and light load condition, this paper proposes a conduction band control method which can reduce the switching losses and provide higher efficiency under entire AC line and load ranges..

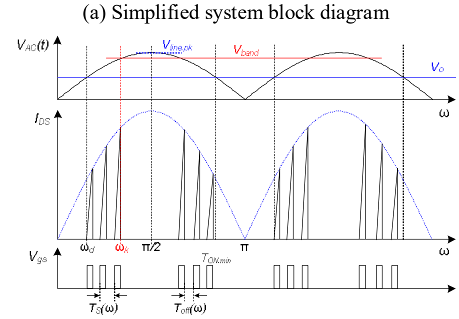
2. Analysis of the proposed band control method

The proposed conduction band control method is shown in Fig. 1. The conduction band control block receives two information in Fig. 1. (a). One is line voltage information $V_{AC}(t)$ sensed by an AC line sensing block. The other information is a band control voltage V_{BAND} which is determined by the output load condition and feedback loop. Then, the conduction band control block determines the switching operation region.

The operational waveform is shown in Fig. 1. (b). For easy explanation, it is assumed that the voltage and time scales are exaggerated and there is no ripple in the output voltage. In low AC line and heavy load condition, if V_{BAND} is higher than the peak voltage of low AC line, the system is controlled by the constant on-time T_{ON} like the conventional CrM buck converter. As the load decreases, and the constant on-time becomes its minimum value, T_{ON} is fixed by $T_{ON.min}$ regardless of output load condition. Then, the system is controlled by the conduction band. In the region where $V_{AC}(t)$ is lower than V_{BAND}, the MOSFET gate switching operates. However, if $V_{AC}(t)$ is higher than V_{BAND}, the gate switching is stopped and then waits until next gate conduction region where $V_{AC}(t)$ is lower than V_{BAND}. On the other hand, in the high AC line, Gate turn on time is fixed as $T_{ON.min}$ and the system is controlled by the conduction band only. Since the proposed conduction band control method has no switching operation when instantaneous AC line voltage is relatively high, and the operating frequency is limited by $T_{ON.min}$, the switching losses are reduced.



(a) Simplified system block diagram



(b) Operational waveform

Fig. 1. The proposed conduction band control method

In Fig. 1. (b), the power is transferred from input to output only when the instantaneous line voltage is higher than the output voltage. This induces dead angle ω_d to the inductor current during $0<\omega<\pi/2$. The dead angle can be expressed by ratio between the output voltage V_o and the line peak voltage $V_{line.pk}$ as below:

$$\omega_d = \sin^{-1} V_o / V_{line.pk} \tag{1}$$

where, $V_{line.pk}$ is peak voltage of the AC line. In the proposed control method, another dead angle is started at ω_k where $V_{AC}(t)$ is higher than V_{BAND}. The conduction dead angle ω_k can be obtained as:

$$\omega_k = \sin^{-1} V_{BAND} / V_{line.pk} \tag{2}$$

In the proposed converter, the inductor peak current during conduction angle between ω_d and ω_k is proportional to difference between the instantaneous line voltage and the output voltage. Thus, the average inductor current for one switching cycle is given by:

$$\left\langle I_L(\omega) \right\rangle_{Ts} = T_{ON.\min}(V_{line.pk}\sin\omega - V_o)/2L \tag{3}$$

So, the output power can be obtained as:

$$\begin{aligned} P_o &= \frac{2}{\pi}\int_{\omega_d}^{\omega_k} V_o \cdot \left\langle I_L(\omega) \right\rangle_{Ts} d\omega \\ &= \frac{V_o T_{ON.\min}}{\pi L} \cdot \left(V_{line.pk}(\cos\omega_d - \cos\omega_k) + V_o(\omega_d - \omega_k) \right) \end{aligned} \tag{4}$$

where, V_o, $T_{ON.min}$, and L are constant. Since the switching start point ω_d is determined by output voltage and the instantaneous line voltage, output power is solely determined by ω_k. Therefore, in the proposed control method, the output power is controlled by the conduction dead angle ω_k which is determined by V_{BAND}.

3. Experimental results

A prototype for the 60W adapter system, which is configured by buck and LLC converter with the proposed control method, is implemented and experimented on to verify the validity of the proposed system as shown in Fig. 2. The prototype shows 92.16% of AC-DC overall efficiency at 90Vac and 20.19 W/in^3 of power density without outer case, and input/output outlets. The specifications are described in Table I. The output voltage V_o of the proposed buck front-end converter and the output voltage $V_{o.LLC}$ of LLC converter are 82Vdc and 12Vdc, respectively. For magnetic components, RM6 core is used to both the buck inductor and the LLC transformer.

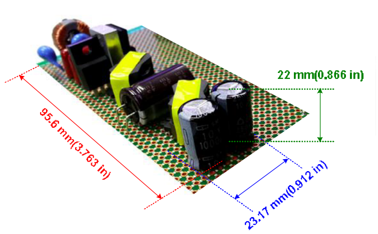


Fig. 2. The prototype of the the proposed 2-stage system

Table I

Input line voltage V_{line}	90~230 Vac
Buck output voltage V_o	82 Vdc
LLC output voltage $V_{o.LLC}$	12 Vdc
LLC output load current I_o	5 A
Rated output power P_o	60 W
Switching freq. of LLC f_s	250 kHz

Fig. 3 shows experimental waveforms with load variation at the 120Vac line. In the low AC line, since the conduction loss is dominant, MOSFET is switched all over the range from ω_d to π-ω_d at full load condition. However, as the output load decreases, the conduction switching range is reduced. As a result, switching losses decrease.

Fig. 4 shows the efficiency of the conventional CRM buck converter and the proposed converter with 90Vac, and 230Vac line. In the conventional converter, the efficiency rapidly decreases when the output load decreases. On the other hand, the proposed converter shows higher efficiency at 230Vac line and light load condition. It proves that the proposed conduction band control method effectively reduces switching loss and increases system efficiency in high line and light load condition.

4. Conclusion

In this paper, a new conduction band control method for a buck front-end converter has been proposed for high efficiency and high power density adapter systems. In the proposed control method, the MOSFET switching region is determined by the comparison between instantaneous line voltage and the conduction band voltage which represents output load condition. When the AC line is high and the output load is light, the MOSFET switching range becomes narrow with fixed minimum turn-on time. Therefore the switching losses are dramatically reduced under high AC line and light load condition. The 60W prototype was used to verify the proposed system. As a result, the proposed converter shows much higher efficiency at the high AC line and light load condition compared to that of the conventional CRM buck converter.

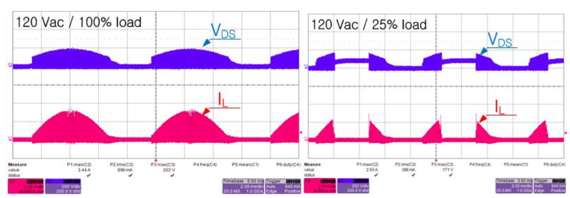


Fig. 3. Experimental waveform of the proposed control with load variation

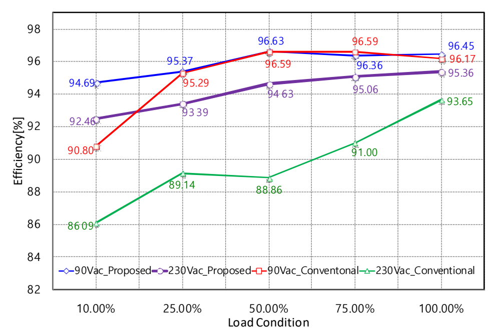


Fig. 4. Efficiency of the conventional CRM buck converter

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