Modulated Carrier Control for Interleaved Continuous Conduction Mode(CCM) Boost Power Factor Correction Converter

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Abstract

In recent years, in an effort to improve the efficiency and the power density of the front-end power factor correction(PFC), the interleaving of multiple converter is employed. The conventional interleaved continuous conduction mode(CCM) boost PFC converter requires input and output voltage sensing and three current sensing to obtain current balancing between modules. In this paper, the interleaved CCM PFC converter based on modulated carrier control is proposed. With the proposed method, two phase interleaved PFC can be realized simply without line voltage sensing resistor and can achieve current balancing without additional current sensing resistor on common return path. The simulation studies are carried out to verify the effectiveness of the proposed control scheme.

1. Introduction

Recently, high efficiency is becoming more important in the PFC design to meet the U.S. Energy Star, Climate Savers program requirements. It indicates the efficiency requirement keeps increasing and is extending to lower power conditions. Higher power density is also desired since it can reduce the converter volume and cost. For the high power density, the key is to reduce the EMI filter and the inductor size without compromising the efficiency. However, for continuously increasing power density and high efficiency requirement, the single-phase PFC shows its limitation in improving the efficiency and power density [1].

The interleaving of multi-phase boost converter is very often employed to improve performance and reduce size of the PFC converter. Because interleaving effectively doubles the switching frequency and also partially cancels the input and output current ripples, the size of the inductor and EMI filter can be reduced and eventually will increase the power density and efficiency.

However, the current balancing technique between interleaved PFC modules operating in CCM is critical. The conventional current balancing scheme for two interleaved PFC requires three current sensing, the total input current and the individual current of each switch shown in Fig.1. The total input current is sensed through sensing resistor on the common return path for the inner current control loop. The switch current on the individual phase is sensed to achieve the current balancing. The current balancing control will adjust the duty cycle of each phase based on the sensed switch current information [2].

In this paper, two interleaved boost PFC converter control technique with modulated carrier control [3] is proposed that does not require input voltage sensing resistor and additional total input current sensing resistor on the common return path. Simulation results show that the proposed method can balance the phase current.

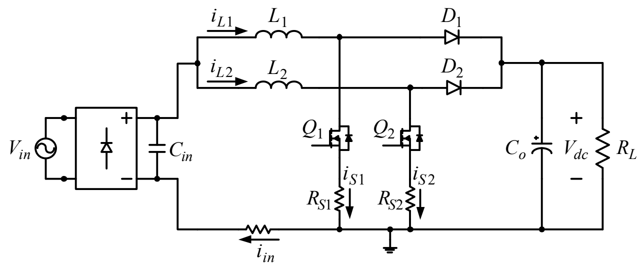


Fig. 1 Circuit diagram of the interleaved boost PFC converter.

2. Proposed control scheme

Fig.2 shows the proposed control method. A current sensing resistor is placed in series with a switch to obtain the inductor current information. As shown in Fig.2, the carrier signal voltage(V_{R1}) of the first module decreases linearly from a maximum voltage(V_M) at the beginning of the switching period at time zero, down to a minimum voltage($-V_M$) at the end of the switching period. The carrier signal voltage(V_{R2}) of the second module also decreases linearly from a maximum voltage(V_M) at the end of the first half of the switching period at time $T_S/2$, down to a minimum voltage($-V_M$) at time $3T_S/2$.

Each sensed switch current increases as the current flows through the switch Q1 and Q2 in the first half of the switching period respectively. At the intersection time T_{X1} and T_{X2}, the carrier voltage V_{R1} and V_{R2} are intersected with the sensed switch voltage.

The controller controls the switch Q_i ($i=1,2$) such that it is ON for a time equal to twice the intersection time $T_{X,i}$ as shown in Fig.2. At the end of the time $2T_{X,i}$, the controller switches off the switch Q_i for the rest of the switching period. Thus, the on time of the switch can be expressed as

$$T_{on,i} = D_i \cdot T_S = 2T_{X,i}$$

where $T_{on,i}$ is the ON time of the switch Q_i, D_i is the duty cycle of the each module and $T_{X,i}$ is the intersection time.

In continuous conduction mode PFC, the switch current of the switch Q_i at the middle of the its conduction time is almost the same as the average of the inductor current($I_{Lavg,i}$). That is, average current control is available with switch current sensing.

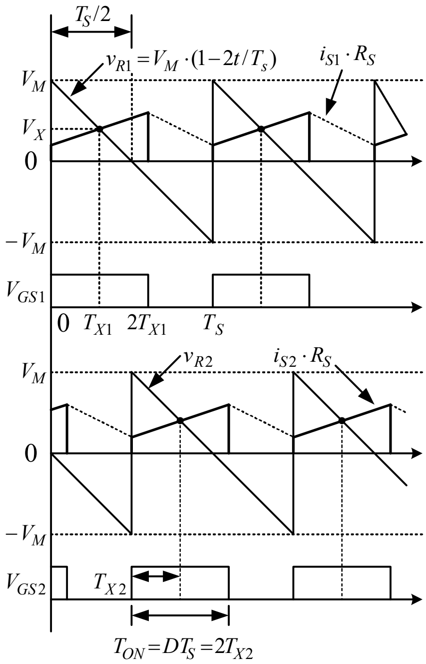


Fig. 2 The operation waveform of the proposed method.

The carrier signal voltage may be described by as,

$$V_R(t)=V_M(1-\frac{2t}{T_S})$$

where $V_R(t)$ is the carrier signal voltage as a function of time, V_M is the maximum voltage of the carrier signal at the beginning of the switching period, and T_S is the time period of the switching cycle. The duty cycle D_i of a continuous conduction mode boost PFC converter is

$$D_i=1-\frac{V_{in}}{V_{dc}}\rightarrow 1-D_i=\frac{V_{in}}{V_{dc}}$$

where V_{dc} is the output voltage and V_{in} is the input ac line voltage. Therefore, Combining (2) and (3) gives

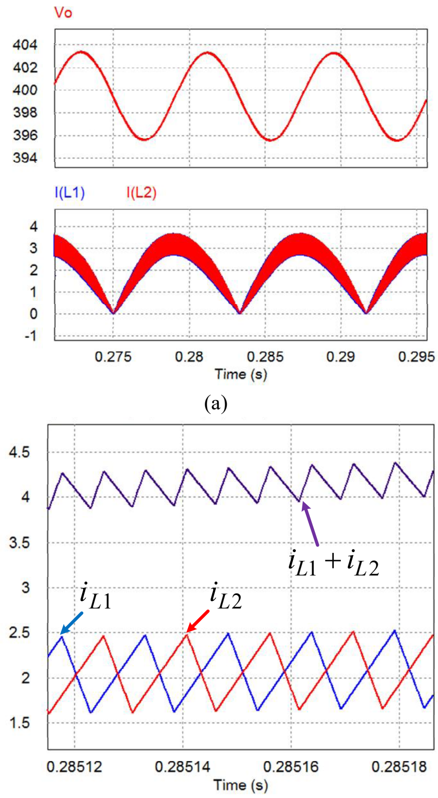
$$I_X\cdot R_{s,i}=V_X=V_M\frac{V_{in}}{V_{dc}}$$

where I_X is the switch current at the intersection time and V_X is the voltage across the resistor R_S at the intersection time. It can be inferred from (4) that the voltage V_X is proportional to the ac line voltage V_{in} and, hence, is in phase with it.

Therefore, the circuit is able to perform continuous conduction mode of PFC without necessarily requiring line voltage sensing resistor to obtain a sinusoidal reference and can achieve equal current balancing without additional current sensing resistor on common return path.

3. Simulation Result

The proposed interleaved CCM boost PFC based on modulated carrier control technique is simulated. Fig.3 (a) shows the results of the inductor current between two phases. It shows that proposed modulated carrier control can balance the current between two phases. Fig.3 (b) shows the inductor current ripple cancellation. From this figure, it can be observed that the input current ripple is reduced compared to the individual inductor current ripple.



(b)

Fig. 3 (a) Simulated PFC inductor current waveforms with the proposed control method (b) Simulated interleaved inductor current waveform.

4. Conclusion

Due to the high efficiency and power density requirement, interleaved CCM PFC converter is desired. The conventional interleaved PFC control requires three current sensing to achieve current balancing between PFC modules. In the proposed approach, modulated carrier control method is used. With the proposed method, the interleaved PFC operation can be realized simply without line voltage sensing resistor and can achieve current balancing without additional current sensing resistor on common return path. The simulation results of the interleaved PFC converter proved the advantage of the proposed control scheme.

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