Novel Control Range Compensation Method in Power Factor Correction Circuit

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Abstract

When Power Factor Correction(PFC) boost converter is designed for the universal input range, unwanted burst operation can be found at high line and light load. This operation may cause an audible noise from the boost inductor or sensitive flicker for human eye can be found in case of the display application.

In order to solve this difficulty, this paper proposes the new control range compensation method and shows the effectiveness than the conventional method thru the experimental result.

1. Introduction

For the efficient use of the transmission line, the necessity of PFC is increasing and that is also true when the load is light. In addition, PFC input voltage typically should cover wide range to support worldwide wall outlet voltages. Thus, stable operation of PFC at wide range of input voltages and load conditions is inevitable.

This requires the control voltage range also should be wide to cover two worst cases, those are the combination of the minimum input voltage and maximum load and the other one is the maximum input voltage and minimum load. The necessary range is too wide to realize by common PWM controllers. Accordingly PFC operation may fall to an unwanted burst operation when input voltage is high and load is lower than some level. The minimum load level is decided by the system requirement, in LED TV case, load can be decreased to 10% of rated load when the minimum dimming is activated to achieve better contrast ratio.

To solve this, this paper firstly explains how control range is determined, then proposes the new method to expand the control range and finally proves the performance with the real converter.

2. Control range of PFC boost converter

2.1 Necessity of wide control range

For PFC embodiment, boost converter is normally chosen because the input current averaging is easier than the buck-boost type owing to the boost inductor at the input side and the boost converter can operate at all input voltage range than the buck converter, this makes no dead-zone nearby AC zero point.

Boost topology, however, also has many short comings. One of them is that output voltage should be higher than the input voltage resulting in the high voltage stress of the components after PFC stage. With the universal range, that is from $85V_{AC}$ to $265V_{AC}$ with a tolerance is considered, PFC output voltage is normally around $400V_{DC}$.

While the boost converter output is fixed, wide input voltage variation needs the wide variation of converter's gain and control voltage. Furthermore, when the load variation comes together, the control voltage range should vary wider range. If the control range is not enough, the converter operation should stop when input voltage is high and load is light in order to control the output voltage. For example, if input voltage is raised 3 times the needed on-time, that is controlled by the control is decreased 1/9 compared to that of the low input voltage. That is described in the Equation (1) and Fig.1, operation mode is assumed CRitical conduction Mode(CRM).

$$
\begin{aligned}
\Delta t_{VIN} &= \frac{L}{V}\Delta i = \frac{1}{V}\cdot L\cdot\Delta i \\
\Delta t_{3VIN} &= \frac{1}{3V}\cdot L\cdot\frac{\Delta i}{3} = \frac{1}{9}\cdot\frac{L}{V}\Delta i = \frac{1}{9}\cdot\Delta t_{VIN}
\end{aligned}
\qquad (1)
$$

When the load is light and the input voltage is high, control voltage may fall into the switching stop level periodically to regulate the output. During this operation output voltage will be regulated, however, input current shape is far from the sinusoidal form because of the intermittent switching on and off.

Fig. 2 is the operating waveforms of the conventional PFC boost converter when input voltage is $230V_{AC}$ and load is 39W, 20% of rated load. Burst frequency is about 20Hz and its multiple frequencies are easy to fall into audible noise range. This may

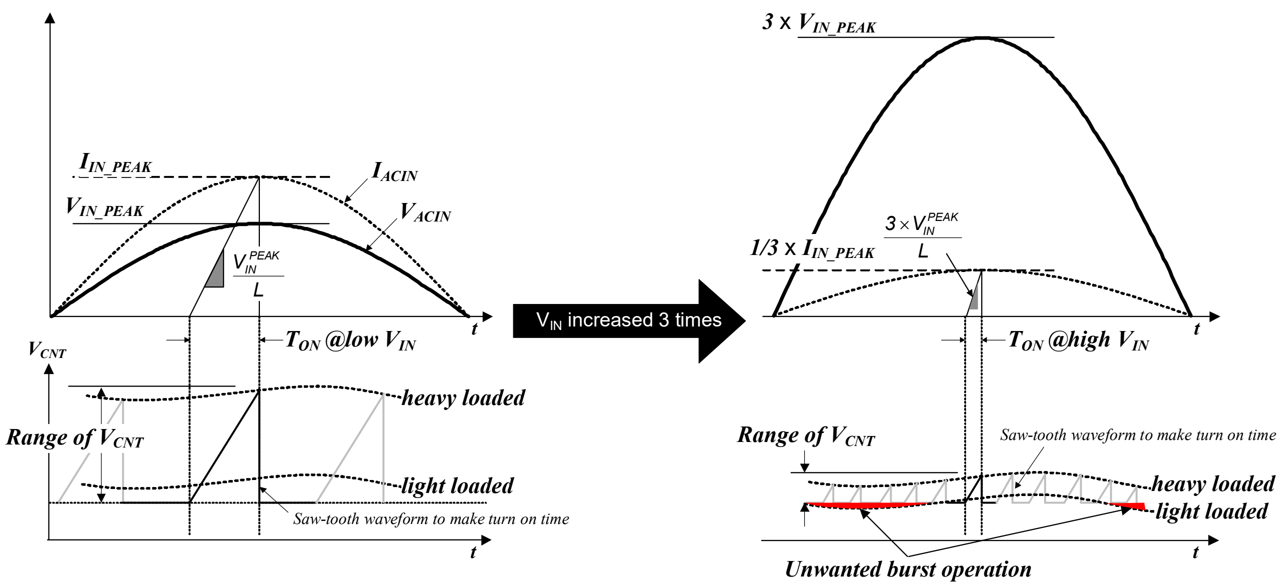


Fig. 1 Control range problem when input voltage is changed a lot

cause the serious audible noise coming from boost inductor and input filter inductor, eye sensitive flicker when PFC is used at display application and deteriorate the power factor too. PFC output voltage is also fluctuating, so that it may give a harm effect to the afterward DC to DC stage.

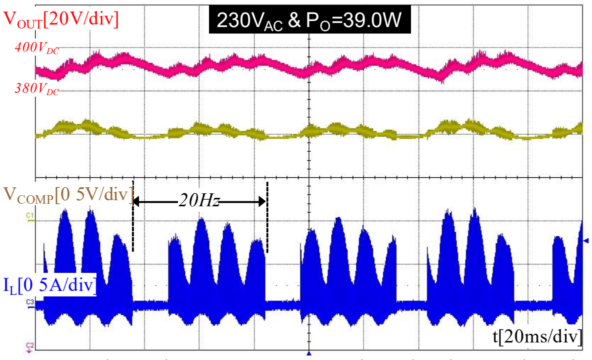


Fig. 2 Normal PFC boost converter operation when input voltage is high and load is light

2.2 Control range compensation

To make the turn-on time of PWM operation, saw-tooth oscillator is normally compared with controlled DC voltage. Thus turn on time is directly proportional to the DC voltage. Saw-tooth waveform can be made by the combination of constant current source and the capacitor. By the periodic or arbitrary trigger signal, ON starts and voltage of saw-tooth generator starts to increase by the constant current source and meets the controlled DC voltage, this finishes ON. Until the next turn on, saw-tooth generator can be clamped to the low level, guarantees the no switching.

Small on-time means controlled DC voltage is small and close to the switching stop level. Even the controlled DC voltage is the same, turn-on time can be changeable according to the slope of saw-tooth waveform. When the saw-tooth slope is steep, turn on time is smaller than the saw-tooth slope is slow. So if we can adjust the slope of saw-tooth generator flexibly during the ON, we can adjust the turn-on time even though the controlled DC voltage is fixed or controlled DC voltage can be adjustable even needed on-time is the same.

Fig. 3 explains how the proposed method can expand the control voltage without changing the turn-on time.

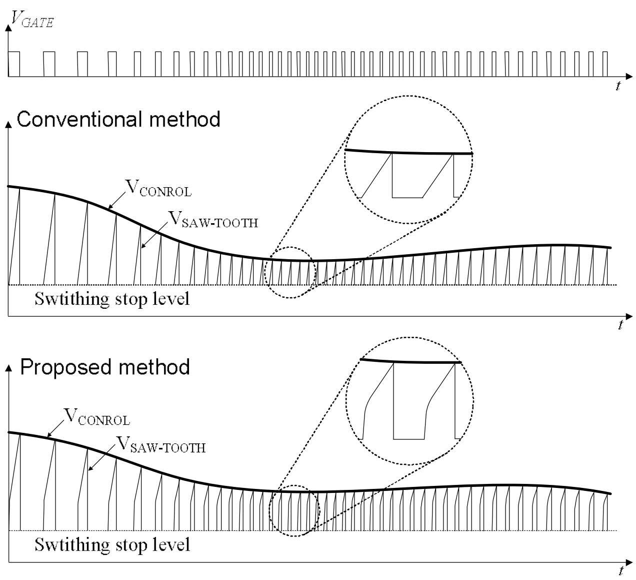


Fig. 3 Saw tooth waveform comparison between conventional and proposed method

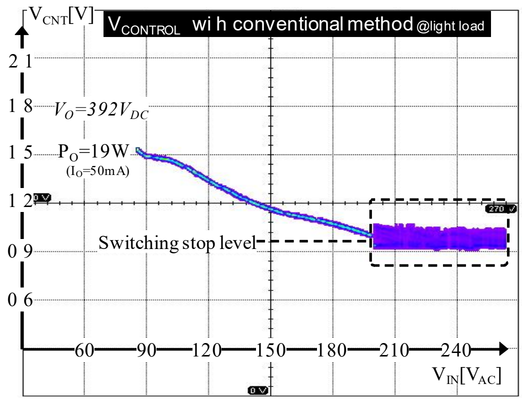
2.3 Experiment result

In order to check the validity of the proposed method, 200W PFC boost converter system is designed and Table 1 shows the specifications of the converter. CRitical conduction Mode(CRM) was chosen because when output power is lower than 300W the performance of CRM is better than Continuous Conduction Mode(CCM).

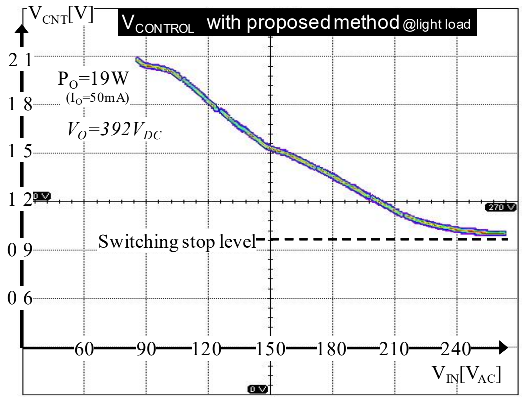
Fig. 4 shows control range is expanded much when the proposed method is adapted.

Table 1 Specifications of the tested converter

Input voltage range	85V_{AC} ~ 265V_{AC}
Output voltage	392V_{DC}
Output current	520mA
Output power	204W
Switching frequency	Variable(50kHz ~ 300kHz)
Boost switch	FCPF20N60
Boost diode	FFPF08H60S
PWM controller	FAN7930B
Boost inductor	194µH with EER3019N core



(a) Control voltage variation with the conventional method



(b) Control voltage variation with the proposed method

Fig. 4 Comparison of the control voltage at light load

3. Conclusion

It was explained that the necessity of wide control range for the PFC boost converter. To expand the control range when input voltage is high and load is light, the paper proposed the nonlinear saw-tooth generator and showed performance with the 200W boost converter.

Reference

[1] Fairchild Semiconductor Application Note "AN-6086, Design Consideration for Interleaved BCM PFC using FAN9612."