AC cycle skipping improves PFC light-load efficiency

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For power supplies with an input power of 75 watts or greater, power factor correction (PFC) is usually required. It forces the input current to follow the input voltage, so that any electrical load appears like a resistor to the voltage source that powers it. This is essential for many server, telecommunications and industrial applications, where energy efficiency and power quality have become more and more strict. The most important criteria to judge PFC performance is efficiency, total harmonic distortion (THD), and power factor (PF). With the help of new semiconductor devices and new control methods, the modern PFC circuit has achieved very good performance at middle and heavy loads. However, during light-load conditions, the efficiency, THD and PF deteriorate significantly.

A typical PFC efficiency curve is shown in Figure 1. Notice how the efficiency gets lower and lower at light loads. This is because the switching loss, driving loss, and reverse-recovery loss of semiconductor components become dominant at light loads. Meanwhile, a PFC may transition from continuous-conduction mode (CCM) to discontinuous-conduction mode (DCM), which causes the converter dynamics to change abruptly and the current-loop bandwidth to reduce significantly. The small current-feedback signal also makes control very difficult. As a result, the THD of the current waveform increases (Figure 2).

This article provides a novel method to increase efficiency and reduce THD when the PFC enters the light-load condition. In this method, when the load is reduced to less than a predefined threshold, the PFC enters a special burst-mode. In this mode, depending on the load, one or more AC cycles are skipped by the PFC. In other words, the PFC turns off for one or more AC cycles, and turns back on for the next AC cycle. The turn-on/turn-off instance is at the AC zero-crossing, such that the whole AC cycle is skipped. Moreover, since PFC turn-on/turn-off occurs when the current equals zero, less stress and electromagnetic interference (EMI) noise are generated. This is different than the traditional PWM pulse-skipping burst-mode, where the PWM pulses are skipped randomly.

The number of AC cycles to be skipped is inversely proportional to the load. If the load continues to decrease below the threshold, additional AC cycles will be skipped.

Figure 1. Example of a typical PFC efficiency curve

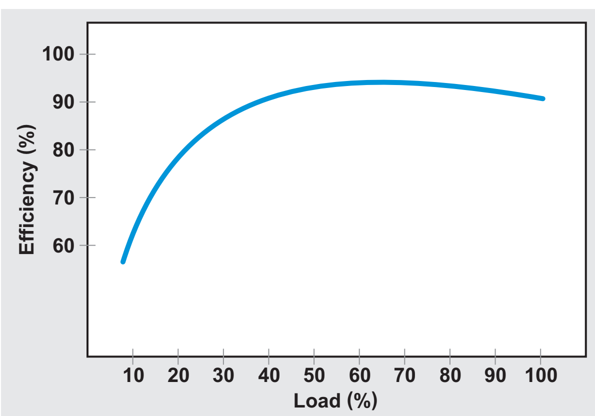
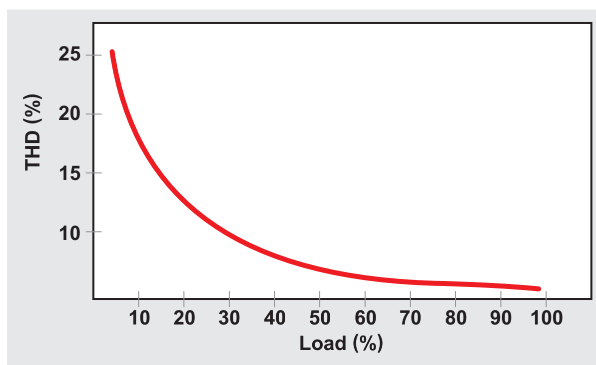


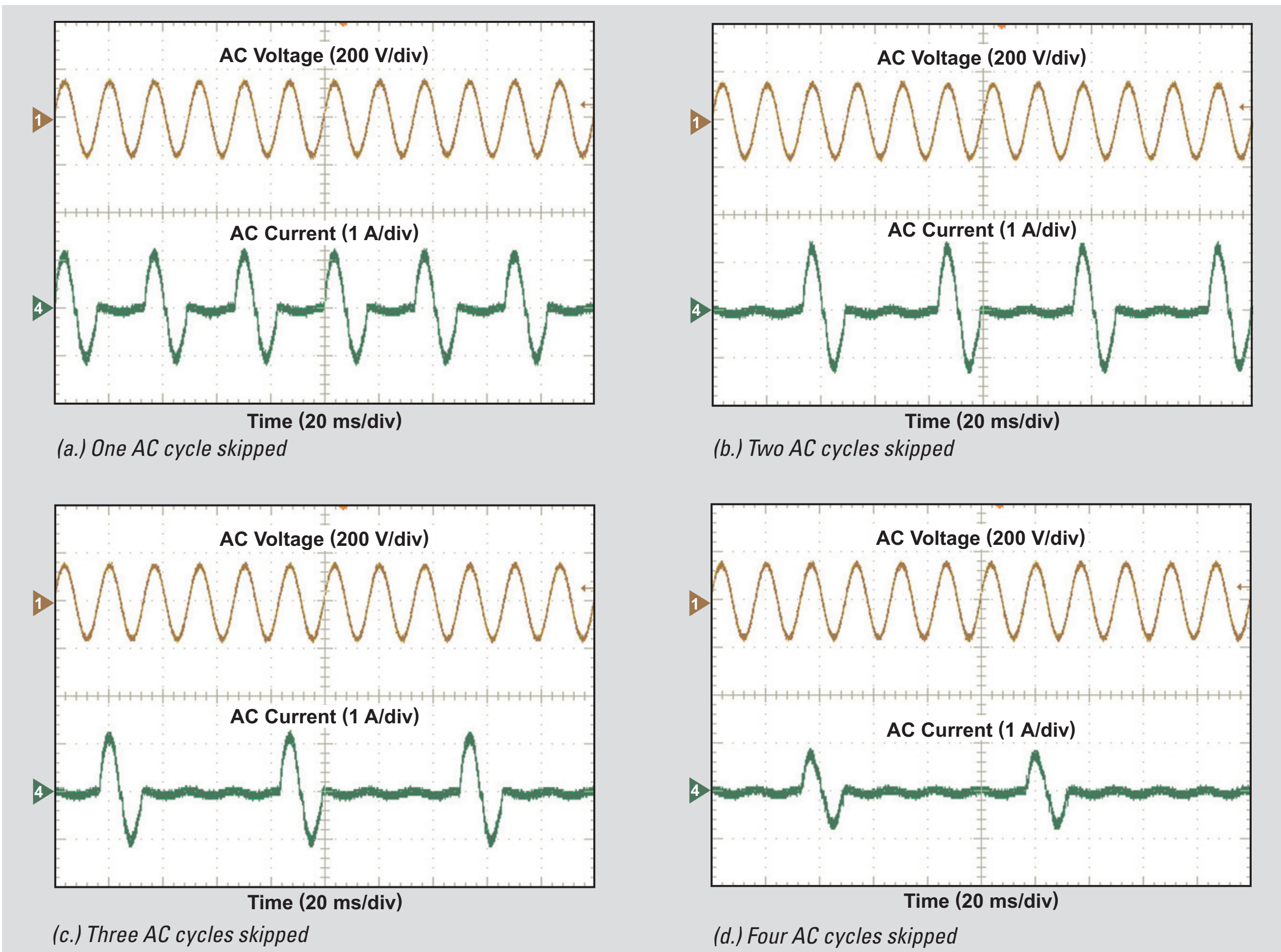
Figure 2. Example of a typical PFC THD curve



A look-up table can be generated with the load versus the number of cycles to be skipped. This table will show the maximum number of AC cycles can be skipped while maintaining the output voltage ripple within a specified range. Figure 3 shows four different AC cycles that are skipped at different loads.

Once the PFC turns off, the switching loss, driving loss, and reverse-recovery loss are all reduced to zero, and the power loss is just the PFC stand-by power. Since the current is zero, THD is zero. When the PFC turns on, it delivers more than the power required by a light load because it needs to compensate for the turn-off period. Because

Figure 3. AC cycles being skipped at different loads



(a.) One AC cycle skipped

(b.) Two AC cycles skipped

(c.) Three AC cycles skipped

(d.) Four AC cycles skipped

the PFC now operates at middle load or completely shuts off to skip AC cycles, the light-load efficiency is increased and THD is reduced. Figures 4 and 5 show the efficiency and THD improvements with this special burst-mode.

Note that when PFC turns off to skip AC cycles, both the current loop and voltage loop need to be frozen. Otherwise, the integrators in these loops build up to generate a big PWM pulse when the PFC turns back on, which causes a large current spike.

To determine whether or not the PFC enters the light-load condition, the load information needs to be monitored. Normally there is no current sensor at the PFC output, so to directly measuring output load is not feasible. However, the PFC voltage-loop output is proportional to the load when V_{IN} is fixed. Therefore, the loop output can be used as a rough indicator to determine whether or not the PFC is operating with a light load.

If there is a requirement for the precise number of AC cycles to be skipped in order to maintain the output voltage ripple within a specified range, accurate load information is required. Since there is a current shunt measuring input current for PFC current-loop regulation, the input power of a PFC can be measured. The input current and voltage can be monitored by analog-to-digital converters (ADCs), and then used to calculate the real input power. This accurate input-power information can be used to

Figure 4: Efficiency comparison

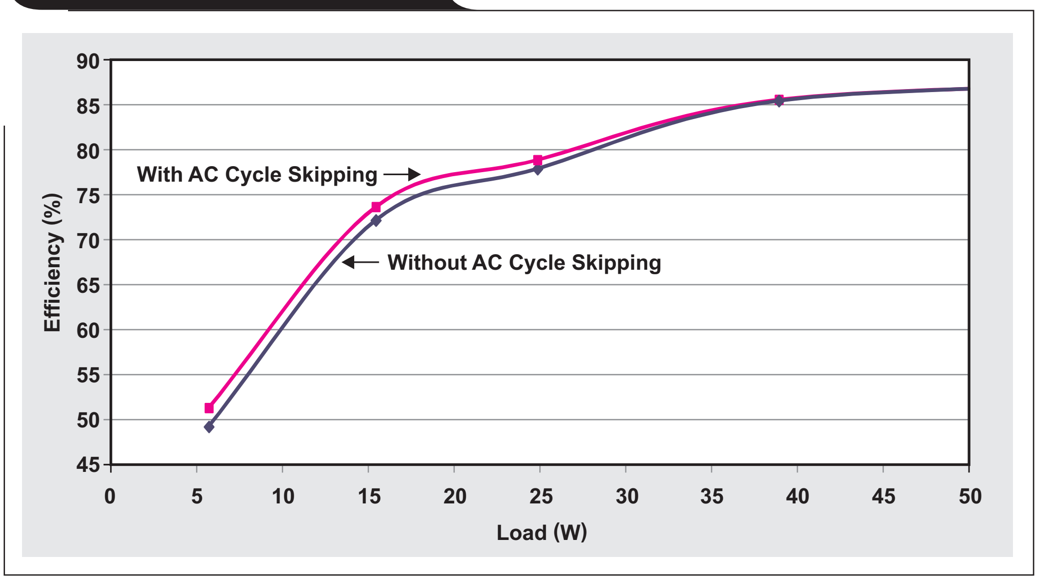


Figure 5: THD comparison

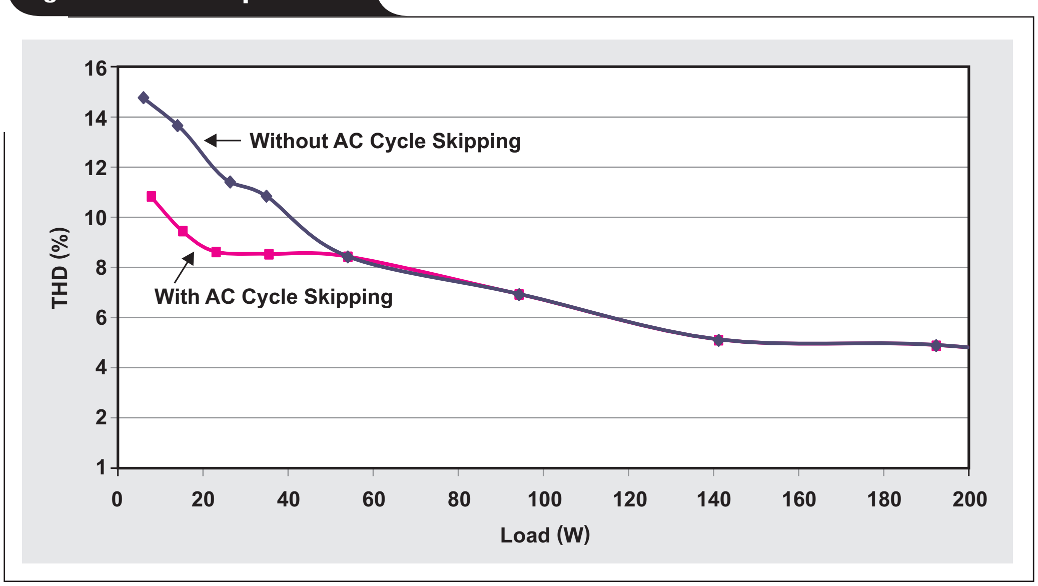
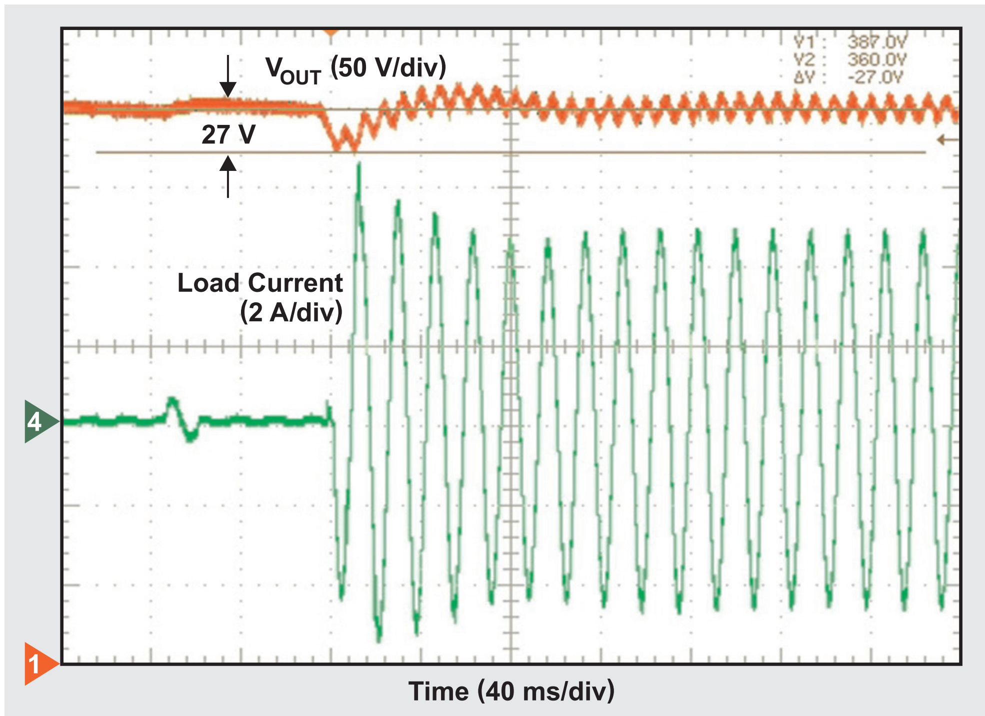


Figure 6. Load transient from zero to 100% during AC cycle skipping



precisely adjust the number of AC cycles to be skipped. There is no need for any extra hardware. For details of accurate PFC input-power measurement, please see Reference 1.

A big concern of this approach is the output voltage drop during a load transient. Assuming a load step-up occurs when the PFC is off, V_{OUT} may drop too much. To address this issue, V_{OUT} is compared with a predefined threshold through a comparator. Once V_{OUT} is below this threshold, the PFC will immediately exit the burst mode, AC cycle skipping is disabled, and the PFC returns to normal operation. It will handle transient response as if there is no special burst mode. Figure 6 shows the effects of a load transient from 0 to 100% during AC cycle skipping. Note that the V_{OUT} drop during the transient is only 27 V, which is very normal for a 360-W PFC.

Conclusion

A novel PFC burst mode allows one or more AC cycles to be skipped when a PFC operates with a light load. As a result, both efficiency and THD are improved. Moreover, since the PFC turns on/off at AC zero-crossing, circuit stress and EMI noise are reduced. The number of AC cycles to be skipped can be precisely adjusted based on load to maximize performance and maintain the output voltage ripple within a specified range. If a load transient occurs when the PFC is off, the burst mode is disabled immediately and the PFC handles the effects of the load transient normally. Finally, the implementation is easy with a digital controller, and no extra hardware is needed.

References

1. Bosheng Sun, “Low-cost solution for measuring input power and RMS current,” Analog Applications Journal, Texas Instruments, 4Q 2013. Available: **www.ti.com/3q14-SLYT545**

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