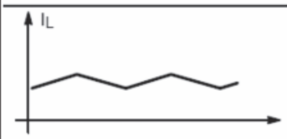
Improving Efficiency and Power Factor at Light Load

Universal input AC/DC power supplies in the range of 80-800W can be found in a variety of applications. Within this power range, the single-stage boost PFC + half-bridge LLC is considered to be a very popular topology, mostly due to the relatively simple structure, mature IC solutions, general good performance, and cost. Multiple global regulatory agencies have proposed standards on efficiency and power factor (PF) for such power supplies. Agencies like DoE, CoC, and Energy Star typically cover a wide range of applications, and others such as 80PLUS are for specific applications, like PC power. **Zhihong Yu, AC/DC & Lighting Product Marketing Manager, Monolithic Power Systems, Dallas, USA**

For some of the standards, traditionally, only the efficiency and PF at full load were listed, but the efficiency and PF at zero to low load have become more important in recent years for nearly all standards, whether it be for residential use or commercial/industrial use. Some standards directly point to low-load performance, and others may specify the average requirement across all load ranges. Such standards force most original equipment manufacturers (OEM) to improve their end products1. It is very desirable for PC power vendors to meet Gold, Platinum, or even Titanium specs of over 90 % efficiency at 50 % load without much additional cost.

As the new standards continue pushing for higher performance limits, OEMs usually take different approaches, such as spending more to get better discrete FETs and diodes, or researching new topologies. However, in the PFC field, a recent market research report that covers more sophisticated bridgeless or interleaved PFC suggests that these topologies will always have a small market share, even beyond 2019. This is mostly because they require more switches/magnetic, which adds to complexity and cost, among other concerns.

The most common PFC topology in the market is by far the traditional, hard-switched, single-phase boost converter that runs at either discontinuous conduction mode (DCM), critical conduction mode (CrM), or continuous conduction mode (CCM). These have all been well-studied for decades at most power IC and power supply companies. However, based on traditional topologies and control modes, they can still meet even the most demanding energy standards without paying a higher price.

Rating	Symbol	Unit
	Continuous Conduction Mode (CCM)	• Always hard-switching • Inductor value is largest • Minimized rms current
	Discontinuous Conduction Mode (DCM)	• Highest rms current • Reduce coil inductance • Best stability
	Critical Conduction Mode (CrM)	• Largest rms current • Switching frequency is not fixed

ABOVE: Figure 1. **Various traditional Boost PFC operation modes (Source: Onsemi Power Factor Correction Handbook)**

How to optimize efficiency at light load for single-phase PFCs

For DCM, CrM, and CCM, the difference is if the inductor current reaches zero during one switching cycle (see Figure 1).

For each operation mode, there are certain pros and cons. Designers usually choose either CrM or CCM at full load. CrM usually applies constant on-time control, and the operating frequency changes to maintain boundary mode operation. Although it has the benefit of soft switching, the high peak current leads to a large magnetic design; therefore, this topology is mostly used at <150 W. CCM

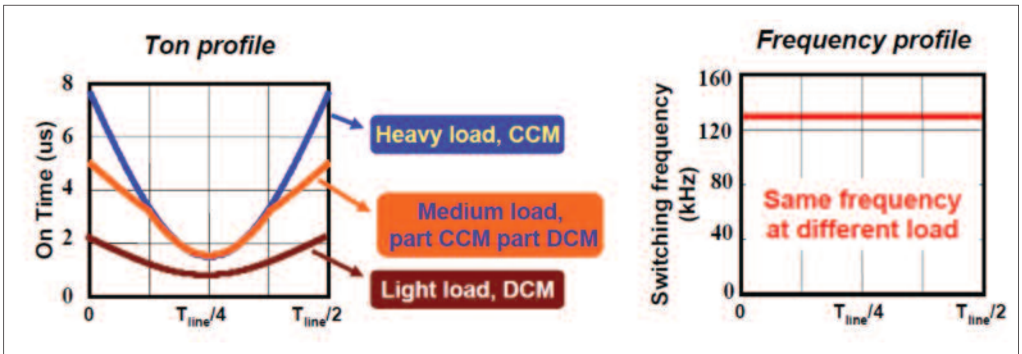


Figure 2. **Traditional CCM PFC turn-on time and frequency change over one AC cycle**

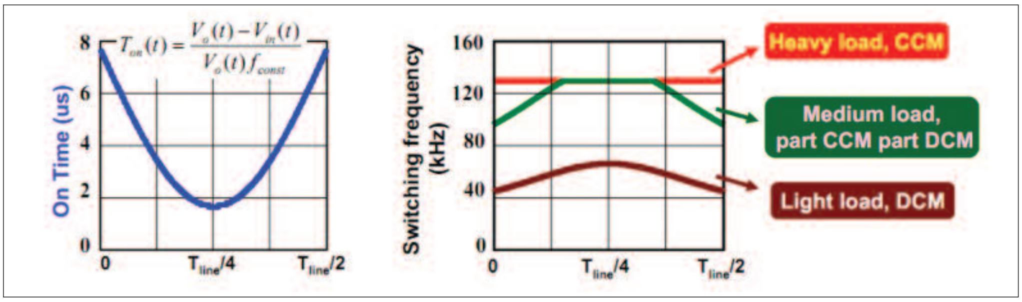


Figure 3. New PFC control strategy – fixed turn-on time and variable frequency control

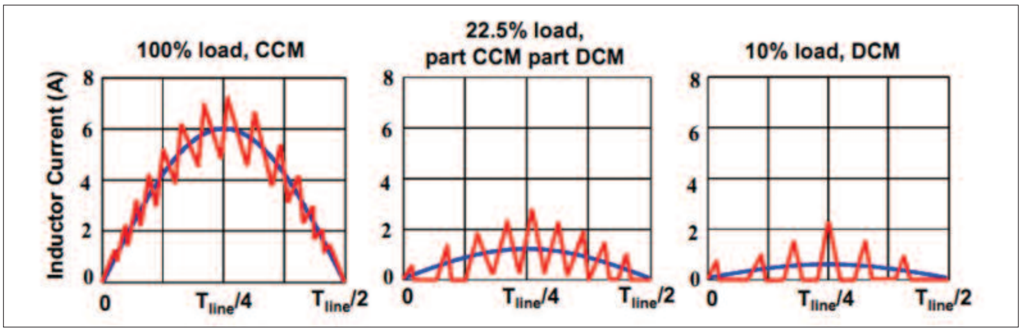


Figure 4. Inductor current waveforms of adaptive on-time PFC at different load conditions

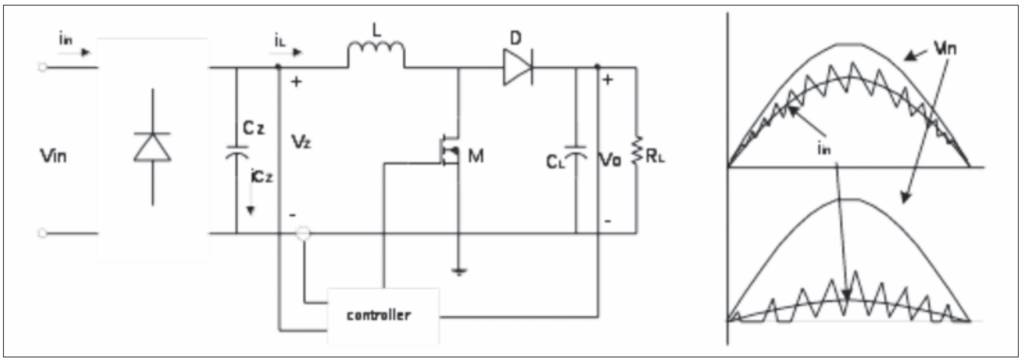


Figure 5. Current distortions due to input capacitor for boost converter

has the benefits of fixed frequency and the lowest RMS current and ripple, which ensures the lowest amount of stress on the power components. The continuous current nature also makes filtering design easier; therefore, this topology is preferred in >150 W applications.

Figure 2 shows the on time profile and switching frequency profile within a half line cycle of a CCM control scheme. The PWM modulator maintains a constant switching frequency regardless of load, so the turn on time of the converter is decreased at light load. One drawback of CCM control, however, is that the high, fixed switching frequency at light load leads to poor light-load efficiency. Only when the load drops to minimum or no load is CCM control able to enter burst mode to save on efficiency. In general, efficiency under CCM can be desirable at 30-100 % or <1 % load, but not optimized from 1-30 % load.

For the new control strategy we are proposing in Figure 3, the turn-on time only varies with the instant input voltage, but it remains the same at different load. With this strategy, the switching frequency of the PFC converter is kept constant at heavy loads to keep the benefit of CCM, but reduces at lighter loads to enter DCM operation (see Figure 3, Figure 4).

This control strategy was first realized with MPS' new PFC + LLC combo controller, the HR1200. This is also applied in MPS' stand-alone PFC controller, the MP44040. The efficiency of the HR1200 PFC stage was measured on a universal input, 12V, 20A output evaluation board across the entire load range.

Features	Benefits
GUI for configurable parameters through I²C	Add to design flexibility, fast development cycle
EEPROM enabled resettable configurations	Last-minute design change without hardware changes
Patented CCM/DCM control and power factor compensation	High efficiency and high power factor at low load
HV start-up current source and X-cap discharger	Low no-load loss
Live function and performance monitoring	Easy debugging
Provides a unique part number for each customer project	Customer design IP protection

Table 1. Key Features and Benefits of MP44040 and HR1200

Single IC solution to achieve the best single-phase PFC performance

In a PFC boost converter, there inevitably is a small capacitor beyond the input rectifier stage, which is used to supply the high-frequency portion of the inductor current via the shortest path and act as an EMI filter. This capacitor must be chosen at the minimum rated input voltage. For CCM

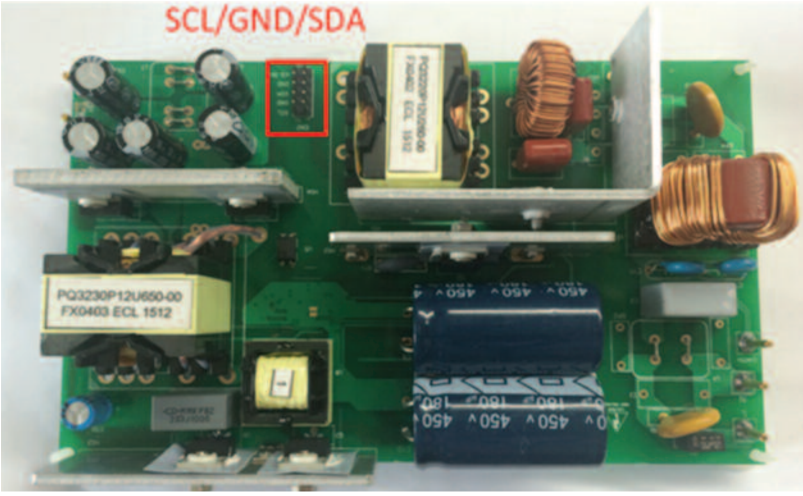


Figure 6. HR1200 PFC + LLC 240W evaluation board

PFCs, only the inductor current (i_L) is sensed and controlled to be in phase with the input voltage (VIN). However, as the input current i_{in}= i_L+i_{cz}, where i_{cz} is the input capacitor current, there is inevitably some current distortion created by the input capacitor (see Figure 5). At a higher V_{IN}, I_{CZ} becomes larger. I_L is smaller at high line compared to low line, so under the condition of the same load, PF is worse at high line.

As most current flows through the inductor at mid-to-peak load, the input capacitor's current distortion is also proportionally smaller, so the PF can be >0.9 with a universal input. However, since IC is not load-dependent at light load, it becomes relatively high and PF becomes worse. Such behavior is also commonly known in other PFC ICs. The actual PF performance may differ from this figure for the actual design, but the trend is always valid.

Naturally, in order to improve PF at low load and high line, we must provide a means to compensate for the capacitor current to the inductor current reference. Instead of the traditional way of matching IL in the same sinusoidal shape as V_{IN}, we will match I_{IN} with V. Since the analog current sensing on the capacitor current requires more components and adds to complexity, we can introduce the digital compensation method without adding extra cost.

MPS has created a digital, stand-alone, CCM/DCM, mix-mode PFC controller (MP44040) and a digital PFC + analog LLC combo controller (HR1200) that both apply the CCM/DCM mix mode and PF compensation technologies and use a graphic user interface (GUI) to configure all major PFC functions. The features and benefits of these parts are summarized in Table 1.

An evaluation board (Figure 6) and various supporting documents are offered to help customers become familiar with this digital platform. The HR1200-based PFC + LLC EVB is rated at 85-265 VAC at input, and 12 V/20 A at output. The EVB is equipped with an I?C-to-USB adaptor, allowing customers to optimize their designs by changing all GUI settings and monitoring live performance differences. For mass production, the configuration can be programmed at the factory with a special part number.