Product Overview

PFC Controller Step-by-Step Selection Guide

From consumer electronics gadgets like laptop to industrial equipment like robotics, anything powered from the AC grid represents a complex load condition and can behave more than just a pure resistor. If the load impedance includes an inductive or capacitive part, the input current is no longer in phase with the instantaneous line voltage, as shown in Figure 1. If the load only takes DC input and diode bridge + input cap is used to provide the DC input, the current will only be conducting when the AC voltage exceeds the DC voltage on the capacitor and the waveform is shown in Figure 2. Both cases incur apparent power transferred between the load and the supply, which demands higher peak power from the grid and wastes energy through the transmission line.

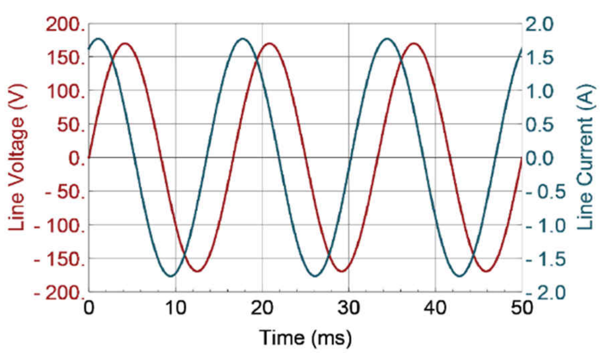

Figure 1. Input Voltage and Current Waveform for an Inductive Load

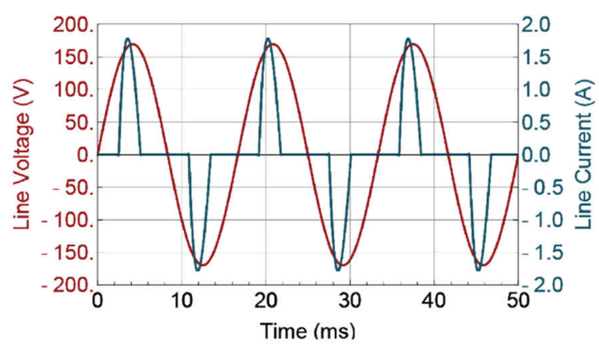

Figure 2. Input Voltage and Current Waveform For Diode Bridge Rectification

Therefore, a power factor correction (PFC) circuit between the load and the grid is needed to shapes the input current to be in phase with the instantaneous AC line voltage to minimizes the energy loss. The PFC function can be achieved through either passive or active means. A passive PFC circuit is comprised with only capacitors and inductors, which can be affordable and simple for certain scenarios, but it is challenging to achieve greater than 0.9 PF value across wide operating conditions. In contrast, a modern active PFC circuit can easily achieve PF value > 0.99 with efficiency greater than 97%.

TI offers variety of PFC solutions and the most common topology is the boost, as shown in Figure 3. The PFC stage resides between the DC/DC and rectified AC line. Because the boost inductor inherently limits the dI/dt of the input current, it makes the topology better equipped to achieve low input current distortion.

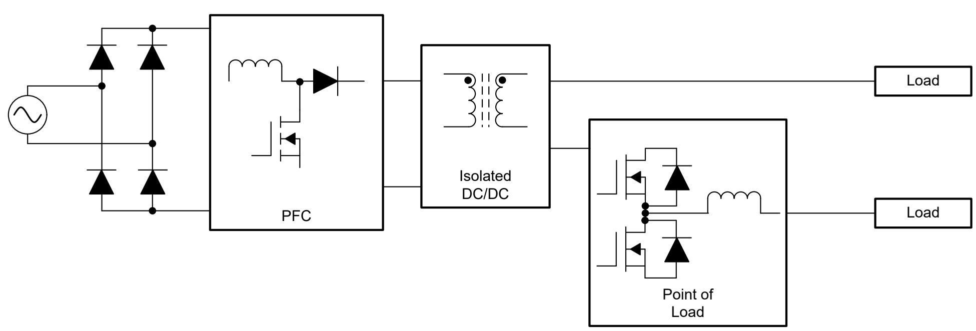

Figure 3. A Common AC/DC Power Supply Block Diagram

The boost PFC has three operation modes based on the inductor current waveform shape: Discontinuous Conduction Mode (DCM), Critical Conduction Mode (CrCM) and Continuous Conduction Mode (CCM). The CrCM is also referred as Transition Mode (TM) in some literature. The inductor current waveform is show in Figure 4 for each mode. One key distinction of DCM and CrCM is that the current always reaches to zero in each switching cycle, where it doesn't in CCM.

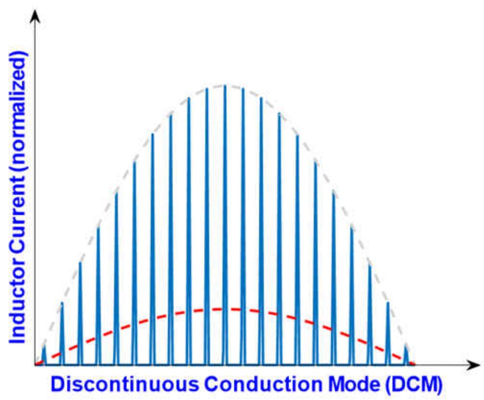

Figure 4. Inductor Current Waveform for DCM Operation

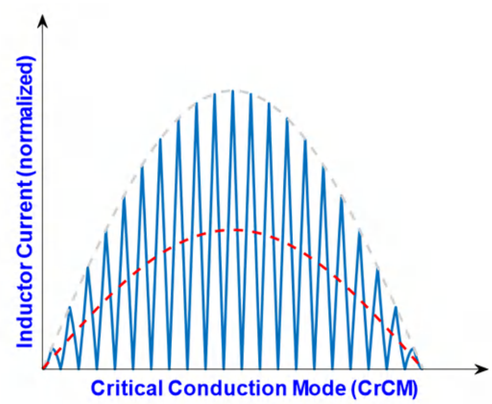

Figure 5. Inductor Current Waveform for CrCM Operation

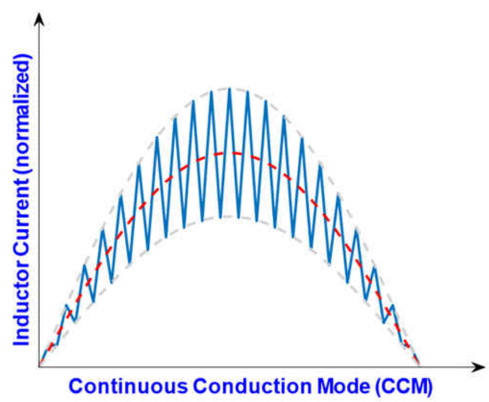

Figure 6. Inductor Current Waveform for CCM Operation

Table 1 highlights the pro and con of each operation mode. In short, DCM/CrCM is more suitable for low power applications and CCM is more suitable for high power applications. Nowadays, CrCM is more popular than just DCM controller because CrCM can deliver more power and the design complexity can be easily addressed by sophisticated IPs with little cost adder. Therefore, this guidebook will focus on CrCM and CCM controllers.

Table 1. Comparison Between Different Operation Modes

Mode	Key Distinctions	Pro	Con
DCM	• Zero current switching (ZCS) • Typically, fixed freq with pulse width modulation	• Higher efficiency at light load (no diode reverse recovery) • Simple IC design and lowest cost	• Worst iTHD (Total Harmonic Distortion) among all • Highest conduction loss at the same output power level
CrCM	• Zero current switching (ZCS) • Typically, variable freq with fixed Ton time	• Higher efficiency at light load (no diode reverse recovery) • Higher efficiency than DCM	• Variable frequency design so more complex than DCM • iTHD is worse than CCM
CCM	• Current valley > zero • Typically, fixed freq with pulse width modulation	• Best iTHD compared to CrCM and CCM • More efficient at higher power application • Need smaller inductor at the same power level	• Require expensive fast recovery diode (Schottky/SiC) • More difficult to design and compensate • Light load efficiency is lower

If more power is needed, a practical approach is to interleave two boost power stages that are operated 180° out of phase from each other as shown below. Figure 7 shows the typical diagram and Figure 8 shows the current waveform for each inductor and the total current seen at the load. In addition to the extended power range, the total ripple current can be significantly reduced by cancellation of two interleaved stages, achieving better iTHD.

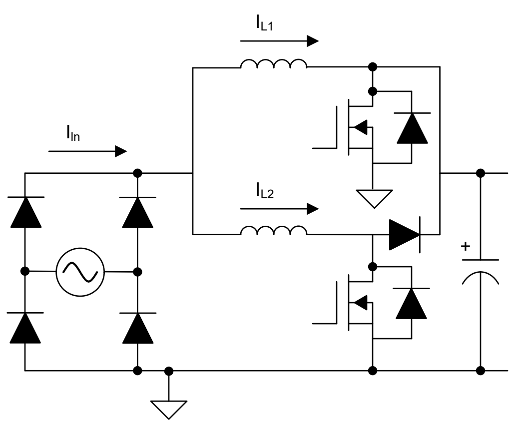

Figure 7. Example Diagram of an Interleaved Boost PFC

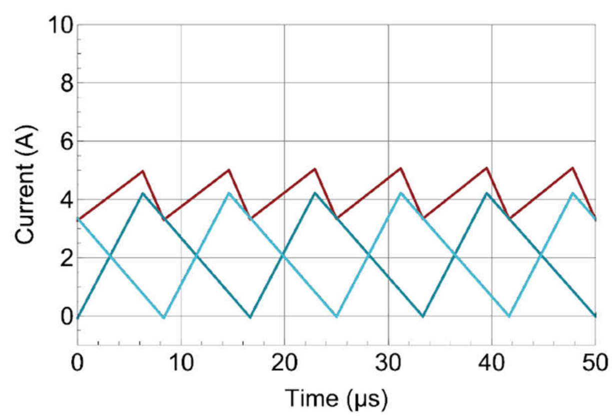

Figure 8. Inductor Current (Two Blue) and Total Current (Red) Waveform

While interleaved CrCM and single phase CCM both can be used in the 300 W to 600 W output power range. Table 2 show the key differences.

Table 2. Comparison Between Interleaved CrCM and Single Phase CCM

Design Characteristics	Interleaved CrCM	Single Phase CCM
Component Stress	Valley switched, less stressful to the power FET	Hard switched, more stressful to the power FET
Power Density	Lower	Higher
System Height	Smaller (for example, more suitable for slim TV design)	Higher
Thermal Management	Easier due to spread over larger space	More challenging in a concentrated area
System Cost	More component counts, but less expensive per component	Fewer component counts, but more expensive per component

TI offers PFC controllers across power range from 75 W all the way to several thousand watts, as shown in Figure 9. In the power range where multiple parts overlap, careful review of the system requirement is needed to provide the best recommendation.

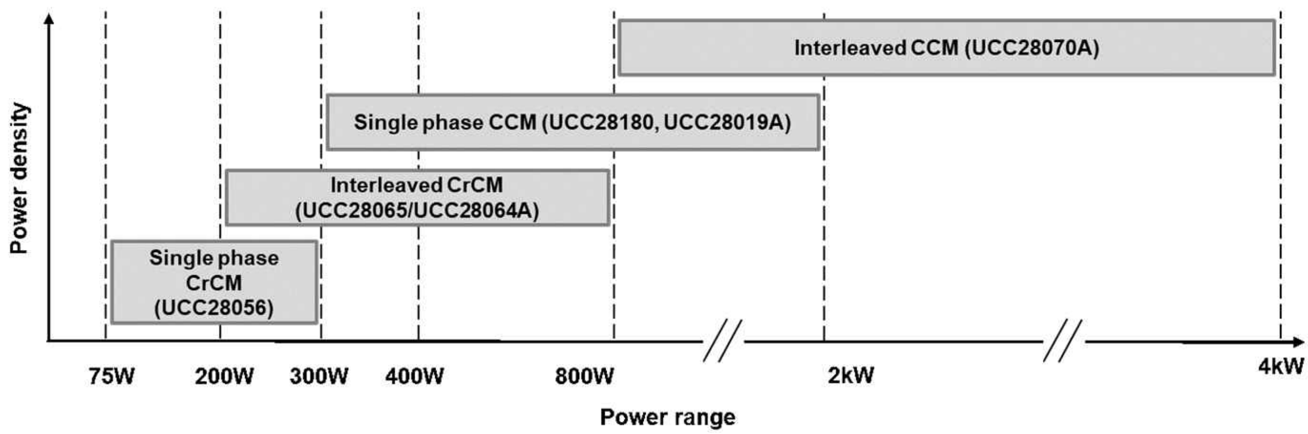

Figure 9. Controller Selection Table by the System Power Requirement

For example, in the interleaved CrCM PFC controller family, while UCC28065 offers consistent low iTHD across frequency and inductor value range, UCC28064A offers superior iTHD performance at low switching frequency range, as shown in the Figure 10. Therefore, UCC28065 is more suitable for system that requires smaller form factor design, such as slim TV, while UCC28064A is more suitable for system seeking absolute low iTHD, such as lighting.

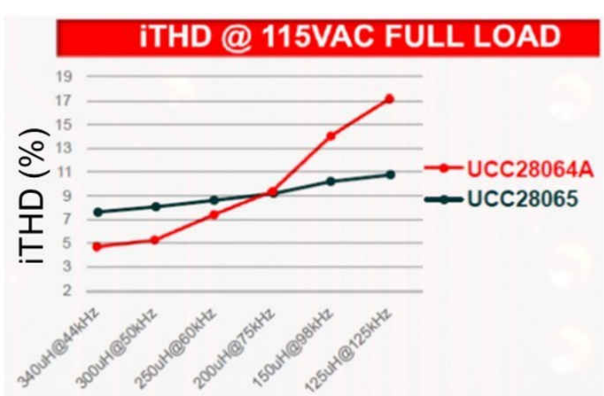

Figure 10. iTHD Performance at Low Line, Across Different Inductor Value and Switching Frequency

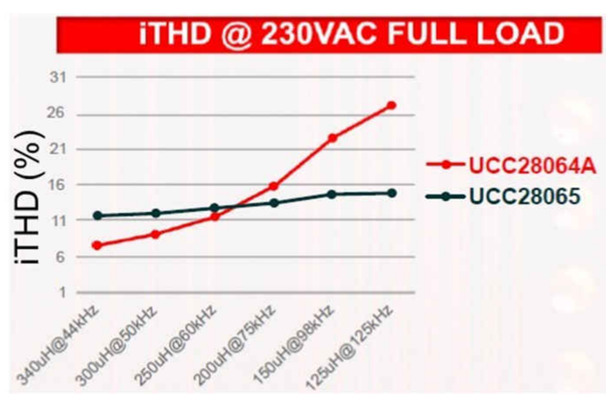

Figure 11. iTHD Performance at High Line, Across Different Inductor Value and Switching Frequency

Take the single phase CCM PFC family as another example, the feature of programmable switching frequency enables UCC28180 to match with wide variety of power FET, whether it is Si, IGBT, or GaN/SiC. The built-in brown-out protection feature makes UCC28019A more popular in safety critical applications such as server PSU.

Table 3 shows the high-level summary of standalone PFC controllers that TI offers. For more product information, please visit the *Power Factor Correction controllers* homepage.

Table 3. High-Level Summary of Standalone PFC Controllers

GPN	Operation Mode	Phase	Soft Current Limit	Open Loop Detection	Output Under Voltage Protection	Brownout Protection	Over Temp Protection	Ext Clock Sync	Noise Reduction	Idle Current	Switching Frequency	Package
UCC28056	CrCM	Single				Yes	Yes		Yes	<45uA	54kHz	SOT23-6
UCC28064A	CrCM	Interleaved		Yes		Yes	Yes		Yes	<200uA	400kHz	SOIC-16
UCC28065	CrCM	Interleaved		Yes		Yes	Yes		Yes	<200uA	800kHz	SOIC-16
UCC28019A	CCM	Single		Yes	Yes	Yes				<200uA	65kHz	SOIC-8
UCC28180	CCM	Single		Yes	Yes				Yes	<75uA	18-150kHz	SOIC-8
UCC28070A	CCM	Interleaved	Yes	Yes			Yes	Yes		<200uA	30-300kHz	SOIC/ SOP-20

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