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Control Circuit Simplifies PFC Boost Converter Design

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A new control circuit enables simple and cost-effective solutions for power factor correction (PFC) boost converter designs. The applications for PFC boost converters include ac-dc power supplies, electronic ballasts, and LED drivers. Each of these applications typically has a boost-type front end to perform the necessary power factor correction of the ac mains input current. This article reviews the basics of PFC boost circuit operation, describes the new control circuit design based on the IRS2505L controller IC, provides design equations for selecting circuit components, and presents final circuit performance data.

Power Factor Correction

Power factor correction (PFC) continues to be a dominant trend across all applications in the power electronics industry due to the need to fulfill mandatory standards and regulations for power factor (PF) and total harmonic distortion (THD). The most popular topology used to fulfill these requirements is the boost circuit. This well-known front-end circuit shapes the ac mains input current to match the shape of the ac input voltage for high PF and low THD. The boost circuit also steps-up the dc bus output voltage such that it is higher than the maximum peak input voltage (typically 400 V or higher).

The boost circuit includes an inductor (L_{PFC}), a switch (M_{PFC}) and a diode (D_{PFC}) (Fig. 1.) The basic principle of operation is to close the switch during the switch on-time to charge the current in the inductor up to a desired peak level, and then to open the switch during the switch off-time and allow the current stored in the inductor to discharge to zero again through the diode to the dc bus capacitor and load. This charge/discharge cycle is then repeated continuously at a given switching period and duty cycle to supply the necessary current to the load and to keep the output voltage maintained at a desired level.

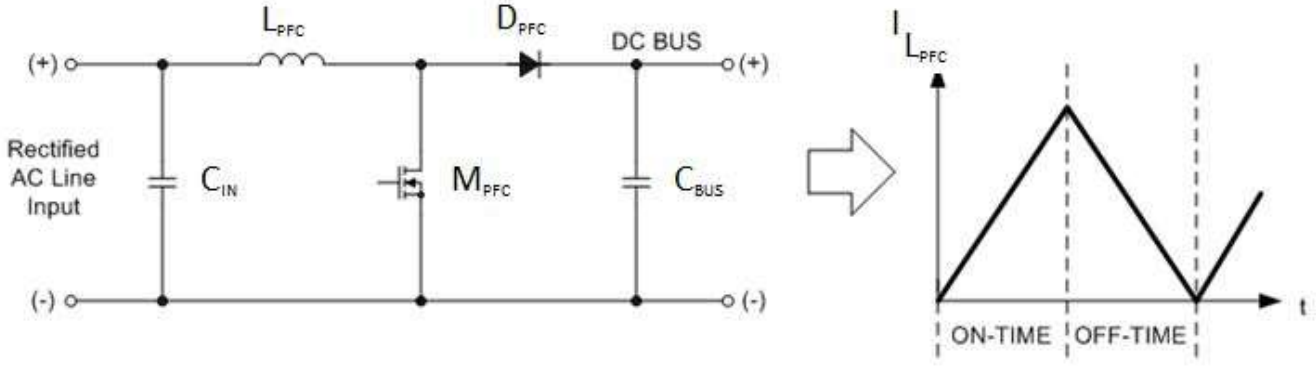

Fig. 1. Boost circuit and inductor current.

The peak level each switching cycle depends on the instantaneous rectified voltage, the boost inductor value and the on-time of M_{PFC}. The off-time is the time it takes for the inductor current to discharge from the peak level to zero. The off-time depends on the inductor value and the difference between the output voltage and the instantaneous rectified voltage. The result after a complete switching period is a "triangular-shaped' inductor current waveform (Fig. 1). This current then gets smoothed by the EMI filter at the front of the power supply causing the average current at the mains input to match the shape and phase of the ac mains input voltage (Fig. 2).

The control circuit also monitors the dc bus voltage at the V_{BUS} pin and continuously adjusts the on-time to regulate the dc bus voltage to a constant level. The loop speed of the control circuit is typically set very slow (20 Hz) to allow the current to accurately follow the shape of the 50- or 60-Hz mains voltage. Also, inherent to

all boost converters, the dc bus voltage must always be higher than the peak input voltage to prevent direct conduction across the boost diode.

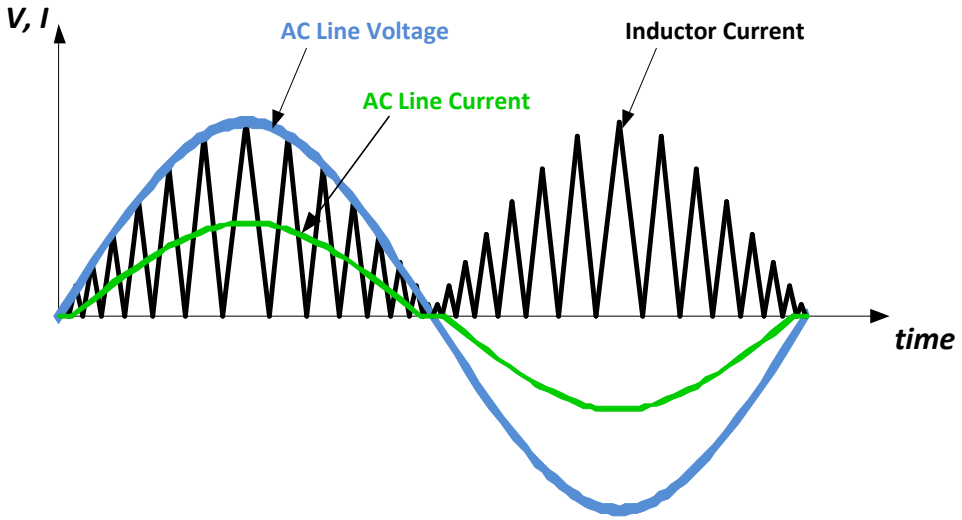

Fig. 2. Boost inductor current and resulting ac line current.

Boost Circuit Design

The following definition of terms (Table 1) applies to the design of the PFC boost circuit. While these definitions and some of the equations that follow apply to PFC boost circuits in general, this discussion relates specifically to the boost converter design shown in Fig. 3. This design leverages the features and capabilities of the IRS2505L PFC controller IC.

Table 1. Boost-circuit-design definition of terms.

Term	Definition
V_{BUS}	Dc bus output voltage
VAC_{PK}	Peak ac input voltage at nominal ac input condition $(VAC_{PK} = VAC_{RMS} \cdot \sqrt{2})$
VAC_{MIN_PK}	Peak ac input voltage at minimum ac input condition $(VAC_{MIN\_PK} = VAC_{RMS} \cdot \sqrt{2})$
η	Boost converter efficiency (typically 0.95)
f_{MIN}	Minimum PFC switching frequency (occurs at VAC_{PK})
P_{OUT}	Output power
I_{PFCMAX}	Maximum peak inductor current (occurs during the minimum ac input voltage)
L_{PFC}	PFC inductance

For good circuit performance, it is necessary to properly select the value of the boost inductor. The inductor value depends on the input voltage range, the dc bus output voltage, the switching period, and the output load power. The following equation can be used to calculate the inductor value in henries (H):

$$L_{PFC} = \frac{(15us) \cdot (V_{BUS} - VAC_{PK}) \cdot VAC_{PK} \cdot \eta}{4 \cdot P_{OUT}} . \quad (1)$$

The minimum switching frequency (Hz) occurs at the peak of the ac input voltage during nominal input voltage conditions and is calculated as:

$$f_{MIN} = \frac{VAC_{PK}^2 (V_{BUS} - VAC_{PK}) \cdot \eta}{4 \cdot L_{PFC} \cdot P_{OUT} \cdot V_{BUS}} . \quad (2)$$

The maximum peak inductor current (A pk) occurs at the peak voltage during minimum ac line input conditions and is calculated as:

$$I_{PFCMAX} = \frac{4 \cdot P_{OUT}}{VAC_{MIN\_PK} \cdot \eta} . \quad (3)$$

The maximum peak inductor cycle-by-cycle current limit is set with an external PFC current-sensing resistor (R_{CS}) and an internal 1.1-V threshold. The current-sensing resistor is then calculated with the following equation:

$$R_{CS} = \frac{1.1}{I_{PFCMAX}} . \quad (4)$$

The dc bus output voltage level is programmed with a resistor-divider network connected between the dc bus voltage, the V_{BUS} pin, and COM. An internal amplifier circuit compares this measurement with an internal reference voltage (4.1 V) and adjusts the switch on-time accordingly to set the peak inductor current level each switching cycle. Assuming the upper resistors R_{VBUS1} and R_{VBUS2} to be fixed (typically 1 MΩ), the lower resistor, R_{VBUS3}, is then calculated using the following equation:

$$R_{VBUS3} = \frac{4.1 \cdot (R_{VBUS1} + R_{VBUS2})}{V_{BUS} - 4.1} . \quad (5)$$

The equations have been entered into a spreadsheet and the calculations have been summarized in Table 2. The calculations were performed for a 90-W, 90- to 265-Vac, PFC boost converter.

Table 2. PFC boost circuit design calculations (90 W, 90 to 265 Vac)

Parameter	User Input Value	Units	Description
VAC	220	Vac	Nominal rms input voltage
VAC_min	90	Vac	Minimum rms input voltage
VAC_max	265	Vac	Maximum rms input voltage
VBUS	420	Vdc	Dc bus output voltage
POUT	90	W	Output power
RVBUS1	1.0	MΩ	Upper dc bus divider resistor value
RVBUS2	1.0	MΩ	Middle dc bus divider resistor value
Parameter	Calculated Value	Units	Description
I_LPFC_max	3.0	A pk	Maximum peak inductor current at Vac_min
LPFC	1.3	mH	PFC inductance value
f_min	49	kHz	Minimum switching frequency at Vac
RVBUS3	19.7	kΩ	Lower dc bus divider resistor value
RCS	0.37	Ω	M_{PFC} current sensing resistor value

The complete 90-W PFC boost converter circuit was designed around the new IRS2505L control IC. This SOT-23 IC is very easy to use and greatly simplifies the complete design. The various circuit blocks include (Fig. 3): an EMI filter to block switching-generated noise (CX1, CX2, LCM, CY1, CY2); a bridge rectifier (BR1); the boost converter (LPFC, MPFC, DPFC); a capacitor for smoothing the dc bus output voltage (CBUS); the IRS2505L control IC; a resistor divider network for monitoring the dc bus voltage level (RVBUS1, RVBUS2, RVBUS3); a shunt resistor for monitoring the switch current (RCS); a capacitor for programming the loop speed of the control circuit (CCMP); and a circuit for starting up and supplying VCC (RVCC1, RVCC2, LPFC:N2, R1, C2, DZ, D2, CVCC2).

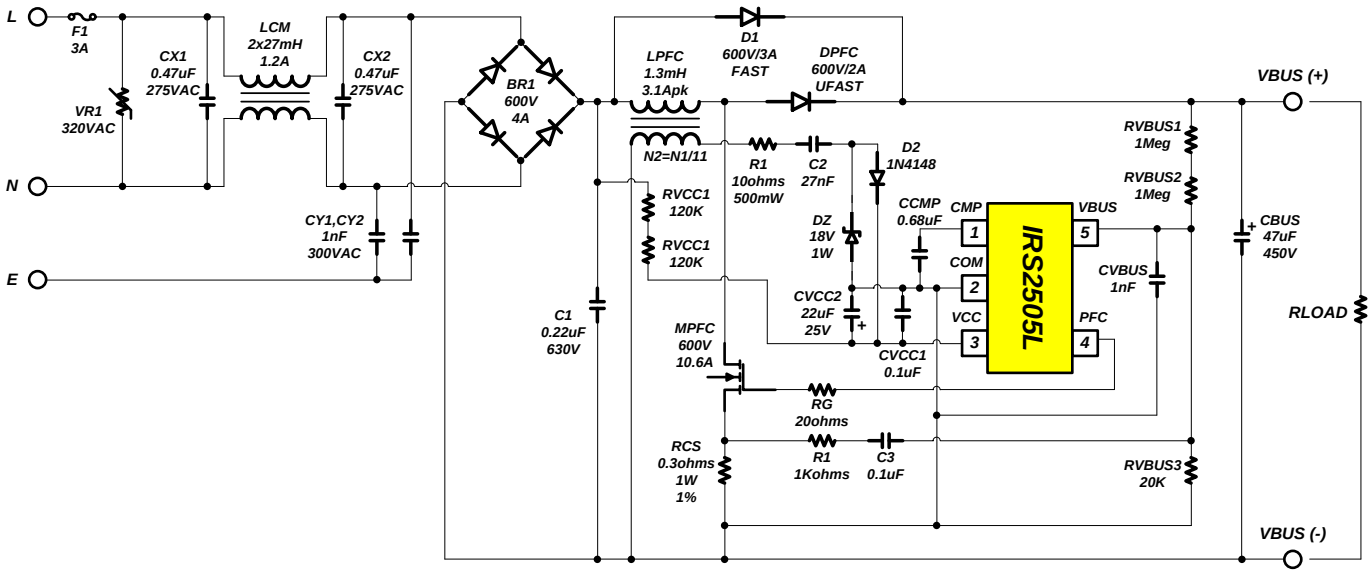

Fig. 3. 90-W PFC boost converter circuit schematic.

Circuit Performance

The circuit performance results show that the peak inductor current correctly follows the ac rectified voltage envelope (Fig. 4.) This produces the desired sinusoidal-shaped current at the input that is in-phase with the ac input voltage. The resulting high power factor (PF) is above 0.95 and the total harmonic distortion (THD) is below 5% across the entire ac line input range (Fig. 5).

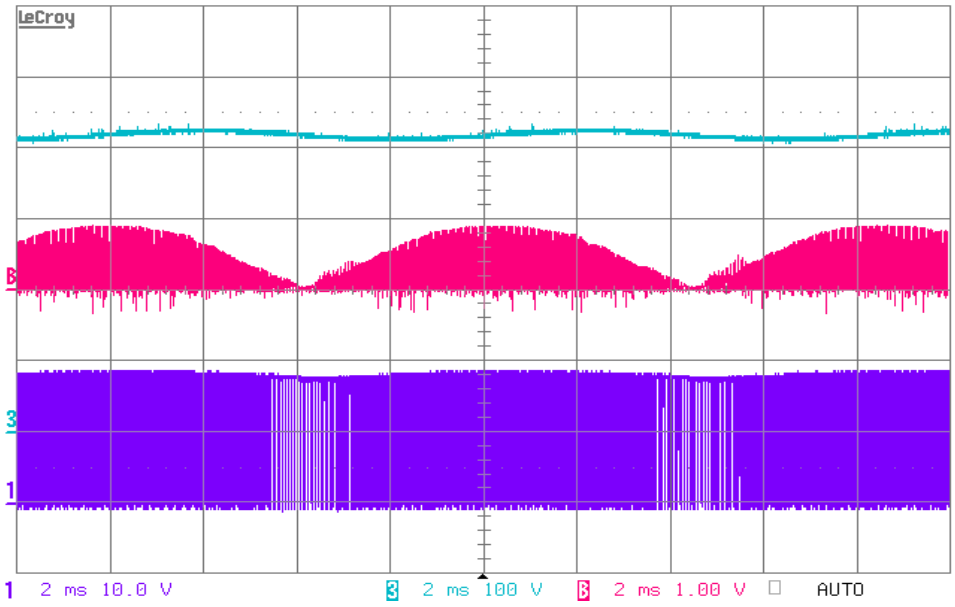

Fig. 4. Dc bus voltage (upper), inductor current (middle) and gate voltage (lower) during normal operation.

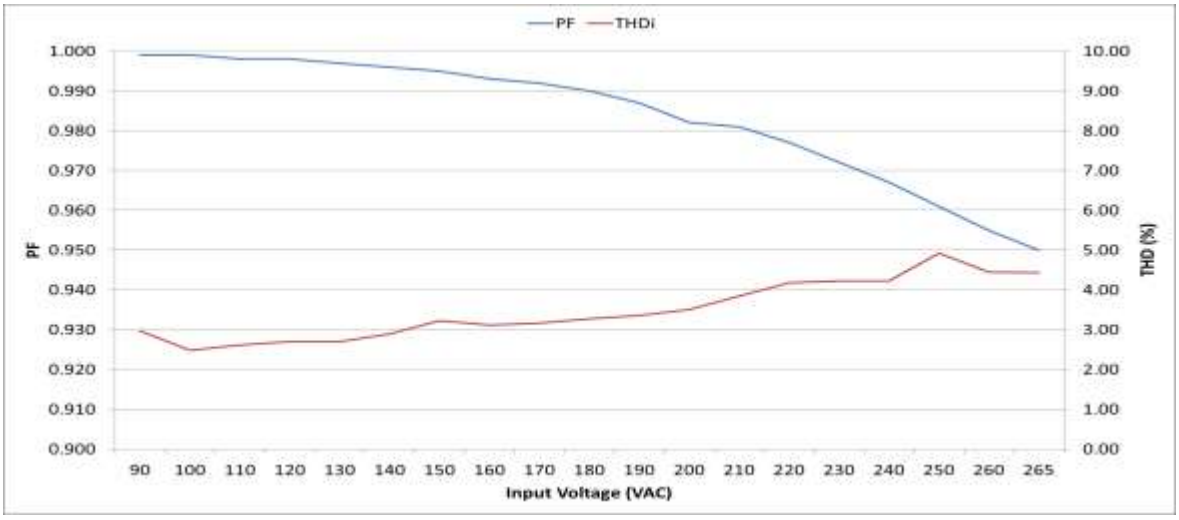

Fig. 5. Power factor (PF) and total harmonic distortion (THD) vs. ac line input voltage.

The EMI filter at the input has also been optimized for proper attenuation of conducted emissions. The EMI testing results (Fig. 6) show that the circuit successfully passes the EMI class B requirements.

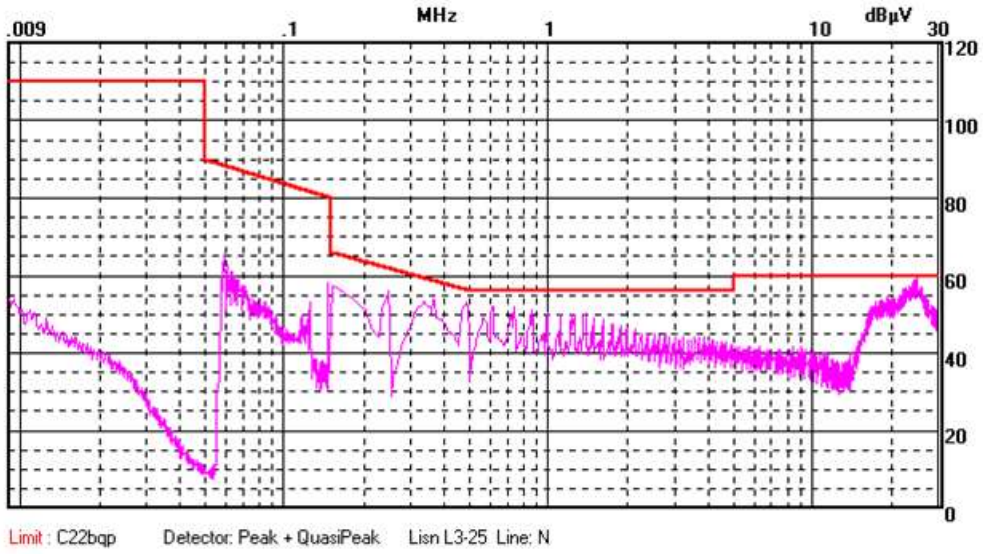

Fig. 6. Conducted EMI results (neutral phase, peak mode, 230 Vac.)

Conclusion

The IRS2505L control IC and PFC boost circuit have demonstrated excellent performance across a wide input-voltage range. Power factor (PF), total harmonic distortion (THD), dc bus regulation and EMI requirements have all been satisfied. Further testing has also demonstrated good performance over a wide load range as well. Design equations have been presented that designers can easily enter into a spreadsheet to calculate values for their own designs. The new IC is simple to understand and use for a fast design cycle time, and has a small package footprint for reducing overall PCB area.

Reference

For more details on the IRS2505L, see the datasheet.

About The Author

Tom Ribarich is director of the Lighting Design Center at International Rectifier, where he is responsible for developing control ICs for the global lighting market, including fluorescent, halogen, HID, LED and LCD backlighting applications. Prior to joining IR in 1996, Tom was employed by Knobel Lighting Components, Switzerland where he designed dimmable electronic ballast systems for a variety of applications including general-purpose office lighting, low-temperature applications and outdoor Swiss Alp tunnel lighting.

Tom received a BSEE degree from California State University, Northridge, and later a Master's degree in ASIC design from the University of Rapperswil, Switzerland. Tom believes the strength in a good design team comes from a creative and motivating environment combined with an international mixture of design cultures. He enjoys beach volleyball, surfing, snowboarding, video production and traveling.

For further reading on design of power factor correction stages, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category and select "Power Factor Correction" in the Popular Topics category.