

A Simple Solution for Powering LED Streetlights

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As LEDs continue to penetrate the market and replace last generation light sources, new engineering challenges arise. These challenges come in the form of thermal, optical and electrical issues. For the electrical engineer, maximizing efficiency is usually at the top of the list. However, selecting the proper LED driver topology sometimes can be dictated by the application. For example, LED screw-in light bulbs are often required to be triac-dimmable, limiting the choices of topology. In the case of LED streetlights, depending on the governing authority, usually isolation is unnecessary while power factor correction (PFC) often is. In these applications, the PFC SEPIC converter provides an elegant solution for driving the LEDs.

Traditionally, PFC has been achieved in end equipment by using a boost converter. The power factor is defined as: the ratio of the real power to apparent power delivered to a system. A PFC boost controller IC forces the input current to follow the shape of the rectified AC line voltage to attain a high power factor. The boost output feeds an isolated DC/DC converter to generate the voltages required by the system. This results in a double conversion and severely limits maximum possible efficiency. Even if both stages are 94 percent efficient, the combined efficiency is only 88 percent ($0.94 * 0.94 = 0.88$). Eliminating a second conversion boosts the power supplies' efficiency, saves power, and reduces thermal load.

With a boost converter, the DC output voltage must be higher than the peak input voltage. For a system required to run from a 265VAC input, the output must be greater than 375VDC. In an LED streetlight application, the output voltage varies depending on the forward voltage drop per LED and the number of LEDs in the series string. The forward drop typically is 3.5V for white LEDs, but has a fairly wide tolerance. The number of LEDs in a string depends on the application, but nearly always results in a total output voltage that is less than 375VDC, which precludes using a boost converter. Figure 1 shows that to regulate the LED voltage, the converter must boost for the portion of the 50Hz/60Hz cycle where the input voltage is less than the output voltage and buck for the remaining portion. The SEPIC

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converter is perhaps the most basic non-isolated topology capable of performing this function.

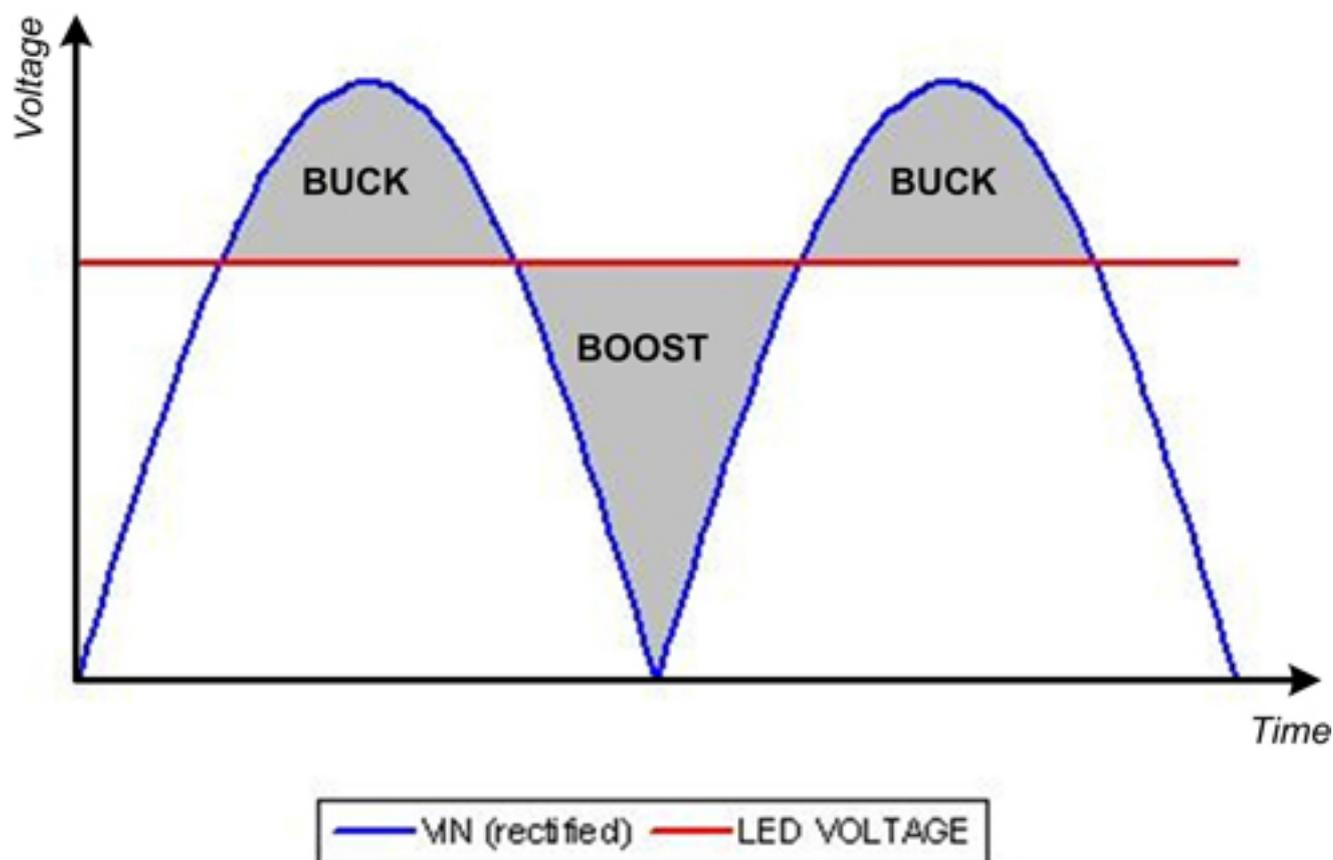


Figure 1. Typically LED streetlights have an output voltage that is lower than the peak AC input voltage and requires a driver that can both buck and boost.

Figure 2 illustrates simplified PFC circuits for the boost and coupled-inductor SEPIC. The fact that the main power FET source is connected to primary ground in both topologies makes them both easy to control. Virtually any boost PFC controller can be used in a SEPIC configuration, regardless of operating mode. Operating in discontinuous conduction mode (DCM) is advantageous because it eliminates the extra power loss associated with reverse recovery of the output diode experienced during continuous conduction mode (CCM).

However, DCM results in higher peak currents, creating potential electromagnetic interference (EMI) issues and increasing the high-frequency AC current in the magnetics. Operating in transition mode (TM) at the DCM and CCM boundary leverages the advantages of DCM while minimizing peak currents. Because of the relatively high peak currents, transition mode is generally limited to output powers of 150W or less.

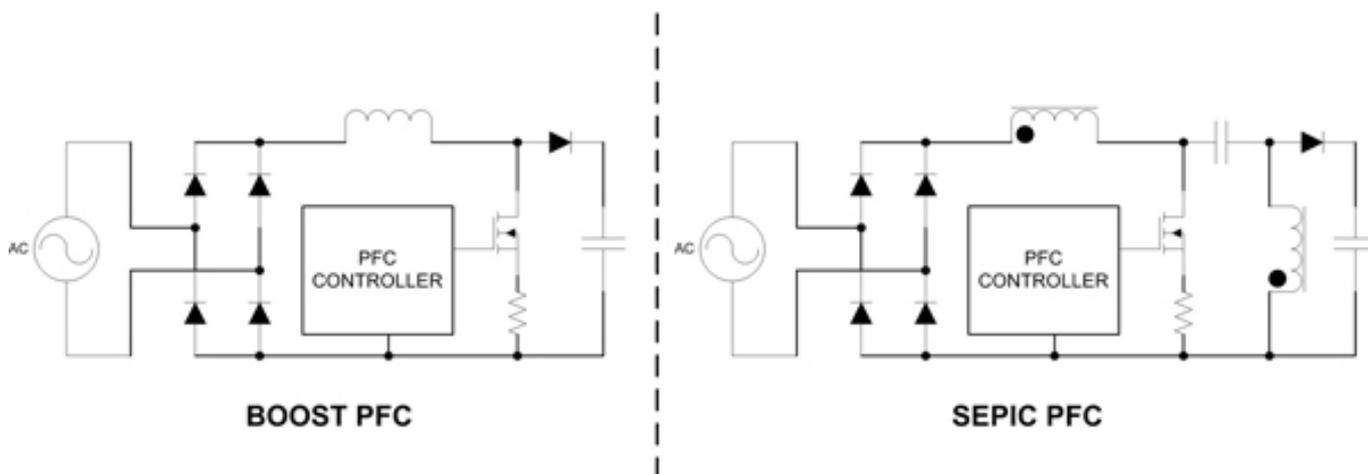


Figure 2. Simplified schematics for boost and SEPIC PFC circuits.

A transition mode PFC controller operates by controlling the peak current in the main power FET. Using the rectified line voltage as a reference, the peak FET current is forced to follow the sine-wave shape of the AC input. In the boost converter, the average input current to the converter at any point of the 50Hz/60Hz sine-wave is given by:

$$I_{IN_BOOST} = \frac{1}{2} \times I_{FET_PEAK} \quad \text{Equation 1}$$

Thus, the peak FET current in a TM boost is always equal to twice the average line current, and the average line current follows the line voltage very closely. In the coupled-inductor TM SEPIC, however, the average line current at any point along the sine-wave is modulated by the duty cycle, and is given by:

$$I_{IN_SEPIC} = \frac{1}{2} \times I_{FET_PEAK} \times D \quad \text{Equation 2}$$

It is the duty cycle term “D” in this equation that distorts the current waveform. The duty cycle is dependent on the output voltage to input voltage ratio and varies across the 50Hz/60Hz cycle. Figure 3 shows the line current waveforms for TM boost and TM SEPIC designs with different output voltages. In many applications, the distortion is low enough to provide adequate power factor and meet all line harmonic requirements.

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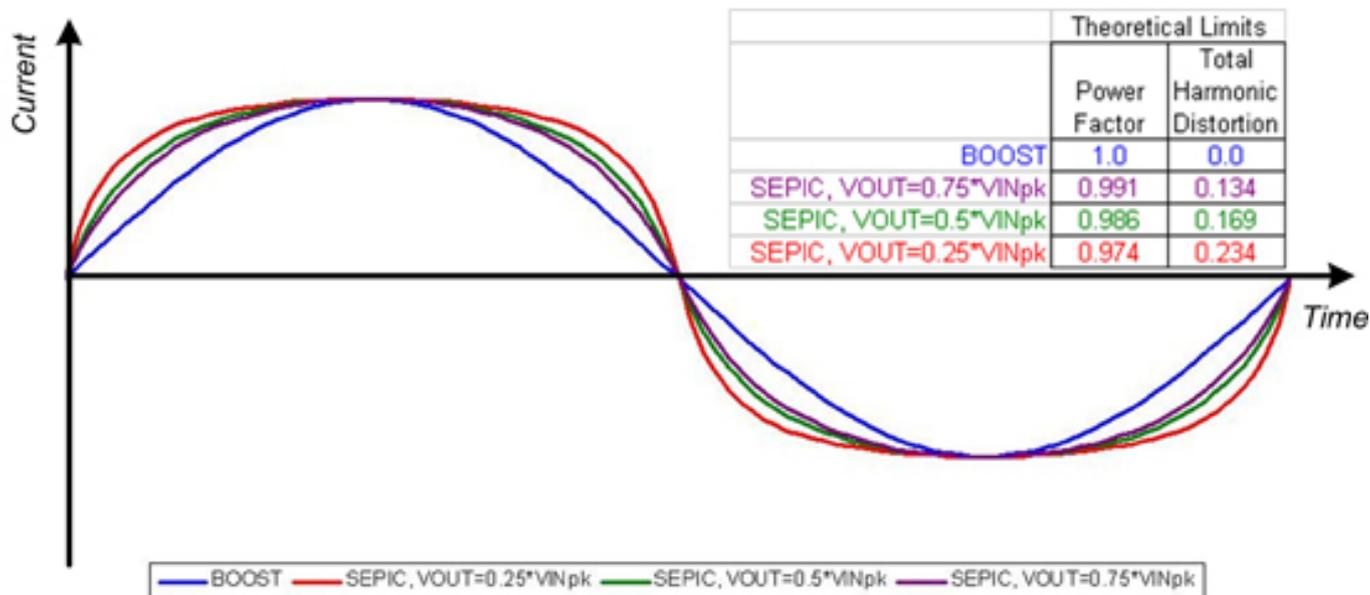


Figure 3. TM Boost provides low distortion and good power factor, while TM SEPIC distortion and power factor are dependent on the output voltage to peak input voltage ratio.

Figure 4 shows a schematic of a TM PFC SEPIC designed for a 230VAC input that powers a string of 80 white LEDs. The voltage drop across the string can vary from 256VDC to 304VDC. The LED current is sensed by R8 and regulated to 350mA by the UCC28810 controller (U2). The controller guarantees transition mode operation by waiting until all of the energy is depleted out of the coupled inductor before starting a new switching cycle. The energy in the inductor is sensed by monitoring the voltage on the auxiliary winding on the zero current detect (ZCD) pin. This auxiliary winding is also used to provide bias power to the IC.

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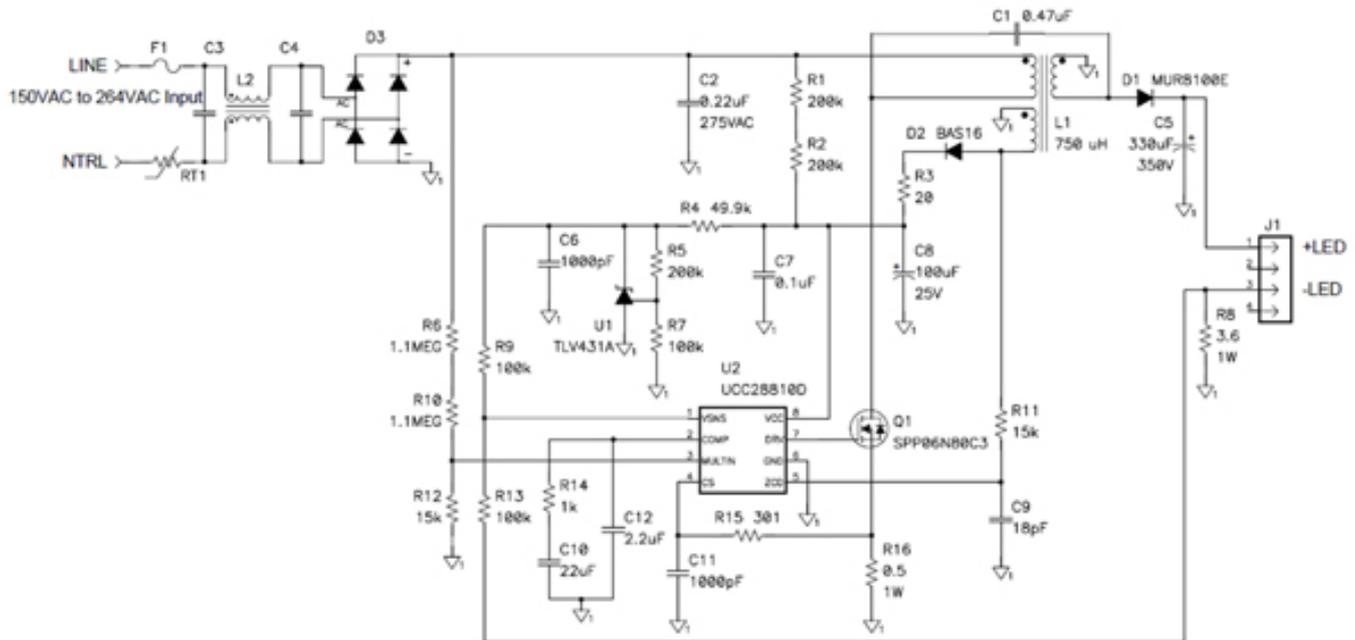


Figure 4. This simple circuit efficiently provides PFC and LED current regulation.

By their nature, PFC converters pass power from input to output at twice the line frequency of 50Hz or 60Hz. This creates a 100Hz or 120Hz ripple voltage on the output capacitor (C5). Dividing this ripple voltage by the LED string series resistance gives the amount of 100Hz/120Hz ripple in the LEDs. Typically, this must be less than 20 percent of the average LED current. There are also significant RMS currents in the output capacitor at both 100Hz/120Hz and the switching frequency. However, selecting a capacitor based on limiting the LED ripple current usually results in an adequately rated capacitor. Figure 5 shows the LED output current for this example.

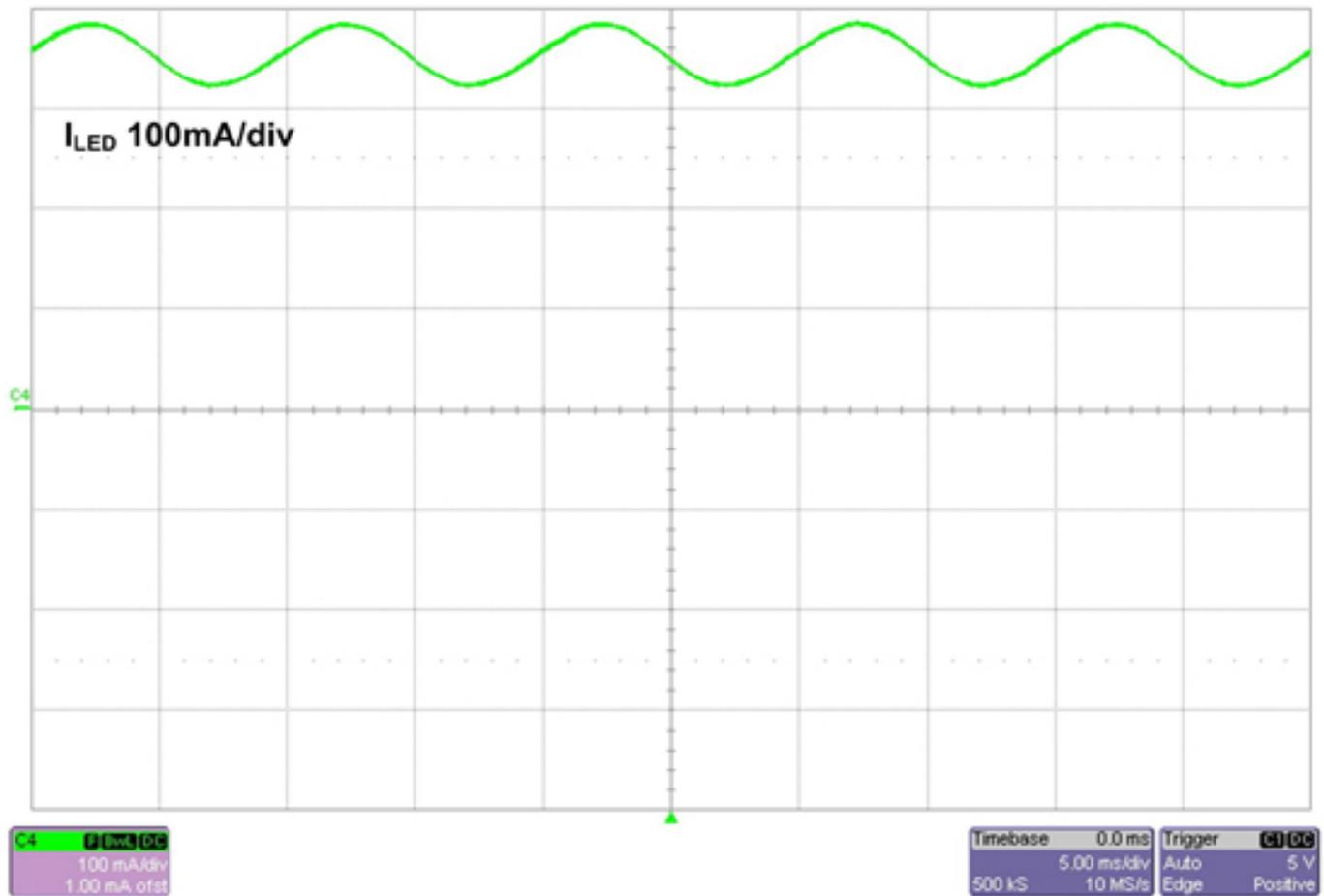


Figure 5. The LED current contains a 100Hz ripple component.

PFC controllers are intended to regulate a high output voltage and, as a result, usually contain a relatively high reference voltage on the feedback pin. In this circuit the reference voltage is 2.5V. In order to reduce the losses in the LED current sensing resistor, an offset was added to the feedback pin using the TLV431A circuit shown in Figure 4. This offset increases efficiency of 0.5 percent by reducing the losses in the sense resistor by 0.44W. Figure 6 shows the resulting efficiency and power factor for this design.

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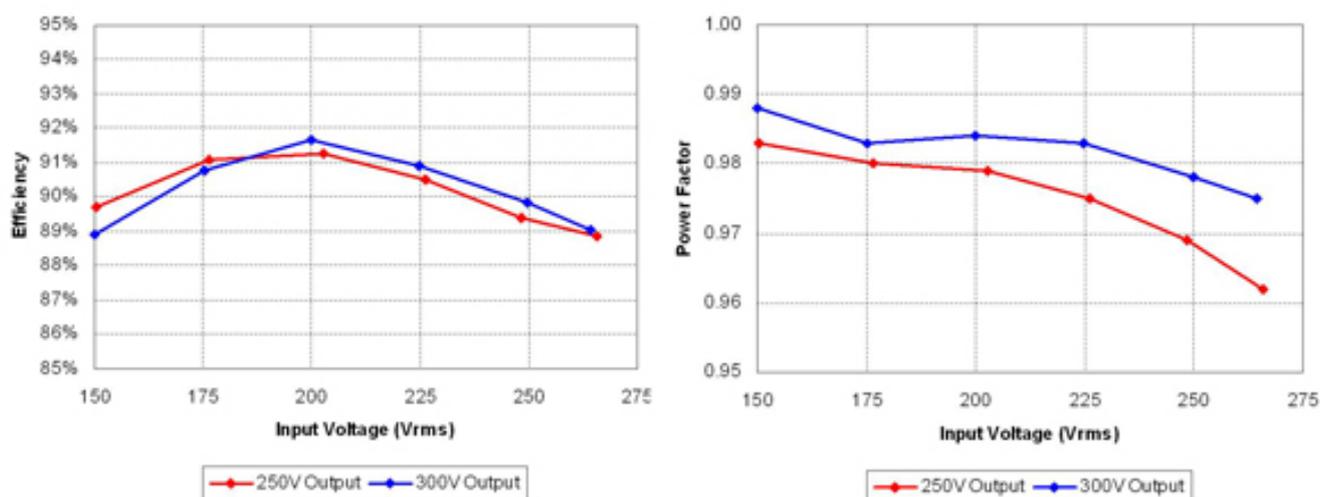


Figure 6. This design provides greater than 90 percent efficiency with a power factor over 0.96.

Using only a single power stage, over 90 percent efficiency is easily achieved for this 100W design. The power factor is over 0.96, which is more than adequate for most applications. With minimal components, accurate current regulation, high power factor and efficiency, you may want to consider the PFC SEPIC when designing your next LED streetlight applications.

References

- Download the UCC28810 datasheet and other technical documents here: www.ti.com/ucc28810-ca [1].
- This article presented a solution for non-isolated LED streetlights. Watch this video clip for isolated LED streetlight and PFC applications: http://e2e.ti.com/videos/m/application_specific/97309.aspx [2].

About the Author

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