Primary-Side, Constant-Voltage Regulation Enables Two-Stage LED Driver With High-Performance And Low Cost

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A new two-stage LED driver solution based on primary-side regulation of a constant voltage output (PSR-CV) in the first stage is proposed in this article. This LED driver design eliminates low-frequency current ripple yet maintains high power factor and low cost compared with currently available single-stage and three-stage solutions applied in analog LED dimming or non-dimming applications. PSR-CV regulation is employed on the primary side to achieve high power factor and simple circuitry in one stage, which is then combined with a secondary dc-dc stage to eliminate low-frequency current ripple and implement the dimming function.

With this approach, system cost is reduced because no circuitry is required for sensing the secondary voltage or current and no opto-coupler is required for transmitting this information across an isolation barrier. In addition, low-voltage-stress components may be used on the secondary side, which further reduces cost.

While this article focuses on the two-stage LED driver solution based on PSR-CV, there is also another PSR-based, two-stage LED driver solution—one that employs constant-current regulation (PSR-CC). Both of these driver designs are described and contrasted in this article with the operation of the PSR-CV solution explained in detail. Finally, this article describes a prototype based on the PSR-CV two-stage LED driver design and presents test results for this prototype. These measurements verify the effectiveness of the proposed driver design.

Market Requires Low Ripple And High Power Factor

Nowadays, a growing trend in LED lighting is the elimination of line-frequency ripple and the minimization of ripple current in general on the output of the LED driver. At the same time, the LED driver is expected to maintain high power factor. The Japanese market requires that the ripple ratio of the lamp current be less than 1.3 and the ripple frequency should be larger than 100 Hz. For the U.S. market, Energy Star has a similar requirement, specifying that output operating frequency be ≥120 Hz (see the table.) [1]


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumen maintenance (L)</td>
<td>16,000 to 26,000 hours depending on type of lamp</td>
</tr>
<tr>
<td>Power factor</td>
<td></td>
</tr>
<tr>
<td>For ≤ 6 W and low voltage lamps</td>
<td>No minimum specification</td>
</tr>
<tr>
<td>For &gt; 6 W lamps</td>
<td>≥ 0.7</td>
</tr>
<tr>
<td>Minimum operating temperature</td>
<td></td>
</tr>
<tr>
<td>Residential (outdoor)</td>
<td>≤ -20°C</td>
</tr>
<tr>
<td>Output operating frequency</td>
<td>≥ 120 Hz</td>
</tr>
<tr>
<td>EMI/RFI</td>
<td>FCC 47 CFR part 15</td>
</tr>
<tr>
<td>Noise</td>
<td>Class A sound rating</td>
</tr>
</tbody>
</table>

Meanwhile, the tendency in designing LED lighting drivers is to use a PSR constant-current (PSR-CC) with single-flyback topology due to its simple circuit and low cost. However, nothing comes for free and the biggest drawback of the PSR-CC solution is its generation of line-frequency ripple current, which requires use of a large output capacitor to suppress the current ripple (Fig. 1.)
In order to achieve high PF, the single-stage power factor corrected PSR-CC LED driver does not include a bulk E-cap. Therefore, this simple solution can’t eliminate line-frequency ripple current. So, in some high-end lighting applications, the single-stage PSR-CC LED driver solution can’t be used. In such applications, designers typically employ a three-stage solution consisting of a PFC stage, a flyback converter stage and a secondary dc-dc stage to solve the current ripple problem, as shown in Fig. 2.

Although the performance of this circuit is good, the circuit is obviously too complex, has too many components, and is not cost effective or space saving. So the three-stage solution does not represent a practical solution for most LED lighting applications.

In this article, an alternative to the three-stage LED driver is described. This new two-stage design based on PSR saves the cost of one stage while maintaining high performance including no line-frequency ripple current and high PF. The proposed two-stage design differs from existing PSR-based LED driver solutions in its use of constant-voltage rather than constant-current regulation, and in its use of two stages rather than a single stage. These differences affect several aspects of the circuit’s performance.
Two-Stage Solution

Depending on your control target, the PSR technique can be implemented using one of two regulation methods: constant-voltage output or constant-current output. Because LED current determines luminous intensity, single-stage PFC PSR-CC is commonly used in lighting applications. A typical design is shown in Fig. 3.

However, this single-stage design has some performance limitations that will prevent its use in current and future LED lighting applications. So, in order to eliminate line-frequency ripple current and meet strict standards we must use a multi-stage solution. Fortunately, the PSR technique doesn’t require a secondary feedback loop or opto-coupler and produces tight regulation. All of these qualities make it possible to apply PSR in the design of a two-stage solution.

Using the three-stage solution described previously as a starting point, we can develop a two-stage solution using the PSR technique applied in one of two ways.

Two-stage PSR-CC

The first two-stage PSR solution combines a flyback converter stage and a secondary dc-dc stage into a single stage to obtain isolation and the dimmable, LED driver function. This stage is identified as the PSR-CC stage in Fig. 4. Prior to the PSR-CC stage, there is a second stage that provides power factor correction. As we can see in Fig. 4, the LED current is controlled on the primary side of the transformer so the solution is named the two-stage PSR-CC.
The two-stage PSR-CC solution is well accepted in the market, especially in the phase-cut dimming area where the dimming signal comes from the ac line. But in applications with analog or PWM dimming, things are different. Since the dimming function is performed on the primary side of the circuit, safety standards require that a transformer be added to isolate the dimming signal. And because it’s primary dimming, dimming control is a little complex and not easy to achieve with good accuracy. Another issue is the relatively poor CC regulation due to PSR-CC, which prevents the application of this topology in high-end lighting applications. Also dimming range is another concern for this topology.

**Two-Stage PSR-CV**

Based on the single-stage solution and the two-stage PSR-CC solution, a new two-stage structure has been developed that is suitable for LED driver applications requiring no line-frequency current ripple. The key point is that this solution combines a PFC stage and a flyback converter stage into a single stage to achieve the familiar PFC and isolation functions. The big difference compared to PSR-CC is that this single stage only controls secondary output voltage not output current, hence it’s called PSR-CV. The PSR-CV stage is followed by a second, dc-dc stage which is used to drive or dim the LED. As shown in Fig. 5, the two-stage PSR-CV design has a very clear division of functions: the PFC function is achieved on the primary side and LED driving is implemented on the secondary side, which will reduce circuit difficulty and make it easier to design.
The two-stage PSR-CV solution maintains two-stage PSR-CC merits, while adding some extra advantages. First, LED current control is simple and controls the LED current more accurately because the secondary dc-dc stage controls the LED current directly. Second, whether 0- to 10-V analog dimming or PWM dimming is used, dimming can be easily implemented in the secondary dc-dc stage and without any isolation.

Third, cost may be lower than PSR-CC. In contrast with PSR-CC, the PSR-CV approach moves power factor correction to the secondary dc-dc stage. As we all know, the PFC stage usually contains high-voltage components. But when implemented in the secondary dc-dc stage, these PFC components become low voltage components.

Finally, the PSR-CV solution gives us more flexibility. For example, we can add a standby power function in the PSR-CV stage to obtain low standby power consumption when the LED string is not connected. Or when we need to drive multiple LED strings, we can choose a suitable dc-dc converter for those applications.

The only drawback of PSR-CV is that output voltage regulation is not very tight. But we can overcome this problem by implementing a secondary dc-dc stage with wide input voltage range.

**PSR-CV Operating Principles**

Currently, the PSR-CV design is implemented by controlling the voltage on the main transformer’s auxiliary winding. Once the auxiliary winding voltage is controlled, the main output voltage is set via transformer coupling. Therefore, in order to produce an accurate output voltage, we need to control the auxiliary winding terminal voltage directly as we can see from Fig. 6.
During the rectifier diode (Dr) conduction time, the sum of output voltage and diode forward-voltage drop is reflected to the auxiliary winding side as (Vo+VF) x Naux/Ns. Since the diode forward-voltage drop decreases as current decreases, the auxiliary winding terminal voltage reflects the output voltage best at the end of diode conduction time, where the diode current diminishes to zero. By sampling the winding voltage at the end of the diode conduction time, a more-accurate reading of output voltage can be obtained (Fig. 7.)
Because the auxiliary winding terminal voltage will move up and down in one switching period, we need to find out the sampling point first. Then, using a sample/hold circuit, we will compare the sensed voltage to that of the internal precise reference. However, the control logic required to perform these steps is a little complex.

An easier, more practical way we can control the rectified auxiliary winding voltage is through the PFC controller's error amplifier as shown in Fig. 8. The drawback of this approach is a loss of output voltage accuracy.
However, it’s a tradeoff between simple control and accurate output voltage. In the two-stage PSR-CV solution, the output voltage accuracy of the first stage is not a big issue, because we can choose a secondary dc-dc stage with a wide input voltage range.

**Test Results And Waveform Measurement**

An evaluation board based on a single FL6961 PFC controller IC, which has an OVP function, can be changed to implement PSR-CV using the FL7701 high-voltage buck controller[3] which has extremely wide input range (Fig. 9.)

Thanks to the PSR-CV solution, we also can easily generate a secondary CV supply to power other functions like an MCU by adding an auxiliary winding on the secondary side.

With PSR-CV Vcc regulation, the CV accuracy that we can achieve is ±4.25% CV tolerance across the whole output load range. If eliminate the light-load voltage drift (caused by burst-mode operation), the CV accuracy will improve to a tolerance of ±1.1% (Fig. 10.)
**FL6961 with primary side VCC regulation**

![Graph showing CV performance of the FL6961 with primary-side VCC regulation](image)

**Total Output Voltage deviation : ±4.25%**
**Except burst period : ±1.1%**

*Fig. 10. CV performance of the FL6961 with primary-side VCC regulation.*

With the FL7701 we can easily help build up the buck dc-dc converter with the analog dimming function included. Thus, the total solution comes out with extremely low ripple current.

![Graph showing dimming performance](image)

*Fig. 11. Dimming performance.*

**Conclusion**

This article introduces and develops a new two-stage PSR-CV solution that produces no line-frequency current ripple, achieves high PF and maintains a simple, easy-to-design circuit. Experimental results have proven the proposed two-stage PSR-CV solution is an excellent candidate for high-end LED analog dimming and PWM dimming applications. In the future, we can add new features such as a standby mode on the primary side to achieve low standby-power in order to satisfy the market trend toward more energy-efficient LED driver solutions.
References


3) Fairchild Semiconductor, FL7701MX (Smart Non-isolated PFC Buck LED driver), 2012.

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