Line Undervoltage and Overvoltage Protection for TPS92210-Based LED Drivers

Bharat Agrawal, Sanjay Dixit

ABSTRACT

Increasing demands for electric power have caused existing power grids to become overloaded. Overloading, inadequate power generation, and inadequate distribution systems are the main causes of line voltage fluctuations. This application report describes implementation of the line undervoltage and overvoltage protection circuit for TPS92210-based LED lighting driver designs. Basic circuit operation and component value modifications required to set desired undervoltage and overvoltage cut-off limits are described here.

Line undervoltage and overvoltage protections, which can be realized using ultra-low-cost discrete components or low-power operational amplifiers, are required to protect the LED driver from high input currents when operating at low input voltage, and significant voltage stress on power MOSFET during operation at high input voltage. It is necessary to disable the driver when the line AC input goes outside a normal operating range, using one of the control pins on the TPS92210.

Contents

1 Need for Undervoltage and Overvoltage Protection ................................................................. 2
2 About TPS92210 .................................................................................................................. 2
2.1 Transformer Zero Energy Detection .................................................................................. 3
3 Application Schematic ........................................................................................................... 4
4 Circuit Operation .................................................................................................................. 5
5 Calculations .......................................................................................................................... 5
6 Modes of Operation .............................................................................................................. 6
7 References .............................................................................................................................. 6

List of Figures

1 Typical Application Schematic for TPS92210 Based LED Driver ........................................... 3
2 TZE and HVMOSFET Drain Voltages for Valley Switching .................................................... 3
3 Schematic for Input Undervoltage and Overvoltage Protection .............................................. 4

List of Tables

1 Different Operating Conditions of LED Driver with use of Protection Circuit..................... 6
1 Need for Undervoltage and Overvoltage Protection

Output power of an LED Driver is given by:
\[ P_{\text{OUT}} = V_{\text{OUT}} \times I_{\text{OUT}} \]
where
- \( P_{\text{OUT}} \) = Output Power
- \( V_{\text{OUT}} \) = Voltage across the LED String
- \( I_{\text{OUT}} \) = Current through the LEDs

Assuming similar system efficiency at constant output power across different line inputs, a decrease in input voltage corresponds to an increase in input current and vice-versa. Hence, when line input voltage drops, the input current to the LED driver increases, while maintaining the same output power. This increased input current may result in heating of components or even permanent damage (when this current exceeds device current rating) and reduced lifetime of the device.

Similarly, electronic devices and components (like MOSFETs, diodes, capacitors, and so forth) are rated for a maximum voltage. Operation beyond these limits may reduce the lifetime or may even cause permanent damage to the device. In an LED driver, maximum voltage stress on power MOSFET, as given in Equation 2, is the sum of peak input voltage, output voltage reflected from secondary during Toff, and voltage spike due to leakage inductance of transformer primary-side winding.

\[ V_{\text{FET(max)}} = V_{\text{in(mss)}} \times \sqrt{2} + N \times (V_{\text{out}} + V_D) + V_{\text{leakage}} \] (2)

With leakage inductance ringing assumed to be approximately 100 V maximum, voltage on primary-side FET drain may exceed its specifications in the event of an overvoltage on the universal line input. In such cases, input undervoltage and overvoltage protection is needed to prevent permanent damage to the components. It is required to inhibit switching/power transfer to the load when operating outside the safe operating range.

2 About TPS92210

The TPS92210 is a natural power factor correction (PFC) light-emitting diode (LED) driver controller with advanced energy features to provide high efficiency control for LED lighting applications. This controller has the following salient features:
- Flexible operation modes
  - Constant on-time enables single-stage PFC implementation
  - Peak primary current
- Cascoded MOSFET configuration
  - Fully-integrated current control without sense resistor
  - Fast and easy startup
- Discontinuous conduction mode or transition mode operation
- Transformer zero energy detection
  - Enables valley switching operation
  - Helps to achieve high efficiency and low EMI
- Open LED detection
- Advanced overcurrent protection
- Output overvoltage protection
- Line surge ruggedness
- Internal over-temperature protection

The TPS92210 cascode architecture enables low switching loss in the primary side and when combined with the discontinuous conduction mode (DCM) operation ensures that there is no reverse recovery loss in the output rectifier. These innovations result in efficiency, reliability, or system cost improvements over a conventional flyback architecture.
Figure 1 shows a typical application of a TPS92210 based LED driver.

![Figure 1. Typical Application Schematic for TPS92210 Based LED Driver](image)

2.1 **Transformer Zero Energy Detection**

The TPS92210 operates in discontinuous mode with the next switching cycle initiated only when the transformer has been completely reset or when its energy is zero. The TZE pin is connected through a resistor divider to the primary-side auxiliary winding for zero energy detection. The transformer zero energy is detected by monitoring the current sourced out of the TZE pin when the primary bias winding of the flyback converter goes negative with respect to ground. It is possible to align the turn-on of the primary switch with the resonant valley of the primary winding waveform to minimize switching losses and optimize efficiency.

When the power MOSFET turns off, the transformer secondary runs out of energy after some time, and ringing is observed on the primary MOSFET drain, as shown in Figure 2. The TZE pin detects this zero cross at the primary auxiliary winding and aligns the next switching cycle with the resonant valley. Figure 2 shows the waveform on the high-voltage MOSFET drain, the voltage at the TZE pin and the primary transformer current.

![Figure 2. TZE and HVMOSFET Drain Voltages for Valley Switching](image)
It is required to fulfill the following three conditions before initiating a new switching cycle:

- The time since the last turn-on edge must be equal to or greater than the time that is requested by the feedback processor as determined by the feedback current, $I_{FB}$.
- The time since the last turn-on edge must be longer than the minimum period that is built into the device (nominally 7.5 µs which equals 133 kHz).
- Immediately following a high-to-low zero crossing of the TZE pin voltage, or, it has been longer than $t_{WAIT,TZE}$ since the last zero crossing of the current has been detected.

This application report describes a circuit which violates the third condition to prevent initiation of the next switching cycle in an event of undervoltage or overvoltage at the input.

3 Application Schematic

Figure 3 shows the circuit for undervoltage and overvoltage protection in TPS92210-based LED driver controllers, using low-power op amp TLC27L4:

In case the line input is outside the safe operating range, this circuit forces a DC voltage on the TZE pin to prevent the occurrence of next zero crossing, thereby violating a necessary condition (third condition) and successive switching cycle. Hence, no power is transferred to the Load (LEDs). When in safe operating range (say, 90–265 VAC input voltage), this circuit does not output this DC voltage on the TZE pin, and there are usual occurrence of zero crosses and switching cycles to deliver power to the output.

Figure 3. Schematic for Input Undervoltage and Overvoltage Protection
4 Circuit Operation

Figure 3 shows the schematic for this protection circuit. Line input voltage at bridge rectifier output (pulsating DC) is input to this protection circuit. This pulsating input is clamped at 12 V with zener D2, and further reduced proportionately using resistors R3 and R4 (for undervoltage protection) and R5 and R6 (for overvoltage protection). The 12-V bias also powers up TLC27L4 (U1), a precision quad single supply micro-power operational amplifier used in this circuit. It is required to use a micro-power opamp, since this circuit is powered up from 12-V zener voltage, which is current limited at low-line inputs. If this opamp is replaced with a greater supply current device, it is possible to observe erratic on-off cycles at low input voltages (30–50 VAC). U1-A works as a peak detector, generating a DC voltage on capacitor C4, which is proportional to \( V_{\text{in(rms)}} \). U1-B buffers this DC voltage and U1-C outputs an error signal at the moment the peak detector voltage goes below undervoltage reference (VR1). Similarly, U1-D compares peak detector output with overvoltage reference (VR2) to provide a HIGH output as an error signal when \( V_{\text{in(rms)}} \) exceeds the overvoltage trigger threshold. Outputs of U1-C and U1-D are clamped at 3.3 V with zener D5, and then buffered with BJT Q1 before being fed to the TZE pin. Hysteresis of approximately 5 V (input RMS voltage) is introduced using resistors R10 and R12, to prevent false triggering at boundary limits. Due to use of small input capacitor C4 in this LED driver, this hysteresis becomes even more important at undervoltage cut-off points, as input current is larger at lower AC mains, and the action of switching the LED driver ON/OFF immediately changes DC bus voltage. This is also the reason why we use a smaller \( R_{12} \) (as compared with \( R_{10} \)) to add a greater hysteresis at the undervoltage trip point.

5 Calculations

Assume the RMS line input undervoltage and overvoltage trip points as \( V_{\text{in(undv)}} \) and \( V_{\text{in(ov)}} \), respectively.

For RMS line input voltage \( V_{\text{in(rms)}} \), peak voltage at non-inverting input (pin 3) of U1-A is given by:

\[
V_{\text{in(U1-A)}} = \frac{V_{\text{in(rms)}} \times \sqrt{2} \times R_2}{R_1 + R_2}
\]

(3)

Due to negative feedback, the same voltage is generated at the output of peak detector. Values of \( R_7 \) and \( C_4 \) are selected such that transients at input are rejected, while peak detecting the 100-Hz input voltage.

From the 12 V generated using D2, R3, and R4 determine the undervoltage trigger threshold, while R5 and R6 determine the overvoltage trigger threshold. These thresholds are set at 1 V and 2.5 V, respectively. Thus, at undervoltage trigger point,

\[
V_{\text{UV}} = 1 \text{ V} = \frac{12 \text{ V}}{R_3 + R_4}
\]

(4)

And at overvoltage trigger point:

\[
V_{\text{OV}} = 2.5 \text{ V} = \frac{12 \text{ V}}{R_5 + R_6}
\]

(5)

For these values of undervoltage and overvoltage cut-off thresholds, we get resistor values as \( R_3 = 220 \text{ k}\Omega \), \( R_4 = 18 \text{ k}\Omega \), \( R_5 = 560 \text{ k}\Omega \) and \( R_6 = 150 \text{ k}\Omega \).

These trip thresholds are inputs to U1-C and U1-D, such that when peak detector output deviates from normal operating range voltage, opamp outputs are triggered HIGH, indicating error, and hence force a DC voltage on TPS92210’s TZE pin through transistor Q1 in emitter-follower configuration. Since TZE input of TPS92210 is continuously being scanned for valley transitions, forcing of this DC voltage inhibits next switching cycles, until input voltage returns to within normal operating range.
6 Modes of Operation

Table 1 lists the different operating conditions of an LED driver using a protection circuit.

Table 1. Different Operating Conditions of LED Driver with use of Protection Circuit

<table>
<thead>
<tr>
<th>Input Range of Operation</th>
<th>AC Input (V)</th>
<th>U1–C Output</th>
<th>U1–D Output</th>
<th>TZE Pin Input</th>
<th>LED Driver Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undervoltage</td>
<td>&lt; 85</td>
<td>High</td>
<td>Low</td>
<td>DC voltage forced</td>
<td>Off</td>
</tr>
<tr>
<td>Normal operating range</td>
<td>85–260</td>
<td>Low</td>
<td>Low</td>
<td>Normal operation</td>
<td>On</td>
</tr>
<tr>
<td>Overvoltage</td>
<td>&gt; 260</td>
<td>Low</td>
<td>High</td>
<td>DC voltage forced</td>
<td>Off</td>
</tr>
</tbody>
</table>

7 References

- TPS92210 Constant-On Time Driver Controller with Cascoded MOSFET for LED Lighting datasheet (SLUS989).
- TLC27L4 Quad Precision Single Supply μPower Operational Amplifier datasheet (SLOS053).
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer’s risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio
www.ti.com/audio

Amplifiers
amplifier.ti.com

Data Converters
dataconverter.ti.com

DLP® Products
www.dlp.com

DSP
dsp.ti.com

Clocks and Timers
www.ti.com/clocks

Interface
interface.ti.com

Logic
logic.ti.com

Power Mgmt
power.ti.com

Microcontrollers
microcontroller.ti.com

RFID
www.ti-rfid.com

OMAP Applications Processors
www.ti.com/omap

Wireless Connectivity
www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation
www.ti.com/automotive

Communications and Telecom
www.ti.com/communications

Computers and Peripherals
www.ti.com/computers

Consumer Electronics
www.ti.com/consumer-apps

Energy and Lighting
www.ti.com/energy

Industrial
www.ti.com/industrial

Medical
www.ti.com/medical

Security
www.ti.com/security

Space, Avionics and Defense
www.ti.com/space-avionics-defense

Video and Imaging
www.ti.com/video

e2e.ti.com