

Non-Isolated Driver Protection for LED Lamps

By Usha Patel, Littelfuse

A combination of legislation (such as the Energy Independence and Security Act of 2007 in the United States) and consumers' desire for greater energy efficiency will likely render the traditional incandescent light bulb obsolete within the next few years. They are already being replaced by new, more efficient lighting technologies, particularly LED lamps. These retrofit lamps include an AC/DC power converter, driver/controller IC for the LEDs, a heat sink for thermal management, and optics to optimize the quality of the light produced.

In an LED lighting assembly, the driver and its topology are crucial to achieving the design's performance objectives. In addition, the devices that protect these circuits will have a major impact on the reliability and life of the assembly. LED lamps, like any piece of equipment that's connected directly to AC mains (120 or 220VAC), can be damaged by short-circuits and overload conditions inside the driver as a result of electronic components. Fuses are the most reliable devices used to ensure the safety of equipment subjected to such overcurrent events, as well as that of the people who use it. An LED lamp contains a power supply that drives the LEDs; if the driver experiences low impedance component failures, it can begin drawing higher levels of current, which can ultimately produce smoke or fire if there's no working fuse or other overcurrent protector in place.

Lightning surges or load switching transients, which originate outside the LED bulb, can create voltage spikes or ring waves that can stress and damage sensitive electronics, causing the bulb to fail. Given that consumers buy LED bulbs because they promise both lower energy usage and longer lifetimes, it's critical to incorporate transient voltage protection in order to eliminate field failures driven by the electrical environment. Transient protection is critical not only for the driver electronics but, more importantly, for the LED load. The ICs can be protected by means of isolated bias windings and filtering elements. However, insufficient spacing on the PCB, flashover of physically small components, or unintentional coupling through transformers and opto-couplers can lead to failure due to inadequate transient protection. A well-designed surge protection scheme will limit the peak voltage and current envelopes to avoid coupling through unintended paths.

The AC/DC power conversion circuit can use either "isolated" or "non-isolated" topologies. What is the difference between isolated and non-isolated topologies?

Isolated Topologies

One of the most common isolated topologies used in LED lighting is a flyback converter. These are generally used in higher power circuits, (>15–20W), which are prevalent in outdoor lighting applications. Flyback circuits consist of an isolating transformer (Fig. 1A), which can provide some degree of protection

against transients and surges occurring on the primary side. This can reduce the number, size and cost of the circuit protection devices needed on the secondary side.

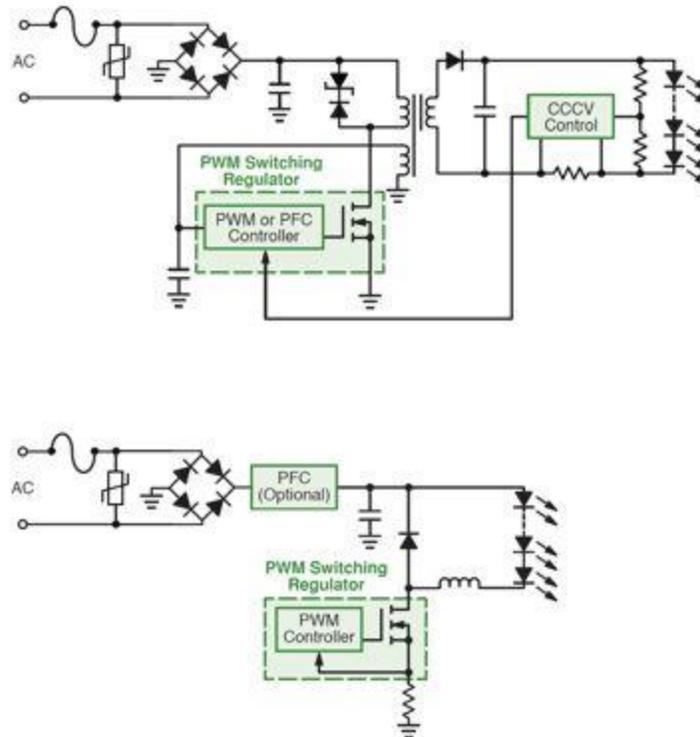


Figure 1A. (upper) Isolated single-stage flyback driver **Figure 1B.** (lower) Non-isolated buck driver (Source: ON Semiconductor)

Non-isolated Topologies

The term “non-isolated” may seem misleading because, even in non-isolated topologies, electrical insulation is still necessary to protect (isolate) users from dangerous voltages per the UL 8750 safety standard.

Low power LED lighting applications (typically <15W), such as indoor retrofit lamps, are typically based on buck or buck-boost topologies that do not use an isolating transformer (see Fig. 1B). These non-isolated solutions employ inductors as an averaging element. Buck-boost topology has several advantages, including the simplicity of its circuitry and low component count, wide input and output voltage ranges, high output current stability and a power factor in the range of 0.95 to 0.98 with proper control techniques.

Most buck-boost driver ICs in the market have short-circuit protection functionality to prevent damage due to short circuits at the DC output trace/wire/connector or LED array module. However, the driver IC has no overcurrent protection covering the AC input to the switching circuitry. Possible component failure in short or low-impedance status will result in high input current flow, which will generate heat, creating conditions that can cause smoke and or fire. Bridge diodes, capacitors, MOSFETs, and driver ICs can fail

short. In addition to component failures, a conductive particle or fragment intruding into the power supply could cause a short-circuit condition.

UL 8750, the safety standard for LED Equipment for Use in Lighting Products, requires component fault (short-circuit) simulation testing on LED luminaires to show no risk of fire or electric shock. It reads, in part:

8.5.2 Component failure test

8.5.2.1 A unit shall not exhibit a risk of fire or electric shock when a simulated short circuit is imposed on electrolytic capacitors or semiconductor devices.

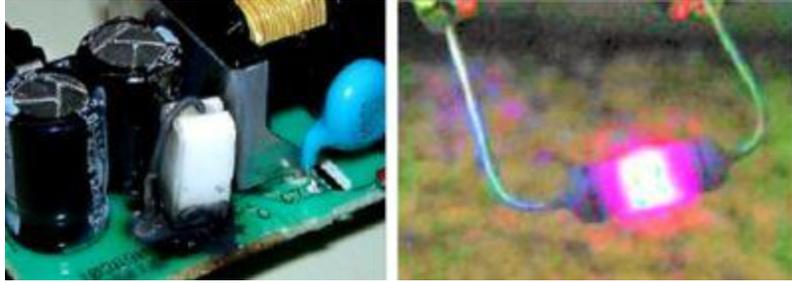
8.5.2.2 Each electrolytic capacitor and semiconductor device is to be short circuited, one at a time (one fault per test). Each test shall continue until either the unit is no longer operable, or until conditions are obviously stable (as determined by no visual changes or detectable thermal increase) for at least 30 minutes.

To provide proper protection to the power supply and luminaire under short-circuit conditions, using a fuse at the AC input circuit is recommended because of its small size, low resistance, low power consumption, and high interrupt rating. Fuses also offer the best precision of interruption over other passive overcurrent protection technologies.

Fuses are the “gold standard” for overcurrent protection, particularly in LED bulb and luminaire assemblies. In some applications, for various reasons, circuit designers have turned to fusible resistors or fusible circuit board traces for overcurrent protection. However, these solutions could pose unsafe failure modes, such as fire, as described below.

Drawbacks of Fusible Resistors

Fusible resistors are manufactured using high temperature alloys that have low thermal coefficients of resistance. This results in stable resistance across a wide temperature range, which is an important characteristic in resistors. In contrast, fuses that offer good overcurrent protection are made of a low temperature alloy with a higher thermal coefficient of resistance. This characteristic of fuses results in a sharp increase in resistance as the fuse element experiences an overcurrent situation, which is highly desirable for bringing the fuse element to its melting temperature quickly. Although fusible resistors are effective at limiting current, they waste energy and do not perform well on low-level overloads. In addition, because their resistance wires melt at 1300–1400°C, they have the potential to pose a fire hazard (Fig. 2).



Material	Typical Use	Melting Temperature (°C)
Copper	Fuse Element	1083
Silver		962
Nichrome	Resistor Element	1400

Figure 2. Using fusible resistors for overload protection can pose a fire hazard.

Littelfuse engineers performed a series of tests to demonstrate the differences in overcurrent protection that fusible resistors and fuses provided. They performed overload and surge immunity tests on a 22Ω, 240V, 2W fusible resistor of the type sometimes used in retrofit LED bulb assemblies. The first test involved emulating a soft overload condition using 1.65A of constant current for the fusible resistor, equivalent to 60W minimum fusing power of that device. In a comparison test, Littelfuse TR5 and TE5 fuses were subjected to 3.2A and 4A of constant current. A step current test was conducted, in which the current was gradually increased by 0.165A every five minutes, starting from 0.33A (at 2W rated power).

Table 1 presents the results of these two sets of overcurrent tests.

	Overcurrent	Fusing Resistor			Fuse #382 1.6A		Fuse #382 1.6A		
		Gradual 0.33A-0.825A	Constant 1.65A	Constant 3.2A	Constant 4A	Constant 3.2A	Constant 4A	Constant 3.2A	Constant 4A
	Fusing Time	16 min.	5 sec.	0.8 sec.	0.4 sec.	7 sec.	1.7 sec.	8.9 sec.	2.5 sec.
During Fusing	Source	■	■	■	■	■	■	■	■
	Glowing	■	■	■	■	■	■	■	■
	Flare	■	■	■	■	■	■	■	■
	Spark	■	■	■	■	■	■	■	■
	Explosive	■	■	■	■	■	■	■	■
After Fusing	Discoloration	■	■	■	■	■	■	■	■
	Crack	■	■	■	■	■	■	■	■
	Reposable	■	■	■	■	■	■	■	■
	Risk of Fire		YES	YES	YES	NO	NO	NO	NO

Table 1. Overcurrent testing results for a fusible resistor and two different fuses made by Littelfuse

The same tests were conducted on 10Ω and 100Ω fusible resistors that had nominal 1W ratings, yielding very similar results.

Additional tests on fusible resistors were performed according to IEC61000-4-5 and the Energy Star surge immunity test standards as described in more detail below. In most cases, these resistors were unable to withstand the number of strikes required by these standards, such as 40 strikes per the IEC

standard. Littelfuse testing revealed that fusible resistors generate excessive heat in surge testing, causing them to open before the required number of strikes were applied. In an LED retrofit bulb, once the fusible resistor opens, the bulb is disconnected from the power source, not only failing EMC testing but rendering it dead.

The lack of transformer isolation in non-isolated topologies means that power conversion circuitry and the LEDs are more susceptible to damage by surge energy coming from the AC mains as a result of load switching transients or secondary lightning energy. Consequently, surge protection components are needed on both the AC and DC sides to provide adequate surge immunity effectively.

The United States is leading the way for establishing uniform performance and safety standards, such as the EPA's Energy Star surge specifications, which apply to A-19, PAR30, PAR38, MR16, Candelabra, G-globe, and R-reflector types of LED retrofit lamps.

In the United States, manufacturers generally must meet Energy Star transient voltage surge specifications for LED replacement bulb assemblies used in residential and certain commercial applications. For example, Version 1.4 of the Energy Star program requirements defines a $0.5\mu\text{s}$ 2.5kV 100kHz ring wave transient test for integral LED lamps. Other test requirements include:

- Test level: 2.5kV/83A, line-to-line (ANSI/IEEE C.62.41-1991, Class A operation).
- Number of surges: Seven strikes in common mode and seven in differential mode, one minute between each strike.
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For countries other than the United States, the surge immunity requirements for LED lamps are outlined in IEC 61000-4-5.

In addition, part of IEC61547, "Equipment for General Lighting Purposes" requires EMC immunity testing based on a combination waveform $1.2\times 50\mu\text{s}$ open circuit voltage and $8\times 20\mu\text{s}$ short circuit current that define rise time and duration of the test voltage and current. Additional test requirements include:

- For self-ballasted lamps and luminaires < 25W, 500V/250A: Apply 500V L-L with 2Ω source impedance and 1kV L-G with 12Ω impedance.
 - For luminaires >25W, 1000V/500A: Apply 1kV L-L with 2Ω source impedance and 2kV L-G with 12Ω impedance.
 - Number of surges: 10 strikes, 5+ and 5- at phase angles 90/270, one minute between each strike.

Placing a metal oxide varistor (MOV) across the AC power input is the key to providing overvoltage clamping protection against the lightning-related or switching transients that are outlined in both the Energy Star and IEC standards. An MOV in this location offers the most cost-effective way to minimize

transient energy that could make its way into downstream electronics. The choice of MOV must be based on a number of parameters, including voltage rating, peak pulse current, energy rating, disk size and lead configuration. Fortunately, varistors with high surge current ratings are available in disk diameters as small as 5mm, allowing them to fit easily into the space-constrained power supply section of an LED lamp.

The MOV and the fuse must be a coordinated solution so that energy required to melt the fuse element (also referred to as “ I^2t ” value) is high enough to allow the MOV to operate under surge conditions without causing the fuse to open (also known as nuisance opening). In other words, the fuse should not open during clamping and dissipation of surge energy; it should only open when an overload or short-circuit condition occurs.

However, there will be instances when the circuit is unable to withstand surge events, even with a varistor on the AC input. In these cases, a TVS (transient voltage suppression) diode can be added at the input of the power converter stage to provide secondary protection against transients (Fig. 3). The “let through” energy from the varistor will be further clamped by the TVS diode to a level that the circuit can survive.

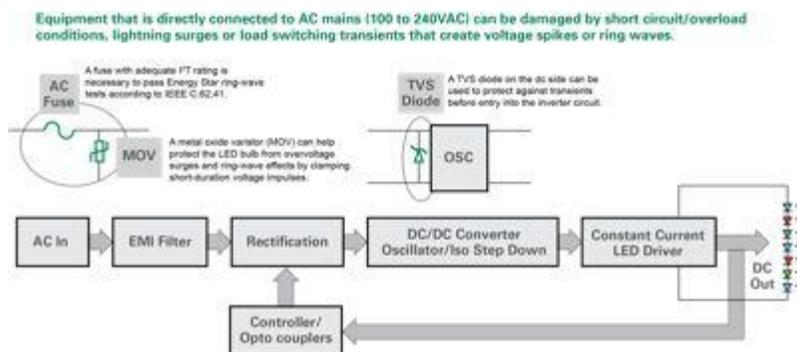


Figure 3. Use of TVS diode for secondary protection against transients

For more information on LED lighting protective devices, download a free copy of the Littelfuse LED Lighting Design Guide. (Registration is required, but just include an email address.)

Biographical Note

Usha Patel has an MSEE degree from the University of Southern California and is a Registered Professional Engineer. Currently she is Director, Latin American Sales and Segment Marketing for Littelfuse. Beyond her responsibilities in Latin America, she leads the company's global initiatives associated with the LED lighting market