

Circuit Protection for Outdoor LED Lighting

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Introduction

Light-emitting diode (LED) lighting is fast-becoming the lighting design of choice for contemporary lighting projects, both residential and commercial. Touted for its green properties such as low maintenance costs, long life and the reduction of power use, LED lighting is becoming very popular, especially in outdoor applications such as airport, highway and street lighting.

In the case of streetlights, LEDs are sold on the basis of low maintenance and long life. So designers must ensure that their designs are well protected in order to realize the expected savings. However, one problem for LED lighting installations is protecting against transient overvoltage events. Two major causes of transient overvoltage have long been recognized; system switching transients and transients triggered or excited by lightning discharges (in contrast to direct lightning discharges to the power systems, which are generally destructive and for which economical protection may be difficult to obtain). Median peak currents can range anywhere between 30 to 50kA per strike.

Typical outdoor lighting includes not only street lighting but also parking lots and walkways. In most traditional lighting designs using sodium lamps, the inductive ballast acts as lamp current limiter and also provides lightning protection for the lamp. In addition, high-pressure sodium and mercury vapor lamps are inherently rugged and therefore there is little need for protection beyond basic fire safety.

LED lighting, on the other hand, is considerably more susceptible to overvoltage transients caused by lightning strikes for a number of reasons. For starters, LED lighting designs use switch mode power supplies (SMPS) whose inputs don't provide the protection afforded by the inductive ballast in traditional street-lighting circuits. Furthermore, an SMPS itself requires sophisticated protection. And LEDs themselves are fragile, solid-state devices. All of these factors combine for a need for additional protection for LED lighting applications.

System Components and Susceptibilities

SMPSs are not typically used in outdoor settings, so there are a number of special considerations for their use in outdoor LED lighting applications.

One particular area of concern is the SMPS front end. Here, the most immediate threat is overvoltage failures. In particular, their pole-mounted outdoor location makes them vulnerable to lightning induced overvoltages and overcurrents, two of the most common failure modes at the front end of an SMPS.

The other weak point in the lighting circuit is the LED itself. LEDs are fragile solid-state devices, essentially diodes, structured as a P-N junction that emits light when forward biased. The main LED failure mechanisms are mechanical and thermal in nature involving thermal cycles, thermal shock, and LEDs operating at high temperatures causing wire bonds to age and fail. As the metal oxidizes and becomes brittle over time, the likelihood of an LED failure increases. Electrostatic discharge (ESD) events or surges induced by nearby lightning events are another common cause of LED failure.

Typical Design Example

Figure 1 shows a typical LED lighting system. In any LED lighting application, there are several areas where effective circuit protection will increase reliability. Those areas include the AC portion of the circuit prior to DC rectification, a DC section, and protection for the LEDs themselves.

AC Section

The first line of defense is the AC line fuse in the SMPS front-end. This fuse provides basic fire protection against major system failures and must be able to tolerate between 3kA to upwards of 6kA surges without opening.

The first selection criterion is the voltage rating. This will depend upon the input line voltage; so, 120VAC in North America and 220VAC in Europe and Asia.

Another important parameter is what is called the breaking capacity, or I^2t value, where I is the current rating of the line and t is the time in which it must open. In this case, the best fuse choice is a slow-blow or time-delay fuse in order to avoid nuisance opening.

Lastly there is thermal derating, or re-rating. This consideration depends on knowing the ambient temperature of the environment in which the fuse will be used because fuses are sensitive to temperature. How much the fuse should be derated can be found by consulting the manufacturers derating curves for particular device families as these vary with voltage ratings, size, current capacity, and fuse type.

On the voltage side, there is the case of handling overvoltage events and dealing with transient voltages. The typical protection devices for overvoltages include MOVs (metal oxide varistors) or solid-state devices.

With energy ratings from 0.1 to 10,000 joules and typical peak current ratings from 40A to 70kA (based on standard 8x20 test waveforms), MOVs divert transient currents to ground and away from sensitive circuits. They are clamping devices, so they don't short the AC input line when they activate (doing so would trip the overcurrent protection), and they recover automatically when the overvoltage is gone. However, MOVs are ceramic devices that degrade slightly with every successive surge activation. So while a MOV can handle repeated large surges, each surge ages the MOV and, over time, its breakover voltage will begin to rise, reducing its effectiveness.

Silicon protectors avoid degradation, but are often rated lower (10kA). However, solid-state devices feature better turn on characteristics, specifically faster switching speeds. Solid-state devices turn on at the trigger of an overvoltage event and reset at a zero crossing point. They are also generally more reliable, but also more expensive than MOVs.

Overvoltage devices have voltage selection criteria, namely the turn-on voltage of the device. This turn-on voltage is the voltage at which the device is activated based on an overvoltage condition. The turn-on voltage should always be higher than the peak line voltage so as to avoid the device switching on intermittently.

Circuitry for power supply protection also requires line isolation from ground to protect against possible shock hazards. These specifications are contained in IEC/UL 60950-1 and IEC/UL 6500.

Figure 2 shows a solution that satisfies both of these requirements. The design combines MOVs with a silicon-based device. A MOV is connected between hot and neutral as well as neutral and ground, with a silicon device also between neutral and ground. This arrangement combines the high surge rating of the MOV together with the non-aging reliability of the silicon device and provides protection for IEC and UL 60950 and UL 6500 requirement for line isolation from ground.

DC Section

The DC fuse in this section is for overcurrent protection. A fuse is placed after the AC voltage is rectified . The fuse provides fast protection to prevent against downstream component failure, such as the DC-to-DC converter and the LED driver section. The need for a slow-blow fuse here shows up in this section. Here, voltages will typically be less than 60VDC.

As for the AC section, the DC voltage rating for the fuse has to have proper voltage rating for that DC line. For instance, you can't use a 15V fuse on a 30V line.

LED Protection

This section deals with proper circuit protection for the LEDs connected in series. Figure 3 shows the LED section of a typical lighting application. Typical LED power ratings are between 1 and 3W. Here, we must determine the current draw from the LED wattage rating. The equation is simply:

$$I = P/V$$

where I is the current, P is the LED wattage rating and V is the LED forward voltage.

LEDs are available in different wattage ratings so these values will differ accordingly. Also, different colored LEDs have different voltage drops. For instance, a red LED typically has a lower forward voltage than a white LED and will therefore draw more current.

A constant current source can be used to drive the LEDs connected in series. A constant current source offers better control of LED brightness, including more uniform LED-to-LED brightness. It's important to know the compliance voltage in order to be able to select the proper open LED

protection. The compliance voltage is the maximum open-circuit voltage of the constant current source.

Open LED Protection

Open LED protection devices provide overvoltage protection to the LED. They provide a switching electronic shunt path when a single LED in an LED array fails as an open circuit, ensuring that the entire string of series-connected LEDs will continue to function. Such devices are compatible with one-, two-, or three-watt LEDs that have a nominal 350mA, 3V forward voltage characteristic, but can support LED applications up to 1000mA.

Employing open LED protection is fairly straightforward. Typically, a protection device is placed in parallel with each LED in a string. A single LED failing by opening in a string of LEDs can cause a partial or full loss of the entire string. Open LED protection provides a shunt current bypass around the open LED, thus saving the LED string from partial or complete failure.

Properly selecting an open LED protector requires that the compliance voltage is known. This is the open-circuit voltage of the constant current source. When an LED fails, the compliance voltage will appear as a voltage drop across the failed LED. So, when placing an open LED protector in parallel with the LED, the compliance voltage must be high enough to turn the LED protector device on. The wattage rating of the LED helps determine the steady-state voltage drop across the LED and is where the open LED protector should not turn on. This sets operating parameters for the device and from here we can determine if we can place an open LED protector across one or two or more LEDs.

Sometimes, two LEDs in series can be protected with one protection device, as a way to lower costs if needed. An LED in the on-state drops approximately 0.7V, which is not sufficient to turn on the protector device. So multiple LEDs can be protected with a single LED protector device since the voltage drops together still do not add up to the minimum voltage needed to turn on the single LED protector device.

With wide operating temperature ranges, from -40 to +150C, open LED protection can be used in extreme environments often with minimal derating. Recall that one of the biggest concerns in LED operation are thermal conditions. Open LED protection devices usually have low on-state voltage, typically 1.5V, and a low off-state current. Therefore, when the overvoltage protection device turns on, it has very low thermal characteristics. So once the protection turns on, no so-called “hot spots” are created nearby, thus avoiding thermal related damage to adjacent LEDs.

Conclusion

Outdoor LED lighting has much to offer, including being a more “greener” source of lighting in addition to the promise of a long, maintenance-free life. In truth, outdoor LED lighting installations can actually be less reliable than conventional lighting, unless designers add the proper circuit protection to guard against the most severe overvoltage conditions.

