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Optimizing Circuit Protection for Series String LED Lighting

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LEDs are fragile devices subject to heat, mechanical shock, electrostatic discharge (ESD) threats, and lightning induced surges; especially in outdoor applications. The increasing use of LED strings for lighting and backlit displays is requiring more attention by designers for LED string reliability. High brightness LEDs, because of their sapphire substrates, are sensitive to electrical transients caused by nearby lightning strikes. Even in household applications, LED strings require ESD protective devices to assure long, reliable operation of the entire assembly. In the absence of such protection, if one LED in a series string fails and opens the circuit, all the other LEDs turn off.

LED Lighting System Protection

A wide variety of protective devices can be considered for the power supply and LED driver, and there are many published articles that provide guidance on their selection. The circuit in Figure 1 is an example that illustrates switch mode power supply (SMPS) protection in an LED street lighting system. In this circuit, the AC fuse provides basic fire protection against major system failures that could cause an overcurrent condition but must be able to tolerate between 3kA to upwards of 6kA surges without opening. The DC fuse is for fast acting overcurrent protection in the event of a downstream component failure in the DC-to-DC converter or LED driver circuit.

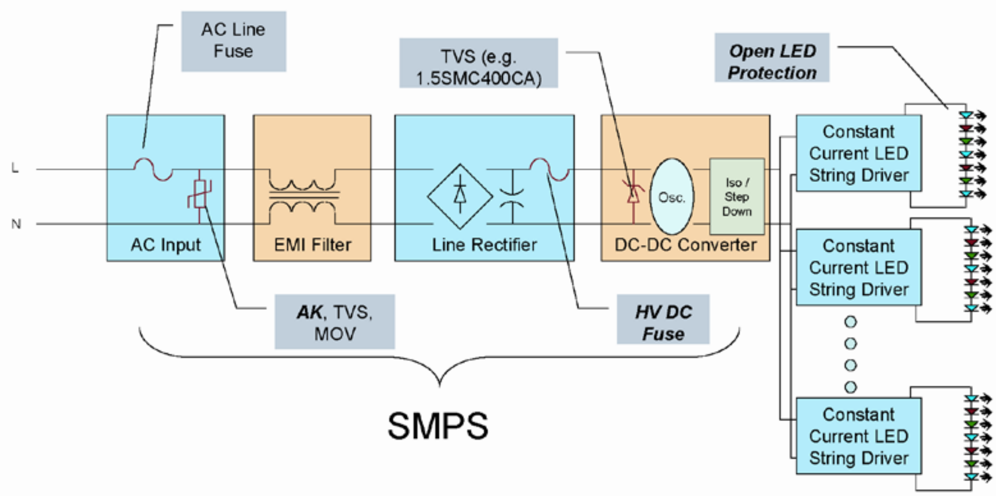

Figure 1. Example of an LED street lighting circuit, including protective devices associated with the switch mode power supply (SMPS).

On the AC input side of the circuit, there is also a need to handle overvoltage events and transients. These are often caused by nearby lightning strikes, but can also be generated by switching transients on power lines. The typical protection devices for these overvoltage conditions are metal oxide varistors (MOVs) possibly combined with transient voltage suppressors (TVSs). 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, UL 1449, and IEC/UL 6500.) Figure 2 shows a solution that satisfies these requirements. The design combines an MOV with a TVS device.

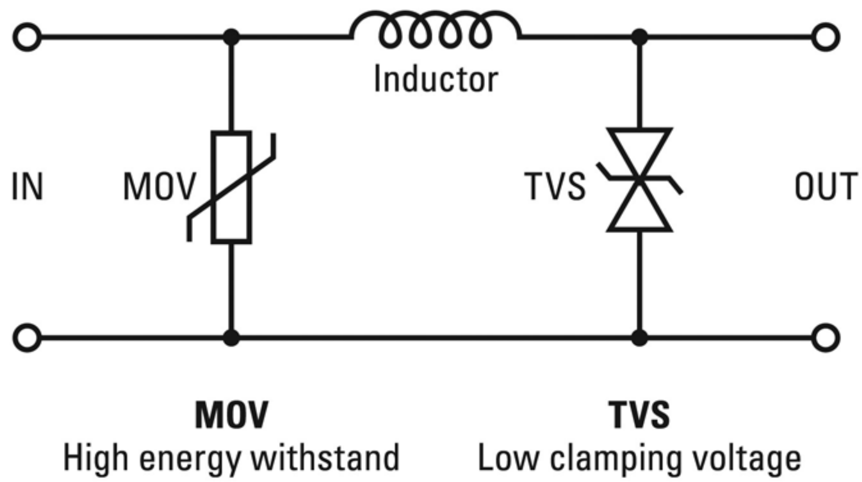

Figure 2. Example of a power input overvoltage protection scheme for LED lighting.

In addition, overvoltage protection should be considered for the LED driver IC. Proper decoupling with a capacitor, along with the inclusion of a TVS device rated at the Line Driver supply voltage, will provide a very stable design. Some LED driver manufacturers include circuitry that senses an open LED string, but that should not be confused with protecting the string or keeping it operating if an LED fails open.

Individual LED Protection

A bypass protection device within an LED string (Figure 3) will allow the string to continue functioning in case a single LED fails in an open state. This will also help protect the LED driver by limiting any excess current or voltage demands on it by the loss of an entire LED string.

When it comes to protecting individual LEDs, and the series circuit leg in which a string of LEDs is installed, selecting the right protective device is crucial. This requires an understanding of potential LED failure mechanisms and how different types of protective devices work. This understanding will help circuit designers select the appropriate device, including one that will keep a series LED string operating when one LEDs fails as an open circuit.

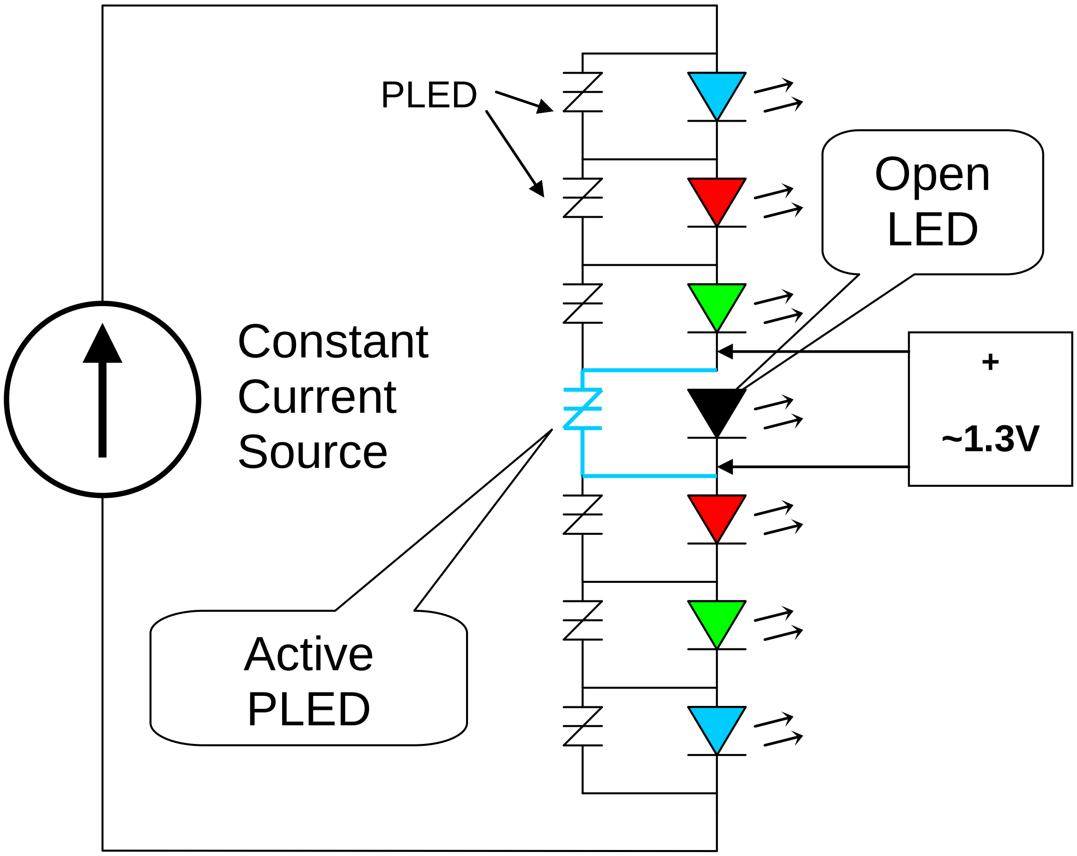

Figure 3. Protecting individual LEDs in a string with the appropriate bypass protective device not only keeps the string lit, but also helps protect the LED driver from excessive current or voltage demands that can be caused by LED failures. [Note: change drawing labels from Littelfuse “PLED” to generic “open LED protectors.”]

LED Control and Failure Modes. A series-connected LED string is powered by a constant current generated by a switch-mode power supply that drives them to full brightness, color, and intensity. This constant-current supply circuit provides better control of LED group brightness as well as a more uniform LED-to-LED brightness.

LEDs are fragile solid-state devices – essentially diodes, structured as P-N junctions that emit 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 that cause 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 strikes are another common cause of LED failure.

Circuit Parameters for Protection Device Selection. The principal parameters in selecting LED protection devices are individual LED current and power ratings, forward operating voltage, and the LED driver compliance voltage. Typical high brightness (HB) LED power ratings are between one and three watts. The maximum current draw of an HB LED at its wattage rating can be determined simply from:

$$I = P/V_F$$

where I is the current, P is the LED wattage rating and V_F is the LED forward voltage. LEDs are available in different wattage ratings so these values will differ accordingly. Also, LEDs that emit at different wavelengths (colors) have different voltage drops. For instance, a red LED typically has a lower V_F than a white LED and will therefore draw more current.

A major reliability issue is the continued operation of the HB LED string if one HB LED fails as an open circuit. In applications that demand a highly reliable light source, this can be crucial. Many outdoor applications are located off of the ground so that readily available access can be problematic, therefore; a single HB LED open circuit failure in a series string can result in major expenses and inconveniences because the entire assembly would have to be serviced.

Analysis of Potential LED Bypass Protection Devices

To protect an HB LED and prevent an entire HB LED series string from going off when a single HB LED fails as an open circuit, a bypass protective device needs to be installed across the HB LED terminals. There are a number of devices that might be considered, including MOVs, SCRs, zener diodes, polymer ESD protectors, and open LED protectors.

MOVs. These devices are best suited for relatively high-energy power line transients typically caused by lightning strikes and the switching of large inductive loads. Unfortunately, they do not respond quickly enough to protect an LED from lower level transients that could cause an LED failure. In addition to that shortcoming, if the LED does fail open, the MOV does not provide a path for the current so the entire LED string would turn off. The resulting heat from an MOV could also be problematic for the LEDs.

SCRs. An SCR can route current around a failed LED to keep the rest of the string lit. Still, these are physically large devices, and they typically require a resistive voltage divider network to set the trigger voltage. The variation of SCR triggering voltage at different temperatures can be quite large. In addition, the reverse blocking voltage is too high, so an SCR cannot provide reverse polarity protection.

Zener Diodes. While zener diodes are typically much smaller than an SCR, they have other problems. When an LED fails as an open circuit, the zener diode must conduct all of the current in the series string. Most zener devices have relatively low current ratings, so their life will be short in this type of application. The zener mode would also cause a micro-environment thermal event that could lead to further LED failures.

Polymer ESD Protectors. Typically these devices are made for high-speed digital circuits, not the protection of DC lines, as in the case with LED strings. They have higher dynamic resistance than a silicon device, so their clamping voltage is much too high to protect a delicate LED. Moreover, they cannot provide surge protection, nor reverse polarity protection.

Open LED Protectors. These devices are designed specifically to keep the rest of a series LED string in operation when one LED fails open. They are compact silicon-based devices that are installed across each LED terminal. As bypass devices they route current around an open LED to keep the rest of the string lit. Some open LED protectors also provide ESD/lighting and reverse polarity protection, which reduces lighting circuit costs by eliminating the need for additional protection components.

Open LED Protector Operation

An open LED protector is an internally triggered two terminal device installed across an LED, which automatically resets if the LED heals itself or is replaced. This protector is a voltage-triggered switch with low leakage on the order of microamps that becomes a low-impedance switch when it is triggered on (Figure 3), which minimizes power consumption. An LED in the on-state drops approximately 0.7V, which is not sufficient to turn on the protector device. Once an LED fails open, there is sufficient circuit voltage to trigger the protector to the on-state (the compliance voltage as supplied by the LED driver circuit). The PLED6 series depicted in Figure 3 also features built-in surge immunity, which helps protect the LED from surges induced by nearby lightning strikes or ESD events.

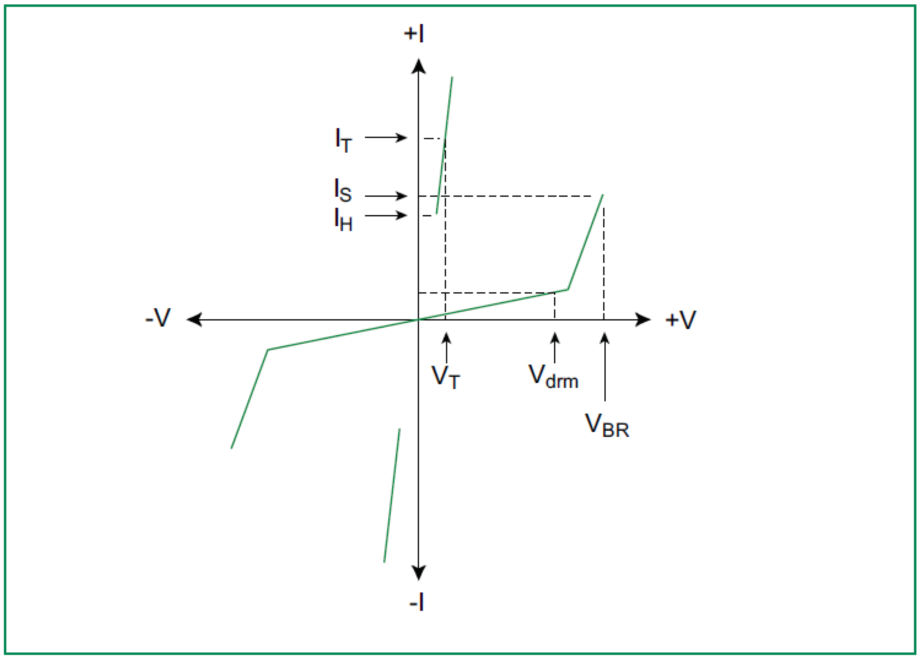

Figure 4. Typical open LED protector V-I characteristics.

Using a Littelfuse PLED6 Series device as an example of a typical open LED protector, Figure 4 shows the key parameters are V_{BR}, I_S, I_H, I_T, and V_T, as shown in the V-I curve. V_{BR} defines the region from the off-state voltage to the breakdown voltage rating of the device. In the off-state, V_{BR} is the continuous peak combination of AC and DC voltage that may be applied to the device, which results in less than 5μA conduction through the device. (Various minimum VBR ratings from 6 to 33VDC are available.) I_S is the value of current that causes the device to switch from the off-state to the on-state when the minimum V_{BR} is applied. Typically, the maximum I_S value is 100mA. Holding current (I_H) is the minimum current required to maintain the device in the on state (typically, 5mA). On-state voltage (V_T) is the maximum voltage across the device during full conduction. I_T is the maximum rated current that can be conducted through the device during the on-state for two seconds (1A max.). Usually, the LED string current is much lower than this, allowing the open LED protector to remain on indefinitely.

There are slight differences in V-I curves as indicated in Figure 5 for the Littelfuse PLED5 Series open LED protector. The 3rd quadrant reaction demonstrates the reverse polarity protection for this Series.

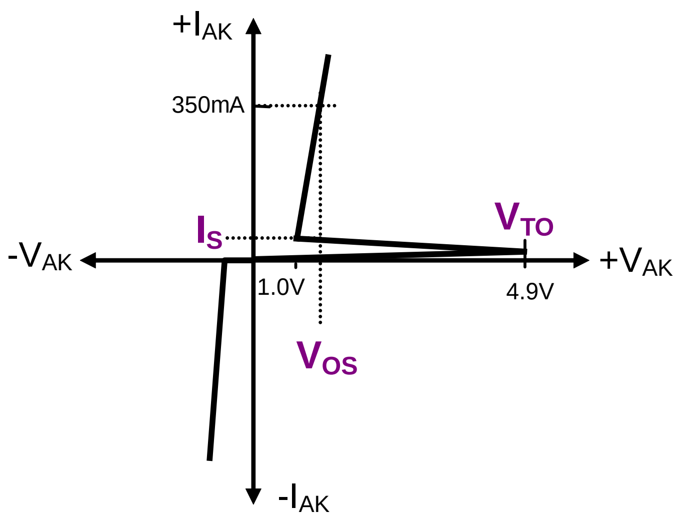

Figure 5. V-I curve illustrating reverse-polarity protection capability in the third quadrant.

Note: Figure 5 needs to be redrawn for better quality; it is badly pixilated.

Since a big concern in LED operation is thermal conditions, another advantage of these open LED protectors is a wide operating temperature range (-40°C to +150°C). In addition, they have a low on-state voltage (about 1.5V) and a low off-state current. Therefore, when the protector turns on, it has a very low thermal dissipation.

Open LED protectors also work well with various LED brightness control methods. Brightness is best controlled by pulse width modulation (PWM) with the switching frequency typically between 60Hz and 1000Hz but the PWM can go much higher. PWM dimming provides a more efficient and more precise dimming control than merely limiting the DC current, which can cause unwanted color shifts. Plus, a linear power control lowers energy efficiency. However, the open LED protection will not interfere with either dimming strategy employed; these open LED protection devices are compatible with LED switching speeds up to 30kHz, which eliminates any negative effects on the lighting control circuit (no flickering).

Ideally, in an open LED protection scheme there is one protective device across each LED. However, a "budget" protection scheme may work too. For instance, it's possible to install one PLED across two LEDs in series when the proper open LED device is selected. One LED failure will result in two LEDs going dark, but this cuts protection costs in half.

Conclusion

Lighting manufacturers are switching to LEDs because of their low cost, high performance, minimum maintenance, and the fact that they can last tens of thousands of hours. Nevertheless, they still require ESD protection, particularly in high-reliability applications such as safety-critical lighting deployed in harsh environments. 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.

The first line of defense is a good circuit-protection scheme, stretching from the input power supply to individual LEDs. Open LED protectors can cope with significant overvoltage transients and keep a series string lit when one LEDs fails as an open circuit. As beneficial as this protection may be, it is still just one part of a total protection solution that should include fuses, MOVs and TVS devices to protect the SMPS and LED driver.

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