Designing for LED Horticulture Applications with Proper Circuit Protection

The future of farming is looking up. Fuji Farm, a Japanese indoor vertical farm, produces 12,000 heads of lettuce a day with LED lighting. Bowery Farming, another tech-filled indoor farm, grows produce in the middle of Manhattan. The world's largest indoor vertical farm operates in Newark, New Jersey – growing food using LED lighting. According to the United Nations, urban farms produce a fifth of the world's food. The vertical farming market is expected to reach $6.81 billion by 2022, says a Research and Markets report. A WinterGreen Research report forecasts the LED light module market for agriculture will grow to $1.8 billion by 2021.

Littelfuse provides a variety of devices designed specifically for the use of LEDs in horticulture, and presents this Application Note to help lighting design engineers select the right solutions for protecting both the LEDs and all the active and passive components up- and downstream from them in the circuit.

Introduction

Satisfying the world's ever-expanding demand for fresh fruits and vegetables is becoming more challenging with every passing year.

A fast-expanding number of fruit, vegetable, and flower growers are turning to indoor horticulture to offset shortages due to loss of arable land, extend the growing season, or grow plants that otherwise couldn't survive in a particular climate.

HPS vs. LED

Although they were developed for use in lighting streets, parking lots, and security areas, high pressure sodium (HPS) lamps have often been used in greenhouses because they deliver very high light intensities and most of the light emitted is in the 565–700 nm range, which can drive photosynthesis. However, today's light emitting diode (LED) lamps offer a variety of advantages over HPS lamps for horticultural applications, particularly the efficacy with which they convert electrical energy into light that plants can use.

LED lighting systems are both easy to control and energy efficient; when properly designed, LED lamps offer long operating lifespans of more than 50,000 hours.

However, horticulture lighting system designers need to understand that LEDs aren't as robust in terms of withstanding electrical disturbances as HPS lamps. Electrical disturbances that affect horticulture lights can be the result of environmental factors like humidity, as well as the kinds of disturbances that can affect

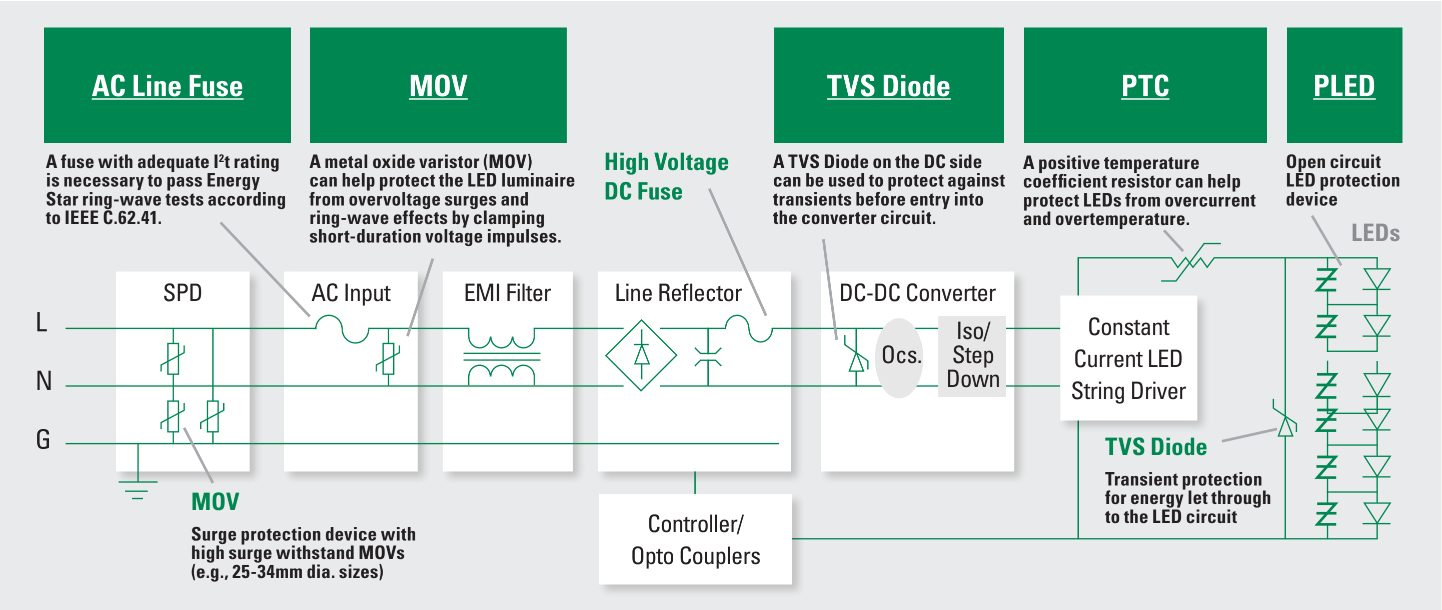

Figure 1. Typical LED luminaire driver circuit with transient and surge energy protection devices

any electrical system, such as switching load surges or power faults. It's critical to keep in mind that LEDs are semiconductor devices that demand comprehensive circuit protection in order to reach their maximum life and provide adequate return on investment. Unlike many general lighting applications, LED lighting systems designed for plant growth are often intended to operate continuously; in addition, the operational environment is often very humid and subject to chemical, biological, or other types of corrosion.

Power and control systems for horticultural LED lighting

Depending on the crops being raised and the design of the growing environment, LED lighting for horticulture may take a variety of form factors, including LED strings, arrays, or discrete LED luminaires like linear LED lamps (often called TLEDs) or flowering lamps. A control circuit is implemented inside a wall mounted control box that controls the timing and power for plant growth.

Providing protection from transients for both the LEDs and all the active and passive components upstream from them in the circuit is one of the most significant challenges associated with indoor LED luminaires. These transients are typically the result of lightning-induced surges on the AC input, switching surges, power faults, ESD events, or moisture intrusion due to high humidity or irrigation. These threats mean that LED luminaires require both overcurrent and overvoltage protection.

Anything directly connected to an AC power source can be damaged by short circuit and overload conditions caused by component and/or circuit failures inside the luminaire. In addition, lightning surges or load switching transients (originating outside the luminaire) can create voltage spikes or ring waves that can stress and ultimately damage components inside the luminaire.

LED luminaire basic circuit blocks

An LED-based light includes the basic circuit blocks illustrated in *Figure 1* (from right to left):

- Multiple, single-chip LEDs configured in series electrically, known as an LED string. Multiple strings are often connected in parallel and driven by a common power source.
- An LED string driver circuit, with corresponding controller circuitry for LED string protection, including a series positive temperature coefficient (PTC) resistor for overcurrent protection (OCP) and a parallel TVS diode for overvoltage protection (OVP).
- A DC-DC converter circuit, which would include a parallel TVS diode on the input as secondary OVP for the downstream components.
- A line rectifier circuit, which would include a series high voltage DC fuse on the output for secondary OCP of downstream components.
- EMI filter components.

- An AC input circuit, which is made up of a line series AC fuse and a line-to-neutral parallel MOV.

The AC input circuit AC fuse is the primary overcurrent protection device for the luminaire. When properly selected for all of the required design parameters, this fuse will adequately protect all downstream components from Electrical Overstress (EOS) damage from induced transients and short circuit or overload conditions by safely disconnecting all circuitry from the AC line input.

Given the tight space constraints associated with LED-based luminaire design, it is critical to select a highly compact AC fuse for the AC input. A fuse's function is to provide protection by reliably and predictably melting during current overload conditions. In other words, a fuse is intended to be the weak link in an electrical circuit. The AC fuse in series with the AC line input will provide protection against short circuit and overload conditions. Today, AC fuses are available in the smallest of form factors, with a wide choice of amperage ratings and voltage ratings. A range of additional key fuse parameters and surface mountable designs are also available to allow design engineers to choose a component that will satisfy all the requirements of the application.

An AC fuse with an adequate I^2t rating is necessary to pass the Energy Star ring-wave tests according to IEEE C.62.41. The nominal melting I^2t rating, measured in ampere squared seconds (A^2sec), specifies the amount of energy required to melt the fusing element. Often, selecting a fuse based on the nominal melting I^2t is meant for applications in which the fuse must endure large current pulses of short duration. Surge immunity testing for LED lighting applications requires complying with 8×20µs combination waveforms. Different fuse constructions may not react the same way to a surge, even if their nominal melting I^2t rating exceeds that of the waveform energy. For example, electrical surge pulses produce thermal cycling that can fatigue the fuse mechanically and shorten its life.

The primary overvoltage protection device for an LED-based light is an AC input circuit Metal Oxide Varistor (MOV). When properly selected for all of the required design parameters, it will protect all downstream components from Electrical Overstress (EOS) damage from induced transients and ring-wave effects by clamping short-duration voltage pulses. A MOV offers a cost-effective way to minimize transient energy that could otherwise make its way into downstream components. Proper MOV selection is based upon a number of electrical parameters, including the voltage rating, peak pulse current, energy rating, disc size and lead configuration.

Designers of LED-based lighting systems for horticulture must consider a variety of important issues in order to select an appropriate AC input circuit AC fuse.

The first step is finding the answers to a number of technical questions about the application. These questions include the luminaire's normal operating current, application voltage, ambient temperature, overload current level and length of time within which the fuse must open, maximum allowable fault current, and the pulses, surge currents, inrush currents, start-up currents and circuit transients, etc.

- A comprehensive list of these questions and guidance in finding the answers is available in the free *Fuseology Selection Guide: Fuse Characteristics, Terms, and Consideration Factors* from Littelfuse.
- Littelfuse also offers the *Design® Fuse Selection Tool*, a robust, web-based tool, based on the *Fuseology Selection Guide*. It is designed to help circuit designers identify the optimal electronic fuses for their projects.

It's crucial to know early in the design process in which geographies the luminaire will be sold. Depending on whether the luminaire is intended for use in the United States, elsewhere in North America, Europe, Asia, or somewhere else, different standards will govern design and testing requirements.

Determine the size limitations that might affect the fuse that can be used. Fuses can be packaged using a variety of methods, but surface mount designs are the most common form factor for LED lighting applications

Fortunately for circuit designers, smaller footprint fuses are now available to protect the AC input, some just half the size of the smallest fuses previously available.

The fuse temperature generated by the current passing through the fuse increases or decreases with ambient temperature change. Be aware that the "ambient temperature" of the fuse is not, as the name might suggest, the same as the "room temperature." Instead, ambient temperature is the temperature of the air immediately surrounding the fuse, which is often much higher than the room temperature because the fuse might be enclosed (such as in a fuseholder) or mounted near heat-producing components on the LED board. For ambient temperatures around 25°C, it's generally recommended that fuses be operated at no more than 75 percent of their nominal current rating for UL rated fuses, and 100 percent of their nominal current rating for IEC rated fuses. Fuses are essentially temperature-sensitive devices, so even small variations in temperature can greatly affect the predicted life of a fuse when it is loaded to its nominal value, usually expressed as 100 percent of rating.

Determine the application's required breaking capacity. This may also be referred to as the interrupting rating or short circuit rating. It is the maximum current that the fuse can safely interrupt at rated voltage. During a fault or short circuit condition, a fuse may experience instantaneous overload current many times greater than its normal operating current. Safe operation requires that the fuse remain intact (no explosion or body rupture) and clear the circuit.

Be sure to allow sufficient time for thorough application testing and verification prior to production to ensure safe operation of the LED power system design in greenhouses.

There will be instances when a specific LED luminaire's operational circuitry is just not able to survive the required transient event levels. In these cases, adding a secondary TVS diode for over-voltage protection is a proven solution that further clamps the "let through" energy from the MOV. For the most extreme cases, a high voltage DC fuse (as shown in the center of *Figure 1*) can be used for DC link overcurrent protection for the LED driver.

To ensure the reliability and robustness of LED strings, the addition of PolySwitch PPTCs in series with the LED can prevent thermal runaway. Also, a single LED that fails open can cause part or all of the string to go out, but connecting an Open LED Protector (PLED) device in parallel with each LED in the string allows shunting or bypassing current around the open-failed LED to keep the rest of the string illuminated. TVS diodes can prevent damage to the LED string due to surge events.

Transient voltage suppression must be part of the initial design process; the device chosen must dissipate the impulse energy of the transient at a sufficiently low voltage so that driver circuit capabilities are not affected.

TVS diodes are among the most commonly used type of suppression device. A TVS diode is specifically designed to protect electronic circuits against transient overvoltage events. Being a silicon avalanche device, it is available in both unidirectional and bidirectional configurations. In the unidirectional version, the specified clamping characteristic is only apparent in one direction, with the other direction exhibiting a forward voltage (V_F) characteristic similar to a conventional rectifier diode. LED lighting power supplies (drivers) typically need TVS diodes at one or more locations in their circuits.

The destructive potential of transients is defined by their peak voltage, the follow-on current, and the time duration of the current flow. The time required for a transient suppressor to begin functioning is extremely important when it is used to protect sensitive components like driver ICs and LEDs. If the suppressor is slow acting and a fast-rise transient spike appears on the system, the voltage across the protected load can rise to damaging levels before suppression begins.

When selecting a TVS diode, several important parameters must be considered:

- *Reverse Standoff Voltage (V_R)*. The most important of these is V_R, which should be equal to, or greater than, the peak operating level of the circuit (or the part of the circuit) to be protected. This will ensure that the TVS diode does not clip the circuit drive voltage.
- *Peak Pulse Current (I_{PP})*. I_{PP} is the maximum current the TVS diode can withstand without damage and is usually stated in reference to an exponential waveform such as 10×1000µs. The required I_{PP} can only be determined by dividing the peak transient voltage by the source impedance.
- *Maximum Clamping Voltage (V_C)*. V_C is the peak voltage that will appear across the TVS device when subjected to the Peak Pulse Current (I_{PP}), based on the referenced exponential waveform.

Finally, consider the coordination of the fuse with the TVS diode. Given that the failure mechanism of a TVS diode is a short circuit, if the TVS diode fails due to a transient, the circuit will still be protected when the fuse opens safely.

Conclusion

Given the prospects for continuing growth in the indoor horticulture market, lighting design engineers need to take all the time necessary to educate themselves about how to protect the LEDs that will be an essential part of this industry. The experts at Littelfuse can help lighting designers keep pace with new fuse, MOV, and TVS diode options available and how to apply them.

Littelfuse, Inc.
8755 West Higgins Road, Suite 500
Chicago, IL 60631 USA
Phone: (773) 628-1000
Littelfuse.com