LEDs MAGAZINE

LED DESIGN FORUM

Understand triac dimmer issues to ensure compatibility

The lighting industry must overcome differences in lamp load, lack of standards, and legacy wiring problems to optimally pair a phase-cut dimmer with an LED lamp write **MARC GALLO** and **MICHAEL NEARY**.

Energy efficiency is driving consumers to replace standard incandescent lamps with LED-based retrofit lamps. Unfortunately, they're often finding that the performance they've come to expect for years isn't being achieved – at least when the solid-state lighting (SSL) products are used with existing triac or phase-cut dimmers. Let's consider the dimmer compatibility problem and the requirements of a universally-compatible dimmer.

We will discuss three main causes for the compatibility issues encountered with dimmers. Legacy dimmers are not designed for LED loads. There are no industry standards that guide performance requirements. And the existing residential wiring infrastructure can limit the capabilities of modern lighting controls.

Current state of lighting controls and lamps

Today, there are more than four billion incandescent lamps in US homes according to the US Department of Energy (DOE). But recent estimates by Philips Lighting predict that LED lighting will capture as much as 50 percent of the consumer market by 2015.

While LED and compact fluorescent (CFL) lamps are drawing market share from incandescent lamps due to energy and cost savings benefits, a problem arises as consumers still need further education about how these new lamps will work with their existing incandescent lighting control devices – most specifically, dimmers.

Many consumers have turned to dimmers or automated dimming controls over standard light switches because dimmed lighting can reduce energy use and offer ambiance. The problem, however, is that nearly all dimmers found in homes today were designed for standard incandescent lamps.

When using an energy-efficient bulb, the homeowner generally expects an experience similar to what incandescent lamps provide. Although some LED lamps are marked as compatible with incandescent dimmers, there are various degrees of what can be defined as "compatible." Dimmable LED lamps tend to interact quite differently when used with these legacy devices. A number of undesirable results may occur when you use a dimmable LED lamp with an incandescent dimmer, including:

- Reduced dimming range
- Flickering or fluttering of the lamp
- Inconsistent performance based on the number and assortment of lamps being controlled by one incandescent dimmer.

Let's dig deeper into the main causes for the compatibility issues, and discuss the solutions the industry is currently offering. The solutions must meet the current technological needs while being mindful of both past and future technological challenges.

Varying loads, mixed results

Although there are applications where LED lamps will operate with an incandescent dimmer, in general, an incandescent dimmer will provide inconsistent performance with SSL. A major issue is in the design of each lamp type. The incandescent lamp by nature represents a simple resistive load with a linear response to the dimmer set point (Fig. 1). Standard incandescent dimmers work particularly well with this type of load by switching on at an adjustable phase angle after the start of each alternating current half-cycle, thereby altering the voltage waveform applied to lamps. By switching instead of absorbing part of the voltage supplied, minimal power is wasted, and dimming can occur almost instantaneously.

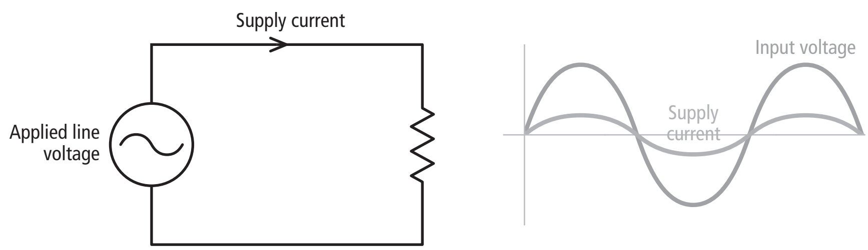

FIG. 1. **A simple resistor models an incandescent lamp. The input voltage and supply current to such a load are linearly related.**

In contrast, LED lamp loads can vary greatly across different manufacturers and designs. But most can be characterized by a diode-capacitor power supply feeding a constant current source (Fig. 2). The diodes rectify the applied AC voltage, allowing it to charge the storage capacitor, while the LED elements draw a constant current from the power supply that is related to the desired dimming level and brightness.

What makes this type of load significantly

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different from incandescent lamps is the non-linear relationship in which the applied voltage and the current flowing into the load are related. In incandescent lamps, as Fig 1 shows, the applied voltage across the load and the resulting current flowing through the load are related linearly by Ohms Law (V = IR). In this case, the resistance sets the scale, and the current waveform follows the voltage waveform, differing only by scale.

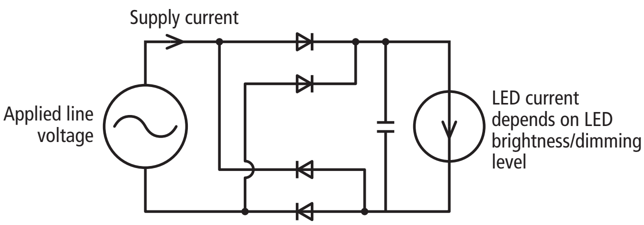

FIG. 2. The model of a typical LED lamp is significantly more complex than that of an incandescent.

In LED loads, the applied voltage and resulting current flow are not related by a simple linear relationship. In the diode-capacitor power supply model of the LED lamp, current flows from the applied voltage to the load only when the magnitude of the applied voltage exceeds the stored voltage on the power supply capacitor. The stored voltage on the power supply capacitor, in turn, depends on the current drawn by the LED elements themselves, which is a function of the LED brightness.

Therefore, the current flowing from the supply to the lamp depends both on the instantaneous value of the input AC voltage waveform and the brightness of the LED lamp. Changing the intensity or dimming level of the LED lamp affects where in the AC line cycle the load begins to draw current. This inflection point also affects the amount of current that surges into the lamp. The relationship between these current peaks, and the times in each line cycle where these current peaks occur, depends non-linearly on the lamp design, the LED brightness and the set dimming level.

State of regulatory affairs

Additional compatibility issues between lamps and dimming devices often stem from a lack of dimming performance standards within the lamp industry and how each uniquely corresponds with LED drivers – leading to a wide-range of inconsistencies among products. This lack of standardization can be seen not only in varying characteristics between manufacturers, but also by product within some manufacturers' product lines. Complications arise from the fact that any given lamp can require a set of electrical and electronic characteristics – current, voltage, amperage and control signals – that are vastly different from any other lamp. While one lamp may be able to be dimmed by a particular dimming device, others cannot.

Efforts to establish a performance standard for solid-state dimming controls have been guided by members of the National Electrical Manufacturers Association (NEMA) and other lighting committees. NEMA, for example, has developed a standard titled SSL 6-20104 which provides guidance to LED lamp manufacturers for suitable operation on standard, incandescent, phase-cut dimmers. However, currently the NEMA standard does not provide a rating scale or detail on what is considered compatible. While serving as a starting point, these standards are still incomplete and require additional amendments to ensure complete consistency among dimming devices and lamps.

Under current UL standards, notably UL 14725, intended to regulate the safety of dimmers, an LED lamp is categorized as an "electronic ballast." One notable issue addressed by UL 1472 is in-rush current which is generated at the start up of many LED lamp loads. High in-rush current can result in failure of switch contacts, which is a safety hazard in many field applications – such as dimmers – where the switch is serving as the disconnect means.

To evaluate the safety of the combination of dimmer and electronic ballasts, UL has taken the systems approach by requiring dimmer manufacturers to provide information on the intended electronic load (i.e., CFL, LED or electronic ballast) for each dimmer. UL listing investigation will involve the use of the specified electronic ballasts or a synthetic load exhibiting the same in-rush and steady-state characteristics in the overload, endurance and temperature tests.

Legacy wiring and synchronization

A third major issue that further exasperates the inconsistency issues among dimmers and lamps is that most of the existing residential wiring infrastructure was built without a neutral wire at the switch box. The absence of the neutral wire is referred to as two-wire lighting control while the inclusion of a neutral at the switch box is referred to as three-wire lighting control. The need of supporting two different wiring scenarios poses certain challenges that lighting-control designers need to account for in planning to control a broader range of lamp types with a single dimmer.

Some dimmers are designed to work with one type or the other only, while some are designed to work in both types of installations. But, for all dimmers, even those that are designed for both two-and three-wire installations, there are significant differences in performance between these two installations in terms of how the dimmer circuitry is powered and how the dimmer synchronizes with the line voltage. When used to drive incandescent lamp loads, these differences are mostly negligible. But, when used to drive LED loads, they present significant challenges to stable dimming and lighting control.

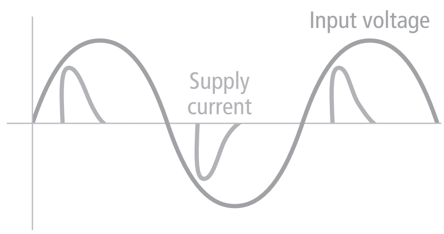

FIG. 3. The supply current to an LED lamp is not linearly related to the voltage.

Regardless of the circuit type, all phase-controlled dimmers need to synchronize with the AC line in order to work correctly. Without the ability to sense the AC line and its zero-crossings, a phase-controlled dimmer would not detect the correct timing for switching the AC voltage, and it would lose its ability to control and dim the lamp load. The end result is flickering and fluttering of the light output.

Three-wire installations

In three-wire installations (Fig. 4), you have line, load and neutral wires in the electrical box. The line wire comes from the AC power source and supplies power for both the dimmer and the load. The load wire is connected to the lamp load and provides a return path for the power delivered to the load. The third wire, the neutral connection, provides the essential return path for the dimmer even when the load is disconnected or is in a state that doesn't draw any current.

The neutral is an important feature of three-wire installations. It ensures that the dimmer device has a direct connection to the AC power source regardless of the state of the load. This third wire not only ensures that the dimmer has power to drive its own internal circuitry even when the load is disconnected or off, it also provides a clean signal of the incoming AC power source for detection of zero-crossings and synchronization with the line. Both of these are essential to stable phase-controlled dimming, and are easier to obtain in three-wire designs.

Two-wire installations

In two-wire devices and installations (Fig. 5), only two wires are present in the electrical box -- the line wire and the load wire. In this case, the dimmer is simply placed in series between the line and the load. With only two wires, the dimmer must rely on the current passing through the load to both power its own internal circuitry and to detect zero-crossings for synchronization with the AC line.

When LED lamps perform poorly with a dimmer, often times, the blame is placed on the dimmer circuit. But, more often than not, the source of the problem really lies in how the LED load current differs from the incandescent lamp in two-wire applications.

If the load current is regular, as is the case for incandescent lamps, then stable line synchronization and ample power for the dimmer's internal circuitry are both easy to obtain. With LED lamps, however, the load current is much smaller and much less regular, and line synchronization becomes difficult. Similarly, the load current of LED lamps in their off state can be so small, that even obtaining a few milliamps to supply the internal dimmer circuitry can be challenging. Without adequate supply and stable line synchronization, lamp flickering may result.

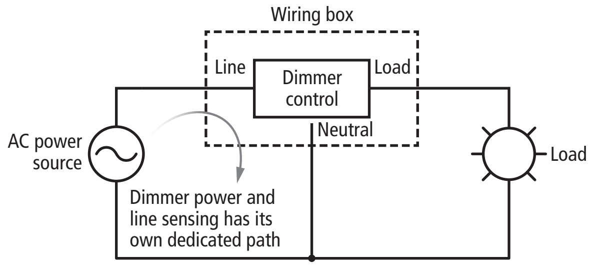

FIG. 4. A three-wire circuit with a neutral wire is now required in switch boxes and improves dimmer operation.

Code changes

In 2011, the National Electrical Code (NEC) added a requirement to new installations requiring a neutral wire in all switch boxes. Although there was strong concern of the additional construction costs, this requirement was added after twelve years of debate and effectively addresses advancements in lighting controls that require a neutral wire for safe and effective operation. Many lighting control devices require that the switch be provided with standby voltage and current at the switch in order to operate.

In the past, many electricians did not include a neutral conductor at switch locations, and the result was the equipment grounding conductor being used as the neutral conductor. While the current on the equipment grounding conductor is typically less than 0.50 mA, the accumulation of many switches can result in an unacceptable amount of current on the equipment grounding conductors. With this change, gone are the days of using dead-end, three-way switches and two-conductor switch loops.

Although the latest NEC requirements include the use of a neutral wire in all new switch boxes, the vast majority of existing installations, pre-2011, likely do not have a neutral wire present. Understanding this, it should be assumed that in all likelihood a home's system is a two-wire system. Therefore, dimming products introduced into the market must be able to offer not only a three-wire solution for meeting all the necessary requirements of today's and tomorrow's lighting advancements, but also remain backwards compatible to work effectively with all two-wire solutions as well.

Universal dimmers

Early products designed to offer compatibility for both two-and three-wire installations used an approach that did not derive the optimal performance from the lamps. The use of basic, low-end trim adjustments and limited programmability to address the different loads resulted in less effective solutions. Advancements have been made, and device manufacturers, such as Leviton, are offering newer options that better interoperate with and utilize the unique characteristics of LED lamps.

The responsibility for providing consumers with optimal lighting solutions falls to both device and lamp manufacturers. Collaborative efforts are essential for not only developing new, compatible devices that meet the changing needs, but to also provide the necessary education to consumers, explaining how the inconsistencies between current incandescent dimmers and energy-efficient lamps can affect their lighting experience.

Leviton collaborated with major lamp manufacturers on joint testing of each company's LED and CFL lamps for the release of the Leviton's Universal Dimmers. As part of the formal product release for the Universal Dimmers, lamp manufacturers participated in product evaluation consisting of dimmer performance with specific lamps. Measurements included dimming range, pop-on voltage, drop-out voltage, appearance of flicker, noise and in-rush current.

Understanding the variations among manufacturers and lack of industry standards, Leviton developed its own internal grading scale to rate lamp performance – a practice that other device manufacturers are also adopting. These company-established standards are subjective based on specific products, and the variances may pose a problem for designers, installers and consumers. As discussed in prior sections, now more than ever, the establishment of industry-wide performance standards is imperative for the lighting and controls industry.

Rigorous testing protocols, however, help ensure that Leviton can continue to address the market demand for energy efficient lighting with sophisticated lighting controls that are compatible with LED and CFL lamps while remaining backwards compatible with incandescent lamps.

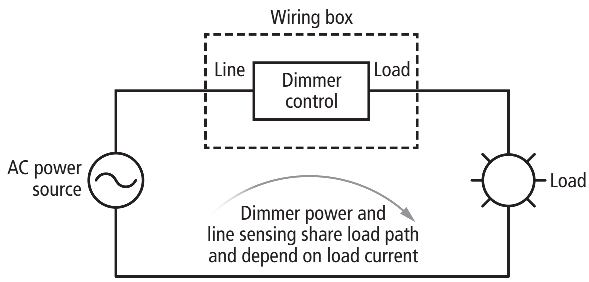

FIG. 5. **Legacy installations with two wires makes dimmer operations with LED lamps problematic.**

Dimmer control design

Leviton's design team used several techniques to ensure that its dimmers work with a broad range of lamps. For example, the dimmers minimize the supply current requirement of the control circuit. Having a dimmer control circuit that requires less supply current means greater compatibility with lower load current applications, such as is typical with LED lamps. The newest designs employ a micro-power circuit design, utilizing low-power control ICs and modern, low-power microcontrollers. These are the essential internal components that enable dimmer functionality. The less power these ICs consume, the more compatibility the dimmer control circuit will have with LED loads in two-wire configurations.

Another important part of a universal design is the utilization of advanced line synchronizing techniques that resist the effects of irregular load currents. In older dimming devices, line synchronization is accomplished using simple zero-crossing detection. This method uses a circuit to detect when the AC line voltage switches polarity and crosses the zero voltage point. The zero-crossing method still is used in older designs because it requires simple circuitry, it is practical and it works for incandescent lamps.

For LED loads in two-wire applications, the simple zero-crossing technique is sometimes not enough. Fortunately, advances in microcontroller technology have made putting advanced synchronization algorithms and approaches within the grasp of cost-sensitive designs with tight power constraints. Utilizing a low-power microcontroller in the dimmer, advanced software can be set against the difficulties of measuring the AC line cycle with the irregular line currents present in two-wire LED load applications.

Lessons learned

As energy efficient lamps continue to penetrate the lighting market, the availability of new lighting controls that meet the specific needs of these lamps is increasing. Consumers can take fuller advantage of all of the benefits of the newer, more energy efficient lamps.

Designers, installers and consumers should become familiar with the nuances of these energy efficient lamps and educate themselves on how they will interact with specific dimming controllers to ensure the maximum benefits of energy savings and ambiance are achieved.