ELECTRIC POWER RESEARCH INSTITUTE

# Lighting Control Systems

*Barriers and the Need for Compatibility*

**1020518**

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Technical Update, November 2009

EPRI Project Manager

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# PRODUCT DESCRIPTION

The demand for lighting control systems in residential, commercial, and industrial facilities is on the rise with the demand for increased energy savings. With lighting accounting for almost 23% of grid load, there is significant opportunity to reduce lighting load while improving the quality of light for customers. Lighting control systems are becoming more intelligent as the need for them to interface with building control systems and demand response systems also increases. Lighting control systems use sensitive electronic circuits, powered by a local internal power supply, to control a number of input and output ports for sensing lighting (and other building conditions) levels and controlling dimmable light sources. The nature of lighting control systems and their important role in building operations warrants the need for these systems to be compatibility tested using EPRI's well-known system compatibility concept. Lighting control systems that can endure electrical disturbances that occur in the common everyday electrical environment of buildings without failure or malfunction will be the ones that are successful in today's energy management environment. Like other industries in lighting, the controls industry is competitive and somewhat fragmented due to the lack of one standardized method for controlling dimmable lighting sources. If manufacturers of lighting control systems would engage with EPRI in system compatibility research and testing, then the performance of such controls could be enhanced.

### Results & Findings

End-use customers are still learning about what aspects of lighting control systems should be considered when specifying and purchasing these systems. In almost all cases, technical specifications of lighting control systems do not address system compatibility and power quality to help ensure that these systems perform as expected in various building environments. This first phase of EPRI research on lighting control systems describes the importance of considering power quality and system compatibility for lighting control systems. The result of such research and testing will allow manufacturers and designers of lighting control systems to determine what types of electrical and electromagnetic disturbances really affect their systems and identify the weakest links in their electronic designs and the approaches to resolve them and improve overall system performance. Improvements in performance will equate to reduced building downtime for customers and reduced warranty claims for manufacturers.

### Challenges & Objective

Utility, energy, and facility engineers are being faced with learning more about lighting control systems and how to specify and install them. With the large number of lighting control systems available in today's market, application of EPRI research in the area of system compatibility for lighting control systems will impact the success of the lighting and lighting controls business. Manufacturers of lighting control systems will face challenges related to compatibility as additional systems are installed in building electrical environments with various types of dimmable light sources. End-use customers can make inquiries to manufacturers of lighting control systems about compatibility and request that EPRI conduct such testing for them. Utilities also can contribute to the success of lighting control systems by continuing to fund this EPRI basic research to help manufacturers learn how to design lighting control systems for compatibility. In addition to end-use customers, lighting designers, system installers, architects, building performance designers, and building owners have a vested interest in helping to ensure that lighting control systems function as expected in their electrical environments. Understanding the compatibility concept described in this report is vital to this mission.

### Applications, Values & Use

Lighting control systems will continue to evolve, thus increasing their intelligence and function. However, if manufacturers of lighting control systems do not recognize the critical need to ensure compatibility of their systems with the electrical environment, then utilities, installers, and end users are likely to be affected in such a way that consumers of these systems will be hesitant to continue using them. As the demand response (DR) industry continues to gain momentum, the need for lighting control systems to be compatible with their intended electrical and electromagnetic environments will be more critical. Utilities are on the forefront of initiating DR programs and engaging in customer programs to dynamically reduce lighting load when power system conditions become strained due to peak demands. Manufacturers of dimmable light sources also will expect lighting control systems to be fully compatible with their environments including the sources themselves.

### EPRI Perspective

Designers of lighting control systems have been primarily focused on form, fit, and function. While safety compliance is highly recommended for any product, including lighting control systems, no other organization other than EPRI can provide the product and compatibility research that is needed to measure user friendliness and ensure compatibility with the electrical and electromagnetic environments. This is the first EPRI document that begins to focus on reasons why EPRI compatibility research is needed in the lighting controls industry. EPRI maintains a strong base of energy, power quality, and compatibility engineers who can address well-understood issues that will impact the performance and life of lighting control systems both now and in the future.

### Approach

The project team's goals were to describe some of the key barriers with lighting control systems and to describe why power quality and compatibility research is vital to the success of the lighting control industry. EPRI's system compatibility concept was applied to lighting controllers paired with dimmable light sources. Industry experts in lighting controls were interviewed along with a review of a number of technical publications on lighting controls. Each resource stressed the importance of lighting control systems having to function without problem in all types of building electrical environments when paired with dimmable light sources.

### Keywords

Lighting controls
Dimmable light sources
System compatibility
Power quality
Lighting design

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# 1
# INTRODUCTION

For years, lighting systems have been operating as stand-alone loads in all types of facilities—residential, commercial, and industrial. Utilities and end users viewed lighting controls as luxury systems that were used only when mood or special effects lighting was needed. Although two industries—broadcast and theatrics—have relied on dimmable lighting and lighting control systems for years as a part of their stage lighting, their systems were very simple and traditionally dimmed only incandescent lamps.

Today, however, the need to provide dimmable lighting is different. End users are finding more applications for dimmable light sources paired with lighting control systems. Lighting researchers are discovering more ways to optimize lighting levels in various spaces by incorporating the use of dimmable light sources and lighting control systems. Commercial facilities are probing deeper into new applications for dimmable light sources and lighting control systems in efforts to improve energy savings. Some installations are even making better use of outdoor light as they strive to harvest as much daylight as possible to offset their energy usage for lighting systems. Utilities are experimenting with various dimmable light sources and various types of lighting control systems while examining customer perceptions and how much energy savings can be achieved without interrupting the customers' business.

The federal government and other supporters of green initiatives are putting pressure on building designers, utilities, and end users to improve energy savings in various types of facilities. Lighting is one of those load types where energy savings is achievable, and if designed correctly, can be employed without introducing lighting problems into customer facilities. With lighting representing as much as 23 % of the grid load and many customer spaces experiencing over illuminated conditions, there is much opportunity to reduce energy demand with the use of dimmable light sources and lighting control systems.

Utilities and customers alike who do engage in using dimmable light sources and lighting control systems do so with reservations. They are aware of some problems that have occurred when pairing dimmable light sources with lighting control systems. Utilities and customers expect these systems to work well together and to function properly in the common everyday electrical environment. When compatibility problems occur with one or both systems, severe lighting problems can occur, and these problems can result in customer dissatisfaction, poor lighting quality, lost downtime and re-installation costs that can add up to the thousands of dollars. The complexity of these systems and the demands for functionality as utilities and end users endure increased pressure to improve building performance and reducing lighting energy costs warrants these systems to work in all electrical environments. This first project on lighting control systems seeks out to describe the importance of achieving compatibility between lighting control systems and the electrical environment while understanding power quality and barriers that typically occur with lighting control systems. Past EPRI research in the area of compatibility has been applied to many types of electronic lighting devices and can also be applied to lighting control systems not only to document energy, emissions and immunity performance, but to harden lighting controls systems just as some electronic lighting devices have been hardened in the past.

# 2

# LIGHTING CONTROLS – BARRIERS AND PERFORMANCE IMPROVEMENT OPPORTUNITIES

Aside from the fact that energy-management systems (EMS), lighting control systems (LCS), and demand response systems (DRS) still present a number of barriers to end users regarding design, programming, calibration, operation, verification, and maintenance, a large majority of the problems with these systems stem from installation and compatibility. Manufacturers strive to design and provide proper installation manuals and steps for contractors and end users to use. Contractors and end users strive to follow them, and install them in various types of facilities of varying conditions. This chapter seeks to begin discussing installation guidelines for these systems and how addressing compatibility, combined with installation guidelines, can help improve system performance.

## Early Simplicity of Basic Load Control

End users are accustomed to simplicity when turning loads 'on' and 'off'. For years, the most complicated load control device in a home was a thermostat with only two switches—one to turn the system 'on' or 'off' and the other to turn the fan 'on' or place it in 'auto' mode—and a temperature adjustment knob. There were no complicated instruction manuals to read and no programming codes to learn. There were no special communications cables to connect or no additional wiring to run. All heating-ventilation-and-air-conditioning (HVAC) contractors knew how to install, diagnose problems, or replace a thermostat.

The knowledge needed to control lamps within a household was even simpler. End users did not need to know anything about installation, programming, or communications. The only knowledge that was needed was that to turn a toggle switch 'on' or 'off' and change a light bulb. Knowledge and accessibility to only two wires was needed to replace a toggle switch in a lighting circuit. When rotary dimmers were invented, they were a success. Why? Because, they were simple. Still, only knowledge and accessibility to only two wires were needed, so the simple toggle switch could be removed and the dimmer installed directly in its place. The dimmer was even the same size as the toggle switch, so no changing of electrical boxes or cutting of sheetrock was needed. The rotary dimmer was designed to be a simple replacement for the toggle switch. Moreover, the dimmer was electrically compatible with all incandescent lamps. Neither the electrical contractor nor end user had to purchase any special dimmer to work with any special incandescent lamp. The power rating of the dimmer was designed such that it could be used with just about any incandescent lamp as long as the total load was less than 600 watts.

However, with fluorescent lighting the steps necessary to achieve a dimmable lighting system were a bit more complicated, yet some simplicity still remained. Ballast designers of magnetic fluorescent ballasts did not anticipate end users wanting to dim fluorescent lamps, so the ballast design did not accommodate for the use of a simple rotary dimmer on the input of a magnetic ballast. Although the magnetic ballast presented an inductive load to the rotary dimmer that constituted an incompatibility between the ballast and the dimmer, the first “rotary” dimmer for magnetic fluorescent lighting ballasts was designed to be compatible with all magnetic fluorescent ballasts as long as the power rating of the dimmer was not exceeded. Electrical contractors did not have to worry about compatibility between these dimmers and the magnetic fluorescent ballasts, but they did have to worry about mixing incandescent and magnetic fluorescent lighting loads together on the same circuit, if that circuit was to use a dimmer to control the lighting output. This could not be done because the incandescent lamp and magnetic ballast presented a different type of load to either of the dimmers—simple rotary dimmer for incandescent lamps and special “rotary” dimmer for magnetic ballasts. Thus, the beginning of the inability to mix these dimmers with these basic lighting loads started in our lighting age.

## Barriers with Lighting Load Control Technologies

Today’s EMS, LCS, and DRS are not that simple rotary dimmer. Designers of these systems set their focus in their designs to integrate every aspect of load control into a system that they could. While this may have achieved the load control necessary to reduce grid load (and this is still under investigation), their designs have not helped the electrical contractor or end user develop a very user friendly relationship with these systems. The interesting part about the user friendliness with these systems is that it not only affects contractors and users but also utility energy engineers, building designers, lighting designers, lighting specifiers, and facility engineers and maintenance personnel (all of these are interested parties). There are a number of challenges with these systems and each one of these challenge areas is presented and briefly discussed below.

With respect to lighting control in any one of these systems, the objectives of load control are the same. The overall objective includes all facets associated with determining the appropriate lighting level for the task without compromising light quality or wasting energy. With this in mind, we also find that these systems are all characteristic of the same basic challenges:

1. **Types of Systems:** There are many types of EMC, LCS, and DRS devices, which makes it difficult for interested parties to learn what they need to know to specify, install, utilize, and maintain them. Although this is the nature of competition among product technologies, increased standardization regarding system design, functionality, utilization, and maintenance would help to reduce confusion among system types.
2. **Control Protocols:** This is one area that definitely confuses interested parties. While it will be unlikely that every manufacturer, every system, and every application will settle on using one lighting control protocol, intelligence can be integrated into the design of each system that will allow them to be protocol-non-specific. With this, interested parties will not have to learn all there is to know about any one protocol. The system device should be the only ‘one’ that needs to know that much about the protocol. Each system should be designed to either allow the building designers, lighting designers, or lighting specifiers to select the protocol that should be used. The contractor should not need to determine whether the protocol selected is correct or not.
3. **Automatic Detection of Dimming Function:** Varying lighting control protocols call for varying dimming functions within dimmable lighting devices. Today’s most commonly used dimming functions include: 1) 0 to 10 volt DC analog systems, 2) DALI-based systems, 3) line-side dimming systems, 4) 3-wire input-side dimming systems, and 5) power-line carrier

systems (e.g., systems that use the X10 protocol). The 0 to 10 volt DC dimming systems are the most common and are used with the majority of the dimmable fluorescent lighting systems. One of the many drawbacks of many lighting control systems is the use of hard wire to interconnect sensors, keypads and other components to the lighting controller. The requirement for hard-wired systems makes it extremely difficult for installers to install lighting control systems in existing facilities, especially older facilities. The dimming systems that involve the use of control wiring include: 1) 0 to 10 volt DC analog systems and 2) DALI-based systems. EMS, LCS, and DRS should incorporate the ability to automatically detect which dimming function is used by a dimmable lighting device. With the use of a microprocessor inside the EMC, LCS and DRS, the lighting controller could detect what type of dimming function that each bank of fixtures (dimmable ballasts or dimmable drivers) uses and make the necessary automatic setup inside the lighting controller to allow the controller and ballasts (or drivers) to communicate.

4. **System Setup and Programming:** Many of today's EMS, LCS, and DRS systems require significant set up by the electrical contractor, facility manager, or end user (manager of the space where the system controls the lighting functions). This is one significant area of challenge where the end user is likely to become confused and stumble when trying to configure one of these systems. Often, the electrical contractor is unaware of the settings that the end user desires and fails to complete the set up and configuration of the system. The end user is not very familiar with the system because it is new and usually poses a steep learning curve to the user. If the end user does try to engage in programming, he/she frequently is unable to complete the process because of difficulties associated with the programming itself and/or the instruction on how to complete the programming.

5. **User Friendliness and Navigation:** It is obvious that intelligent systems to control lighting devices and other electronic loads must make use of programming code, graphical user interfaces (GUIs), and menu structures. Careful thought should be given to designing the GUIs and menus. End users and others who must navigate through these systems must be able to achieve their objectives without getting trapped in the system and forcing a manual reset.

6. **Calibration:** EMS, LCS, and DRS that involve closed-loop lighting control involve the calibration of daylighting and occupancy sensors with dimming control functions. Not all of these systems use the same daylighting or occupancy sensors. Moreover, not all of these systems use the same dimming control functions or control protocols. A manually operated calibration technique in any one of these systems is not appropriate for the interested parties, especially the end user, to learn or deal with. Some systems are incorporating the use of automatic calibration of daylighting and occupancy sensors.

7. **Interfacing with Other Systems:** It is becoming more common for the need to interface these systems with other building control systems. However, like lighting control systems (LCS), not all building control systems operate from the same principles or control protocols. However, most building control systems utilize some standard control protocol. The design of these systems should incorporate a universal communications port that can be used to interface to any LCS. These systems should also incorporate intelligence to allow any LCS to recognize any building control system and the parameters necessary to provide the interfacing necessary for the two systems to work together.

8. **Failure of a System to Control the Lights:** For several reasons, end users also experience problems with these systems regarding their ability to control the lights according to end user specifications even when programming can be accomplished. In many cases, end users report the observation of fixtures that were 'on' that were supposed to be 'off' and vice versa.

9. **Measurement, Display and Verification of Energy Usage and Savings Data:** A critical part of any EMS, LCS, and DRS is the ability of the system to measure power-related input parameters associated with the lighting system under control. Each system must be able to measure input voltage and current for the lighting systems. Some systems are capable of making these measurements directly at each lighting device (i.e., fixture, ballast, or driver). Although a system may be capable of making these measurements, it may not be capable of calculating the correct power usage. Careful selection and implementation of the algorithms necessary to calculate true RMS (root-mean-squared) power must be carried out during the system design process.

   This also requires that the system be able to interpret true RMS voltage and current. In addition, true power factor and input total harmonic current distortion should also be calculated within these systems. Even if all necessary power-related quantities are measured and calculated does not mean that they are displayed to the end user in the proper format. The end user should be able to access and display the present energy usage data without any difficulty. A one-touch display is ideal. Regarding the format, the end user should be able to select the desired format for displaying energy usage data with the touch of a button on the display screen.

   When end users utilize high-efficiency energy-savings lighting devices and an EMS, LCS, or DRS, they also frequently want to know how much energy has been saved in comparison to their prior lighting system. Obviously, it is impossible to measure the energy usage of a system that has been removed. However, it is not impossible to calculate the energy usage for a previous system if enough about the system is known. Each EMS, LCS, and DRS should be capable of calculating the energy usage of the previous system by simply entering a few characteristics of the previous system. With this information, the end user can simply compare the energy usage and savings for both the old and new lighting systems.

10. **Mis-wiring – Connecting the Wrong Cable to the Wrong Terminals:** Wiring errors also account for a large majority of system problems with ECS, LCS, and DRS. From Figure 2-1, one can see that each device is required to be wired to a dedicated set of terminals on the LCS. The chances for a wiring error here are significant. As with other electrical systems, the installation procedure involves the pulling of all the control wiring from each device location down to a central point where the LCS will be installed. In many device applications, the same type and color of wiring cables are used, and the likelihood of mislabeling a cable is also high. The use of control wiring increases the likelihood that the controllers and its subcomponents (e.g., daylighting sensors) will be upset or damaged by electrical and electromagnetic disturbances. Control wiring runs act like long antennas which pick up high-frequency noise and some high-frequency electrical disturbances.

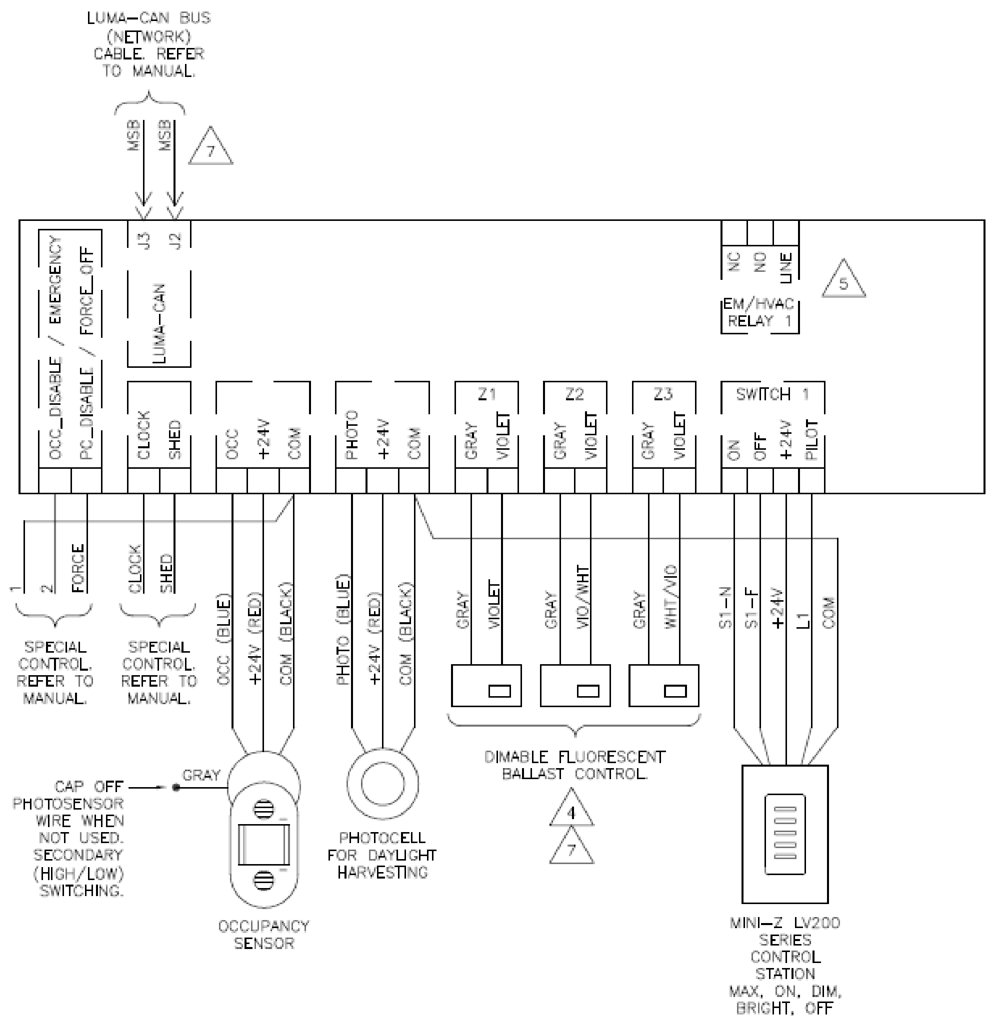



**Figure 2-1**
**Wiring Diagram for a Daylight Sensor-Type Lighting Control System**

11. **Mis-wiring – Swapping the Wiring Terminations:** From the above figure, one can also see how easy it can be to swap two conductors on any two two-conductor cables. The design of a different type of cabling system would prevent this error.

### Compatibility Problems with Lighting Controls

Regardless of the type of communication link that controllable light sources have with a lighting controller, the network spreads out into the electrical and electromagnetic environment. Lighting control systems may use various types of communication links:

- Hard-wired, low-voltage, 0 – 10 volt, analog control
- Line-side, high-voltage control
- Line-side, low-voltage, three-wire control
- Wireless (e.g., Zigbee)
- Line-side, power-line carrier
- Hard-wired, low-voltage, DALI (Digitally Addressable Lighting Interface)

The electrical and electromagnetic environment can both interact with each of these communication types to cause any of the following compatibility problems, which have all been witnessed in the field.

- Inability to turn light source on
- Inability to turn light source off
- Inability to dim light source up (increase intensity)
- Inability to dim light source down (decrease intensity)
- Complete malfunction of lighting controller (light sources will not turn on)
- Unstable operation of light sources (flickering lamps, random turn on, random turn off, etc.)
- Complete failure of lighting controller

The sources of electrical and electromagnetic disturbances that can affect lighting controls include many types of defined waveforms and random waveforms that extend from a few kilohertz up to hundreds of megahertz. Such disturbances can be generated from a wide variety of equipment and operations inside a commercial or industrial facility. Although the number of disturbance sources is not as many in residential settings as they are in commercial and industrial settings, the types of equipment that can generate these disturbances in residential settings is increasing as end users acquire more non-linear electronic loads. Example sources include the following

- Transients generated by the switching on and off of large loads such as heat pumps, refrigerators, ovens, pumps, washers, dryers, etc.
- Electrical fast transients (EFTs) inductively coupled into control wiring caused by voltage transients and notches in nearby wiring supporting loads like adjustable speed drives (ASDs)
- Conducted noise generated on the power line by electronic loads including electronic lighting devices using electronic ballasts
- Voltage notching generated by the operation of highly-inductive loads (appliances that contain motors)
- Voltage distortion generated by increasing penetration levels of electronic appliances that inject harmonic currents into the customer wiring system

- Electrical noise on the branch circuits generated by radiated emissions from radio transmitters, wireless devices, etc.
- Transients (surges) generated by thunderstorms and lightning strikes

Moreover, with the use of lighting controllers there is another opportunity for control system upset caused by transients and high-frequency emissions that are coupled onto any one of the hard-wired communications links. The thousands of feet, or miles (in some cases), of control cable is exposed to these fields and may allow penetration of undesired distortion or corruption of control signals. In almost all cases, these cables are either not shielded or contain the very minimum amount of cable shielding due to the added expense of shielded cables.

Figure 2-2 illustrates the basic concept of the primary ports commonly used on a lighting controller. The line input port is a high-voltage power port usually rated at 120 volts AC but may also be rated at a universal voltage or higher AC line voltage. The dimming control ports (four shown in Figure 2-2, other controllers may have fewer or more of these ports) are low-voltage ports and usually rated for up to 10 volts DC. These ports deliver a very small power to the dimming control circuit of a dimmable lighting device. Most lighting controllers have two or more sensor ports which may be used to support one or a series of sensors. In Figure 2-2, these are the photocell (daylight sensor) port and the occupancy sensor port. To operate these sensors, a separate DC supply voltage is required—usually 12, 15, or 24 volts DC. The communications port is also a low-voltage port with multiple conductors which can be Ethernet, RS-232, or RS-485. The wireless port is one that is showing up more on lighting controllers. This port may be of an open (e.g., Zigbee) or closed architecture.

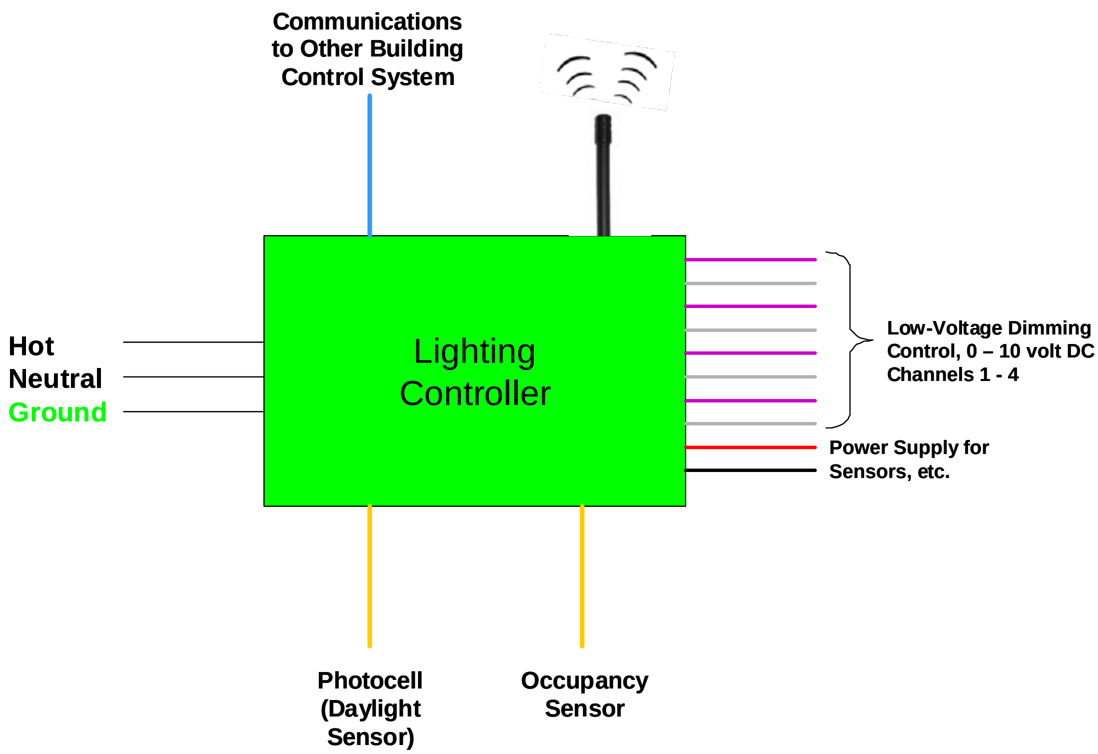



**Figure 2-2**
**Example of Lighting Control System with Multiple Circuits**

## Exposure to Electrical and Electromagnetic Disturbances

A lighting controller installed in a facility, whether the facility is a residential, commercial, or industrial one, is subject to the same exposure to electrical and electromagnetic disturbances as any other piece of electronic equipment (e.g. a computer). Figure 2-3 illustrates several scenarios where disturbances can impinge upon the hard-wired and wireless ports of a lighting controller. Each port is susceptible to these disturbances, and this susceptibility will, at some level and frequency, cause the lighting controller to malfunction, be upset, or be damaged. The question is "How susceptible are lighting controllers to these disturbances?" The only way to definitively determine their susceptibility is to test them.

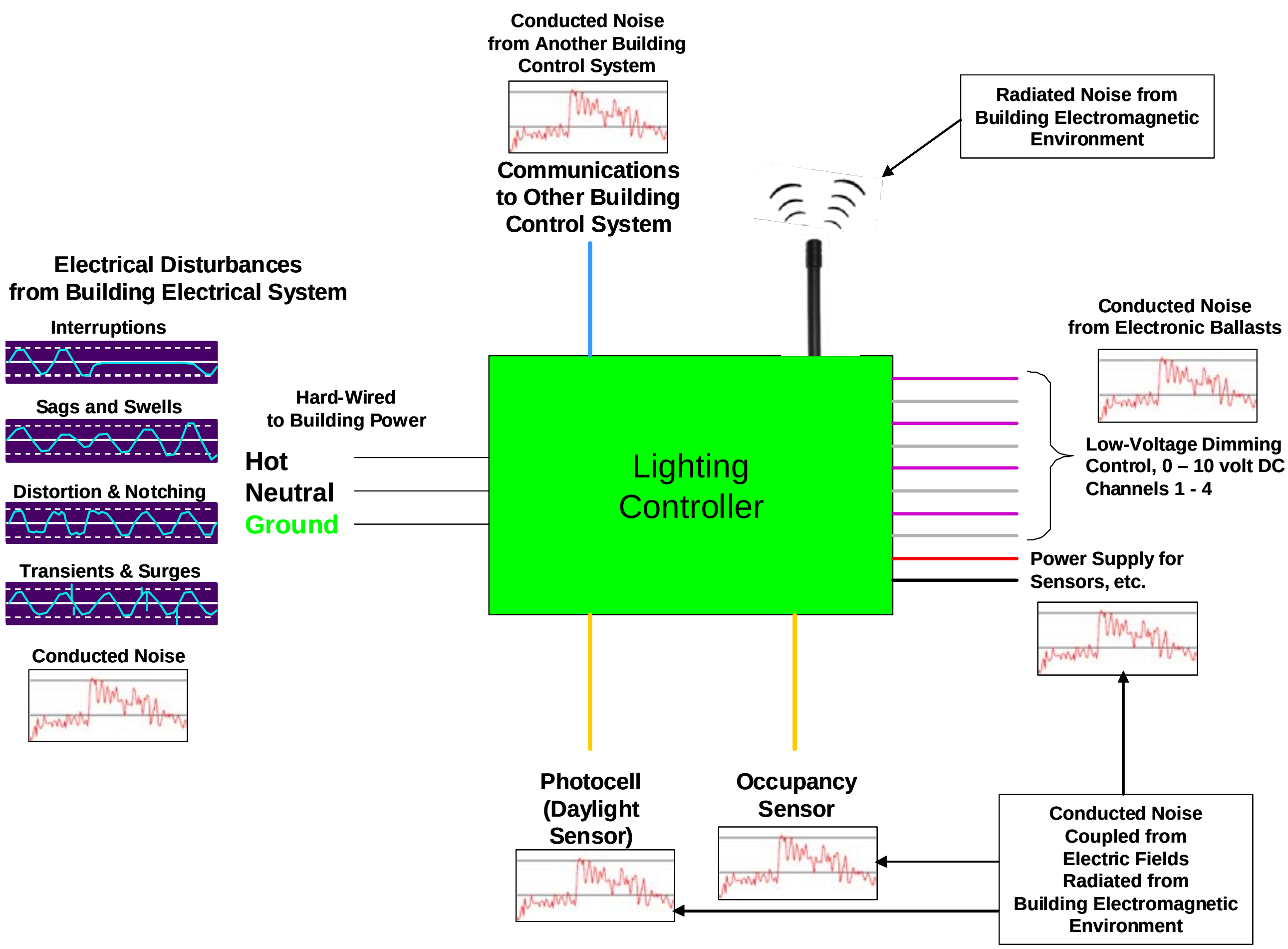
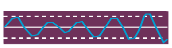
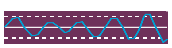
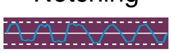
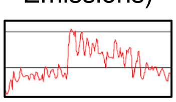



**Figure 2-3**
**Electrical and Electromagnetic Disturbances that Can Impinge Upon a Lighting Controller**

## Opportunities to Improve Lighting Control Performance

Because of the nature of lighting control systems and the electrical and electromagnetic environments where they must live, there is significant opportunity to improve their performance. Table 2-1 lists various types of malfunctions and failures that may occur with lighting controls. Each one of these has occurred in the field as reported by various manufacturers and end users. Some of these may be resolved with a system reset and some require hardware replacement. Regardless, these present problems to the end user that will likely interrupt the nature of their business and function of the lighting control system.

**Table 2-1**
**Cross-Reference between Electrical and Electromagnetic Disturbances and Malfunctions or Failures of Lighting Control Systems**

| Electrical or Electromagnetic Disturbance | Malfunction or Failure with Lighting Controls | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Potential Damage to Front End Circuitry | Potential Damage to Low-Voltage Input[1] | Complete System Shutdown | System Lockup | Overheating of Power Supply Component | Loss of System Settings | Dimming Malfunction | Sensor Malfunction |
| Interruption  | | | ● | ● | | ● | | |
| Sags  | ● | | | ● | | | | |
| Swells  | ● | | ● | | ● | | | |
| Distortion  | | | ● | ● | ● | ● | | |
| Notching  | | | ● | ● | | ● | | |
| Transients & Surges[2]  | ● | ● | ● | ● | | ● | ● | ● |
| Electrical Noise (Conducted Emissions)  | | ● | ● | ● | | ● | ● | ● |

[1] Dimming port, sensor port, or other low-voltage port
[2] Includes ring wave, combination wave, capacitor switching, and electrical fast transients (EFTs)

Discussions with manufacturers of lighting controls and end users who have installed them in the past few years have revealed that the nature of compatibility problems as listed in Table 2-1 are indeed occurring and that performance of lighting control systems (like electronic ballasts have had in the past ten years) can be improved with the application of EPRI's system compatibility concept.

In visually inspecting MOV failures in lighting controls, thermal runaway was observed and may occur if an MOV with too low of a maximum allowable voltage is applied in the common everyday equipment. In such a case, an MOV's exposure to a long-term overvoltage may be higher than the MOV's maximum allowable voltage, and thermal runaway of the MOV may occur without blowing the line fuse. Figures 2-4 and 2-5 show two examples of MOVs in lighting controllers, which failed as a result of thermal runaway. In both examples, the MOV ignited and a significant part of the MOV material was burned by the fire caused by its own thermal runaway. The fire from the MOV damaged other nearby electronic components and the enclosure for the lighting controller. If investigators discover this type of MOV failure surrounded by other burned insulation and electronic components, then thermal runaway can be suspected. These susceptibilities, or weak links in the design of these lighting controllers, can be identified through compatibility analysis and testing at EPRI.

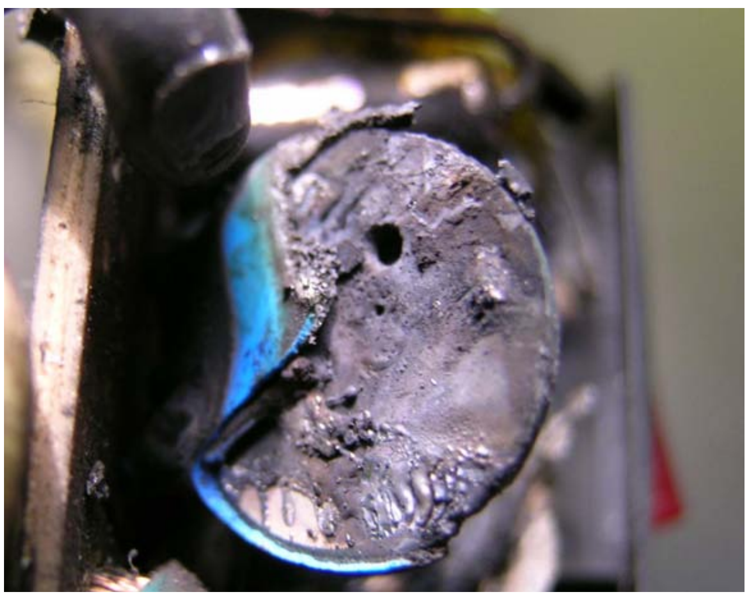


**Figure 2-4**
**MOV Failure Caused by Thermal Runaway and Internal Equipment Fire in a Lighting Controller**

**Figure 2-5**
**MOV Failure Caused by Thermal Runaway and Internal Equipment Fire in another Lighting Controller**

### The Ideal Lighting Control System

Several of the major installation and end-use complaints with lighting control systems are centered around installation and setup (i.e., programming). Installers sometimes complain about not knowing where to connect certain devices and malfunction of devices after they are connected to the lighting controller. Both installers and end users often complain about having setup and programming problems such as problems with setting up dimming channels (which channel on the lighting controllers controls which bank of light fixtures), calibration of daylight sensors with ambient light and coordination of this setting with dimmed light levels. One approach to alleviating these problems is to develop an intelligent auto-setup lighting controller with a universal cable and connector system like that shown in Figure 2-6. This approach will eliminate the common problems that occur with lighting controllers. Some of the benefits of such a controller are listed on the next page.

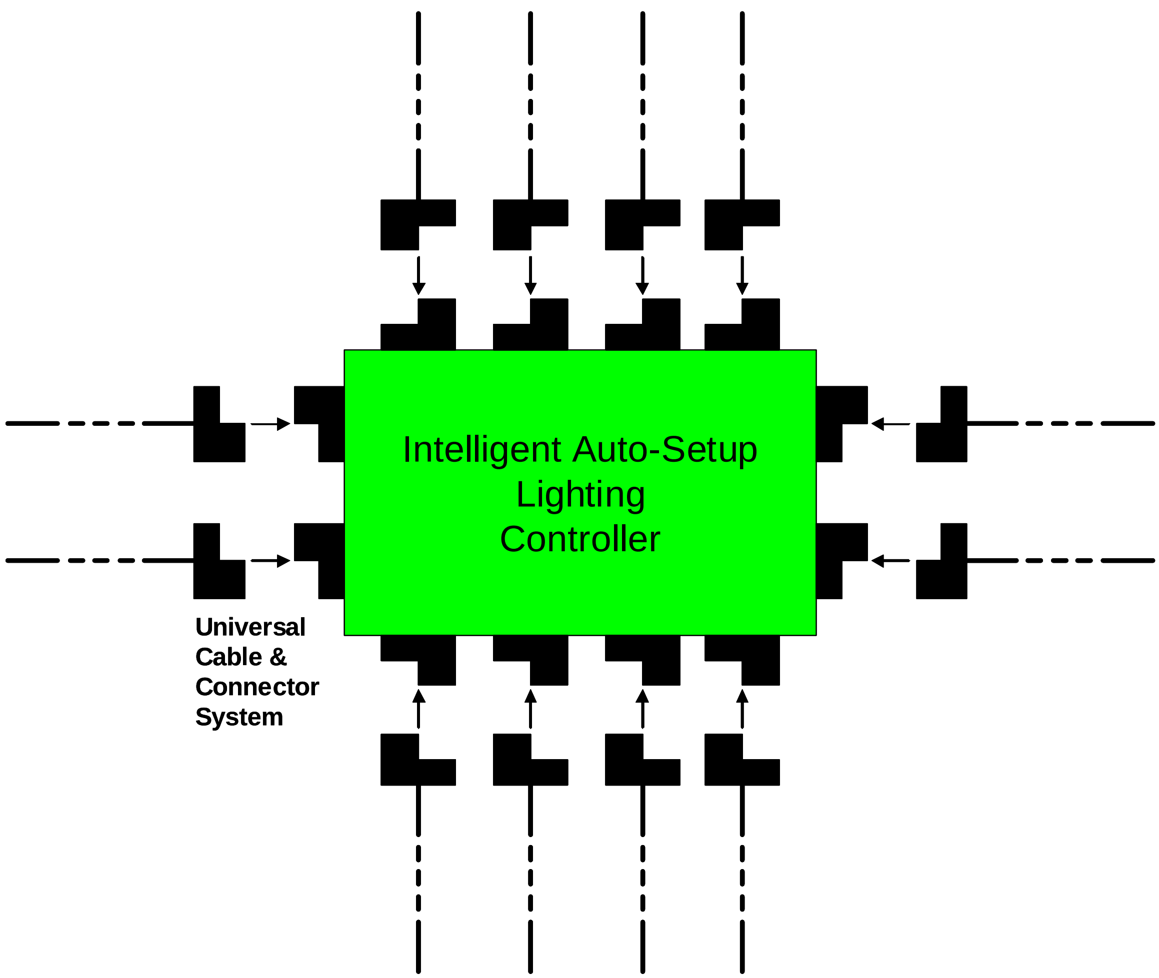



**Figure 2-6**
**Basic Diagram of the Ideal Lighting Controller with Universal Cable and Connector System**

Listed below are some benefits of an intelligent auto-setup lighting controllers with a universal cable and connector system.

- Any connector can be plugged into any port.
- The cable-connector system is universal in that it contains a power section (for low-voltage power, if needed) and a data-signal section (for data and signals used with sensors, etc.).
- Any port on the lighting controller may be used as a low-voltage power port for operating sensors or a dimming channel port for any type of dimming system (low-voltage 0-10 volt DC analog, DALI, etc.)
- If the other end of the universal cable is connected to a device (e.g., a daylighting sensor, photocell, or dimmable electronic ballast), then the lighting controller recognizes that device and sets up the parameters of that port to operate that device according to a prescribed set of conditions.
- All ports are protected against damage from low-voltage surges.
- If the port is not connected to a universal cable, then the port is deactivated and electrically closed so it cannot be influences by radiated emissions.

## System Compatibility and Power Quality

What is a power quality problem? Imagine this. . . . The fluorescent lights connected to a lighting controller in a manufacturing facility blink, indicating that the voltage has briefly dipped. A split second later, the high-intensity discharge (HID) lights drop out, adjustable-speed drives that control process motors trip, and scrap material gathers on the floor of the now dimly lit manufacturing facility. Or this. . . . Lightning strikes near a telemarketing facility. The uninterruptible power supplies connected to the computer systems switch on, but some of the computers lock up, disrupting data processing and vaporizing data. The light from the overhead dimmable fluorescent lighting system fades as about one-third of the fixtures go out. Or perhaps you don't have to imagine if you use magnetic HID ballasts with metal halide lamps and have been left in the dark for 15 to 20 minutes before the lamps cool down enough to restrike. Imagine this type of problem when your lights are connected to a lighting controller. The lighting controller is in full command of the lights, but the lights cannot be turned back on because the controller already says they are on.

Every year, problems with electricity and electrical equipment cost U.S. companies billions of dollars in scrap material, down time, damaged data, and delayed orders. Every year, electric utilities produce and deliver almost two billion cycles of electricity. If just a few of those cycles are disturbed, computers in commercial offices may crash, industrial equipment may shut down, and entire processes may grind to a halt. Moreover, equipment in one facility may cause other equipment in the same facility or in a neighboring facility to malfunction, even when the quality of delivered power is perfect. With lighting controls, which are embedded within a facility's electrical system, these problems become even more compounded. Each wired port on a lighting controller is a "door" for an electrical or electromagnetic disturbance to enter the controller. With facilities becoming more cluttered with electronic equipment, the frequency of occurrence for disturbances, their disturbance levels (both low and high frequency) are increasing. As buildings become more intelligent, more compatibility problems will surface and render equipment inoperable.

### *Applying Power Quality to Lighting Controls*

*Power quality* is the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment as defined by the IEEE Standard 1100, The Emerald Book. Power quality is a concept that was developed to study and improve the quality of electric power as it is generated, transmitted, and distributed to utility customers and consumers by electrical and electronic equipment.

Manufacturers and consumers often misapply the definition of power quality. Without even a basic understanding of power quality, they often think of quality power as power that contains absolutely no imperfections. Mistakenly, they apply the same thinking to lighting controllers and the data cables they depend upon. Similarly, an electrical engineer unfamiliar with the power quality concept may think of quality power with a 'perfect sine wave' with no irregular waveshapes or distortion whatsoever and a data string as a perfect stream of zeroes and ones. Both of these are incorrect perceptions of power quality as the input power to lighting controllers and the data they must deliver and receive contain artifacts resulting from electrical and electromagnetic disturbances.

Figure 2-7 illustrates a rising data pulse captured on a port of a lighting controller that receives a command from a daylighting sensor. This pulse is supposed to be a zero traversing to a one (e.g., 0 volts traversing to 5 volts) in an attempt to activate dimming of a bank of fixtures connected to one of the dimming ports of a lighting controller. The pulse below contains conducted noise. This noise has entered the control cable that runs from the controller to the daylight sensor. The cable was shielded, but the shielding material failed to reduce the current in the shield that resulted from the in flux of a high-frequency radiated electric field in the building. The electric field was generated by a set of input power cables running from an electrical panel to a set of adjustable speed drives. The lighting controller was rendered inoperable as a result of this compatibility problem. This indicates a couple of major points: 1) the shielding of the control cable was insufficient to protect the data signal inside the cable from the radiated electric field and 2) the port of the lighting controller could not filter out this noise in the data signal and allowed the controller to lockup.

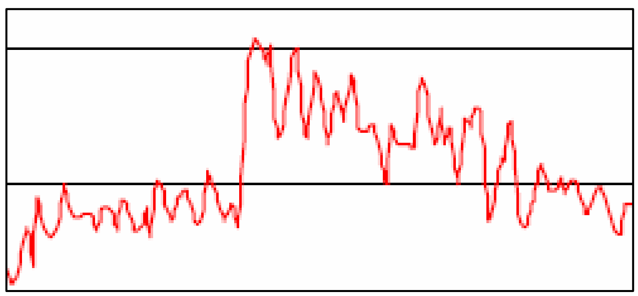


**Figure 2-7**
**A Rising Data Pulse (Going from Zero to One) Corrupted with Conducted Noise**

In order to better understand power quality and how it can be applied to the characterization of end-use equipment like lighting controls, EPRI with the assistance of electrical power system engineers and the IEEE have developed detailed a concept called system compatibility which can be applied to any electronic device including lighting controls. A series of system compatibility tests can be applied to a lighting control to determine its energy, emissions, and immunity performance. A test procedure exists which allows each type of electrical and electromagnetic disturbance to be applied to the proper ports of a lighting control. The low-frequency disturbances are derived from definitions for each type of variation and disturbance that occurs on the power system. These definitions, which are now standardized and part of an IEEE standard 1159-1995 (R2001), *IEEE Recommended Practice for Monitoring Electric Power Quality*, were developed through actual power quality studies conducted on various power systems across the United States in the last 15 to 20 years. Through having developed a thorough understanding of power quality, power system engineers and system compatibility engineers (engineers who study the compatibility between the power system and end-use electrical and electronic equipment) have been able to determine how equipment responds to each type of variation and disturbance.

### *What is System Compatibility?*

When equipment and appliances get along in the same electrical environment, they are said to be in a state of *system compatibility*. System compatibility is defined as the ability of a device, equipment or system, generally a load, to function satisfactorily with respect to its power-supply electrical environment without introducing intolerable electrical disturbances to anything in that environment. However, in today's complex and diverse electrical environment, achieving system compatibility is often a steep challenge for any product designer, especially for multiport systems like lighting controllers. For example, modern industrial processes rely on sophisticated electronics for precise and continuous control, and these electronics can jeopardize process reliability. Industrial plants that rely on process reliability also rely on quality lighting systems. An increasing number of lighting controllers rely on feedback from daylighting sensors spread throughout a facility to determine what appropriate levels of light are needed in the areas where the sensors (and windows) are located.

There is more to the quality of a lighting system than measuring the photometrics of the light. A quality lighting system includes the following, some of which are directly influenced by a lighting controller and are highlighted in bold.

### Photometry

- Providing a stable arc (discharge) inside an HID lamp
- Providing a sable DC current for an LED fixture (a driver function)
- **The correct amount of foot-candles targeted toward the area where the light is needed**
- The correct color of the light where the light is needed
- **Adjusting the appropriate light levels based on how much ambient light enters a room or space**

### Lamp-Ballast System Performance, Compatibility and Power Quality

- **Keeping the lights on when they are needed**
- Minimizing the number of lamp drop outs
- **Maintaining as much lumen output for the life of the lamp as possible – called lumen depreciation**
- Avoiding lamp flicker as the load inside and outside a facility changes

### Lamp and Ballast Reliability, and Economics

- Maintaining efficacy (efficiency) for the expected life of the ballast and lamp
- Achieving enough lamp and ballast reliability to achieve a return on the investment that the customer has made in purchasing and installing the modern lighting system
- **Ensuring that the dimming system of an electronic ballast remains fully operational over the life of the ballast so that lighting load can be adjusted according to customer needs or the utility's desire to reduce peak load in future demand response applications**

Each of the above categories involves the use of a lighting control. Considering a few examples, the first two categories in the above list are centered around the lamp and the fixture. The next four bullets are related to the performance of the lamp-ballast system. This performance also depends on how the lamp-ballast system responds to variations or disturbances in the AC line voltage powering the lamp-ballast system. The last three bullets are related to the reliability of the lamp and ballast. When the customer makes an investment to purchase and install a modern lighting system, that customer expects the system to operate reliably for at least a minimum of the warranty period offered by the lamp, ballast and fixture manufacturer; the lighting specifier, retrofitter, and/or installer, unless a severe electrical event occurs or the facility environment reaches a high temperature.

## The Age of Electronics and Compatibility

Obtaining electromagnetic compatibility between electrical equipment and the environment in which the equipment must operate is not a new agenda, even for lighting controllers. Part of the ongoing evolution of our electric power system, the introduction of new equipment, such as the various types of dimmable electronic HID ballasts, and new environments creates new types of incompatibilities and upsets when an additional system (like a lighting control) is included in a facility's lighting system. Perhaps the most extraordinary aspect of this evolution is the variety and the magnitude of changes brought about by electronics technologies. Advances included in today's modern lighting control systems are only the beginning of new advances in lighting and demand response systems. Today's lighting control engineers have realized that much more sophistication in control design is needed to optimize the operation of advanced dimmable lighting systems. It is not as simple as just turn a lamp 'on' or 'off' anymore. This sophistication can only be possible through designing electronic ballasts that will allow lamp control on a point-by-point basis—controlling lamps on the 'fly'.

The advent of the transistor—followed shortly by the integrated circuit and all of its related micro-electronic technology—revolutionized information-processing systems, and lighting controllers are prime examples. In much the same way, power electronics technology, teaming up with micro-electronic control, is revolutionizing the way we use electric energy. And with lighting control systems, it is managing the way that demand response systems regulate lighting loads, whether the need to adjust load is based on light levels, customer-initiated energy savings, or utility-initiated energy savings. In many ways, power-electronics has combined with micro-electronic technology to make old appliance technologies (like some lighting systems) better and to create new technologies such as electronic ballasts. Even in the near future, the modern digital signal processor (DSP), now being used in uninterruptible power supplies (UPSs) among other technologies, will soon take electronic lighting (ballasts and lighting controls) into a new dimension.

From the kids' toys to Dad's tools to Mother's microwave oven, we find electronics in every room of our homes. Personal computers, VCRs, CD players and digital clocks are now past commonplace. Now, we find electronically driven heat pumps, washing machines and advanced electronic lighting devices. In addition, we see microwave clothes drying, electric vehicle charging units, and the "all-electronic kitchen. Soon, residential facilities will find more use of lighting controls to operate hard-wired lighting fixtures and even table lamps. In the workplace, PCs, facsimiles, copiers, printers, electronic fluorescent lighting, adjustable-speed HVAC and various electronic communications are integral parts of the "all-electronic office." Commercial facilities are finding more use of lighting controllers mixed with other building control systems using various types of communication (hard-wired and wireless) media. The bottom line is that our electric power systems are changing radically. Will it all work?

With the effective use of electricity at the heart of its business, the utility industry is playing an important role in evaluating and promoting end-use equipment compatibility in the public power system. It is well known that electronic systems can interfere with one another: Transient events, such as voltage sags and surges, in the electric power system can disrupt sensitive processing equipment, and certain electronic equipment may contribute to the overload of a building's transformers, wiring and grounding. Lighting controllers are all subject to malfunction from these events, and compatibility can harden them to virtually eliminate these problems.

## Why Apply System Compatibility to Lighting Systems?

Traditionally, lighting systems from the days of Thomas Edison were of the incandescent type. No energy conversion device was needed between the power system and the lamp, and no lighting controls were used. This does not mean that disturbances in the power system did not affect incandescent lamps. This simply means that the incandescent lamp is under direct influence of disturbances that occur on the power system. Compatibility tests conducted on incandescent lamps have shown that the reliability of lamp filaments are affected by disturbances such as voltage sags, voltage swells, and voltage surges. With respect to the end user, a change in illumination is usually noticeable with these disturbances until the lamp fails to produce light when the filament is severed. With lighting control systems, failures and malfunctions in lamps are also possible and can actually be initiated by malfunctions in lighting controllers.

Early fluorescent-based lighting systems were developed by leading manufacturers such as General Electric and Sylvania and soon became popular lighting products for end users of all types. These systems through the use of a magnetic ballast were connected to a fluorescent lamp. The purpose of a ballast is to produce enough energy to ignite a lamp and then control its illumination through either voltage or current control.

In magnetic fluorescent lighting systems, the magnetic ballast is a simple core-and-coil type of device with no sophisticated electronic components for controlling lamp performance. These ballasts also respond to various types of steady-state and transient power-line disturbances. With vary little voltage regulation built into a magnetic ballast, the ballast will allow an increase in illumination with an overvoltage or a voltage swell and a decrease in illumination with a voltage sag. However, the core and coil of a magnetic ballast system have the distinct advantage of having a more-than-acceptable immunity to voltage surges.

Although this type of immunity helps to increase ballast reliability, end users often complain about issues other than ballast failures such as noticeable variations in light fluctuations. These fluctuations in light output are called lamp flicker. All types of lamps and lamp-ballast systems have their own characteristic response to various types of voltage fluctuations—the type of line-side disturbance that causes lamp flicker.

Lamps and lamp-ballast systems may act as amplifiers of voltage fluctuations or they may act as attenuators to fluctuations. Each component of the lamp-ballast system plays a different role in determining the extent to which the lamp-ballast system acts as an amplifier or attenuator of fluctuations. When acting as an amplifier, a small fluctuation incident on the AC input of a lamp-ballast system, for example, will result in a large change in light output. The same is true for lighting controllers—disturbances initiated at the line input may find their way through the lighting controller and into the signal that controls the light output of electronic ballasts.

With respect to end users, each human eye also has a distinct frequency response to lamp flicker. Some people can notice a lamp flickering when others cannot. Some will indicate that what may be defined by some as a mild lamp flicker will actually cause severe headaches, thus preventing users from functioning in a work environment. This is because their perception to lamp flicker varies from person to person. Lamp flicker studies have been conducted on many types of incandescent and fluorescent lamps and ballasts with the results varying among lamp and ballast models as expected. As more lighting systems become electronic, lamp flicker studies will continue to gain more attention, especially for systems operating at higher lamp wattages such as HID lamps where a small amount of flicker in a fluorescent lamp may not be very noticeable as compared to that same amount of flicker in an HID lamp that may be more noticeable.

While the human perception-related performance issues in lighting systems can gain much attention from utility customers, professionals in the lighting industry traditionally focus on lamp and ballast performance and reliability. These professional groups include architects, lighting specifiers, facility electrical designers, lighting engineers, and lamp and ballast designers. Each of these groups strives to provide acceptable lighting systems for their customers that meet their expectations in terms of lamp and ballast performance and reliability. Each strive to 1) provide lighting systems that maintain acceptable light output for the majority of the life of the lighting system and 2) provide lighting systems that function at an acceptable level for at least the term of the product warranty.

Manufacturers of electronic fluorescent ballasts learned about performance and reliability the hard way. Many of them did not understand the whole-system performance: how to design a high-frequency inverter type of power supply, populate a printed circuit board with components rated for an elevated operating temperature, solder them to the board, place that board inside a metal can, pour hot potting material over the circuit, and install it into a lighting fixture. Many lessons regarding circuit design, component reliability, soldering, specifications, and potting were learned. With some knowledge about ballast reliability and the warranty term, many manufacturers did not have enough data to reasonably design and specify their warranty programs. Both manufacturers and end users experienced significant financial losses from poor lamp and ballast reliability.

Many have asked how system compatibility testing could have prevented much of these financial losses. At the time when the first electronic fluorescent ballasts were being designed, component manufacturers were also not familiar with applying their devices in ballasts. Component engineering combined with a temperature-based compatibility study might have helped reduce the number of failures cause by the overheating of electronic components. Compatibility testing would not have had much of an effect on manufacturing defects including soldering. However, during many of the forensic studies that were conducted on failed electronic fluorescent ballasts, it was found that disturbances which would not normally affect a well-designed electronic ballast would have a much more negative effect on the performance and reliability of a ballast with design problems. Disturbances such as voltage transients and voltage sags were found to cause premature failure of ballast circuits and the component lead-to-solder joint junction. Compatibility testing on such samples prior to production would have resulted in the identification of ballast reliability issues prior to the installation of thousands of ballasts that eventually failed when powered in a normal electrical environment.

For these reasons, manufacturers and end users of electronic ballasts, whether they produce or use fluorescent or HID lamp-ballast systems, have a keen awareness of the compatibility of these systems with the power system. Many are integrating compatibility testing into their ballast design processes with the goal of identifying compatibility problems long before the start of production. EPRI has worked with dozens of ballast manufacturers and applied the compatibility concept to their products. If lighting controls are to be a key part of a facility's lighting system to help reduce energy usage, then the same needs to happen for lighting controllers. .

Figure 2-8 illustrates the design process with integrated system compatibility testing. This process served as the guideline during the development and testing of the many electronic ballast products. Lighting control designers can learn to apply the compatibility concept just as easy as ballast manufacturers have done. The process is basically the same, but the results will be different and just as valuable.

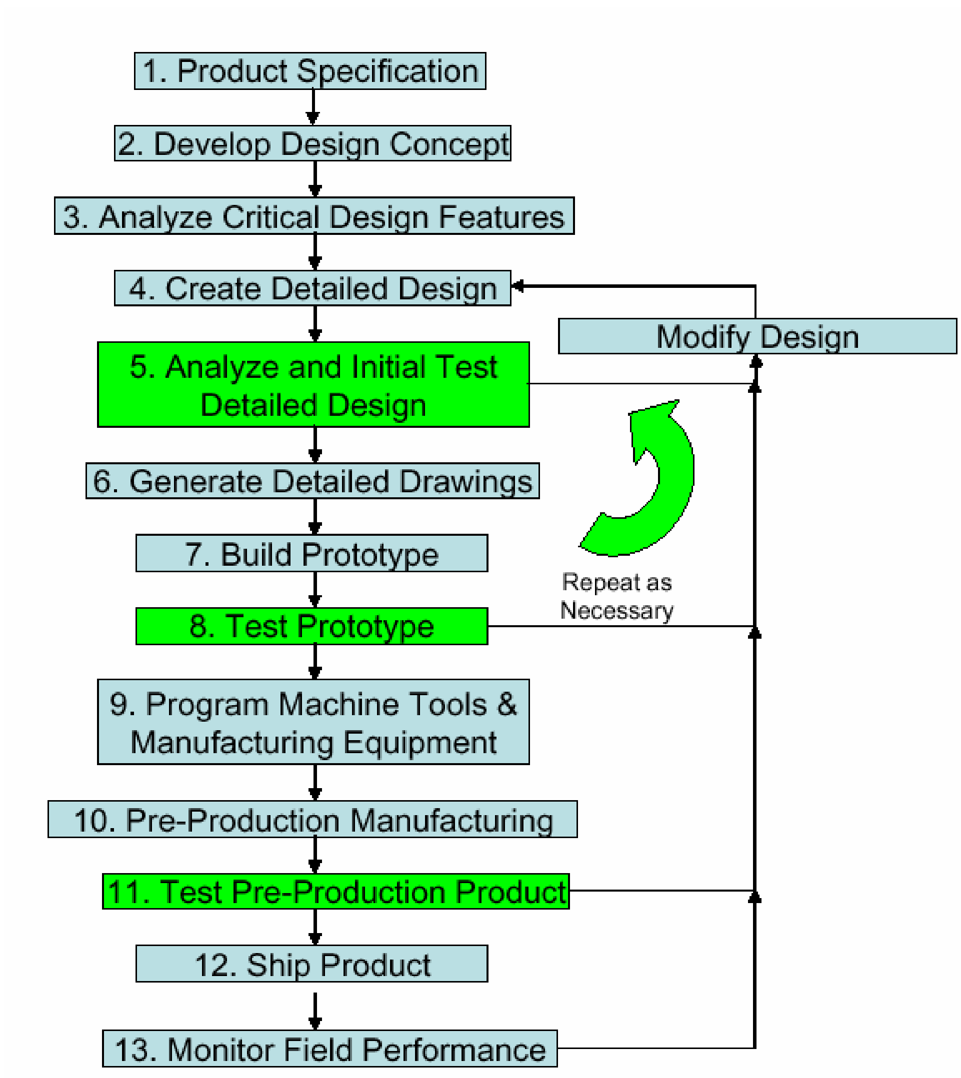



**Figure 2-8**
**The Design Process with Integrated System Compatibility Testing**

### Why is System Compatibility Important for Lighting Controls?

As stated earlier, lighting controls are becoming a key part of a facility's operating system. Prior to the use of lighting control, lights in a facility were just turned 'on' at the beginning of a day and turned 'off' at the end of a day. Now, facilities are having to become more intelligent and vary light levels according to occupant usage, space purpose, and ambient light levels. If facilities are to engage in energy savings using lighting controls, then the controls that they use must be hardened to the point where facility manages and occupants can expect them to function as desired in all types of electrical environments and building operating conditions.

Lighting controllers will need to function during thunderstorms, during electrical disturbances initiated by the public, and during electrical disturbances initiated by the utility. Lighting control designers may even want to consider integrating intelligence into the control that alerts the end user when an adverse condition exists such as the presence of a high level of electrical noise on one of the communication or port channels. Resolving a compatibility problem with a lighting controller before it shuts the building lighting system down would be very valuable. End users simply cannot work in the dark, and in some conditions the failure of a lighting control system would present safety problems requiring the building to be evacuated.

## How Compatibility Enables Lighting Control to be Demand Responsive

With lighting controllers having been developed several years ago, some with fairly mature designs, many controllers will continue to be used as individual systems separate from demand response (DR) systems. However, while the compatibility of a DR system is just as important as the compatibility of a lighting control system, the overall compatibility of a combined DR-lighting control system will be critical for facilities that begin to rely on them. Figure 2-9 illustrates this concept. Interestingly enough, many of the lessons to be learned regarding compatibility for lighting controllers will also be applicable to DR systems.

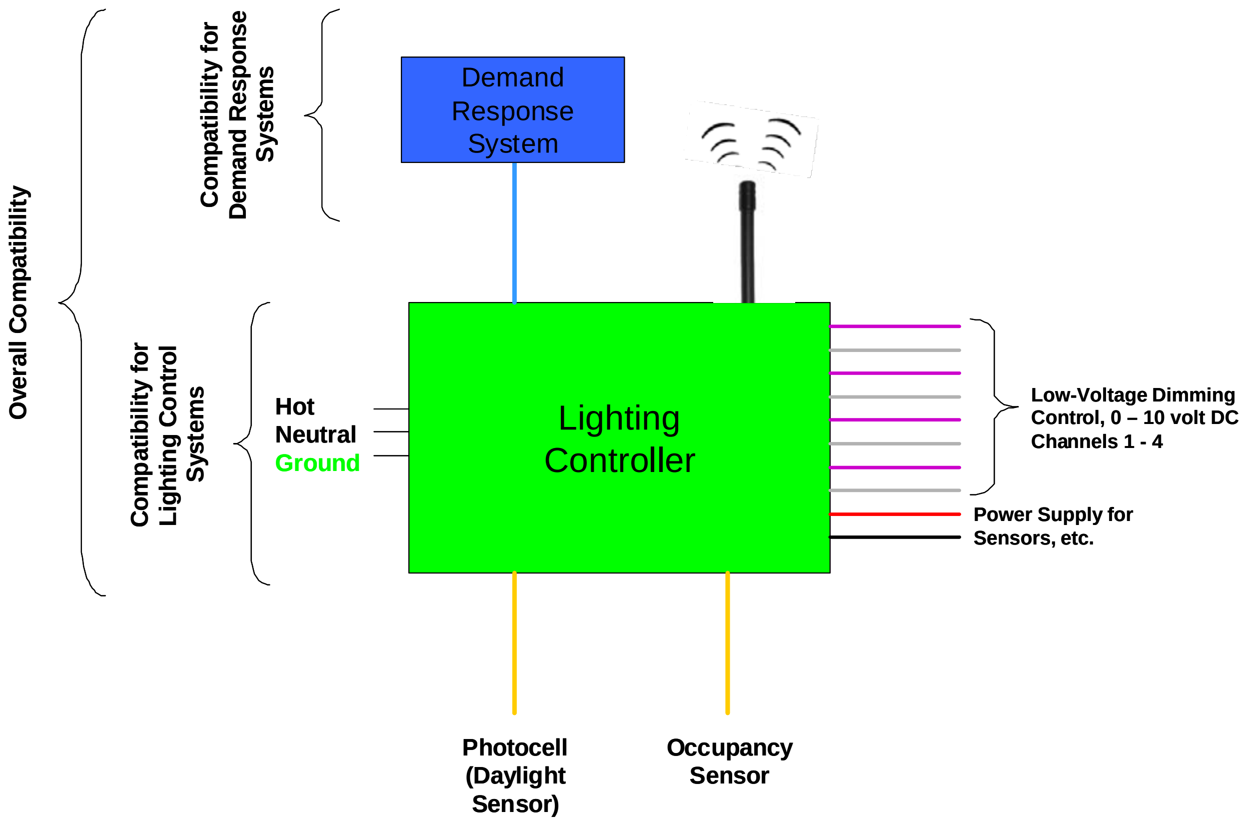



**Figure 2-9**
**Compatibility Concept Applied to Lighting Controller, Demand Response System, and Overall System**

# 3 FUTURE WORK

There are significant opportunities for future work in the area of lighting control systems. These opportunities are centered around several areas including

- User friendliness (including plug-and-play) and human interface
- Installation guidelines to improve performance
- Compatibility between different brands of sensors and lighting control systems
- Compatibility between lighting control systems and facility electrical environments
- Grounding
- Lightning protection
- Immunity to high-frequency radiated emissions
- Immunity to high-frequency conducted emissions on power, ground, and control cables

Many utilities and end users are interested in determining the degree of user friendliness of lighting control systems. This would include setup and programming for different types of lighting control scenarios with different types of dimmable light sources—0 to 10 volt DC analog, DALI, power-line carrier, and wireless among others. Utilities and end users already know that many systems are not user friendly, and such EPRI research could help guide manufacturers on how to improve user friendliness and human interface.

Electricians, building control installers, and lighting control specialists all complain about some of the difficulties in installing lighting control systems. Most instructions and application notes do not even address critical issues like compatibility and power quality—what to look for in a facility that might present threatening emissions and immunity issues to lighting control systems. Such a guide would improve installation practices and reduce the number of failed and malfunctioning systems.

Compatibility is the largest and most critical issue regarding the reliability performance of lighting control systems. Because lighting control systems play such a critical role in building performance, and now also in energy savings and future demand response, compatibility is becoming an even more critical issue. The development of a system compatibility test protocol, *Test Protocol for Compatibility: SC-465 – Lighting Control Systems*, will be carried out in 2010 EPRI research in Program 170. This protocol will address the compatibility between lighting control systems and the electrical environment and sensors as well as a measure of the degree of user friendliness and human interface.

Other issues that are important to the compatibility and protection of lighting control systems are grounding, lightning protection, and immunity to high-frequency radiated emissions and conducted emissions on power, ground, and control cables. Future EPRI research on lighting control systems will address these issues, thus helping to ensure a broader spectrum of compatibility for lighting control systems when paired with dimmable light sources in various types of building electrical and electromagnetic environments.

# 4
# CONCLUSION

The growth in the demand for energy-efficient lighting products and the demand for energy savings are good indicators that lighting control systems will be in increasing demand in the next several years. The majority of existing facilities still do not utilize lighting controls, and even fewer use controls that are connected to demand response systems. The time to focus on documenting the performance of lighting control systems and hardening them so they can function in common everyday electrical environments is now. Several failures and malfunctions have already been reported in the industry. These events, like those that occurred with electronic lighting devices now in growing use, indicate that similar compatibility problems exist with lighting control systems that existed with electronic ballasts.

EPRI has already established the ground work for application of the compatibility concept to any electronic system, and the application of this concept to lighting control systems is a worthwhile extension of that work. Some manufacturers of lighting control systems are eager to undertake this type of work so they can identify the weakest links that exist in their systems and cost-effective yet reliable methods to resolve them. The results of such work can also be used to strengthen application guides, installation practices, and technical specifications for lighting control systems.

Utilities and their customers invite the opportunity to have EPRI investigate the compatibility issues with lighting control systems. Utilities and their customers must be prepared to ramp up the widespread application, installation, and use of these systems as the demand for energy savings and load reduction continues. The application of EPRI's compatibility concept, like that seen in other industries, will result in cost savings to manufacturers and installers of lighting control systems as well as utilities and end-use customers who will begin to rely more on them for improved building performance and increased energy savings.

The need for new standards in the lighting control systems area regarding compatibility and power quality is also evident. Presently, no dedicated product standards exist for lighting control systems, including their usage with dimmable light sources. The development of such standards can be lead by EPRI research as compatibility issues are identified and understood, just as standards development occurred with electronic ballasts. Manufactures of lighting control systems will learn the importance of considering compatibility and power quality in their design efforts as the need to ensure reliable function and communication of these systems continues to be on their forefront. This concept can be applied to inexpensive one-channel lighting control systems and to multi-channel systems that are interfaced with other building systems and demand response systems in the future. The customer who experiences a failure with a single-pole lighting control device that controls one lighting circuit in a residential facility is just as important as that commercial customer who experiences failure of a 42-channel system driving the lighting systems for s ten-story building. Lighting controls systems will soon become the backbone for energy management and load control for each type of customer facility alike as end users strive to reduce their operating budgets as well.

# 5
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