

**NATIONAL
LIGHTING
PRODUCT
INFORMATION
PROGRAM**

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Lighting Circuit Power Reducers

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Introduction

Lighting circuit power reducers are retrofit devices designed to reduce the energy use of a lighting circuit. These power reducers, also called lighting controllers, are installed at electrical panels between a circuit breaker and the lighting load to reduce the active power of the entire lighting circuit. Reducing the lighting load, however, reduces illuminances and may also reduce system efficacy.

Manufacturers may claim that lighting circuit power reducers save energy without a perceptible reduction in light output. Their product catalogs contain many anecdotal reports of successful applications. However, there are few test data that support these claims and anecdotes. NLPIP produced this report to provide information about lighting circuit power reducers to specifiers. NLPIP tested products for single-phase fluorescent lighting systems from three manufacturers for this report. The report also includes information on products for HID lighting systems, although NLPIP did not test these products.

Background

Lighting circuit power reducers reduce the active power of a lighting circuit. This issue of *Specifier Reports* focuses on those which reduce active power by a discrete amount. There are two types available in the market: autotransformer lighting circuit power reducers and electronic lighting circuit power reducers.

Manufacturers use the cost savings from the reduced power to justify the initial cost of lighting circuit power reducers, usually over \$1000 per unit.

Contents

Introduction	1
Background	1
Performance Characteristics	3
Performance Evaluations	7
Alternative Technologies	10
Further Information	12
Data Table Terms and Definitions	13
Manufacturer-Supplied Information	14
NLPIP-Measured Data	15
Publication Information	16
Ordering Information	16

Autotransformer Lighting Circuit Power Reducers

Autotransformer lighting circuit power reducers reduce the voltage supplied to the lighting load (see the sidebar, “Autotransformers”), but they preserve the voltage waveform from the line to the load and have little, if any, effect on power quality. Reducing voltage, however, can affect lamp and ballast performance.

Most of these products use variable step autotransformers, and they are used primarily in high intensity discharge (HID) lamp systems with constant wattage autotransformer (CWA) ballasts. Typically, they are heavy and bulky, often weighing more than 50 kilograms (110 pounds). Many start and operate lamps at full voltage for a time [often about 15–30 minutes (min)] and then reduce voltage

gradually to maintain the stability of the lamp arc. Many of these devices also offer variable power reduction when operating as part of a variable lighting control system (photosensor control) or an energy management system. This report focuses on the discrete power reduction applications of these products.

Electronic Lighting Circuit Power Reducers

Electronic lighting circuit power reducers typically decrease the root-mean-square (rms) voltage supplied to the lighting load by chopping part of each voltage cycle (see the sidebar “Waveform Chopping” on p. 3). The peak voltage may or may not remain constant, depending upon the specific product’s design. Electronic lighting circuit power reducers are lighter and more compact than autotransformer types. However, waveform chopping can reduce power quality as well as lamp and ballast performance.

Electronic lighting circuit power reducers are available for use with HID and fluorescent systems with magnetic ballasts. [One manufacturer, LTI, claims that its product for fluorescent lighting systems works with electronic ballasts that use passive power factor correction to filter total harmonic distortion (THD)]. These devices provide full voltage to start the lamps and continue to provide full voltage for a warm-up period ranging from 2–12 min. After warm-up, some electronic lighting circuit power reducers reduce power gradually to a preset level, while others reduce power immediately. As with autotransformer products, some electronic products can interface with photosensors, time clocks, and other energy management systems.

Autotransformers

An autotransformer is a type of transformer that has one winding, a portion of which is common to both the primary and the secondary circuits. The current in the high-voltage circuit flows through the series and common windings.

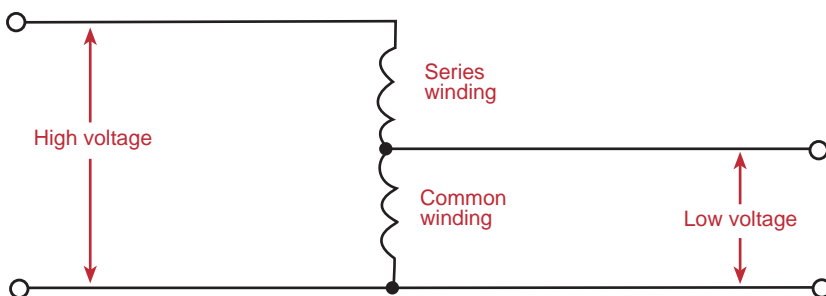
The current in the low-voltage circuit flows through the common winding and adds vectorially to the current in the high-voltage circuit to give the common winding current. Thus an electrical connection exists between the high- and low-voltage windings.

Because of the sharing of parts of the winding, an autotransformer is generally smaller and lighter than a two-winding transformer of equal apparent power output. Autotransformers generally have lower no-load loss, exciting current, and load loss (energy efficiency parameters) than transformers of equivalent rating. In addition, the impedance and regulation normally are lower because of the connection between the two circuits.

Taps can be provided in the autotransformer to adjust the turns ratio. This provides control of the output voltage over the operating range of the transformer. In the case of the lighting circuit power reducer, it is this turns ratio that is adjusted to reduce the power to the desired amount.

(from Sutherland, J.R.1983. *McGraw-Hill Encyclopedia of Engineering*. New York: McGraw-Hill: pp. 74–75)

Typical Autotransformer Circuit



Performance Characteristics

Power Reduction

Lighting circuit power reducers are installed primarily to obtain energy savings by reducing power to a lighting system. These products can reduce peak power demand.

Most lighting circuit power reducers have adjustable settings of power reduction, typically from 10–40%. Users can choose one of the settings when a lighting circuit power reducer is installed. Although the settings on many products can be changed after installation, such practice usually does not occur because the products are installed at the electric panel, which is generally not readily accessible to users.

Power reducer manufacturers typically recommend reducing power by 25% for most applications. Therefore, NLRIP tested the products included in this report at the setting nearest this value.

Light Output & System Efficacy

Power reduction using lighting circuit power reducers always reduces light output and may affect system efficacy. While greater power reduction is attractive because it means more energy savings, the reduced light output may be unacceptable to users and reduce visibility in the space. Many power reducer manufacturers recommend cleaning and relamping luminaires at the time of installation of lighting circuit power reducers to offset the immediate reduction in light output. However, this practice does not compensate for the reduced illuminance that results over time from luminaire dirt depreciation (LDD) and lamp lumen depreciation (LLD). Specifiers and users should consider the effect of reducing light output on users before installing lighting circuit power reducers.

Power Quality

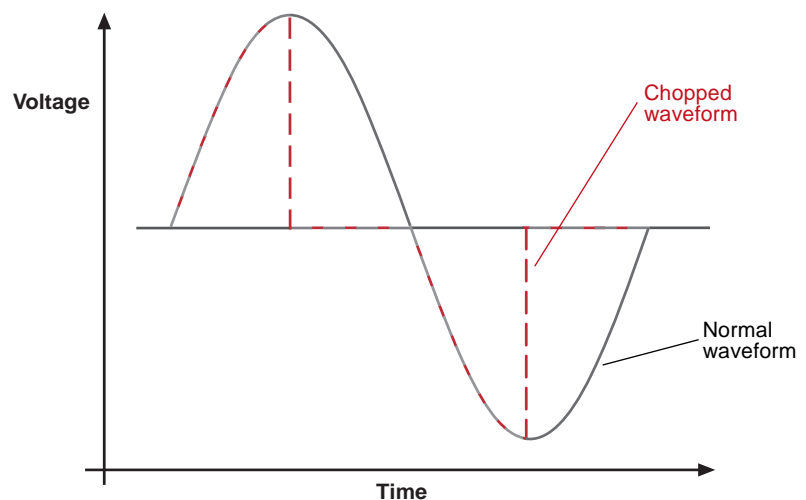
Power quality is the extent to which current and voltage waves are in synchrony with each other and conform to a sinusoidal shape. Poor power quality can negatively affect efficient and reliable operation of an

electrical system. Power factor and THD are metrics for power quality.

Power factor. Power factor is defined as the ratio of active power to apparent power, which is the product of rms voltage and rms current; power factor ranges from 0–1.0. A power factor of 1.0 means that the voltage and current waveforms are identical and in phase. Power factor is reduced if there is a phase shift between current and voltage or if there is a distortion of the sinusoidal waveforms. Although low power factor devices do not necessarily use more energy than high power factor devices, they draw more current into the circuit. Larger supply equipment (including conductors, transformers, and switch gear) is needed for low power factor devices to handle the added current, which is called reactive current. Resistive losses in the wires caused by the reactive current flow wastes energy in the electrical distribution system. Many utilities penalize customers whose facilities have power factors less than 0.8 or 0.9 because utilities incur additional costs supplying the reactive current.

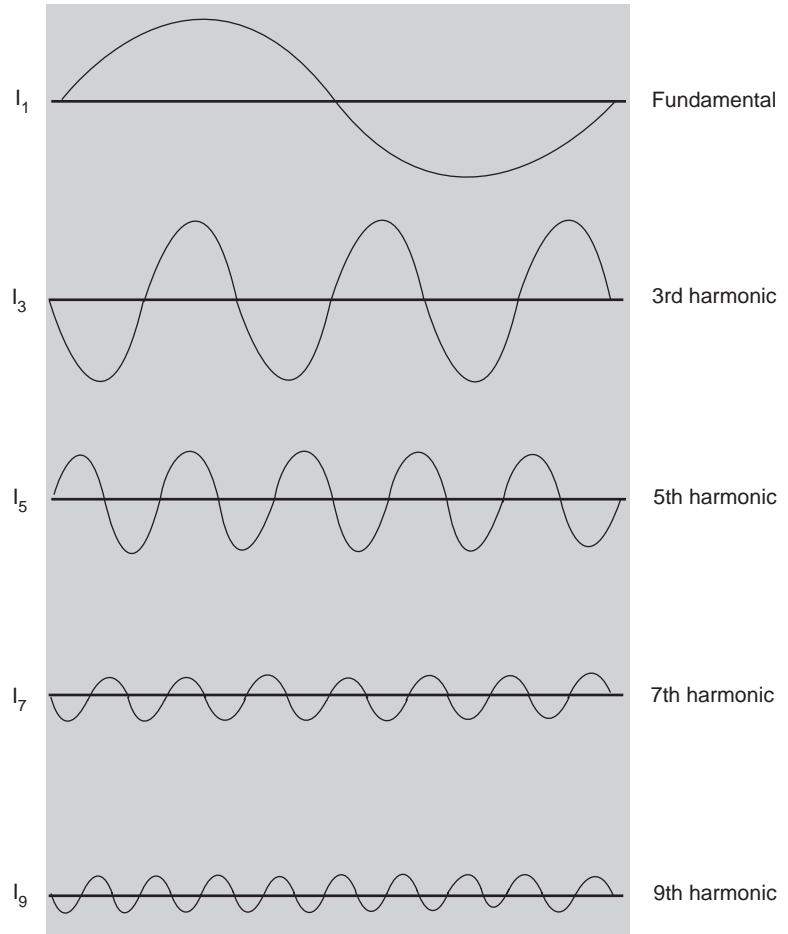
Waveform Chopping

Waveform chopping reduces the area under the curve rather than reducing the amplitude of the wave to reduce active power. Some lighting circuit power reducers switch power off to produce energy savings, which produces a chopped voltage waveform. However, because waveform chopping alters the shape of the wave, the process increases harmonic distortion.



Harmonic Analysis

Harmonic of waveform



From IAEEEL newsletter 3-4/95, used with permission.

Root-Mean-Square (rms)

The term *root-mean-square* refers to the procedure used to calculate the average value of a periodic waveform, such as voltage or current. Mathematically, it is the square root of the mean of the squared values (volts or amps) taken over one complete cycle. Thus, the term rms voltage expresses the average voltage.

Definition and Standards for Harmonic Distortion

Higher values of THD indicate greater distortion. American National Standards Institute (ANSI) Standard C82.11 sets a limit of 32% current harmonic factor for electronic ballast systems. The United States Department of Energy has proposed limiting current THD to 20% on all lighting equipment. Many utilities only include ballasts that have THD less than 20% in their energy-efficiency programs.

Harmonics that are odd triple multiples of the fundamental frequency (3rd, 9th, 15th, ...) have the greatest potential impact on electrical systems because the current from these harmonics flows on the neutral conductor and may overload this conductor. ANSI C82.11 also sets limits for odd triples and other harmonics.

In this report, NLPPI uses the definition of the Institute of Electrical and Electronic Engineers (IEEE 1035-1989) because that is how ballast manufacturers typically report THD. This definition coincides with the definition of harmonic factor used by ANSI, Canadian Standards Association (CSA) and the International Electrotechnical Commission (IEC).

$$\text{THD} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 + \dots}{I_1^2}} \times 100$$

where

I_1 = fundamental current,
 I_2 = current in second harmonic,
 I_3 = current in third harmonic,
 I_4 = current in fourth harmonic

ANSI, CSA, and IEC define THD as the ratio of the harmonic content to the rms value of the periodic current (all of the harmonic components including the fundamental), which is expressed as

$$\text{THD} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 + \dots}{I_1^2 + I_2^2 + I_3^2 + I_4^2 + \dots}} \times 100$$

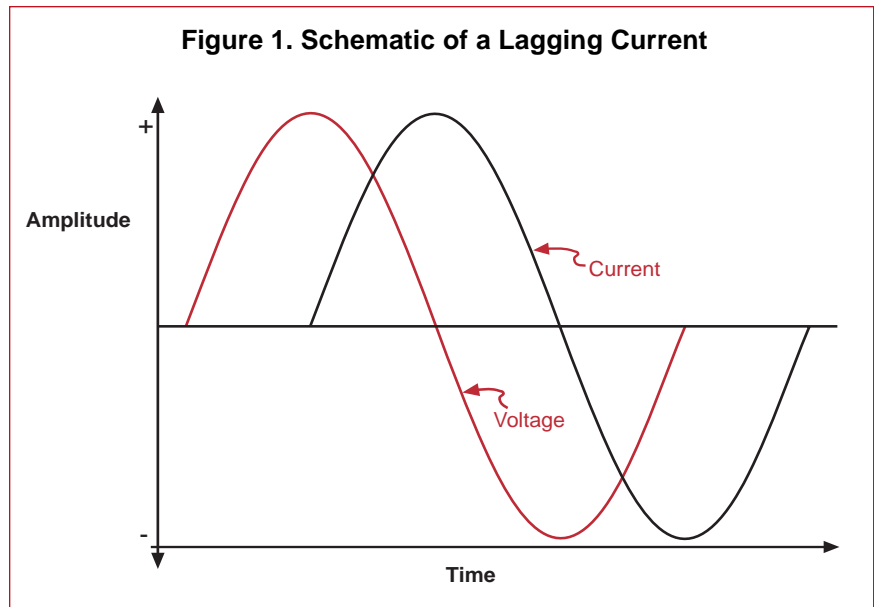
Phase shift. Power factor is reduced if the current phase leads or lags behind the voltage phase (see Figure 1). Most facilities have inductive loads such as motors which cause lagging currents.

The reduction in power factor due to phase shift between current and voltage can be easily corrected. Leading and lagging power factor devices on the same circuit can partially or completely offset each other, resulting in an overall improvement in power factor. For most facilities with inductive loads such as motors, external capacitor banks are traditionally used to correct power factor, and reactive current only flows in the wires in the facility's devices and the capacitors instead of flowing back to the utility.

Harmonic distortion. Distortion of the sinusoidal current waveform, which can be expressed as THD, reduces power factor and is difficult to correct. A distorted periodic waveform can be represented as a harmonic series of sinusoidal waveforms of different amplitude and phase. A harmonic series is a group of different frequency waveforms that are multiples of the lowest fundamental frequency. THD is a measure of the degree to which a sinusoidal waveform is distorted by harmonics. It is defined mathematically as the rms sum of the harmonic components expressed as a percentage of the fundamental component (see the sidebar "Definition and Standards for Harmonic Distortion" on p. 4). High levels of distortion in the distribution system can also harm electrical equipment.

Ballast Life

Ballast operating temperature affects ballast life. For fluorescent lamp ballasts operating in luminaires at an ambient temperature of 25° Celsius (C), Underwriters Laboratories (UL) and the American National Standards Institute (ANSI) specify a maximum ballast case temperature of 90°C. For ballast life ratings, ballast manufacturers often specify a maximum ballast case temperature lower than 90°C. Some manufacturers state as a rule of thumb that every 10°C increase above the rated ballast case temperature reduces the ballast life by 50%. Higher operating



temperatures also reduce the life of ballasts for HID lamps.

Because lighting circuit power reducers reduce active power, they should also reduce ballast operating temperatures and therefore have the potential to extend ballast life. Accurately measuring ballast case temperature requires long stabilization periods due to the thermal mass of ballasts and luminaires. NLRIP did not measure ballast case temperature for this report.

Lamp Life

Fluorescent lamp life can be affected by lamp current crest factor (CCF) and electrode starting temperature (see NLRIP's *Guide to Selecting Frequently Switched T8 Lamp-Ballast Systems*).

CCF is defined as the peak current divided by the rms current. The CCF of a sinusoidal wave is 1.41. High CCF indicates that the current waveform has high peaks that can reduce lamp life by increasing sputtering, which is the loss of the emissive material on the electrodes. Most lamp manufacturers void their warranties when CCF is greater than 1.70, which is also the limit adopted by ANSI C82.1-1985 (R1992).

High electrode temperatures can also reduce lamp life by increasing evaporation of the emissive coating on the lamp electrode. Low electrode temperatures can also increase sputtering. Both temperature

conditions can also increase lamp-end blackening. Due to the difficulty of measuring electrode temperature directly, operating electrode voltage is used as a related parameter in lighting standards. For instance, manufacturers assume that the electrode operating voltages of rapid-start lamps is maintained between 2.5 and 4.0 volts (V) when rating lamp life; these values have also been adopted by ANSI C82.1-1985 (R1992).

No published reports document the effect on lamp life of operating HID lamps at lower than the rated power. Therefore, NLRIP recommends that specifiers contact both the lamp and power reducer manufacturers to obtain more information about the effects of reduced power operation on HID lamps.

Human Perception

Flicker. Alternating current modulates the light output of lamps, which can cause perceptible flicker. Flicker is a source of worker complaints of eyestrain and headache. For lamps operated at a frequency of 60 hertz (Hz), the light output oscillates 120 times per second, which is generally imperceptible. At high light levels, the highest frequency the human eye can detect is approximately 75 Hz (Collins and Hopkinson, 1957). But electronic components, such as lighting circuit power reducers, used in the lighting circuit can introduce lower frequencies of different modulation to the lamp current and cause perceptible flicker.

Color. Lamp color appearance or chromaticity coordinates may change when power to a lighting system is reduced. The correlated color temperature of halophosphor fluorescent lamps does not vary substantially during dimming from 100–20% light output. The color of triphosphor fluorescent lamps becomes bluer below 50% light output (IESNA, 1993).

The color characteristics of HID lamps are greatly affected by changes in lamp power, with the most pronounced color shift occurring when the lamp is operating below 60% of the rated value. In *Lighting Answers: HID Dimming*, NLRIP reported that the correlated color temperature (CCT) of a 400-watt (W) coated metal halide lamp shifts from 3850 kelvin (K) at full power to 4310 K at 50% power. Previous research (Gibson, 1994) showed that this color shift is more pronounced in clear metal halide lamps than in coated lamps.

Illuminance change. After a warm-up period, power reducers reduce power which reduces lamp light output. Manufacturers preset the rate of change and may be able to adjust the settings according to customer specifications. NLRIP recommends that specifiers ask manufacturers about adjustments that can be made to the rate of illuminance change.

Sound. Magnetic ballasts and transformers sometimes produce a humming noise, which is caused by vibrations in the laminated magnetic core. NLRIP researchers did not hear noise coming from the ballasts or power reducer products during the testing, although NLRIP did not measure sound for this report.

Performance Evaluations

NLPIP identified five manufacturers of lighting circuit power reducers through equipment directories and advertisements and invited them to participate in this project. All five agreed to participate.

Some manufacturers sell a series of models for different line voltages, circuit currents, phases (single or three phase), and lighting control strategies. Others customize a product to meet customer requirements. Table 1 on p. 14 lists the lighting circuit power reducers available from these manufacturers.

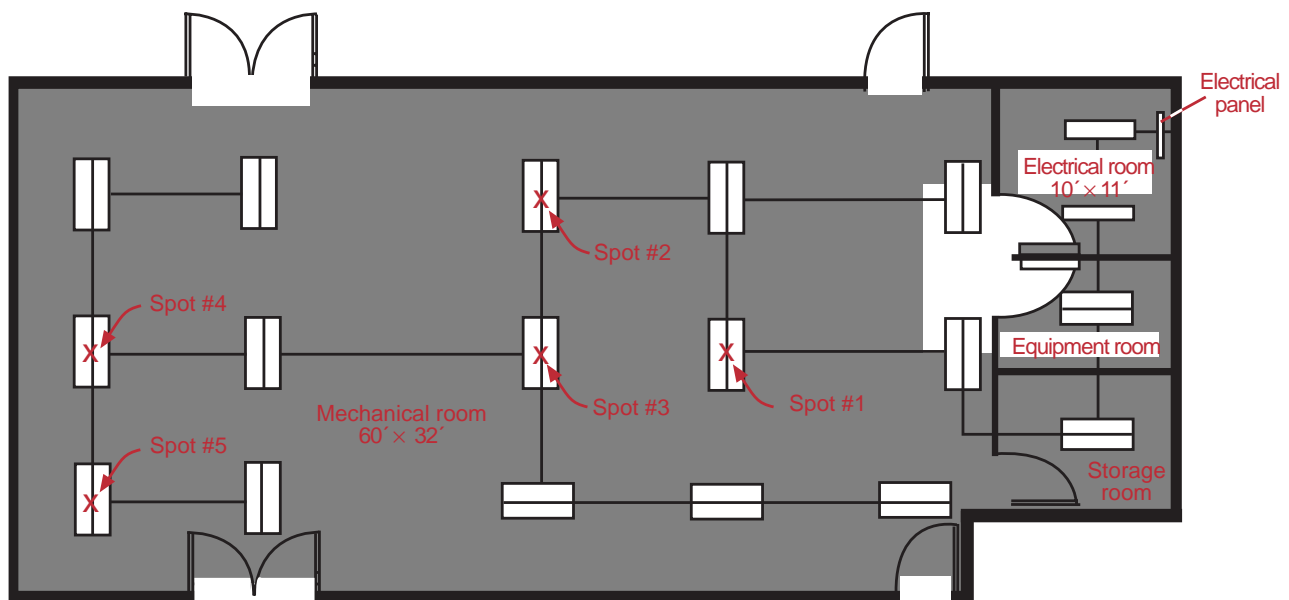
NLPIP Testing Procedure

NLPIP tested lighting circuit power reducers using the fluorescent lighting systems in the mechanical room and three adjacent small rooms at the Iowa Energy Center's Energy Resource Station in Ankeny, Iowa. Figure 2 is a reflected ceiling plan of these spaces. The luminaires in these rooms are wired to a single circuit breaker. The rooms have white walls and ceilings and light gray concrete floors. Light output was measured in the mechanical room. Photomet-

ric measurements were also taken in the mechanical room, which is approximately 60 × 32 ft [18.3 × 9.7 meters (m)]. Electrical and thermal parameters were measured in the electrical room, which is approximately 10 × 11 ft (3.0 × 3.3 m) and contains all the electrical panels for the building. During the testing period, the input voltage to the entire circuit was at 280 ± 2 V, and the room temperature was at $22.4 \pm 0.2^\circ\text{C}$. The lighting system (with high power factor ballasts) had a power factor of 0.99 and leading voltage.

A total of 36 fluorescent lamp luminaires were connected to the circuit breaker. These were two-lamp luminaires with white reflectors but no lenses or enclosures (Thomas Day-Brite IA240-120). The lamps were rapid-start 40-W T12 lamps (Sylvania F40/D41 RS), with a CCT of 4100 K and a color rendering index (CRI) of 70. Energy-saving magnetic ballasts (MagneTek Universal 443-L-SLH-TC-P) for two F40T12 lamps operated the lamps at 277 V and 60 Hz. All the lamps, ballasts, and fixtures were newly purchased and installed at the Iowa Energy Center specifically for this testing, replacing the existing electronic ballasted T8 lamp system. The lamps and ballasts were seasoned for 120 hours prior to testing.

Figure 2. Testing Locations



NLPIP tested three lighting circuit power reducers, one each from Energy Automation System, Inc.; ESI Lighting Controls; and LTI International, Inc. Although the product from ESI Lighting Controls operates HID systems, NLPIP tested it for this report because the manufacturer promotes it for use with fluorescent systems with magnetic ballasts.

The ESI product is an autotransformer lighting circuit power reducer, and the EASI and the LTI products are electronic lighting circuit power reducers. NLPIP also obtained a fourth product from its manufacturer, EMAC, but could not get it to work properly, even after consulting with the manufacturer. Since the time frame for testing was limited, EMAC could not replace the product in time.

One manufacturer, LTI, would only participate if a representative could be present during the installation of their product. NLPIP agreed to this request but did not allow any manufacturer to be present during testing.

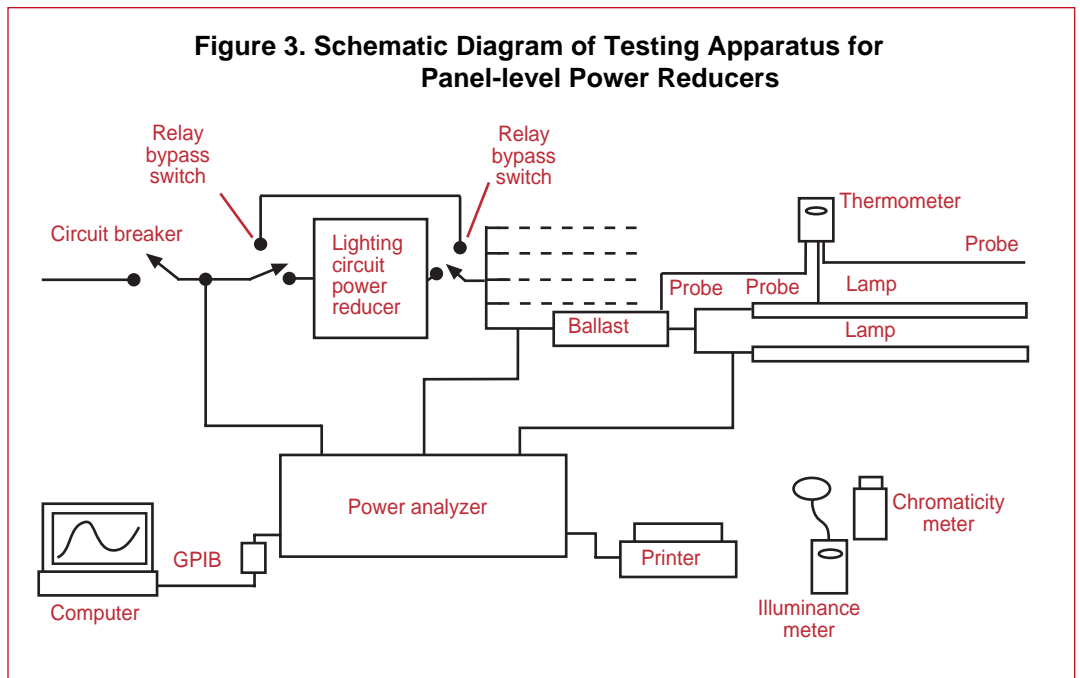
Each lighting circuit power reducer was installed between the circuit breaker and the lighting load, according to the manufacturers' instructions. A relay allowed NLPIP to bypass the power reducer.

A power analyzer (Xitron model 2503H-3CH+INT-A) was used to measure electrical parameters (voltage, current, active power, power factor, current crest factor, current THD, and frequency). The power

The ESI Power Reducer, Ready for Testing



analyzer interfaced through a General Purpose Interface Bus (GPIB) board to a personal computer with data acquisition software (LabVIEW). Electrical parameters were measured at the input to the power reducer, between the power reducer and the ballasts, and between the ballast and the lamps. Measurements were taken with the power reducers in operation and bypassed. A Pearson current



LTI Power Reducer Used in Testing



transformer was used between the ballast and the lamps for measurement of lamp current. NLPIP also measured lamp arc voltage and lamp electrode voltage at this point. A digital thermometer (Cooper SH66A) was used to measure the temperatures of the ballast case and room. None of the ballast case temperatures exceeded 50°C.

NLPIP measured illuminance at five spots on the floor of the mechanical room, using an illuminance meter (United Detector, Model #351). Each of the spots was directly beneath one of the luminaires.

NLPIP measured color shift by placing a diffuse white plate at spot #5 (see Figure 2 on p. 7) and measured the chromaticity values of the plate for each test condition using a Minolta CS 100 meter.

NLPIP tested each product at its closest setting to 25% power reduction. When a lighting circuit power reducer was first installed, the switches were set to bypass the power reducer. After a 30 minute warm-up, baseline measurements were taken. The switches were then set to include the power reducer in the circuit. Data were collected 30 minutes after the power reducer began operating.

Results

Tables 2 and 3 show that the products NLPIP tested for fluorescent lighting systems reduced input voltage by 21.0, 22.8, and 24.1% and illuminances by 31, 21, and 26% respectively. For HID lighting systems, independent test reports provided to NLPIP by manufacturers reported light loss percentages ranging from 26–39% with lighting circuit power reducers.

NLPIP describes the impact of lighting circuit power reducers on the lighting system by the power reducer efficiency factor (PREF), which is the ratio of the lighting system efficacy with power reducers installed to the system efficacy without power reducers.

A PREF greater than 1 indicates that the lighting circuit power reducer increases the efficacy of the lighting system, while a PREF less than 1 indicates that the product reduces the system efficacy. NLPIP calculated the PREF to be 1.02 for the LTI product, 0.97 for the ESI product, and 0.87 for the EASI product.

Of the three lighting circuit power reducers tested by NLPIP, the EASI lighting circuit power reducer caused CCF to rise to 1.90, in excess of the ANSI limit; both the LTI and the ESI products held CCF below 1.70. However, none of the power reducers maintained operating lamp electrode voltage above 2.5 V.

The ESI autotransformer power reducer preserves the voltage waveform from the line to the load and consequently does not significantly increase current THD to the circuit (see Table 4). However, the electronic lighting circuit power reducers chop part of each voltage cycle, which can produce harmonic distortions. NLPIP found that the EASI electronic lighting circuit power reducer had current THD as high as 45%, which is above the ANSI limit. The sum of its odd triple harmonics was also 45%, while the ANSI limit is 30%. LTI claims that the design of its product reduces harmonic distortion from its power reducer and provides a leading current. None of the harmonics produced by the LTI power reducer exceeded ANSI limits.

NLPIP found that the LTI and the ESI power reducers reduced the illuminance at the rate of about 0.3–0.4% per second, which was unnoticeable to the NLPIP researchers. However, the EASI product reduced the illuminance almost instantly; this change was noticeable.

NLPIP observed no flicker with either the LTI or the ESI lighting circuit power reducers tested at either full or 25% reduced power but observed that the EASI product caused flicker at both settings. NLPIP determined that the EASI product introduced a new frequency to the lighting load current. Ranging from 70–90 Hz, this new current frequency had an amplitude up to 50% of the amplitude at 60 Hz of the fundamental frequency. When the power level was reduced, the combination of the fundamental frequency with this additional frequency resulted in a lamp current modulation frequency between 10 and 30 Hz. This, in turn, produced a 20–60 Hz light output oscillation, which is perceptible.

The F40T12/RE741 fluorescent lamps, which were specially installed at the Iowa

Energy Center where the NLPIP testing took place, combine a halophosphor coating with a triphosphor coating. NLPIP found no change in chromaticity for any of the three products evaluated when the products reduced system power by 25%.

Alternative Technologies

Alternatives to installing lighting circuit power reducers for fluorescent lighting systems include energy-saving fluorescent lamps, specular reflectors, T8 lamps with electronic ballasts, dimming electronic ballasts, and power reducers that are hardwired between the ballast and the lamps. Some of these technologies can be used in combination with lighting circuit power reducers. Few alternatives exist for lighting circuit power reducers for HID lighting systems. Other alternatives, such as time clocks or occupancy sensors, reduce the operating time of lamp and ballasts, not their active power, and are not described in this section.

The EASI Power Reducer



Energy-Saving Lamps

Energy-saving lamps reduce power demand, typically by 15% for rapid-start lamps and 20% for instant-start lamps. Reduced light output is proportional to reduced power. The installation of energy-saving lamps is an easy retrofit that requires no rewiring. Although energy-saving lamps are compatible with most ballasts, they may reduce the ballast life of some magnetic ballasts due to increased heat from ballast winding losses. Another disadvantage to this technology is that energy-saving lamps can be easily replaced at any time by non-energy-saving lamps.

Delamping with Specular Reflectors

The most common application of specular reflectors is in 2×4 -ft four-lamp fluorescent luminaires. Usually, the installer removes two of the existing lamps, disconnects one ballast, repositions the sockets for the remaining two lamps, and then inserts a specular reflector, which has been designed to reflect and redirect light output from the lamps. Typically 40–50% power reductions can be achieved with 35–45% decreased light output. NLRIP's *Specifier Reports: Specular Reflectors* (1992) contains more details on this technology. Installing specular reflectors in conjunction with delamping may only be an acceptable option in areas where the existing illuminance is high. Building occupants may react negatively since this approach affects light distribution and may cause non-uniform illuminance.

T8 Lamps and Electronic Ballasts

Replacing T12 lamps and magnetic ballasts with T8 lamps and electronic ballasts is the most common efficiency upgrade for fluorescent lighting systems. NLRIP's *Lighting Answers: T8 Fluorescent Lamps* (1993) and *Specifier Reports: Electronic Ballasts* (1994), with supplements in 1995, 1996, and 1997 address these systems.

T8 lamps achieve both high color rendering and high efficacy by employing

rare-earth phosphors. Electronic ballasts further improve the efficacy of T8 lamps by 10–15% by operating them at much higher frequencies (typically above 20 kHz) than the standard 60 Hz at which magnetic ballasts operate lamps. Thus, a fluorescent lighting system using high-frequency electronic ballasts requires lower power to produce the same amount of light as a 60 Hz magnetic ballast system. Many electronic ballasts offer other advantages, such as reduced flicker and less heat, weight, and noise. However, installation cost is high because of the labor needed to replace the ballast in each luminaire.

Most commercially available electronic ballasts operate T8 lamps at a slightly reduced light output level while demanding significantly reduced power compared to magnetic ballasts. However, the light output of a luminaire using T8 lamps and electronic ballasts is not necessarily less than that of a luminaire using T12 lamps and magnetic ballasts, due to thermal and optical effects within the luminaire. T8 lamps also exhibit less lumen depreciation than T12 lamps.

Dimming Electronic Ballasts

Dimming electronic ballasts provide all the benefits offered by electronic ballasts plus the ability to vary light output, either through manual or automatic control. NLRIP's *Specifier Reports: Dimming Electronic Ballasts* (1995) provides details on these products.

Dimming electronic ballasts that reduce light output to 20% of maximum are widely available and are suitable for most energy-saving applications. They can be controlled by occupancy sensors to dim lamps when no motion is detected in a space, by photosensors where daylight is available, or by other energy management systems to dim lamps during peak demand hours. However, the installation cost for this retrofit is high because of the cost of the ballasts and the associated control products and the labor for replacing ballasts in individual fixtures.

Power Reducers Hardwired Between the Ballast and the Lamps

Individual power reducers are available to control luminaires. Both power and light output are reduced by a fixed amount, although the power reduction is usually greater than the light output reduction. The photometric distribution of the luminaire is not affected by the power reduction.

Most power reducers require some rewiring and mounting, so the installation costs are similar to those for electronic ballasts. Nearly all the power reducers previously tested by NLRIP reduced power factor and increased THD (see *Specifier Reports: Power Reducers*, 1992). Most power reducer manufacturers recommend that their products be used only with certain types of fluorescent lamp-ballast systems.

Further Information

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Data Table Terms and Definitions

The following data tables present information obtained by NLPIP during product testing. Most of the performance characteristics listed in these tables are discussed previously in this report, but the column headings are defined.

Active power. System input in watts.

Apparent power. The product of rms voltage and rms current.

Average illuminance. The average of the five illuminance measurements taken within the space controlled by the circuit level power reducer.

CCF. Defined as the peak current divided by the rms current of a lamp. CCF ranges from one to infinity.

Current THD. A measure of the degree to which the current waveform is distorted, expressed as a percentage.

Harmonics. Distortions of a periodic sinusoidal waveform represented as a harmonic series of sinusoidal waveforms of different amplitude and phase. A harmonic series is a group of different frequency waveforms that are multiples of the lowest or fundamental frequency.

Lamp electrode voltage. Voltage to the electrodes to operate the lamp.

Light loss (%). The reduced light output caused by the circuit level power reducer expressed as a percentage of the light output without the circuit level power reducer. (Full system output minus reduced output with a lighting circuit power reducer divided by the full system output times 100.)

Power factor. The ratio of active power to apparent power.

Power reduction. The amount by which active power to the lighting system is reduced by the lighting circuit power reducer.

Power reduction efficiency factor. A measure of the efficiency of a power reducer, representing the reduced light output in percent from a lighting circuit power reducer divided by the reduced active power in percent from a lighting circuit power reducer.

rms current. Root-mean-square current, an expression that quantifies the magnitude of a current that varies with time (as in ac circuits). Rms current is calculated as the square root of the mean of the squared values of current over one complete cycle. Rms current delivers the same power to a resistive load as an equivalent steady dc current.

Table 1. Manufacturer-Supplied Information

Lighting Circuit Power Reducers for Fluorescent Lighting Systems

Circuit (V)	Magnetic Ballast								Electronic Ballast							
	120		208		240		277		120		208		240		277	
Circuit (A)	12	16	12	16	12	16	12	16	12	16	12	16	12	16	12	16
Manufacturer																
EMAC 800-631-7995		•				•		•		•				•		•
Energy Automation System, Inc. 615-822-7250		•		•		•		•								
ESI Lighting Controls 416-763-3017	•		•		•		•		•		•		•		•	
LTI International, Inc. 800-584-5515		•						•		•						• ^a

^a Only for passive power correction electronic ballasts.

Lighting Circuit Power Reducers for Single-Phase HID Lighting Systems (MH, HPS, and Mercury Vapor) with CWA Ballasts

Circuit (V)	120						208			240				277				
	12	16	24	32	45	85	12	16	32	12	16	32	85	12	16	24	32	85
Manufacturer																		
EMAC ^{b, c, d, e} 800-631-7995	•	•									•	•			•	•		
Energy Automation System, Inc. ^f 615-822-7250		• ^g				•		• ^g		• ^g		•		• ^g				•
ESI Lighting Controls ^{b, e} 416-763-3017	•						•			•				•				
LTI International, Inc. ^h 800-584-5515		•		•				•	•		•	•			•			•
Warner Electric ^{b, c, e, f} 860-585-4500	•	•	•	•	•						•				•	•	•	

^a Only for passive power correction electronic ballasts.

^b Higher voltage models available.

^c Four-circuit models available.

^d Dual and three-circuit models available.

^e Also works with some fluorescent lighting systems.

^f Three-phase models available.

^g For 400-W lamps or greater.

^h For 175-W or greater metal halide and mercury vapor lamps and 250-W or greater high pressure sodium lamps

Table 2. NLPIP-Measured Data: Circuit Lighting Power Reducer Performance Measured at the Electrical Panel and at the Luminaire

Manufacturer	Trade Name	Catalog Number	System Performance				Luminaire Performance					
			Input rms Voltage (V)	Input rms Current (A)	Apparent Power (kVA)	Active Power (kW)	Input rms Voltage (V)	Input rms Current (mA)	Apparent Power (VA)	Active Power (W)	CCF ^a	Lamp Electrode Voltage ^b (rms V)
Baseline	NA	NA	280.8	12.0	3.4	3.3	280.0	330	92.4	91.5	1.63	3.1
EASI	FLC Fluorescent Light Controller	FLC-IV	280.0	14.1	3.9	2.6	227.3	385	87.4	70.4	1.90	2.4
ESI	NA	A12CS	279.9	9.28	2.6	2.5	211.1	326	68.8	67.0	1.55	2.2
LTI	Ultrawatt	LBU6A	281.8	11.7	3.3	2.6	220.0	322	70.9	69.8	1.45	2.3

NA = not applicable

^a ANSI standard for maximum CCF is 1.70.

^b ANSI standard for rapid-start lamps is 2.5–4.0.

Table 3. NLPIP-Measured Data: Power Reduction and Light Loss

Manufacturer	Trade Name	Catalog Number	Power Reduction (%)	Light Loss (%)	Power Reduction Efficiency Factor
Baseline	NA	NA	0	0	1
EASI	FLC Fluorescent Light Controller	FLC-IV	21.0	31	0.87
ESI	NA	A12CS	24.1	26	0.97
LTI	Ultrawatt	LBU6A	22.8	21	1.0

NA = not applicable

Table 4. NLPIP-Measured Data: Lighting Circuit Power Quality

Manufacturer	Trade Name	Catalog Number	Power Factor	Current THD (%)	Harmonics			
					Second (%)	Third (%)	Ninth (%)	Fifteenth (%)
Baseline ^a	NA	NA	0.989 lead	14.4	0.3	9.9	1.6	0.4
EASI	FLC Fluorescent Light Controller	FLC-IV	0.670 lag	45.2	2.1	44.6	2.0	0.4
ESI	NA	A12CS	0.974 lag	18.5	0.2	17.7	1.1	0.3
LTI	Ultrawatt	LBU6A	0.779 lead	17.3	1.8	13.7	1.3	0.2
ANSI Standard ^b	NA	NA	NA	<32	<5	<30	<30	<7

NA = not applicable

^a Measurements were taken with power reducer bypassed.

^b For comparison only. ANSI standard applies to the ballast and not to the entire circuit.

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Lighting Circuit Power Reducers

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Lighting Circuit Power Reducers

Introduction

This supplement to *Specifier Reports: Lighting Circuit Power Reducers* presents manufacturer-supplied and NLPIP-measured data on a product not tested in the original document. For background information on this technology, consult the original report at www.lrc.rpi.edu/programs/NLPIP/publications.asp.

Performance Evaluations

NLPIP evaluated the Electric City model ES-1060-277-MONO-N1 (ECC-SU10) lighting circuit power reducer, shown in Figure 1. Manufacturer information gathered from product literature about this lighting circuit power reducer is contained in Table 1.

NLPIP tested this product with fluorescent lighting systems consisting of four different lamp/ballast combinations, referred to in this study as Groups 1 through 4. Table 2 defines these four lamp/ballast combinations. The lamp/ballast combination in Group 1, which used magnetic rapid-start ballasts and T12 fluorescent lamps, was also used in the original report. Because T8 fluorescent systems now outsell T12 fluorescent systems in the United States (US Census Bureau 2005), NLPIP also evaluated the performance of the lighting circuit power reducer with three other combinations of T8 fluorescent lamps and electronic instant-start ballasts. These lamp/ballast combinations, with components from different manufacturers, are referred to as Groups 2 through 4.

Figure 1. Electric City lighting circuit power reducer



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NLPIP Testing Procedure

As in the original study, NLPIP tested the Electric City lighting circuit power reducer on the fluorescent lighting systems already installed in the utility room of the Iowa Energy Center's Energy Resource Station in Ankeny, Iowa. NLPIP used the same testing space again, which is shown on p. 7 of the original report. The testing occurred from August 9, 2004 to August 11, 2004.

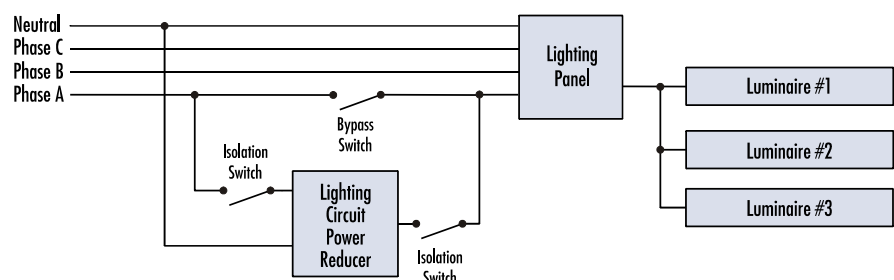
Electric City provides lighting circuit power reducers with a variety of current-carrying capacities (shown in Table 1), as well as single-phase and three-phase options. The lighting circuit power reducer tested in this supplement had a current capacity of 60 amps (A); in the original report, the products had a 20 A capacity. To evaluate this larger capacity, NLPIP loaded the lighting circuit power reducer with other fluorescent lighting loads from within the building. For purposes of this study, NLPIP adjusted the voltage setting by a keypad located on the front panel of the lighting circuit power reducer. While Electric City also provides software to control the lighting circuit power reducer from a remote location, NLPIP did not evaluate this software.

Prior to testing, NLPIP seasoned all of the T8 fluorescent lamps for 100 hours (h), as specified by the Illuminating Engineering Society of North America (IESNA) in the *IESNA Guide to Lamp Seasoning* (1999). NLPIP used the standard 3-hours-on, 20-minutes-off cycle. Seasoning occurred in the NLPIP fluorescent lamp testing laboratory in Watervliet, New York. The T12 fluorescent lamps were installed in the test site's lighting system and seasoned there to at least 100 h before testing.

Electricians from the Energy Resource Station installed the lighting circuit power reducer, according to manufacturer's instructions, in the electrical circuit before the lighting panel (see Figure 2). Representatives from Electric City commissioned the lighting circuit power reducer and verified that it was installed properly. However, they were not present for testing.

Before testing each group, NLPIP took baseline measurements with the lighting circuit power reducer out of the circuit. The lighting circuit power reducer was then removed from the system by opening the two isolation switches and closing the bypass switch (see Figure 2). After operating the system for a 30-minute (min) warm-up period, which allowed the lamps and ballasts to stabilize, NLPIP took baseline measurements of voltage, current, temperature, and illuminance. They compared these measurements to each group's performance data to evaluate power and light output reduction for the system.

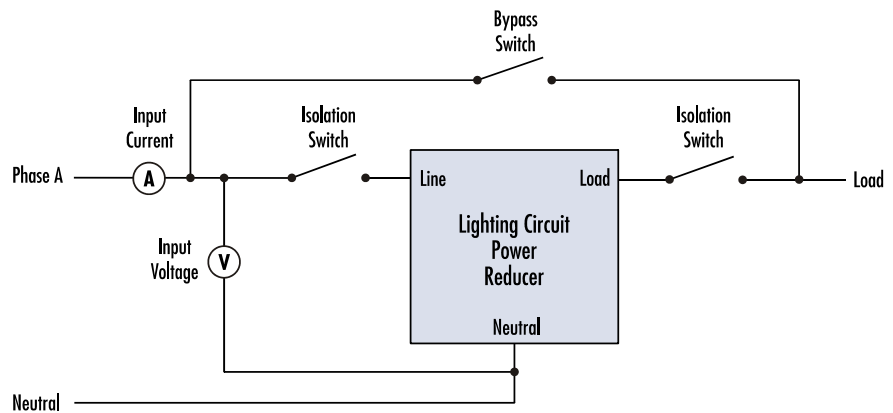
Figure 2. Lighting circuit power reducer schematic



To switch on the lighting circuit power reducer for testing, NLPPI opened the bypass switch and closed the isolation switches (see Figure 2). After another 30-min warm-up period, testing began on Group 1, which consisted of the magnetic rapid-start ballasts that were already installed at the test site. Performance measurements were taken (see Figures 3 and 4):

- at the input to the lighting circuit power reducer
- at the input to the ballasts
- between the ballasts and the lamps
- under three luminaires

Figure 3. Lighting circuit power reducer measurement locations



When the Group 1 test was complete, NLPPI replaced all of the T12 fluorescent lamps and magnetic rapid-start ballasts in the 35 luminaires with the T8 fluorescent lamps and electronic instant-start ballasts. This combination was designated Group 2. After a baseline measurement was made, NLPPI took test measurements at the same locations used for Group 1.

Figure 4a. Group 1: Magnetic rapid-start ballast and T12 fluorescent lamp combination

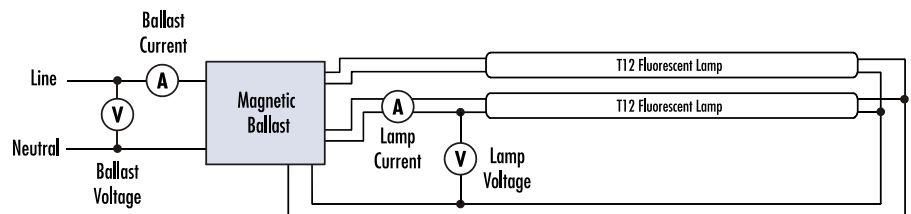
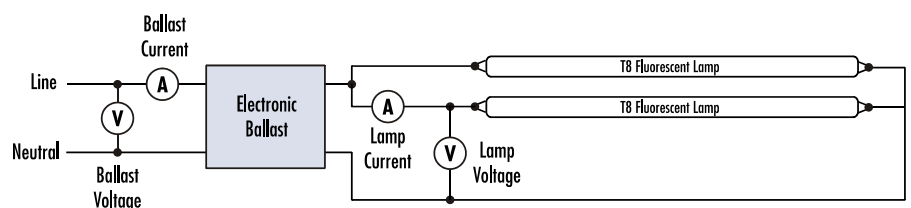


Figure 4b. Groups 2 through 4: Electronic instant-start ballast and T8 fluorescent lamp combination



Because Groups 3 and 4 also used T8 fluorescent lamps and electronic instant-start ballasts, NLRIP changed the individual lamp/ballast combinations for those groups only at the three measured luminaires. Baseline and test measurements for Groups 3 and 4 were made in the same manner as for the other groups.

Prior to testing, Electric City provided settings for using the lighting circuit power reducer with T8 fluorescent lamps. These individual settings were based on minimal lamp current values for the different lamp models. To achieve this, NLRIP adjusted the lighting circuit power reducer voltage setting to meet the lamp current requirement for each manufacturer's lamp. No recommended setting was provided for the T12 fluorescent lamp, so NLRIP tested it at the setting most closely corresponding to a 25% power reduction, the amount of the power reduction tested in the original study.

An oscilloscope (LeCroy WaveRunner, model 6050) was used to measure the following electrical parameters:

- input root-mean-squared (rms) voltage
- input rms current
- active power

NLRIP used a differential voltage probe (LeCroy, model ADP305) to measure voltage at the inputs to both the lighting circuit power reducer and the ballast. The same probe also measured lamp voltage. NLRIP used a current probe (LeCroy, model CP150) to measure the current at the input of the lighting circuit power reducer, while different current probe (LeCroy, model CP015) was used to measure the current at the inputs to the ballasts and lamps. A digital thermometer (Omega, model 872A) with a type J thermocouple measured the temperature of the room, which was maintained at $25 \pm 2^\circ\text{C}$. NLRIP measured light output by measuring the illuminance directly below each of the three luminaires tested, using an illuminance meter (Gigahertz-Optik, model X91). All test equipment was calibrated prior to usage.

Results

Tables 3 and 4 show system performance and average luminaire performance of the products tested by NLRIP. Power reductions between 14.5% and 22.4% occurred in the four fluorescent lighting systems when using the Electric City lighting circuit power reducer. These performance data were based on the average measurements of the three luminaires. Light losses were between 15.0% and 21.5%. The differences in power reduction and light loss for Groups 2 through 4 were primarily due to the different voltage settings used on each of the T8 fluorescent lamps. As mentioned, these settings were based on the lamp current values provided by Electric City, by manufacturer, for each lamp type. This raises an important issue: the settings on the lighting circuit power reducer may need to be adjusted if these lamps are replaced with different manufacturer's lamps. End users are advised to contact Electric City to discuss this issue.

NLRIP evaluated power in several ways. Apparent power was calculated by multiplying rms voltage and rms current. The power reducer efficiency factor (PREF) in Table 4, which describes the impact of a lighting circuit power reducer on the efficiency of a lighting system, is the ratio of lighting system efficiency with the power reducer installed to the system efficiency without the power reducer. A PREF greater than 1.0 indicates that the lighting circuit power reducer increases the efficiency of the lighting system, while a PREF less than 1.0 indicates that the product reduces system efficiency. For Group 1, NLRIP calculated a PREF of 1.03 using the Electric City product, while the

Active Power Factor Correction

Electric City does not recommend using the lighting circuit power reducer examined in this study with an electronic ballast that has active power factor correction. Therefore, NLPPI performed an additional test with this type of ballast to demonstrate the effects. As expected, there was no power reduction and no light loss when the voltage of the lighting circuit power reducer was lowered 18%, from 280 to 230 volts. Although there was no change in light output or power due to the lower voltage, more current was needed to operate the lamp at a constant power. This additional current could potentially overload an electrical distribution system, if it was operating near its limits. If you are unsure if a particular ballast has active power factor correction, contact the manufacturer.

other three groups each had a PREF just below 1.0. Presumably, the PREF for Group 1 was greater than 1.0 because the magnetic rapid-start ballasts in Group 1 had lower resistive losses when operated at a lower voltage due to a lower current, thereby making the system more efficient. In all test instances, there was a load reduction that would contribute to energy savings. For a discussion of the potential merit and application of lighting circuit power reducers, see *Lighting Circuit Power Reducers: Are They (Cost) Effective?* (Krepchin 2003).

As in the original *Specifier Reports*, current crest factor (CCF) was calculated by dividing peak current by rms current. Of the four groups, the CCF of Group 1 reduced slightly when compared to baseline measurements, while the CCF for Groups 2 through 4 increased slightly when compared to baseline measurements. In three of four cases, the CCF was below the American National Standards Institute (ANSI) specification of 1.70 given in *High Frequency Fluorescent Lamp Ballasts—Supplements* (2002). The CCF in the other case was 1.73.

Table 5 shows NLPPI-measured data for lighting circuit power quality. Power factor was calculated by dividing active power by apparent power. In all cases the power factor was above 0.99. The Electric City lighting circuit power reducer preserved the voltage waveform from the line to the load and, consequently, did not significantly increase current total harmonic distribution (THD) on the electrical distribution system. The THD was calculated from the current waveforms, measured at the input to the lighting circuit power reducer.

In all cases the THD, odd triples, and individual harmonics above the 11th harmonic were under the limit specified in *High Frequency Fluorescent Lamp Ballasts—Supplements* (2002). In Groups 2 through 4, which used electronic instant-start ballasts, the Electric City lighting circuit power reducer actually lowered the current THD from approximately 10.5% to approximately 6.5%, when compared to the baseline measurements. For a discussion of harmonics and odd triples, see p. 4 of the original report.

Data Tables and Terms

Table 1 contains manufacturer product information gathered by NLPPI for the Electric City lighting circuit power reducer. Table 2 contains the lamp and ballast combinations used in testing. Tables 3 through 5 contain performance data measured and calculated by NLPPI as follows:

- Table 3: system and luminaire performance data
- Table 4: power reduction and light loss data
- Table 5: lighting circuit power quality data

Although most of the performance characteristics listed in these tables are either self-explanatory or discussed in the report, some items require further explanation. Please refer to Data Tables and Terms on p. 13 in *Specifier Reports: Lighting Circuit Power Reducers* for definitions of other terms used in this document that are not explained here.

Illuminance. The amount of light (luminous flux) incident on a surface area, measured in lumens per square meter (lux).

Individual >11th (max). Measured according to ANSI standard C82.11 Consolidated-2002 (2002), the highest individual value of each of the 12th to 33rd harmonics.

Odd triples. The root-mean-squared (rms) of the 3rd, 9th, 15th, 21st, 27th and 33rd harmonics. These harmonic currents potentially have the greatest impact on electrical systems, because they add on the neutral conductor in a three-phase system, increasing the risk of overload.

Table 1. Manufacturer-Supplied Information: Lighting Circuit Power Reducers for Fluorescent Lighting Systems

Circuit voltage (V)	120/208					120/240					277/480				
	40	60	80	120	200	40	60	80	120	200	40	60	80	120	200
Electric City ^a ES-1060-277-MONO-N1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

^aShould only be used with passive power correction ballasts.

Table 2. NLPIP Test Groups

Group	Lamp Type	Lamp Manufacturer	Lamp Model Number	Ballast Type	Starting Method	Ballast Manufacturer	Ballast Model Number
1	T12	OSRAM SYLVANIA	F40/D41/ECO	Magnetic	Rapid-start	MagneTek (Universal)	443-L-SLH-TC-P
2	T8	GE Lighting	F32T8/SP41/ECO	Electronic	Instant-start	Universal	B2321277RHA
3	T8	OSRAM SYLVANIA	F032/741/ECO	Electronic	Instant-start	OSRAM SYLVANIA	QT2x32T8/277ISN SC
4	T8	Philips	F32T8/TL741/ALTO	Electronic	Instant-start	Advance	VEL-2P332-MC

Table 3. NLPIP-Measured Data: Lighting Circuit Power Reducer Performance Measured at the Electrical Panel and at the Luminaire

Group	Manufacturer	System Performance					Average Luminaire Performance						
		Voltage Setting (V)	Input rms Voltage (V)	Input rms Current (A)	Apparent Power (kVA)	Active Power (kW)	Input rms Voltage (V)	Input rms Current (mA)	Apparent Power (VA)	Active Power (W)	Illuminance (lux)	Lamp rms Current (mA)	CCF ^a
1	Baseline ^b	NA	278.9	29.1	8.12	8.09	275.7	322.8	89.0	87.8	1213	369	1.67
	Electric City	214	279.2	23.4	6.53	6.47	213.6	326.6	69.8	68.1	974	286	1.56
2	Baseline ^b	NA	279.4	25.8	7.21	7.17	277.4	214.6	59.5	58.3	1101	186	1.58
	Electric City	237	279.0	22.6	6.31	6.26	235.9	210.8	49.7	47.5	882	144	1.61
3	Baseline ^b	NA	281.8	25.8	7.26	7.22	278.6	215.5	60.0	59.2	1163	195	1.69
	Electric City	231	281.4	22.0	6.19	6.13	230.8	213.4	49.3	47.8	913	145	1.73
4	Baseline ^b	NA	281.4	26.0	7.32	7.28	278.2	222.0	61.8	60.9	1169	186	1.60
	Electric City	244	278.8	24.1	6.72	6.68	243.5	220.8	53.8	52.0	994	152	1.63

NA = Not Applicable

^aANSI standard C82.11 Supplement-2002 for maximum CCF is 1.70.

^bMeasurements were taken with the lighting circuit power reducer bypassed.

Table 4. NLPIP-Measured Data: Power Reduction and Light Loss

Group	Voltage Setting (V)	Power Reduction (%)	Light Loss (%)	Power Reduction Efficiency Factor
1	214	22.4	19.7	1.03
2	237	18.6	19.9	0.98
3	231	19.2	21.5	0.97
4	244	14.5	15.0	0.99

Table 5. NLPIP-Measured Data: Lighting Circuit Power Quality

Group	Manufacturer	Voltage Setting (V)	Power Factor	Current THD (%)	Harmonics			
					Second (%)	Third (%)	Odd Triples (%)	Individual >11 th (max) (%)
1	Baseline ^a	NA	0.996	8.2	0.3	2.9	3.0	0.3
	Electric City	214	0.991	7.3	0.2	6.3	6.4	0.3
2	Baseline ^a	NA	0.994	10.5	0.2	6.8	7.0	0.8
	Electric City	237	0.992	6.5	0.1	3.8	3.9	0.5
3	Baseline ^a	NA	0.994	10.6	0.1	7.0	7.2	0.8
	Electric City	231	0.992	6.5	0.1	3.9	3.9	0.4
4	Baseline ^a	NA	0.994	10.4	0.2	6.6	6.8	0.8
	Electric City	244	0.994	6.8	0.1	3.8	3.0	0.3
	ANSI Standard ^b	NA	NA	<32	<5	<30	<30	<7

NA = Not Applicable

^a Measurements were taken with the lighting circuit power reducer bypassed.

^b For comparison only. ANSI standard C82.11 Consolidated–2002 applies to the ballast and not the entire circuit.

Further Information

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Lighting Answers

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