Impact of LED Lighting on Electrical Networks

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Executive summary

Buildings are responsible for 40% of total energy consumption and lighting represents 32% of consumption in an average office building. Most buildings are equipped with inefficient lighting. This results in higher energy costs. Compared with traditional incandescent lighting, Light Emitting Diode (LED) technology is more efficient (consumes 75% less energy). This paper reviews LED technology and offers advice for integrating LED into existing electrical networks.

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Introduction

It is sound public policy and good business to consider options for controlling the energy we consume in the buildings that we occupy every day. In 2013, for example, 40% of total U.S. energy was consumed by residential and commercial buildings.[1] Many organizations are beginning to consider the carbon consumption of their ongoing operations and are realizing that inefficient lighting is a significant contributor to the environmental burden of business and industry. In fact, lighting represents 32% of energy consumption in an average office building (see **Figure 1**) [2].

Research has shown that lighting efficiency varies widely across different buildings and the actual efficiencies of real installations are well below the practical achievable best-in-class values. In order to address this issue, this paper will focus on the power consumption and efficiency of Energy Star-rated LED systems which use at least 75% less energy, and last 25 times longer, than incandescent lighting.[3] In fact, a conventional incandescent lamp has a luminous efficiency ranging between 5 lm/W and 20 lm/W, while lamps employing LED technology can achieve a luminous efficiency of 140 lm/W. In addition to efficiency, LED technology benefits include cost savings, compliance to new energy saving regulations (e.g., RT2012 in France, for example) and reliable comfort.

An internal Schneider Electric study assessed the impact of LED lighting loads on low-voltage electrical networks and on the associated control and protection devices. This paper reviews some of those observations and test results.

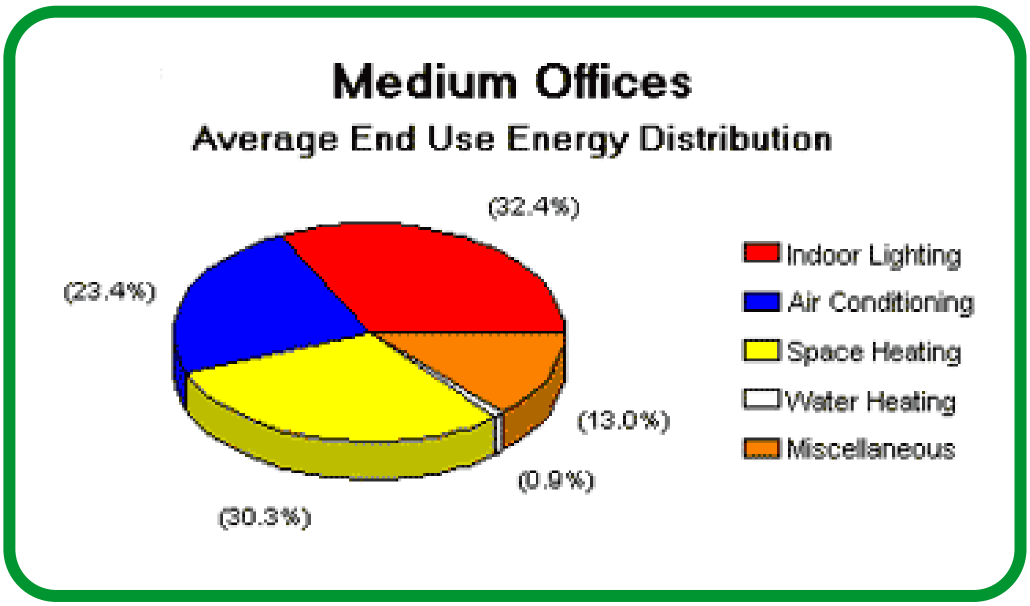

Figure 1
Profile of medium-sized offices in terms of energy consumption distribution (courtesy of Alabama Power)

Some terminology

To better understand why the use of LED lighting can result in these remarkable efficiency gains, basic terminology needs to first be explained. Later, the technical specification will be reviewed so that users can best assess how to integrate LED into existing building power networks. Listed below are definitions of the key terms utilized in this paper:

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[1] US Energy Information Administration, "Frequently asked questions", 2014 http://www.eia.gov/tools/faqs/faq.cfm?id=86&t=1

[2] Alabama Power, "Compare your energy spending against others in the Retail and Office Building industries" http://www.alabamapower.com/business/save-money-energy/energy-know-how/compare-costs/retail-industry.asp#OfficeBuildingData

[3] http://energy.gov/energysaver/articles/led-lighting

- **LED** (Light Emitting Diode) - A diode type semiconductor which emits light when a current passes through it. LED semiconductor materials convert electrical energy into visible electromagnetic radiation (i.e., into light).
- **LED component -** The substrate and primary optical unit of the light assembly. The purpose of the LED component is to protect the semiconductor and to conduct the heat generated from LED to dissipation systems.
- **LED module -** The assembly of one or more LED components with optical, mechanical and thermal elements.
- **LED luminaire -** A complete system consisting of an LED module, a housing, an optical reflector, wiring, connectors, joints, heat dissipation system (heat sink or fan), and, in most cases, the driver.
- **Driver -** An electronic device which can convert the electric power of a low-voltage AC electrical network into electric power appropriate for the LED luminaire (direct voltage and current). The driver may be external or internal to the luminaire. A driver can power one or more luminaires. Light dimming function can be embedded in this component.

Figure 2 illustrates the relationship of these various components to one another.

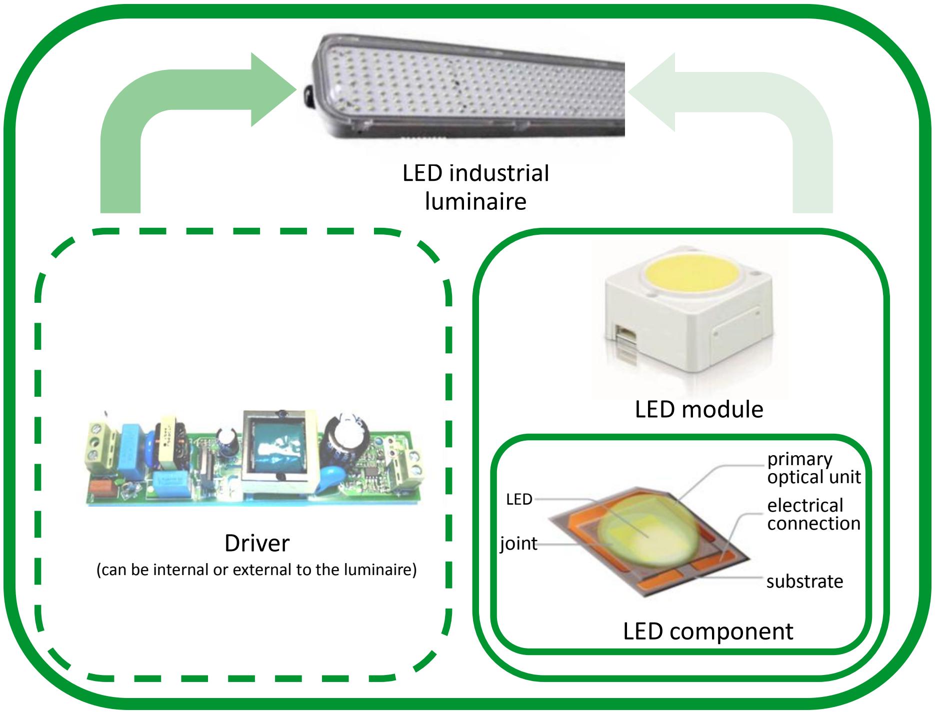


Figure 2
An LED is just one small element within a larger construct that is sold commercially as an assembled luminaire

Electrical characteristics

Schneider Electric laboratories conducted a series of studies to determine how LED technology integrates into the electrical networks of common office buildings. The study included evaluation of start states, the role and impact of the driver, the role of the power supply, and behaviors exhibited at steady state (once the light is “on’).

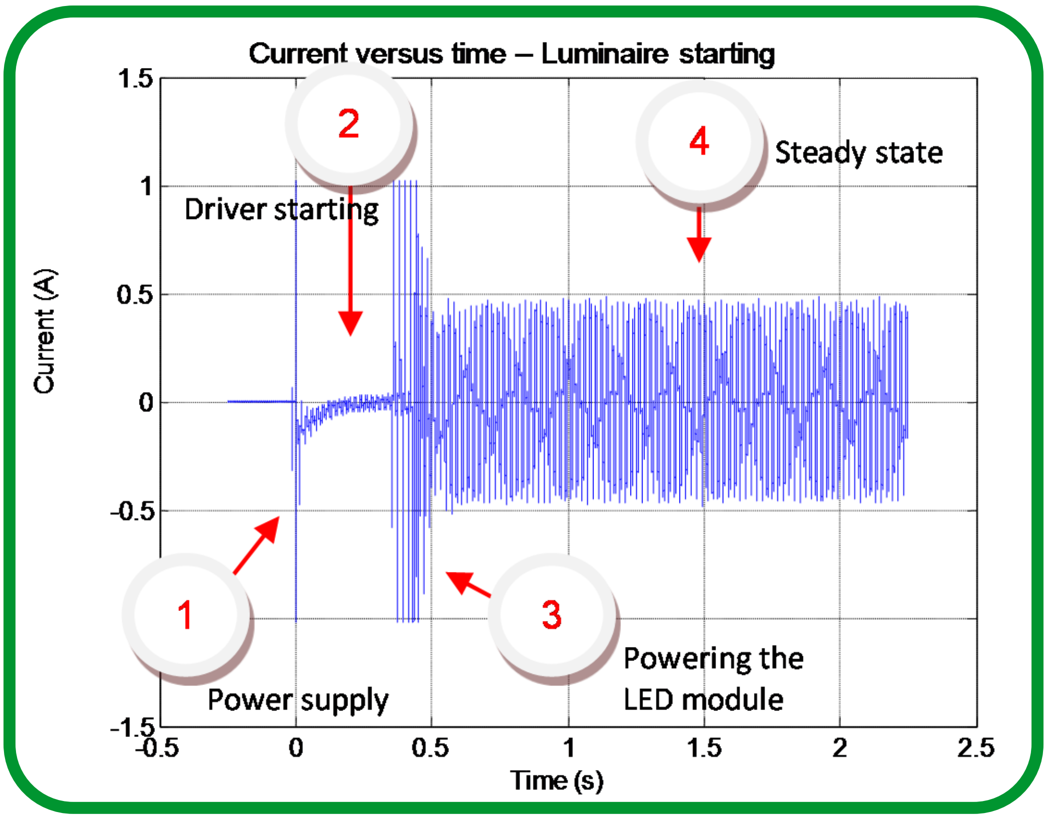
When an LED luminaire is first energized, a variable current is required by the luminaire during the first second time interval, and then the current stabilizes as soon as rated operating conditions are reached. Three transient fundamental events occur during the start up phase: the energizing of the power supply of the luminaire, the start of the driver, and the powering of the LED module (light is on). Then the luminaire transitions to the steady state operating condition.

In the initial moments after a luminaire is energized, a significant transient current appears (up to 253 times the rated current according to Schneider Electric measurements) due to the capacitors used to perform the power factor correction (the power factor of LED luminaires is generally greater than 90%, since the luminaire drivers include a power factor correction stage). The duration of this transient current is less than 1 millisecond (ms) for one luminaire. When the luminaire is powered on, the current will be at its higher level when the voltage angle is 90° (in that case, the voltage is at its peak value of 325 V for a 230 Volt AC network). When switching on at zero angle voltage, the inrush current is far smaller.

Once the inrush current has passed, a time range of between 100 ms and 1.5 seconds elapses. During this time, the driver is initialized (power supply for electronic control circuits, are energized, for example). The current consumed during this phase is less than the rated current.

Once the driver is initialized, the LED module is energized and light appears. An overload of about twice the rated current occurs during the initial period of power supply of the module containing the LEDs. **Figure 3** illustrates the various stages involved in energizing the luminaire. Note that state 4 in **Figure 3** represents the steady state operating condition.

Figure 3
Illustration of four states of an LED being energized



In the steady-state condition, the current consumed by LED luminaires is not perfectly sinusoidal. The total harmonic distortion of current (THDI) ranges between 10% and 20%. Given that the rated currents of LED luminaires are low, the impact of these currents on network voltage is slight. Measurements in various industrial plants powered by the public low-voltage power supply system (on which the short-circuit impedance is low) show that the total voltage harmonic distortion (THDV) is generally less than 3%. According to the IEC 61000-2-4[4] standard relating to the compatibility levels of voltage tolerances, if the THDV is

[4] IEC 61000-2-4 standard: Electromagnetic compatibility (EMC) – Part 2: Environment – Section 4: Compatibility levels in industrial plants for low-frequency conducted disturbances

less than 5% (class 1 electromagnetic environment), the network is considered sound and compliant.

Common mode currents

When currents flow without close-by opposing currents, the unopposed portion of current is referred to as common mode current. Common mode currents can result in radiation which can then result in interference or distortion.

A series of tests was performed to see how LED technology deals with this challenge. In Schneider Electric's testing, measurements were performed by first energizing 20 luminaires that were isolated from earth. Given the configuration, the leakage current could only be looped back via the protective earth (PE) conductor of the power cable. The current flowing in this conductor at the energizing stage is presented below (see **Figure 4**).

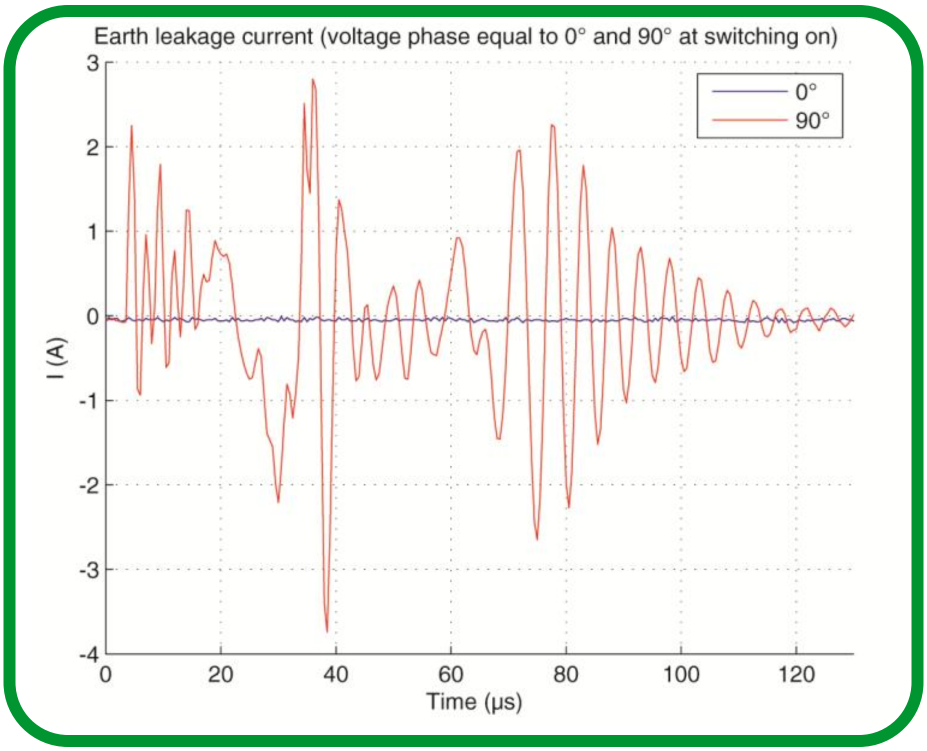


Figure 4
Depiction of earth leakage current test results

During testing, earth leakage currents and voltage peaks were observed to determine maximum amounts. For switching on at zero voltage, the leakage current was almost zero. The frequency of the transient current is high (about 100 kHz). At the steady state stage, for the 20 luminaires isolated from earth, the leakage current value measured at 50 Hz was about 2 mA.

Impact on electrical networks

In order to understand the impact that LED technologies will have on existing electrical networks, it is important to analyze the behavior of all key elements in the network. Below is a list of potential risks to consider and also some recommendations for mitigating those risks.

Issue: Improper choice of circuit breakers

The choice of circuit-breaker characteristics depends on the nature of the load powered. The rating depends on the cross section of the cables to be protected and the curves are chosen according to the loads' inrush current. When switching on LED luminaires, very significant inrush currents occur. Normative curves (the "standard" curves as defined by NF EN 60898[5] and NF EN 61947-2[6]) used for circuit-breaker certifications (which characterize fault currents of a duration exceeding 10 ms) give the circuit breakers' tripping threshold for currents maintained for 10 ms or more. For transient currents of duration less than 10 ms, no normalized curve exists.

In what can be deemed a typical situation, Schneider Electric performed measurements during a lighting installation in a commercial building. A B-curve 20 A rating circuit breaker (see **Figure 5**) was tripped upon energizing a circuit powering 25 luminaires (with a capacity of 56 watts each). The following was observed:

- a rated power of 1400W,
- a maximum transient inrush current is 237 A,
- the duration of the transient current was 2.5 ms

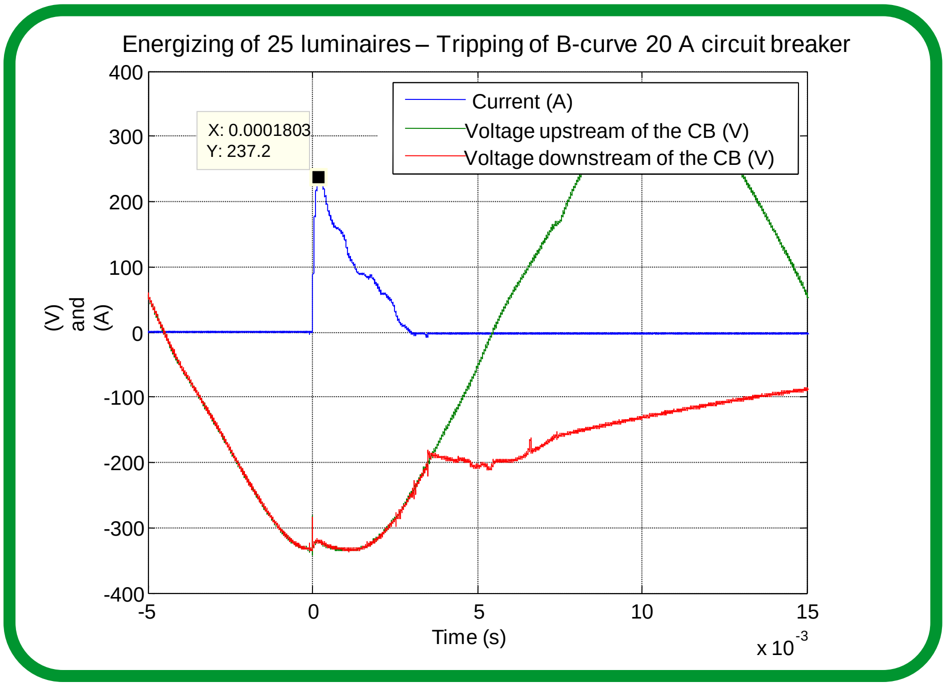


Figure 5
Tripping of a B-curve 20 A circuit breaker

Recommendation:

In order to address this situation, an appropriate choice of the circuit breaker device must be made during the design phase (see **Figures 6a, 6b and 6c**). The peak value of the current at switching on depends on the energizing time, the number of luminaires forming the lighting circuit, and the short-circuit power and architecture of the network.

The curves presented in **Figures 6a, 6b and 6c** provide information relating to the number of luminaires that can be connected downstream of a circuit breaker depending on its characteristics (rating and tripping curve of the magnetic protective device). These curves were produced based on the unfavorable conditions which generate a maximum current peak at circuit energizing.

[5] NF EN 60898 standard: Electrical accessories – Circuit breakers for overcurrent protection for household and similar installations

[6] NF EN 60947-2 standard: Low-voltage switchgear and controlgear - Part 2: Circuit breakers

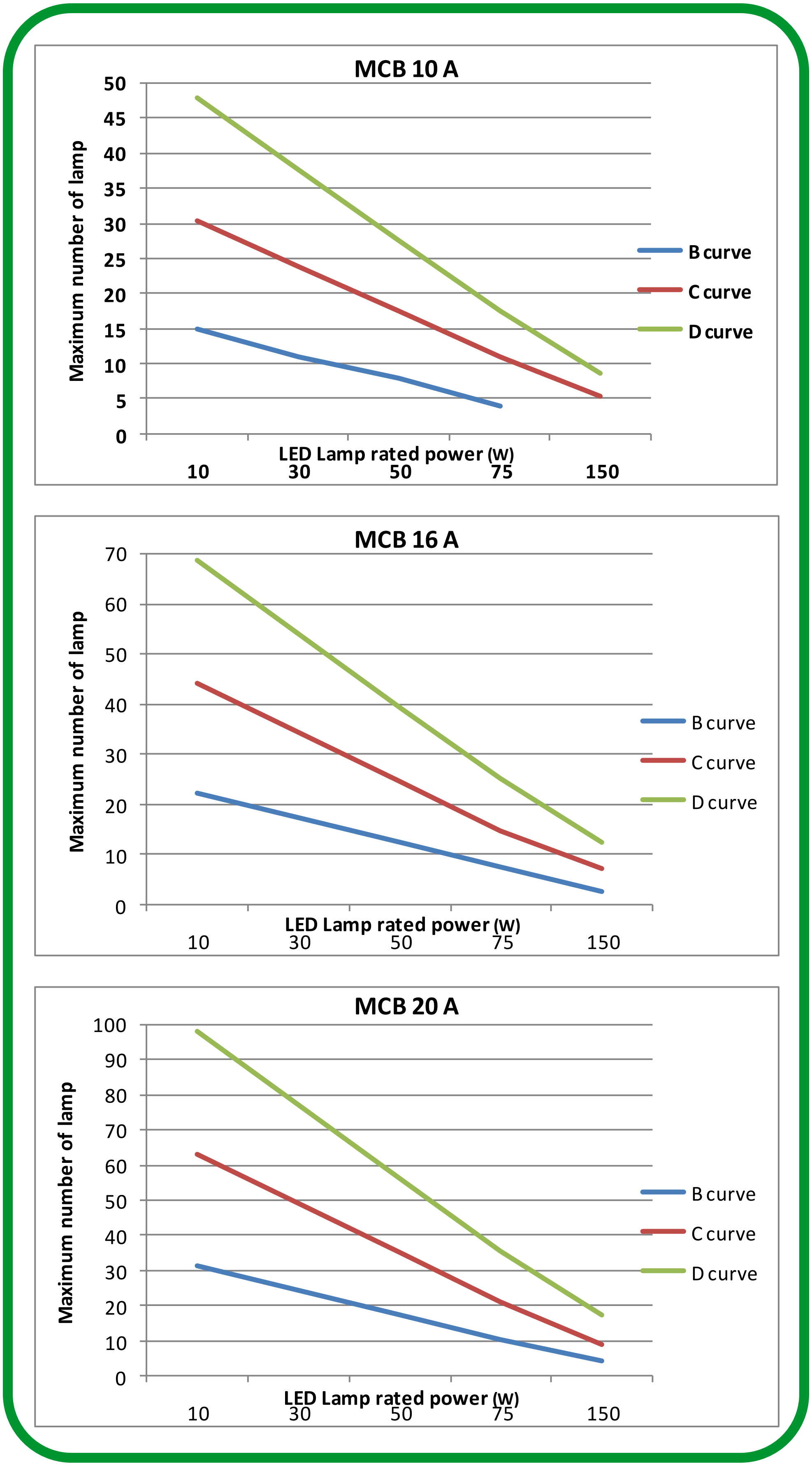


Figure 6 a, b, c

Number of luminaries that can be connected within watt ranges at various amperage ratings

Issue: Earth leakage current

The Schneider Electric measurements showed that the leakage current is at maximum for switching on at the voltage peak. The frequency of this transient current is high (about 100 kHz). For switching on at zero voltage, the leakage current is practically zero (see **Figure 4**).

Recommendation:

The permanent earth leakage current at 50 Hz is generally less than 1 mA for a luminaire. Given that lighting circuits are protected by earth leakage protection devices of 300 mA rating, a large number of luminaires can be installed downstream of a protective device. For a frequency of 100 kHz, the current is not detected by the earth leakage protection devices.

Issue: Premature wear of contactors

The standardized classes of use (NF EN 60947-4-1 [7] and IEC 61095 [8]) stipulate the current values that the contactor must establish or cut off. These depend on the nature of the load controlled and the conditions under which circuit closing and breaking is performed. Only lighting loads employing conventional technologies are covered by this standard, and no test is required to certify contactors for controlling luminaires that employ LED technology. For switchgear and controlgear, the main constraints of LED lighting technology are the high transient currents which generate premature wear of contact pad materials (see **Figure 7**).

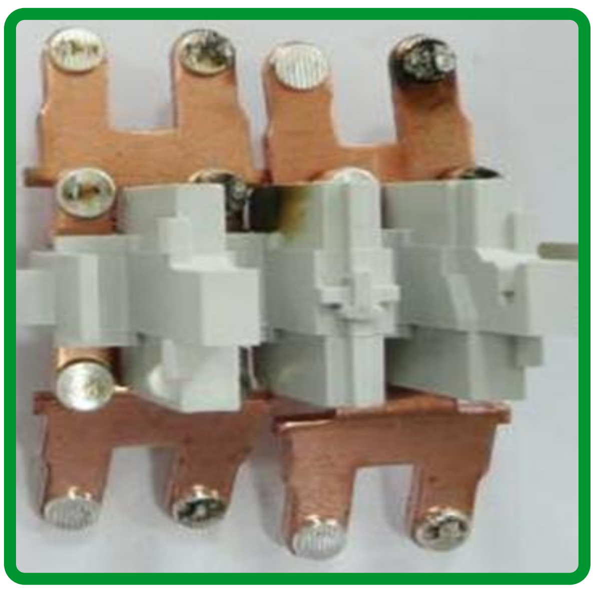


Figure 7
Example of worn contact pads

Recommendations:

1. Contactor deratings given by manufacturers must be taken into account in the design phase in order to obtain the best adapted coordination with LED luminaires and performances compliance (electrical endurance).
2. For three-phase circuits (power supply of luminaires between a phase conductor and the neutral conductor), switchgear and controlgear of the three-pole type is preferable to a control device of the four-pole type. Not switched, the neutral conductor will help to prevent a harmful voltage surge at power frequency from being applied across the terminals of the luminaire if the neutral conductor fails to close.

[7] NF EN 60947-4-1: Low-voltage switchgear and controlgear - Part 4-1: Contactors and motor-starters - Electromechanical contactors and motor-starters

[8] IEC 61095: Electromechanical contactors for household and similar purposes

Issue: Overheating of the neutral conductor

Luminaires employing LED technology are characterized as nonlinear loads which generate harmonic currents. Three-phase circuits can be passed through by harmonic currents of harmonic number 3 and multiples of 3 which can lead to overcurrent in the neutral conductor.

Recommendation:

In three-phase circuits that could be passed through by harmonic currents of harmonic number 3 and multiples of 3, the NFC 15-100[9] and IEC 60364[10] installation standards specify the sizing rules for the neutral conductor to prevent harmful overcurrents. The effects concern the thermal consequences on switchgear and controlgear, cables and equipment. They are due to harmonic levels maintained for durations equal to or greater than 10 minutes.

Other suggestions:

- **Smart relays - Smart contactor activated by voltage zero crossing**

  The operating principle of the static relay consists of the following: when the control voltage is applied to the relay input, an internal static component performs the switching function at zero crossing of the voltage wave. The precision at switching (connection to the network) is very good. The inrush current is then reduced (see **Figure 8**). As a result, it is possible to use circuit breakers without derating. The number of luminaires that can be powered by a single circuit is limited only by the thermal withstand of the smart relay.

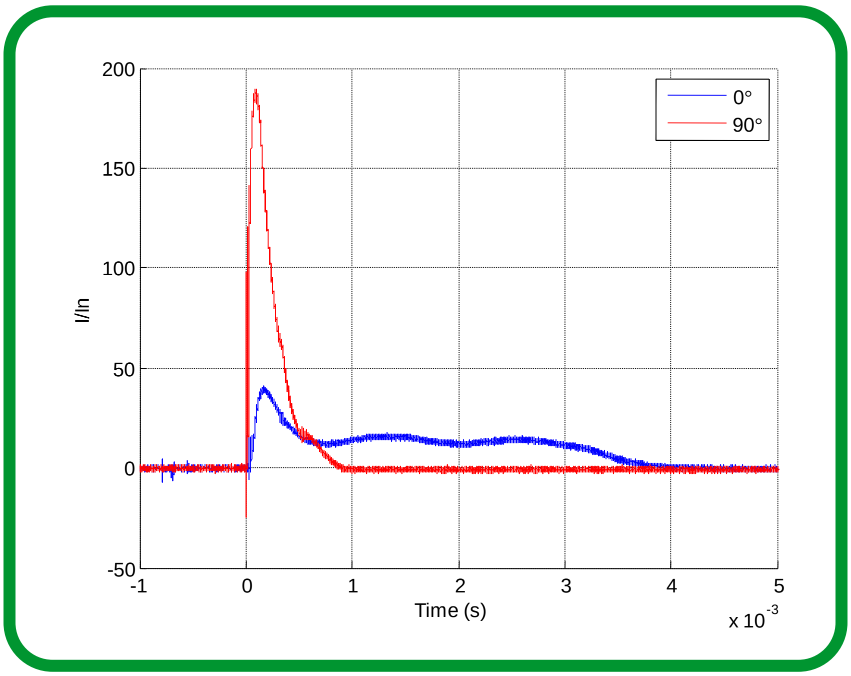


Figure 8
Current at switching "on" according to voltage angle (zero crossing and 90°)

- **Protection against the indirect effects of lightning**

  The luminaire consists of electronic parts that are sensitive to overvoltages. The installation of "surge arrester" type protective devices is recommended for exposed installations such as, for example, public lighting.

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[9] NF C 15-100 standard: Low-voltage electrical installations

[10] IEC 60364 standard: Low-voltage electrical installations

Conclusion

The drive for increased worldwide reduction of energy consumption is being accelerated by government regulators, cost conscious businesses, and ordinary citizens. Lighting in buidlings is one area where significant energy efficency gains can be made. Most buildings today still use inefficient lighting technologies which result in higher energy costs, increased maintenance (because of shorter lighting technology life cycles) and higher CO_2 emissions. This situation is avoidable. Organizations wishing to initiate a migration to an LED lighting technology should consider the following short and long term steps:

Within the next few weeks: Begin to plan a roadmap. Assess what steps need to be taken in order to evaluate the existing lighting and electrical network in the building. Conduct an assessment of environment requirements.

Within the next 6 months: Determine how much work needs to be done to implement a cutover to LED, what the energy cost savings will be, and what the impact will be on the building occupants. Consider to effects of the new lighting on the existing power network.

Within the next year: Enlist a trusted partner with expertise in both building electrical systems and lighting technologies to help maximize operational efficiencies.

About the authors

Sébastien Mathiou is an electrical engineer who joined Schneider Electric in 2010 as a power systems expert. Previously, he had worked with the Socotec Group. He is responsible for carrying out high and low voltage power systems studies around different segment applications such as oil and gas, renewable energy, data center, utility and smart grid. He has been personally involved in resolving equipment failure and malfunction issues in different areas of industrial plants.

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Philippe Jammet is currently responsible for safety and dependability analysis at Schneider Electric. He joined Telemecanique in 1985 as test laboratory leader. He then held numerous positions within Schneider Electric laboratories and worked on projects that focused on power conversion for motor control, electric vehicle recharging, and lighting. Mr. Jammet who graduated with a degree in Physics, is also a member of the Schneider Electric EMC competencies network.