

Inrush Related Problems Caused by Lamps with Electronic Drivers and Their Mitigation

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Abstract: - New types of appliances sometimes bring unexpected power quality problems. On several locations it was reported that energy-saving lamps cause random false tripping of circuit breakers. In all of these cases these lamps had electronic drivers. An investigation of this phenomenon is presented in the paper. Laboratory measurements were done on several types of LED and gas-discharge lamps to obtain their inrush characteristics. Some lamps are found not to cause the problem even in large numbers, while other lamps show the ability to cause a false trip even in small numbers. Different solutions to the problem are considered. One of the proposed solutions is mitigation through an external device, and a prototype of such a device was built and tested in the laboratory.

Key-Words: - energy-saving lamp, false tripping, inrush, mitigation, power quality

1 Introduction

Energy efficiency initiatives brought a lot of development in the area of lighting systems. New types of gas-discharge and solid-state lamps are known to have considerably lower power consumption than the incandescent lamps with the same luminous flux. This led to legislations of gradual banning out the incandescent lamps in a number of countries.

Switching from incandescent lamps to energy saving lamps does not create protection issues in households, but large office buildings sometimes suffer from false operation of circuit breakers or residual current devices due to the energy saving lamps with electronic drivers. Large inrush currents of these lamps were reported in [1] and [2], and their importance for emergency lighting systems was investigated in [2].

Several recently built office buildings experience the problem of random false tripping of circuit breakers dedicated for lighting with LED lamps. These complaints have led to this investigation, and the goal of the research is to find the source of false tripping, and to propose a solution to the problem.

Laboratory experiments were conducted in the Power Quality laboratory of the Eindhoven University of Technology to determine the nature of inrushes. Different solutions to the problem are proposed in Section 4. One of the possible solutions is mitigating the problem with an external device.

One working principle of such a device is proposed in the paper, and a low-cost prototype was built and tested in the laboratory. Results showed that the problem can be solved through such a device.

2 Laboratory experiments

The experiment was set up according to Fig. 1. Voltage was supplied to one or several lamps from the California Instruments MX45 programmable voltage source, controlled by a computer. Voltage and current were conditioned with a voltage and current probe, and measured with a USB oscilloscope. The whole measurement process was automated with a Matlab script, which sets up measurement conditions, starts and stops the source, and does the measurement and post-processing, as described in [3].

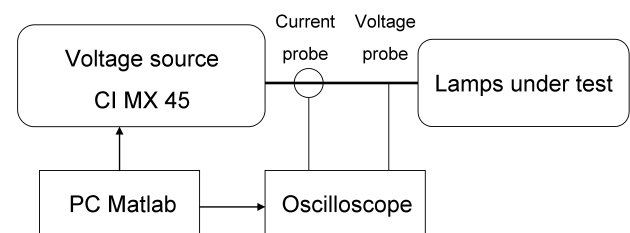


Fig. 1 – Diagram of the laboratory setup

The test consists of a series of lamp starts, with different starting voltage phase angles. The inrush

differences could be examined with other voltage changes as well (like the voltage level itself or because of voltage harmonics), but the starting phase angle was found as the dominant factor so the results presented here contain only starting angle changes. The phase step used was 15°, which gives 24 intervals within 360°.

2.1 Measurement results

Measurements were done on several types of gas-discharge (fluorescent and compact-fluorescent) and LED lamps (labeled as LED1 to LED5), both for single lamps and lamps connected in parallel.

Some of the current waveforms for two types of LED lamps are given in Fig. 2 and Fig. 3. A time shift is inserted between the two waveforms in these figures, for easier distinguishing of the two types of lamps. Both lamp types were used in an office building experiencing false tripping of circuit breakers.

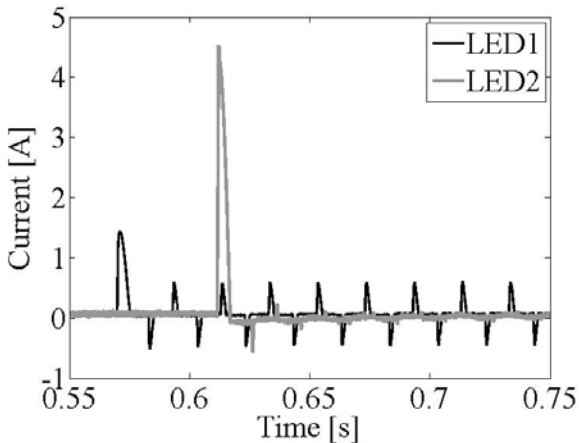


Fig. 2 – Inrush current of two 20 W LED lamps with a voltage starting phase of 0°

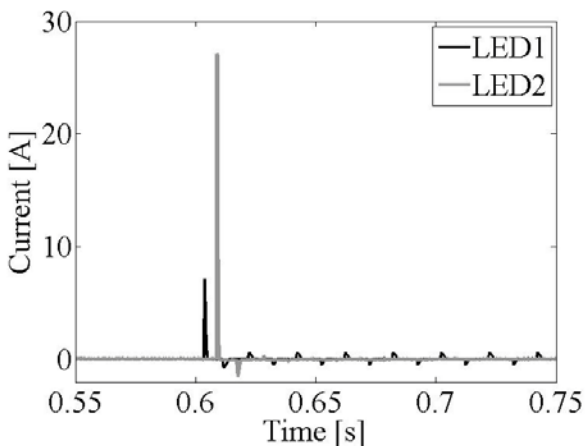


Fig. 3 - Inrush current of two 20 W LED lamps with a voltage starting phase of 90°

Lamp LED1 has an integrated driver, while the lamp LED2 uses an external driver. The inrush

current is much larger for the lamp with an external driver, and in both cases it is larger with the starting angle of 90° than 0°. The relation between the inrush current and the starting voltage phase angle can be seen in Fig. 4 and Fig. 5 for these two types of LED lamps. Fluorescent and compact-fluorescent lamps exhibit a similar behavior.

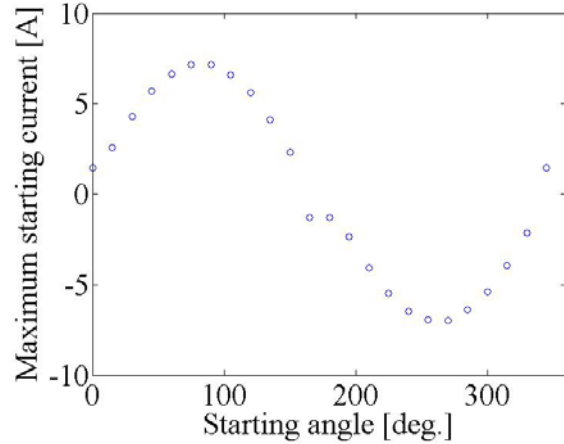


Fig. 4 – Peak inrush currents with different voltage starting angles for LED1

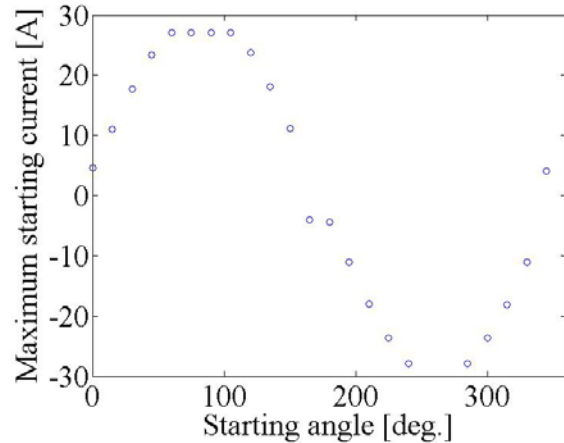


Fig. 5 – Peak inrush currents with different voltage starting angles for LED2

Maximum inrush currents of all tested lamps are presented in Table 1.

Table 1 – Maximum inrush currents of different types of lamps

Lamp type and driver type	Maximum inrush current [A]
LED1 20W internal driver	7.15
LED2 20W external driver	30.23
LED3 25W external driver	30.25
LED4 6W internal driver	7.80
LED5 3W internal driver	14.60
Fluorescent 22W electronic driver	6.52
CFL 11W	4.80

When more lamps are started together, the total inrush current is close to multiplication of a single inrush current. Fig. 6 presents the total inrush current of four 11W CFL lamps, and Fig. 7 shows the total inrush current of two 3W LED5 lamps with an internal starter. Both figures are also presenting the inrush current of one lamp multiplied by the number of lamps.

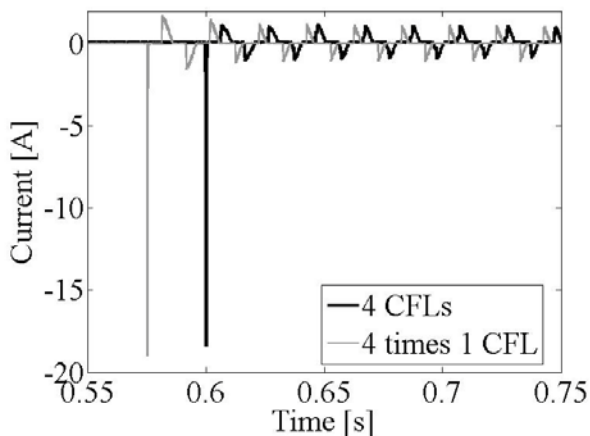


Fig. 6 – Inrush of four CFL lamps and one CFL multiplied by four; starting angle 270°

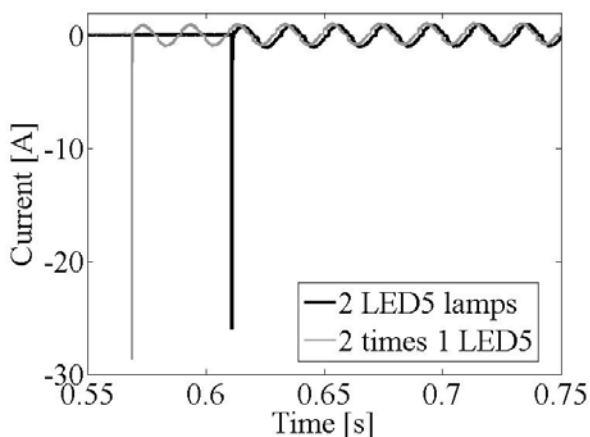


Fig. 7 – Inrush of two LED5 lamps and one LED5 multiplied by two; starting angle 270°

In both cases the inrushes of multiple lamps are added up almost as multiplying one inrush with the number of lamps. For a greater number of lamps we can expect a similar result.

3 Analysis of the problem

Fig. 4 and 5 are showing an inrush characteristic which is almost the same as for a capacitor, with deviations around 0° and 180° . This means that the inrush is mostly affected by the parallel capacitance in the driver circuit. The inrush with starting angles 0° and 180° is determined by the inrush of the rest

of the driver circuit, whose effect is much smaller than of the capacitor.

Inrushes of these lamps originate from the mitigation of another power quality issue. Large penetration of energy saving lamps raised the question of their non-linearity, and the influence that they would have on harmonic voltages in distributive networks, as discussed in [4]-[7]. Presently, limits for harmonic currents of lamps are set by a standard [8].

One of the methods used to limit harmonic currents of lamps is using an EMC (Electro-Magnetic Compatibility) filter, which is usually just a capacitor connected in parallel with the load. This solution works well as a filter and it can also filter out a part of the harmonic emission of nearby devices. However, a capacitor connected directly at the input can have a relatively large inrush current, dependent of the voltage phase angle at the moment of switching on. This is not a problem in households, where the number of lamps per switch is small, but in office buildings this number can be 10 or more, and the total inrush current can be large.

Bigger values of capacitance in the EMC filter correspond to higher maximum inrush current values. As an example, the lamp labeled as LED5 in Table 1 has a total harmonic distortion of the current of only 9 % (while other lamps have values around a 100 %) which implies that LED5 has a very effective EMC filter. On the other hand, it has the apparent power of 65 VA (capacitive) with only 3 W of active power, and the maximum inrush current of 14.6 A. This capacitive behavior is a result of a relatively large capacitor connected in parallel with the rest of the circuit. Other lamps have better DPF (Displacement Power Factor) values, most of them around 0.7 capacitive.

A higher network impedance can limit the effect of parallel capacitance to smaller inrush values, but standard low voltage connections usually have similar system impedance values.

The duration of the inrush is very short, it lasts only a few milliseconds, but it can still trigger a circuit breaker if the current reaches its highest permitted value. Circuit breakers of type B react on short duration currents with magnitudes higher than $(3\div 5)\cdot I_n$ (three to five times the rated current). Type C circuit breakers react on short currents of $(5\div 10)\cdot I_n$, and type D with $(10\div 20)\cdot I_n$.

For a 16 A circuit breaker, which is standard for lighting systems, this limits the number of lamps that can be connected to one switch without creating false trips. Taking into account only the power of the lamps and their power factor, e.g. $P = 20\text{W}$ and $\text{PF} = 0.5$, we can calculate the maximal number of

92 lamps per one circuit breaker and switch. Table 2 gives the maximal number of lamps per switch without inrush problems, for different types of circuit breakers. In this table it is assumed that the ratios between the maximum and rated current are 5, 10, and 14 for types B, C, and D of circuit breakers, respectively.

It is noticeable in Table 2 that some lamps do not create a problem, since a lot of them can be started with one switch even with type B circuit breakers. That is the reason why this problem is not occurring in every office building with a large number of lamps. On the other hand, two types of LED lamps can trigger a B type circuit breaker already with three lamps on one switch, if the starting angle is very close to 90° , or 270° .

Table 2 – Maximal number of lamps per switch without inrush problems

Lamp type and driver type	Max. number		
	B	C	D
LED1 20W internal driver	11	22	31
LED2 20W external driver	2	5	7
LED3 25W external driver	2	5	7
LED4 6W internal driver	10	20	28
LED5 3W internal driver	5	10	15
Fluorescent 22W electronic driver	12	24	34
CFL 11W	16	33	46

On a few locations it was also noticed that the lamps can trigger the residual current protection device when starting. This problem occurs because of the winding difference of the transformer in these devices which transforms a small part of the phase current into the residual current (unequally wound phase and neutral). If the current is large enough, like during an inrush, this error can be large enough to reach the threshold of $30 \div 300$ mA.

4 Mitigation of the problem

There is a number of ways to mitigate this problem. The simplest way is to use lamps that do not have a large inrush current, but that information is usually not available. Whenever this information is available, the problem can be avoided in the first place.

Another simple solution is using fuses instead of circuit breakers. Fuses are not sensitive to this problem because lamp inrushes are very short, and the energy ($I^2 \cdot t$) is too small to melt the fuse. A practical problem of using fuses is that they are nowadays considered old-fashioned for modern office buildings.

One way to reduce the peak current is altering the impedance of the circuit. A higher inductance can reduce the inrush at all starting phase angles, but this comes with a price of larger voltage variations.

The mitigation approach used here is control of the starting phase angle. If the inrush always starts at voltage zero-crossing, all capacitive loads have the lowest possible inrush current. Such an approach was already proposed for power factor capacitor banks, as described in [9].

A low-cost zero-crossing switch can easily be built with off-the-shelf elements since some solid state relays already have a zero-crossing function. A prototype of such a switch was built, shown in Fig. 8, and tested in the laboratory.

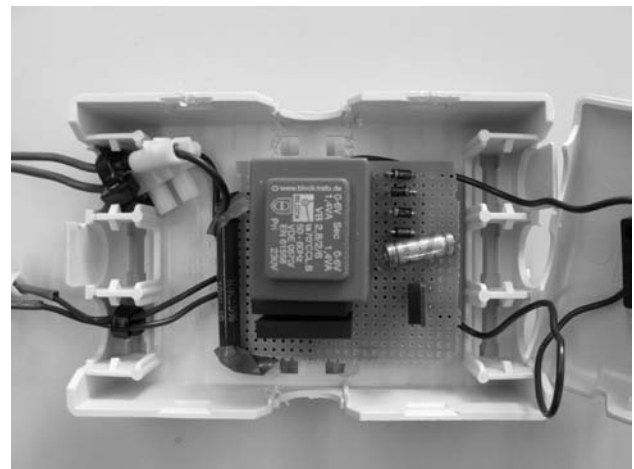


Fig. 8 - Prototype of a low-cost zero-crossing switch for lamps with a capacitive inrush

Inrush characteristics of lamps LED1 and LED2 used with this switch are presented in Fig. 9 and Fig. 10.

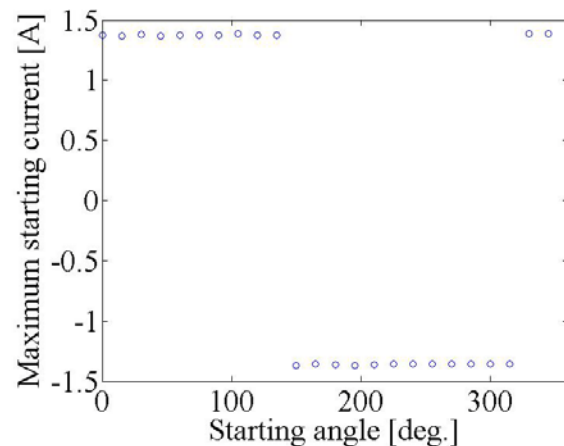


Fig. 9 - Maximum inrush currents with different voltage starting angles for LED1 with mitigation

It is interesting to compare these results with Fig. 4 and Fig. 5, which contain the results of the same

lamps without mitigation. The maximum peak current is reduced from 7.1 A to 1.4 A for LED1, and from 30.2 A to 4.1 A for LED2. In both cases the currents are varying very slightly around only two values (0° and 180° of an uncontrolled inrush).

It is important to mention that a zero-crossing switch reduces inrushes only for capacitive loads. Inductive loads, such as lamps with electromagnetic ballasts, would have a worst case inrush with such a switch. For inductive loads the switch would need to have a starting voltage phase of 90° and 270° instead of 0° and 180° .

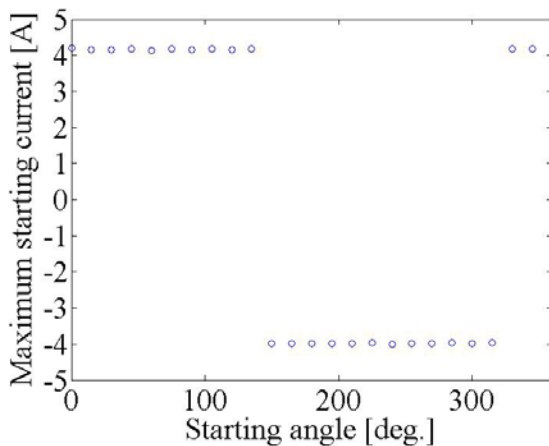


Fig. 10 - Maximum inrush currents with different voltage starting angles for LED2 with mitigation

5 Conclusions

An analysis of inrush related problems caused by lamps with electronic ballasts is made in the paper. Random false tripping of circuit breakers is sometimes caused by several lamps started with one switch.

Laboratory measurements show that these large inrushes originate from the capacitor connected in parallel with the lamp driver, which is used to reduce the harmonic currents of the lamp.

Some of the tested lamps do not show large inrush currents; this means that sometimes the problem doesn't exist even with a large number of lamps. The problem with device selection is that the inrush characteristic is usually not known.

Other lamps have large inrushes of short duration, capable of causing a false trip even in small numbers. Application of fuses instead of circuit breakers can avoid false trips even with large currents.

A mitigation device is proposed to reduce inrush currents. A zero-crossing switch can be used for capacitive drivers, causing the inrush to always have the lowest value of an uncontrolled inrush. A

prototype of such a device was built with a size of a normal switch for lamps. The prototype was tested in the lab and validated by the results.

6 Acknowledgments

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