PQTN BRIEF

Power Quality Testing Network

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Harmonic Distortion and Immunity Performance of Compact Fluorescent Lamps

Background

Utility customers install compact fluorescent lamps (CFLs) in homes and buildings to save energy and reduce the frequency of lamp replacement. Few end users are concerned about how CFLs affect the power system. As the market for electricity becomes deregulated and therefore more competitive, utilities—especially those that promote the use of high-efficiency modern lighting—must consider how CFLs perform in and affect the typical electrical environment so that they can confidently recommend trouble-free CFLs to their customers. CFLs that conserve energy yet are vulnerable to surges or generate high current distortion may be unsuitable for lighting retrofits and new installations.

Objective

The objective of the tests performed at the EPRI Power Electronics Applications Center (PEAC) was to determine the harmonic emissions and immunity characteristics of off-the-shelf electronic and magnetic compact fluorescent lamps.

Test Setup

Fourteen 1992-vintage CFLs (nine electronic and five magnetic) were tested. All models were rated at 120 V_{ac} and were designed to replace screw-base incandescent lamps from 40 to 150 watts. Before testing, each CFL was "burned in" by operating it for 100 hours. To ensure that the temperature of each CFL was stabilized during testing, each sample was operated for 10 minutes just before testing. During the harmonic emissions test, 120-V_{ac} power was supplied to each CFL under test. During the immunity tests, a disturbance simulator subjected each CFL under test to a voltage sag; voltage swell; 6-kV, 100-kHz Ring Wave surge; and 6-kV Combination Wave surge. The Ring Wave represents an oscillatory circuit-switching transient, and the Combination Wave represents an impulsive transient similar to one caused by lightning striking directly on or near the utility distribution line. Both surges were applied as described in ANSI/IEEE C62.41–1991. Light output was measured with a photometer mounted in a test chamber, and a temperature probe measured the temperature inside the test chamber. Tests were conducted and measurements were taken only after the light output and temperature stabilized. Figure 1 shows the test setup.

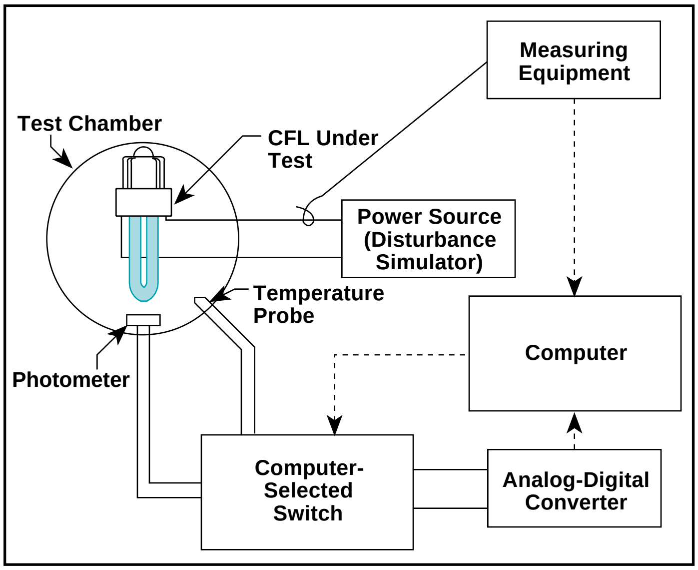

Figure 1. Test Setup

Test Results

Harmonic Emissions To determine how much CFLs contribute to power system distortion, the total harmonic current distortion of each CFL was measured during nominal power supply conditions. As shown in Figure 2, harmonic distortion not only varied widely among the electronic CFLs (from a low of 17% to a high of 201%) but they also had a much higher average distortion than the magnetic models (65% compared to 14% for the magnetic models).

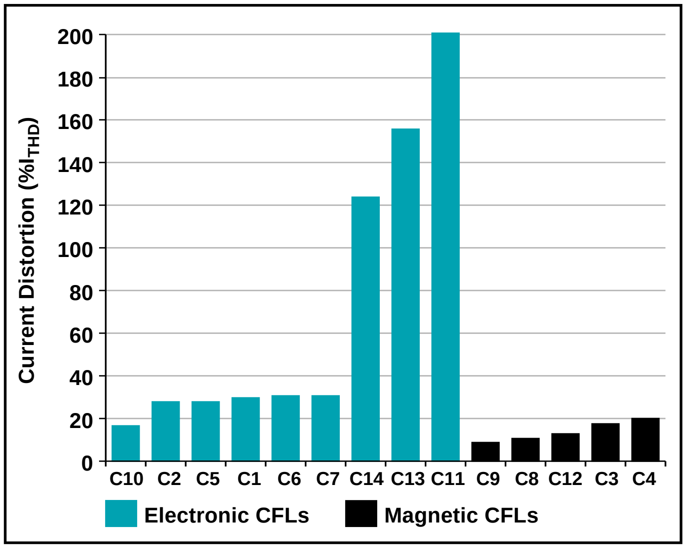

Figure 2. Current Harmonic Distortion of Tested Electronic and Magnetic CFLs

Voltage Disturbance Immunity To determine how well CFLs tolerate common electrical disturbances, each CFL was subjected to voltage sags, voltage swells, Ring Wave surges, and Combination Wave surges. During the voltage-sag test, each CFL was subjected to four 10-cycle sags with the following magnitudes: 67%, 42%, 12%, and 0% of the nominal voltage (120 V_{ac}). While the light output of all the CFLs decreased during the sags, the light output of the electronic CFLs dropped to zero only during the 12% and 0% voltage sags. The light output of the magnetic models dropped to zero for all sags, regardless of the sag magnitude. The restoration time, the time it takes a ballast to restore nominal light output after a 10-cycle voltage sag to zero, was measured for each CFL. As shown in Table 1, the restoration times of the magnetic CFLs were much longer than the electronic CFLs. Moreover, some magnetic CFLs had trouble restarting after a sag, while the electronic CFLs restarted more quickly.

The only criterion to determine how well the CFLs tolerated overvoltages (voltage swells and surges) was whether a CFL worked after the overvoltage as it did before (that is, it "survived"). As shown in Table 1, all but one CFL (an electronic model) survived the five applications of 10-cycle voltage swells of the following magnitudes: 110%, 120%, 130%, 140%, and 150% of the nominal voltage. The model that did not survive emitted smoke and lost its light output after a 140% swell. All magnetic models survived the 6-kV Ring Wave surge, but two electronic models failed during the surge. Half of all the CFLs failed the 6-kV Combination Wave surge, which deposits a substantial amount of energy in the ballast circuit.

Table 1. Results of Immunity Tests: Voltage Sag, Voltage Swell, Ring Wave Surge, and Combination Wave Surge

CFL Type	*Immunity Test*			
	Restoration Time (ms)	Voltage Swell (Survive 150 %?)	Ring Wave (Survive 6-kV?)	Combination Wave (Survive 6-kV?)
Electronic-C1	15	Yes	Yes	Yes
Electronic-C2	15	Yes	Yes	Yes
Electronic-C5	10	Yes	Yes	Yes
Electronic-C6	10	Yes	Yes	Yes
Electronic-C7	10	Yes	Yes	Yes
Electronic-C10	5	Yes	No	No
Electronic-C11	5	No	Yes	No
Electronic-C13	5	Yes	No	No
Electronic-C14	25	Yes	Yes	No
Magnetic-C3*	273	Yes	Yes	No
Magnetic-C4**	122	Yes	Yes	No
Magnetic-C8**	223	Yes	Yes	Yes
Magnetic-C9*	463	Yes	Yes	No
Magnetic-C12**	327	Yes	Yes	Yes
Incandescent	0	Yes	No†	No‡

*During some tests, this model would not restart on the first try. The recorded restoration time was the average of a successful first restart and a restart that took several tries.

**During some tests, this model would not restart within the test period (one second). When the ballast did restart, the restoration time varied widely.

†Typical 60-watt incandescent lamp failed at an average of less than 2 kV.

‡Typical 60-watt incandescent lamp failed at an average of less than 1 kV.

DISCUSSION

The higher average current distortion of the electronic CFLs can be attributed to their high-frequency switching circuits. CFLs with electronic ballasts generally cause higher harmonic distortion than CFLs with magnetic ballasts because the nonlinear components in electronic ballasts draw non-sinusoidal ac current. The wide range of current distortion in the electronic CFLs can be attributed to the various types of power-factor-correction circuits among the models. The electronic CFLs with low distortion had current-shaping diodes to reduce the distortion inherent in electronic ballasts. The electronic CFLs with high distortion had no correction circuits. The immunity tests revealed that the electronic CFLs not only had better immunity to voltage sags than the magnetic models but also recovered more quickly after a sag extinguished the lamp (see the Tutorial). All but two of the tested CFLs survived the 6-kV Ring Wave surge, whereas only half survived a 6-kV Combination Wave surge. However, even the least robust CFL can withstand surges better than a typical 60-watt incandescent bulb, which fails at about 2 kV for Ring Wave surges and about 1 kV for Combination Wave surges.

SIGNIFICANCE

Although compact fluorescent lamps typically cost about 20 times as much as a standard incandescent lamp, CFLs are replacing incandescent lighting because of their superlative energy performance and long life. Yet along with their primary benefits—energy savings and fewer replacements—they may distort the power system current. Industry standards for harmonic current distortion from CFLs have not been formally established. ANSI C82.11, a standard under development, recommends a maximum current harmonic distortion of 33%, while many demand-side-management and shared-savings programs promote the use of fluorescent ballasts with a current distortion of no more than 20%. Although electronic CFLs are generally more efficient than magnetic models, they can generate much more current distortion. In fact, only one of the tested electronic models met the 20% limit recommended by demand-side-management programs, whereas all the tested magnetic models were under the limit. However, the distortion created by CFLs does not pose a potential problem unless many lamps are concentrated in one building. In areas with frequent lightning and switching surges, CFLs offer another advantage over incandescent lighting—they better survive such surges.

TUTORIAL: Lamp Dropout & Restoration Time

The two components of a voltage sag—duration and magnitude—determine the duration of reduced CFL light output during and after a voltage sag. Because the light output of a typical CFL will decrease as soon as the input voltage decreases, most CFLs cannot ride through a sag without a reduction of light output, regardless of the sag magnitude. (Even a change in input voltage of less than one percent can cause a perceptible reduction in light output.) However, sag magnitude does affect the duration of reduced light output when the sag extinguishes the fluorescent lamp (lamp dropout), after which the ballast must restart the lamp. As shown in Figure A, the light output of an electronic CFL decreases during a 10-cycle sag to 42% of the nominal input voltage, but the lamp is not extinguished. In this case, the duration of reduced light output is determined only by the duration of the sag. However, the same sag extinguishes a lamp powered by a magnetic ballast (see Figure B).

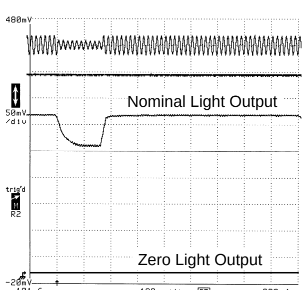

Figure A

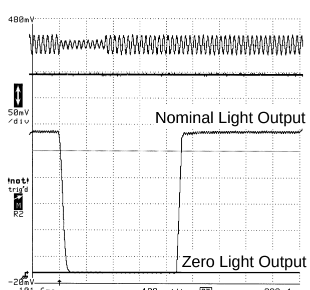

Figure B

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TUTORIAL, Continued

Once a lamp is extinguished, it may take several cycles for the ballast to restart it. In this case, the duration of reduced light output is determined by both the duration of the sag and the lamp restoration time, which is the time it takes a ballast to restart the lamp after the input voltage has been restored. As shown in Figure C, a typical electronic ballast will restart the lamp very quickly, usually within 20 milliseconds. Magnetic CFLs take much longer to restart, and some may "false start" a number of times before finally restoring nominal light output (see Figure D). The long restoration time and erratic restarting of a magnetic CFL can be attributed to its reliance on a preheat type of starter. Because magnetic ballasts use a relatively low voltage to excite the lamp plasma, filaments within the lamp must be preheated before the ballast can restart the lamp. Therefore, the restoration time of magnetic CFLs depends upon the temperature of the lamp when the input voltage is restored.

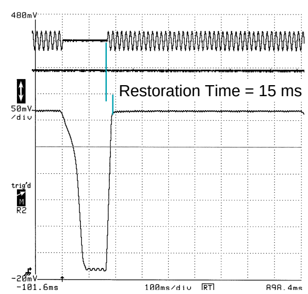

Figure C

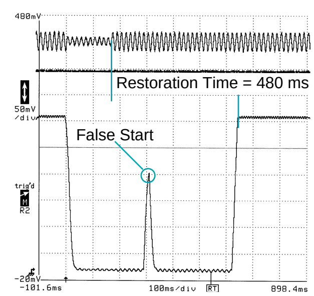

Figure D

ACKNOWLEDGMENTS

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