Household Dimmers: Dimming Behavior of LED Lamps

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Objectives

• Follow-up on action items:
  – Compare performance of various triac dimmers
    • Different dimmers with the same incandescent lamp
    • Different SSL, Incandescent and CFL lamps with the same triac dimmer
  – Analysis of inrush and repetitive peak current
  – Analysis of flicker
• Possible future work
Industry Status

The industry presently does not have a good definition for SSL dimming

• NEMA White Paper: LSD 49-2010
    • Released February, 2010
    • Defines problem, discusses scope, proposes performance metrics
    • http://www.nema.org/stds/lsd49.cfm

• NEMA Standard SSL-6
  – “Solid State Lighting for Incandescent Replacement—Dimming”
    • Released February 2011
    • Specifies performance metrics

• Energy Star
  – Energy Star Program Requirements for Integral LED Lamps
    • Integral LED lamps must be clearly labeled as “dimmable” or “non-dimmable”
    • Manufacturers labeling product as dimmable must maintain a website stating information regarding dimmer compatibility
    • Working with NEMA on standards development
Triac Dimmer

Voltage across an Incandescent lamp on a triac dimmer
(Low Light Level example, reduced light output by reduced RMS voltage to load).

RMS voltage to load depends on triac firing angle, controlled by the user-operated variable resistor.

Triac fires, allowing current to flow to load.

Voltage to load decreases to zero at zero crossing, preventing current from flowing to load.

Triac turns off at zero crossing, allowing current to flow to load.

Image: NEMA LSD-49-2010
Test Setup

- Computer
- Oscilloscope
- LabVIEW
- Current Probe
- Voltage Probe
- Amplifier (light measurement)
- Lamp under test
- Dimmer
- Dimmer bypass switch
- Photosensor
- Watt meter, AC power supply (not shown)
## Possible Specifications for LED Dimming

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proposed Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimming profile</td>
<td>Similar to Incandescent ~linear on log scale</td>
</tr>
<tr>
<td>Max/Min dimming level</td>
<td>Similar to Incandescent; Max &gt;80%, Min &lt;1% Varies based on dimmer</td>
</tr>
<tr>
<td>Low end turn on/cut out</td>
<td>No portion of dimmer travel for which light is off</td>
</tr>
<tr>
<td>Max/min units for reliable performance</td>
<td>Same number of units per dimmer as incandescent (ex. 6 100W lamps for 600W dimmer)</td>
</tr>
<tr>
<td>Color shift</td>
<td>TBD: color shift difficult to achieve with SSL without multi-chip solution</td>
</tr>
<tr>
<td>Flicker</td>
<td>No visible flicker during any portion of dimming range</td>
</tr>
<tr>
<td>Repetitive peak voltage</td>
<td>TBD: evaluate impact of repetitive peak on driver and on other electrical devices on the line</td>
</tr>
<tr>
<td>Max inrush current</td>
<td>TBD: evaluate impact of inrush on driver and on other electrical devices on the line</td>
</tr>
</tbody>
</table>
Performance of Various Commercial Triac Dimmers

- The dimming profile of similar dimmers (even from the same manufacturer) can be significantly different
  - Four commercial dimmers with the same 40W incandescent lamp

<table>
<thead>
<tr>
<th>Dimmer</th>
<th>Minimum light output</th>
<th>Maximum light output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimmer 1</td>
<td>0.25%</td>
<td>83.6%</td>
</tr>
<tr>
<td>Dimmer 2</td>
<td>13.29%</td>
<td>93.5%</td>
</tr>
<tr>
<td>Dimmer 3</td>
<td>0.16%</td>
<td>93.0%</td>
</tr>
<tr>
<td>Dimmer 4</td>
<td>3.85%</td>
<td>80.1%</td>
</tr>
</tbody>
</table>
Performance of Various Commercial Triac Dimmers

• Dimmer control does not necessarily change phase angle linearly
Dimming Definition

- Seven SSL replacement lamps, an incandescent lamp, and a CFL were tested on the same dimmer.
Dimming Definition

- Seven SSL replacement lamps, an incandescent lamp, and a CFL were tested on another dimmer
Inrush Current

- Lamp Current: normal operating current and dimmed current

“repetitive peak current”
Inrush Current

• Compared to inrush/repetitive peak currents specified in NEMA 410-2004, “Performance Testing for Lighting Controls and Switching Devices with Electronic Fluorescent Ballasts.”
• NEMA 410-2004 max inrush current ranges from 192 to 242 Amps.
• $I^2t$ value of Lamp 5 is less than 1mA$^2$s. NEMA 410-2004 specifies max values of 74-117 A$^2$s.
• SSL-6: max allowable repetitive peak current for 600W dimmer is 9 amps; Lamp 5 fails requirements of SSL-6
Inrush Current

- Inrush and repetitive peak current were measured for seven SSL replacement lamps, an incandescent and a CFL on four different dimmers.
- Data normalized to the normal operating peak current (without a dimmer).

![Normalized Repetitive Peak Current: Various Lamp/Dimmer Combinations](image)
Flicker

Lamp/dimmer combination measured in two dimmer settings, one resulting in no visible flicker, and one with clearly visible low frequency flicker.
Flicker

Light signal was normalized to the same average for the purpose of Fourier analysis.
Flicker

Lamp 1 with Dimmer 3

Tabulated Data - Power Spectral Density, normalized light response

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>No Flicker (arbitrary power units)</th>
<th>Flicker (arbitrary power units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2.1E-07</td>
<td>3.4E-04</td>
</tr>
<tr>
<td>7</td>
<td>5.0E-08</td>
<td>7.4E-04</td>
</tr>
<tr>
<td>8</td>
<td>2.1E-07</td>
<td>1.9E-04</td>
</tr>
<tr>
<td>9</td>
<td>2.3E-07</td>
<td>6.2E-06</td>
</tr>
<tr>
<td>10</td>
<td>2.7E-08</td>
<td>1.1E-05</td>
</tr>
<tr>
<td>120</td>
<td>1.9E-05</td>
<td>9.2E-05</td>
</tr>
</tbody>
</table>
Conclusions

• Performance of different lamp/dimmer combinations vary considerably, even within a dimmer brand or a lamp technology (ex. incandescent).

• Typical Inrush currents seen by the lamp and dimmer combinations do not pose a threat to system components based on fluorescent ballast standards, but not all combinations pass SSL-6 criteria.

• This case demonstrates PSD of light waveform clearly predicting low frequency flicker.
Possible Further Investigations

• Human factors study to better understand dimming preference
  – Dimmer travel versus light output (profile)
  – Minimum light output
  – Flicker

• Test a sample of commercial LED integral lamps to see if they fall within the requirements set in NEMA SSL-6.
A quick pilot study was conducted to understand people’s preference for dimmers in terms of the dimming profile.
Thank you!

To Members of ASSIST

Questions?