FLICKER/VOLTAGE FLUCTUATION RESPONSE OF MODERN LAMPS INCLUDING THOSE WITH DIMMABLE CAPABILITY AND OTHER LOW VOLTAGE SENSITIVE EQUIPMENT

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ABSTRACT

The key objective of the work presented in this paper is to gain improved and updated understanding of the flicker performance of the latest lighting technologies. The work presented in this paper summarizes the detailed testing that has been performed to characterize the response of modern lighting to voltage fluctuations in the supply. The test plan was devised to capture the flicker response over a broad frequency range from 5 to 25 Hz. The modulation signal parameters were also varied to allow the study of the impact of amplitude and wave shape. Then, the impact of the operation of dimmers on the flicker performance of dimmable lighting technologies was evaluated. Finally, the impacts of excessive voltage fluctuations on other sensitive low voltage (LV) equipment were also investigated. The information in this paper should prove useful to decision makers in industry standard groups.

INTRODUCTION

The existing industry standards on flicker measurement are based on the response of general purpose incandescent lamps. [1] However, worldwide these lamps are being replaced with more energy efficient lamps including Compact Fluorescent Lamps (CFLs) and Light emitting Diode (LED) lamps. In order to keep the flicker standards relevant, the industry standard bodies on the subject are in need of evidence that compares the flicker performance of new lighting technologies with that of incandescent lamp under a variety of system conditions. [2]

Humans have different perception thresholds for different lamp types as documented in a publication by EPRI on the testing that it carried out on different lamp types. [3] Gain factor (GF) is a measure that may be used to quantify flicker performance of a lamp type and is computed as a ratio of percentage change in its light output (luminous flux) to the percentage change in input voltage. A higher value of GF for a lamp signifies its greater sensitivity to flicker. This approach allows comparison of lamp sensitivities in systematic and reproducible manner. EPRI used this approach in computing the gain factors for different lamp types in the mid 1990's [4]. More tests [5] were carried out by EPRI on 1995-vintage lighting products that suggested lower flicker sensitivity of fluorescent fixtures in comparison to incandescent lamps.

The follow-up testing work during years 2011-2012 has been carried out to satisfy the need for thorough evaluation of the flicker performance of various lighting technology choices that are available to consumers. The work has involved comprehensive testing of multiple lamp samples that involved varying the modulation signal parameters such as frequency, amplitude and wave shape. This work complements other recent work [6] on studying the flicker effect of different types of light sources as an attempt to fill the gap in the knowledge of the impact of dimmer operation on the flicker sensitivity of dimmable lamps.

LABORATORY SETUP

The laboratory setup that was used for the testing is shown in Fig. 1 and shows the connections of the various test equipment that were used. The arbitrary waveform generator and amplifier were used to create a modulating signal of desired shape and frequency that was superimposed on the source voltage to create a flicker test voltage waveform. The test voltage was fed through an electronic dimmer to the test lamp housed inside the integrating sphere. The dimmer was only in the circuit for the dimmable lamp tests. The power meter and flicker meter were connected at the input connection before the dimmer. The digital oscilloscope used voltage and photodetector signals as inputs and recorded the information in real time. Necessary post-processing was carried out on the recorded signals for the purpose of computing gain factors.

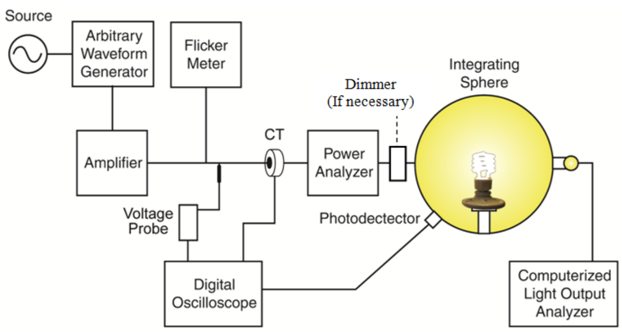

Fig.1: Laboratory Test Setup for Flicker Testing

TEST RESULTS

The testing was mainly focused on the LED and CFL lamps and both dimmable and non-dimmable technologies were included. The tested lamps are off-the-shelf items and the details of the evaluation sample are listed below. All the tested lamps were designed to replace 60 watt (W) incandescent lamp and are listed below.

- Incandescent lamp - 1 sample (60 W)
- Non-dimmable CFL - 2 samples (13 W, 14 W)
- Dimmable CFL - 2 samples (15 W, 15 W)
- Non-dimmable LED - 2 samples (9 W, 13.5 W)
- Dimmable LED - 2 samples (10 W, 12 W)

The gain factors were computed for the various tests that were carried out on the selected lamps. It may be noted that for each of the test sequences, the frequency of the modulating signal was varied from 5 Hz to a value of 25 Hz in steps of 5 Hz. Firstly, all the lamps were subjected to the test sequence by operating them at full brightness by applying the nominal voltage. In the case of dimmable lamps, the impact of dimmer operation was tested by repeating the test sequence by varying the lamp brightness to 75% and 50% of the nominal brightness.

Impact of Lamp Type

The computed gain factor values of various lamp types are summarized in Fig. 2. The results in this figure correspond to the modulation signal having a square wave shape and a peak-to-peak magnitude of 1% of rated rms supply voltage. Also, to exclude the impact of dimmer operation, all these values correspond to the lamps operating at 100% brightness.

It is found that gain factor of the majority of lamp types (i.e. dimmable and non-dimmable CFL and dimmable LED) is less than that of incandescent lamp. This signifies less flicker sensitivity to fluctuating voltage of these lamp types in comparison to incandescent lamp. However, the gain factor values for the two samples of non-dimmable LED lamps were found to be higher than the incandescent lamp. This signifies potentially higher flicker sensitivity to fluctuating voltage by this lamp type in comparison to incandescent lamp. It may be noted that the samples for this particular technology were very difficult to obtain because the majority of the LED lamps in the market during the testing period belonged to the dimmable category. All incandescent lamps having same voltage and watt ratings are known to have similar frequency response. However, the gain factor values of the two samples belonging to each technology class were found to be different even though the trend over the test frequency range is found to be similar. It is found that the gain factor of incandescent lamp reduces as the flicker frequency is increased. However, the gain factor of CFL and LED lamps was found to be somewhat independent of the test frequency.

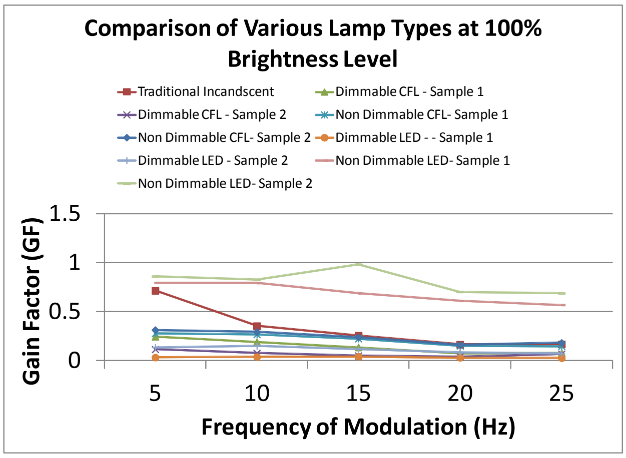

Fig.2: Gain Factor Comparison of Various Lamp Types

Impact of Dimmer Operation

The impact of dimmer operation on the flicker performance of individual lamps was captured by controlling the dimmer in the test circuit to adjust the brightness to 100%, 75% and 50% of nominal brightness. Once the correct brightness level was achieved, the gain factor of the lamp was computed. Again, these results correspond to the modulation signal having a square wave shape and peak-to-peak magnitude of 1% Vrms of rated supply voltage.

The gain factors that were computed for the incandescent lamp at different levels of brightness are shown in Fig. 3. It is found that the dimmer operation invariably contributes to an increase in the gain factor for all the test frequencies.

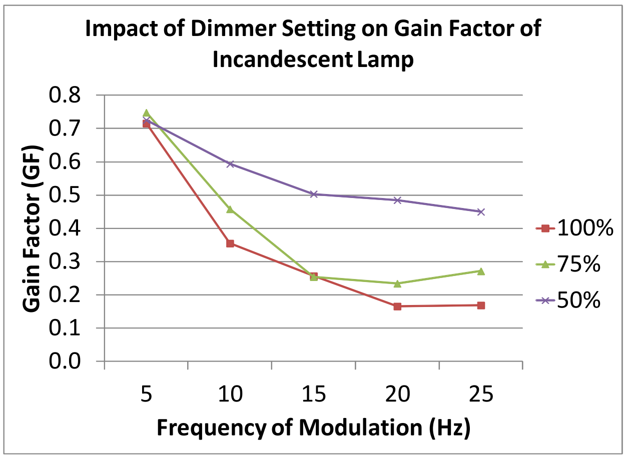

Fig.3: Impact of Dimmer Operation on Gain Factor of Incandescent Lamp

The gain factors that were obtained for dimmable CFL and LED lamps were normalized using the corresponding values for incandescent lamp and the same are plotted in Fig. 4 through Fig. 7. A value greater than 1.0 for the normalized gain factor for a lamp signifies its higher sensitivity to flicker than that of an incandescent lamp at that frequency.

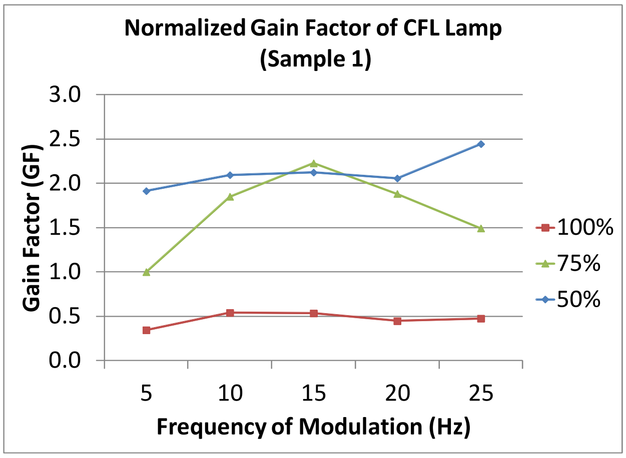

Fig.4: Impact of Dimmer Operation on Gain Factor of CFL Lamp (Sample 1)

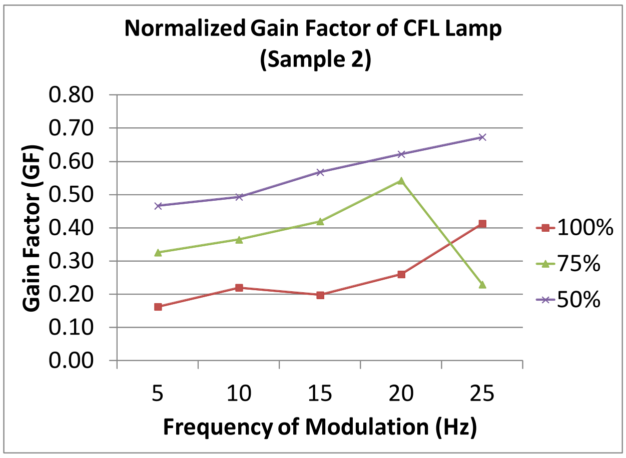

Fig.5: Impact of Dimmer Operation on Gain Factor of CFL Lamp (Sample 2)

With regards to dimmable CFLs, it is found that reducing lamp brightness through the use of a dimmer resulted in increase in the value of the normalized gain factors. It was found that for one of the two samples (see Fig. 4); the normalized gain factor was higher than that of an incandescent lamp, showing a high susceptibility to flicker. For the other sample (see Fig. 5), the normalized gain factor increased for low brightness operation but the values were still under one. Therefore, one can conclude that usage of dimmers can be expected to increase the flicker susceptibility of CFLs and in some cases the flicker susceptibility may be actually worse than the incandescent lamp.

On the other hand, the impact of dimmer operation on the normalized gain factor is less pronounced for dimmable LED lamps. Also, there is no conclusive evidence that the dimmer operation would increase the normalized gain factors. For example, the normalized gain factor of one of the LED lamp samples (see Fig. 7) actually decreases at reduced brightness levels. However, the normalized gain factor was found to be well under 1.0 for both samples for all the brightness levels that were tested. It can be concluded that dimmer operation would influence the flicker sensitivity of LED lamps. However, these lamps can still be expected to have much less flicker sensitivity than incandescent lamps.

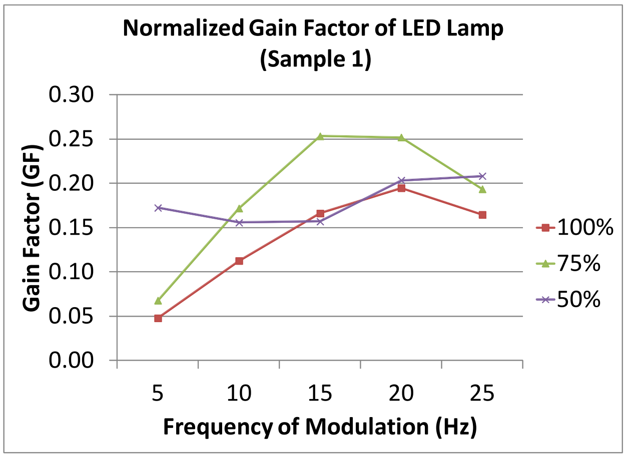

Fig.6: Impact of Dimmer Operation on Gain Factor of CFL LED Lamp (Sample 1)

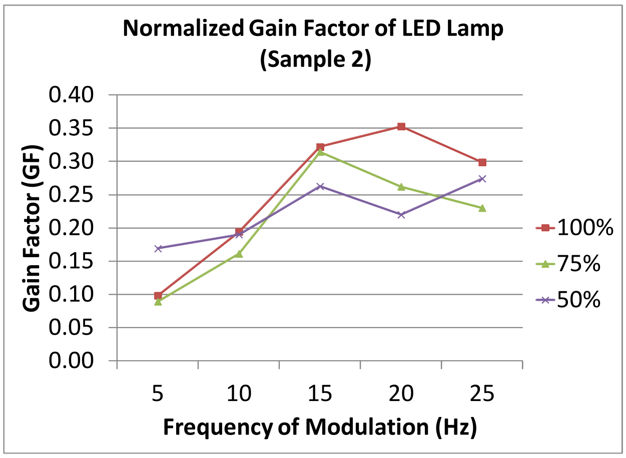

Fig.7: Impact of Dimmer Operation on Gain Factor of LED Lamp (Sample 2)

Impact of Modulation Waveform Characteristics

The parameters of the three scenarios that were evaluated are shown in Table 1 and the normalized gain factors are summarized in Fig. 8. It can be seen that varying the amplitude of the modulation signal has negligible impact on the normalized gain factor of CFL lamps. The impact is more pronounced for LED lamps as the normalized gain factor is actually lower for 3 out of 4 tested samples. However, changing the wave shape of the modulating signal from rectangular to triangular did not result in significant change in normalized gain factors for either CFL or LED lamps.

Table 1: Modulating Signal parameters

S. No.	Frequency (Hz)	Amplitude (%)	Waveshape
1	10	1	Rectangular
2	10	2	Rectangular
3	10	1	Triangular

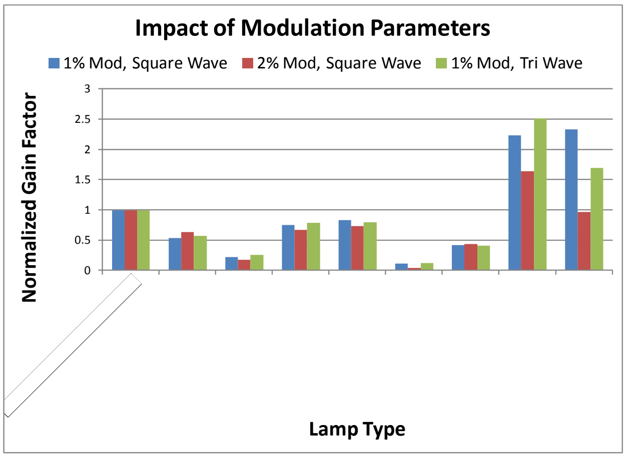

Fig.8: Impact of Modulation Signal Parameters on Gain Factors

Non-Lighting Devices

In addition to lamps, a few non-lighting voltage sensitive household appliances were also subjected to fluctuation testing to determine their voltage fluctuation immunity levels. These load types are listed below:

- CRT (Cathode Ray Tube) Television
- Plasma Television
- LCD (Liquid Crystal Display) Television
- Video Gaming console

Input voltage to the test equipment was modulated with modulating signal using the peak-to-peak magnitude of 2% Vrms of rated supply voltage at a frequency of 10 Hz. The modulation signal magnitude was increased to as high as 10% Vrms of rated voltage. During this testing no visible ill-effects were observed by the testing engineer. The engineer was looking for any performance issues including those listed below:

- Disruption in normal operation
- Slowing of frame-rate
- Image flicker
- Controller communication interruptions in case of gaming console

CONCLUSIONS AND RECOMMENDATIONS

Based on the limited test samples in this project, findings confirm that unlike incandescent lamps, the flicker response of CFL and LED lamps is nearly independent of test frequency. Furthermore, the gain factor values of the two samples belonging to the same technology class are found to be different even though the variation trend over the test frequency range is found to be similar.

The majority of lamp types (i.e. dimmable and non-dimmable CFL and dimmable LED lamps) exhibited less flicker sensitivity to fluctuating voltage in comparison to an incandescent lamp. However, the two samples of non-dimmable LED lamps are found to have potentially higher flicker sensitivity to fluctuating voltage in comparison to incandescent lamps. For dimmable CFL lamps, the usage of dimmers can be expected to increase their flicker susceptibility and in some cases the flicker sensitivity may be actually worse than the incandescent lamp. However, the impact of dimmer operation on the flicker sensitivity of dimmable LED lamps is comparatively less. Also, these lamps can still be expected to have much less flicker sensitivity than incandescent lamps.

It is recommended to consider these findings in industry discussions related to any changes to the existing flicker limits as some of the newer lighting technologies may be even more susceptible to flicker than incandescent lamps. The evidence is especially strong to suggest worsening of the flicker performance of dimmable lamps when operating at reduced brightness levels.

Acknowledgments

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