LIGHT FLICKER PERFORMANCE OF LOW POWER LED UNITS

Hend A. E. Salama
Higher Institute of Eng. and Technology
Fifth Settlement - Egypt
h.d.61@hotmail.com

Fahmy Bendary
Benha University- Faculty of Eng.
(Shoupra) - Egypt
Fahmybendary10@gmail.com

ABSTRACT

Currently, most countries in the world have been interested to reduce the power consumption due to energy resources shortage. So, manufacturers excited to expand in lot of production of low-power LEDs for huge benefits that summarized in over age life span and the least power consumption. Standard Specifications evaluated few low power LEDs types compared to rapid production of lighting units which leads the shortage of technical datasheet in general. This aims to establish actual studies in this paper to stand and detect the performance requirements of low LED units. Light flicker phenomenon is one of the important power quality criteria of LEDs especially for interiors because of its effects on human healthy. So, causative factors on flickers must be studied and analysed. Several meter systems have been established to measure flicker metrics (flicker index and percent flicker) of lighting units. Reference meter system (PNNL system) is one of these meters composed of portable measurement device which is simulated and designed in this paper to test low power LED samples in experimental procedure. Also, the measures are evaluated under Standards and compared with sample Compact Fluorescent Lamp (CFL) unit. Also, the light flicker waveform of low frequency LEDs is investigated

INTRODUCTION

Power quality of LED units has essential requirements that affect on the electric power network and human healthy for consumers like Light Flicker phenomenon [1]. Mostly, electrical flicker may be generated in power system due to the power supply problems and this is different from the photometric flicker creating from light source itself. It has typical periodic with variant waveform in amplitudes, periodic frequency, shape, average level and even duty cycles in some cases. It is defined as a rapid repetitive change in lighting unit brightness [2]. In previous literature, light flicker phenomenon is defined as the change of luminance intensity perceived by human [3][4]. It may be visible where human neurons responds to luminance modulation by sensation and perceptible or invisible which output modulation luminance is sensed but not perceived [5]. Drive lighting unit is the essential parameter caused light flicker because of its components quality which depends on costing [2]. Dimmers cause rising in the flicker percent and change the LEDs performance [6]. LED unit itself or power source problems may produce lighting flicker of LED's units [7][8]. All lighting units ultimately derive their power from the AC resources that produce voltage flicker. LEDs particularly have flicker index (depth of modulation) which is typically worse than conventional light sources [9]. Currently, studies deduce that the LED drive frequency is the importance factor affecting on light flicker as explained later. Light flicker is varied basically according to the voltage fluctuation occurred due to source frequency, fluctuating loads or power system impedance [10]. To get satisfied results, standards must be applied on LEDs types whose power factor PF equal or more than 0.9 but in fact, most LEDs production have phase out [11].

Light flicker has mainly stroboscopic effect and phantom array effect where the first happens when Luminance modulation become perceptible by the motion of objects and the observer's eyes is still while the second effect absolutely is the opposite. Therefore, neurological disorders due to source frequency are affected on flicker performance which may cause health problems of population.

LIGHT FLICKER FREQUANCY

Light flicker metrics which are flicker index and flicker percent identified by two basic metrics only for several decades and they are examined for single cycle of periodic waveform [2]. Later, expand of LEDs with its electronic drives enable the researchers to examine practically its characteristics that may be concluded in four parameters; the difference between maximum and minimum levels over the periodic cycle (its amplitude modulation), its average value over a periodic cycle, its duty cycle and number of recurring cycles per second (periodic frequency) [5][12][13]. Even now, limits of allowable practical flicker modulation percent associate light frequency levels have been considered. Taking into account the recommended IEEE Standard, two limits of frequencies are ; one is identified by no observable level called Noel Level and the second identified by Low Risk Level [5][13][14][15]. First limit is the safe zone at which point the flicker is considered fully safe according to IEEE PAR1789 while the second level describes a flicker level where adverse reactions are unusual. Estimation of the two levels has been established according to the frequency classification which achieves the maximum flicker modulation within the frequency above or below 90 Hz. When flicker frequency may be above 90 Hz; maximum modulation percent in Noel Level $\leq$ than flicker frequency $\times$ 0.033 or it becomes $\leq$ flicker frequency × 0.08 in Low Risk Level. When flicker frequency is below 90 Hz, maximum modulation percent in Noel Level must be less or equal than flicker frequency × 0.01 or it becomes less or equal than flicker frequency × 0.025 in Low Risk Level. Maximum flicker modulation is assessed upon the lighting unit itself through permitted frequency levels as explained and indicated in App. 1[16].

LIGHT FLICKER MEASUREMENT METHODS

Several measurement methods are available through several programs or light flicker devices with software programs where each one has specified circuit like; Admesy Asteria SC-ASTR-01 High Speed Luminance Photometer device, Gigahertz-Optik BTS256-EF BiTec Sensor Light meter device, EVERFINE LFA-2000 Light Flicker Analyzer device and PNNL (Pacific Northwest National Laboratory) Photoelectric Characterization System (reference meter) [9]. The last measurement system has several techniques; one of them is practically applied in this paper where light portable device is designed composed of capacitance of 22 µF, TSL257 IC Instek, GDS-1022 oscilloscope [10]. TSL257 IC has high sensitive of the luminance output from lighting unit transferred the signal to oscilloscope plotting the analog light signal and so, the two basic metrics of light flicker can be detected and estimated. It is examined by several samples of low power LED units.

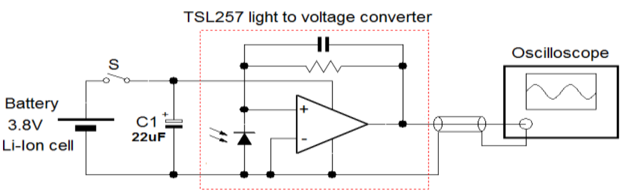


Fig. 1 Light portable measurement device

LIGHT FLICKER ESTIMATION

All mentioned methods have been activated to estimate the two basic light flicker metrics. Another definitions of them that summarized: the first is a relative measure of the cyclic variation in light source output while the second has a reliable relative measure of the cyclic variation of various sources outputs at a given power frequency.

In general, they are calculated according to the differences in waveform shape as shown in Fig. 2 and equations; (1) and (2). This is applied in accordance with basic frequency or amplitude and it is not sensitive for sudden variation in voltage or current. The two basic metrics are the most common employing for quantified light flicker. Percent flicker is known peak to peak contrast and it has the ability to use in scale range from zero to 100 percent. The second, flicker index rating range from zero to unity and it is not used very frequently [2] [6] [7] [8].

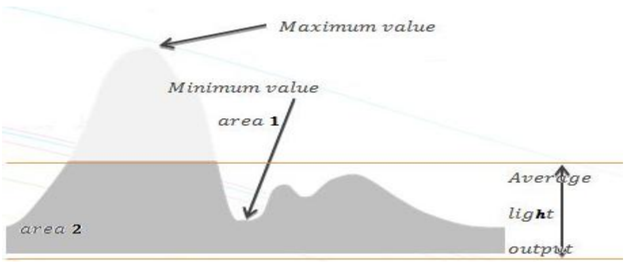


Fig.2 Flicker Index and Percent Flicker Identify (IES Lighting Hand book, 1984)

$$Flicker\ Index = \frac{Area\ 1}{Area\ 1 + Area\ 2} \tag{1}$$

$$Percent\ Flicker = 100\% \ \frac{A-B}{A+B} \tag{2}$$

According to the actual measurement parameters gained from experimental procedure, percentage of light flicker of selected samples is estimated as follows:

If light flicker waveform is sin wave, then,

$$Pecent\ Flicker = \frac{peak\ to\ peak\ value}{2 \times average\ value} \tag{3}$$

Or, if light flicker waveform is not sine wave, then,

$$Percent\ Flicker = 100 \times \frac{max.value - min.value}{max.value + min.value} \tag{4}$$

TYPES OF TESTED UNITS

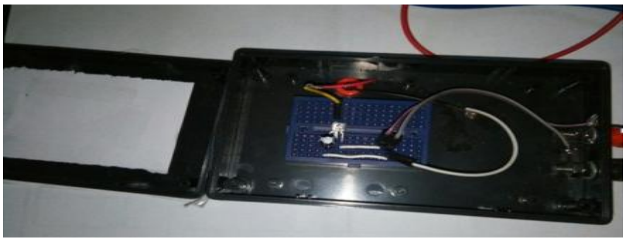
The selected samples are identified in table 1 including the measured power factor (PF) which is poor for the some and total harmonic distortion (THD) is high for the others [1]. The selected tested types are seven types; LEDs types from type 1 to type 5 are bulbs and they have various power ratings, type 6 is spot 6 W, and type 7 is CFL sample unit selected for comparison. Two unit types 1, 2 and type 3, types 4 are identical in specifications but type 2 and type 4 have operated time up to 1000 Hrs. as shown in Table 1. Measured consumed power of identical tested units is different like for unit 4 (new) and unit 5 (operated time up to 1000 Hr.).

Table 1 Selected tested types to measure light flicker

Number & performance	Light color	Lumen	Code Number (Model)	Measured THD %	Measured PF
Type (1) Bulb 4.7 W, New	3000 K Yellow	400	E14 Guarrantee 20160607	79-80.5 I= .38mA	0.46
Type (2) Bulb 4.7 W, up to 1000 Hrs	3000 K Yellow	400	E14 Guarrantee 20160607	78.5-81.2 I= .37mA	0.45-0.47
Type (3) Candle, bulb 6 W, transparent cover, New	4000.K Day light	480	E14	14.1	0.75
Type (4) Bulb, Milky 8.6 W New	6500 K White	880	E27- 865779	79.5-80.5 I= .73mA	0.5
Type (5) Bulb, Milky 8.6 W, up to 1000 Hrs	6500 K White	880	E27- 865779	16-18 I= .39	0.88
Type (6) Spot, 6W, New	3600 K Day light	224	MIR16 6W	83	0.52
Type (7) CFL 12 W, New	6500 K Cool day light	741	TORANDO1 2W	78	0.47

PROCEDURES SETUP

Testing circuit is connected as indicated in Fig. 3 (a) and circuit of light flicker portable measurement device is designed as shown in Fig. 3(b). Light flicker waveform of tested types from type 1 to type 5 is recorded when light flicker waveform time reference is 10 millisecond except light flicker waveform of type 6 and type 7 which have 50 µ second and 25 µ second respectively. Measured parameters from oscilloscope; average voltage (V_{av}), maximum voltage (V_{max}), and minimum voltage (V_{min}) are recorded in Table 2. Also, flicker percent is estimated and recorded in this table according to equation 4. Flicker light waveform of tested units is shown in Fig. 4.



(a) Light portable measurement device components

(b) Testing circuit

Fig. 3 Light flicker testing circuit

The two limits of safe level and risk level according to IEEE Standard are evaluated as shown in Table 2.

Table 2 Measured Percent Flicker for tested unit types

Unit Type	V_{av} (m V) Negative	V_{max} (V)	V_{min} (V) Negative	Flicker %	Average Frequency	IEEE Standard Application	
						Safe mode	Risk mode
(1)	35	1.44	1.31	4.73	50 Hz	0.5	1.25
(2)	33	1.19	1.42	8.81	50 Hz	0.5	1.25
(3)	44	1.12	1.22	4.27	50 Hz	0.5	1.25
(4)	33	1.39	1.35	1.46	50 Hz	0.5	1.25
(5)	31	1.29	1.45	5.84	50 Hz	0.5	1.25
(6)	850	1.06	1.45	15.53	2.4 KHz	N/A	N/A
(7)	+375	3.15	3.72	8.3	18 KHz	N/A	N/A

RESULTS ANALYSIS

Light flicker waveforms of tested types from type 1 to type 5 are nearly identical in shape at a measured time reference is 10 ms. Type 6 and type 7 have various light flicker waveforms where their frequency are higher as indicated in Table 2.

- The main contribution of the experiment is the new tested type 1 or type 4 that have higher flicker percent if compared with their identical types 2 and 5 respectively, which have operating time up to 10000 Hrs. Then, with increasing the operating time of low power LEDs, light flicker percent aims to increase.

- IEEE Standard limits of flicker modulation frequency ratings of tested types are evaluated in the seventh and eighth columns of Table 2. Tested types from type 1 to type 5 that have frequencies ≤ 90 Hz would be classified up to risk mode value.

- Based on IEEE Standards simplest form concludes that the maximum allowable flicker is 10 % if frequency flicker at 120 Hz (double of 60 Hz) and the maximum allowable flicker is 100 % when frequency is 1250 Hz. Evaluating this fact, all tested types have allowable flicker percent [5].

- CFL tested type has light flicker percent in moderate level as compared to LEDs tested types.

- In spite of light flicker waveform is generated due to ripple current waveform, the measured light flicker percent of tested types are independent of their measured THD percent .

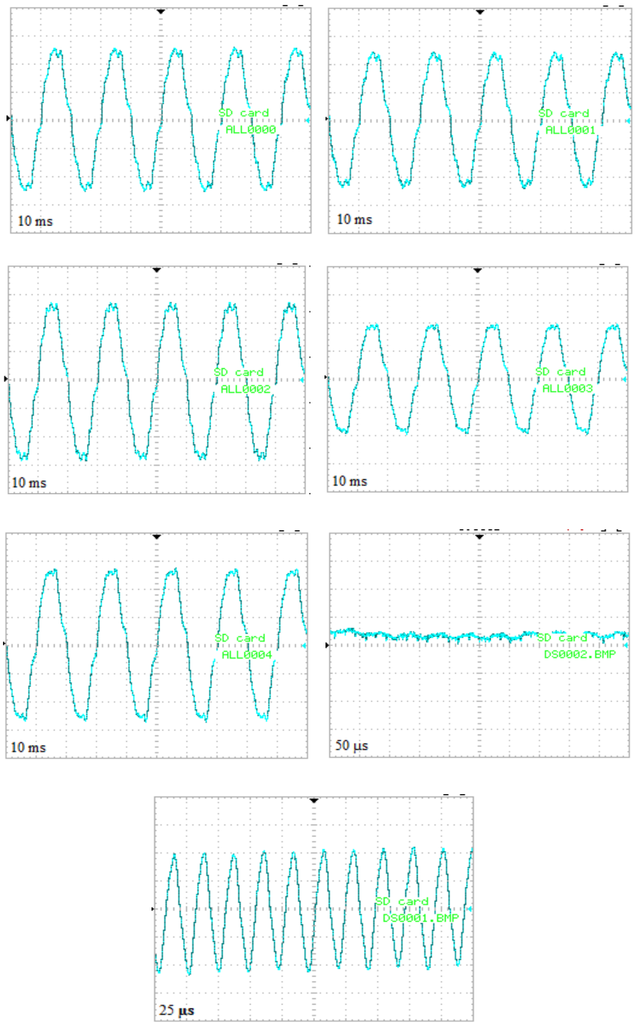


Fig. 4 Light flicker waveform of tested types (from type 1 to type 7 respectively) measured by light flicker portable device and recorded by oscilloscope

INVESTIGATION OF LOW FREQUANCY LIGHT FLICKER LEDS ESTIMATION

Light flicker periodic time signal is analyzed individually into Fourier series components in a period equal T where signal frequency (f) = 1/ T. Then,

$$\omega = 2\pi f$$

The signal may be represented by Fourier Series Equation as [17]:

$$x(t) = X_{avg} + \sum_{m=1}^{\infty} C_m \cos(m\,\omega t + \varphi_m) \quad (5)$$

Where

X_{avg} = the average value of $x(t)$.

C_m = the amplitude of Fourier and corresponding to angular frequency $m\,\omega t$.

φ_m = the angular phase shift of the frequency signal.

Based on low frequency of light flicker, the signal $x(t)$ can be approximated by n- term truncation, $X_{trunc}(t)$. This is truncated Fourier series that is composed of terms within frequency range: 0 < n (integer no.) × f < $t_{hreshold}$, where $t_{hreshold}$ depends on type application. Then, if terms below increase, $X_{trunc}(t)$ improves.

Therefore, the two basic metrics for low harmonic frequency only can be identified through Truncated Fourier Series representation of $x(t)$ by $X_{trunc}(t)$.

$$X_{trunc}(t) = X_{avg} + C_1 \cos(\omega t + \varphi_1) + C_2 \cos(2\omega t + \varphi_2) + \ldots + C_n \cos(n\omega t + \varphi_n) \quad (6)$$

Signal $X_{trunc}(t)$ is only composed of low frequency harmonic index range,

Let f*(t) = [Max. trunc X (t) – Xavg.(0)]*, then:

Low Frequency Flicker Index, *(LFFI)*

$$LFFI = \frac{\int_t^{t+T} f(\lambda)d\lambda}{\int_t^{t+T} Xtrunk(\lambda)d\lambda} \quad (7)$$

Low Frequency Percent Flicker, (*LFPF*)

$$LFPF = \frac{Max.[X_{trunc(t)}] - Min.[X_{trunc(t)}]}{Max.[X_{trunc(t)}] + Min.[X_{trunc(t)}]} \times 100 \quad (8)$$

To simplify the above equations (7) and (8):

LFFI can be estimated independent on phase shift φ_1, assuming zero, according to the first signal harmonic and then, there is one term is estimated, C_1 with notice the symmetry of cosine functions:

$$LFFI = \frac{\int_0^{T/4} C_1 cos\omega(t)dt + \int_{T/2}^{3T/4} C_1 cos\omega(t)dt}{T \times X_{avg} + \int_0^T C_1 cos\omega(t)dt}$$

and it becomes directly as:

Low Frequency Flicker Index, *(LFFI)* =

$$LFFI = \left[\frac{C_1}{X_{avg}}\right] \quad (9)$$

Also, *LFPF* can be simplified where $Max.[X_{trunc(t)}]$ and $Min.[X_{trunc(t)}]$ are equal to $X_{avg} + C_1$ and $X_{avg} - C_1$ respectively.

Then, it becomes:

Low Frequency Percent Flicker =

$$LFPF = \left[\frac{C_1}{X_{avg}}\right] \times 100 \quad (10)$$

Then, equations (9) and (10) are examined for the tested units as follows:

The tested types units from type 1 to type 5 have been examined by Fourier Series Application except types 6 and 7 which have frequency up to 2 kHz.

- *LFFI* estimated from equation (9) that is available for low frequency LEDs only. The readings are matching with measures readings of Percent *LFPF* as indicated in Table 3.

- *LFPF* can be estimated for tested units according to equation (8) which is similar to light flicker percent estimation in equation (4) where approximated equation (10) is not satisfied for tested LED units.

- For the identical tested units; type 1 and type 2 or type 4 and type 5, *LFFI* and *LFPF* percent increases with the operating time of the unit.

Table 3. Flicker Index and Flicker Percent estimated by Fourier series for one signal

Unit Type	Type (1)	Type (2)	Type (3)	Type (4)	Type (5)
LFFI	0.44	0.85	0.31	0.14	0.6
LFPF %	4.73	8.81	4.27	1.46	5.84

CONCLUSIONS

From the experimental procedure with the previous practical issues for the actual LEDs production with standards evaluation, low power LEDs units have low Flicker Percent and low Flicker Index. Due to non-uniform specifications for identical low power LEDs and its drives, this may lead variable performance of light flicker waveforms and different light Flicker Percent. Manufactures must uniform the specifications of LEDs drives designs with good quality since it has the essential effects of light flicker percent. Due to higher frequencies of CFLs unit, moderate light flicker percent are recorded. Light Flicker Percent for tested LEDs units which having operating time up to 10000Hrs is higher than the identical one having no operating time. This may return to LED junction material quality or LED drive components. New production of low power LEDs must be matching to standard specifications. Light flicker for low power LEDs is not related with THD percent for them. Light flicker estimation by algorithms must have more studies especially for low power LEDs units. Residential LEDs units' data sheet must include the necessary knowledge for fixture methods satisfied for consumers to reduce the problems affecting on the LEDs performance on the long run.

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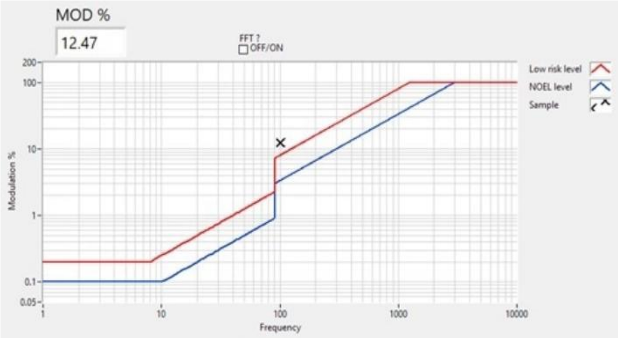
APPENDIX



App. 1 Noel Level and Low Risk Level have relationship between light frequency and flicker modulation when frequency ≤ 90 Hz or frequency ≥ 90 Hz.