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Posted Date: 3 September 2024

doi: 10.20944/preprints202409.0249.v1

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Research on Flicker Effect in Modern Light Sources Powered from Electrical Network

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Abstract: Disruptions in power quality have a negative impact on many energy consumers. These include lighting, where interference manifests itself, among others, in the form of light flickering. The article presents phenomena accompanying the operation of modern light sources against the background of exemplary results of studies on the flicker of conventional light sources, such as incandescent or fluorescent lamps. To assess the effects of these phenomena, it is necessary to use measures other than those traditionally used. The results of measurements carried out in accordance with different recommendations take into account both power supply disturbances and the properties of modern light sources.

Keywords: light flicker; modern light sources; light flicker standards, light intensity measurement system.

1. Introduction

Electricity is generated by converting primary sources like coal, oil, gas, solar power, and hydropower. Fossil fuels are typically burned to generate heat, which produces steam to rotate a generator to produce electricity. While this method is highly efficient, it is not renewable and has a significant environmental impact. In contrast, renewable energy sources (RES) generate electricity in various ways that do not rely on burning fuels. Currently, renewable sources like hydropower account for over 30% of the total global installed capacity and contribute about 23% of the world's electricity production [1].

Electric light sources have been in use for about 100 years. Until the early 2000s, incandescent and fluorescent lamps were the primary types used in households, industrial and public facilities. However, voltage disturbances in the electrical network can cause fluctuations in lighting, which significantly affect the sensory experience of people exposed to them [2,3]. These fluctuations are typically due to periodic or random changes in the voltage supplying the light source. Such disturbances cause the lamp to emit temporally modulated light, leading to several effects [4,5]. The effects can be grouped as follows:

- affecting visual perception,
- neurobiological effects,
- reduction in performance and cognitive abilities.

The observer's visual perception can be affected by flickers resulting from varying intensity of light (illuminance), stroboscopic effects related to a moving objects observed to be frozen, or phantom array perceived as a view of the multiplied pattern. Neurobiological effects manifest themselves as eyestrain, headache, epilepsy, etc. Reduction in performance and cognitive abilities is expressed as visual and cognitive performance limitations, a bad mood, or mental discomfort, etc.

Flicker is one of the phenomena associated with the operation of electric light sources, resulting from the emission of time-modulated light, and can be perceived by the user in a visible or invisible

 doi:10.20944/preprints202409.0249.v1

form. Depending on the frequency and amplitude of this modulation, flicker can lead to various health issues, such as nausea, headaches, or even trigger epileptic seizures [3,5].

Visible flicker refers to flicker that can be seen by the human eye and is linked to serious health risks, including seizures. It also poses safety concerns in environments like roads and parking lots. Under typical conditions, most people cannot perceive light flicker at frequencies above 80 Hz, which is considered the cut-off frequency for LED lighting. However, even at higher frequencies, flicker can still cause health problems. For those with photosensitive conditions, epileptic seizures can occur within the 3 to 70 Hz range, while photosensitive epilepsy commonly triggers seizures between 15 and 20 Hz [6,7].

Invisible flicker is flicker that isn't easily noticeable to the human eye but can still cause issues such as dizziness and migraines. The most concerning effect of flicker at frequencies above 70 Hz, even if imperceptible, is that prolonged exposure can lead to symptoms like headaches, mood disturbances, and potentially impaired vision.

The Phantom Array effect occurs when a non-static observer, such as someone moving their head or driving a car, perceives a change in the shape or spatial arrangement of objects in a static environment. This effect typically occurs within the frequency range of 80 Hz to 2500 Hz.

Within a similar frequency range, the stroboscopic effect can also occur. This effect involves a change in perception, where flicker frequencies interact with the movement of an object. If the flicker frequency matches the movement frequency of an object, the object may appear to be stationary to the observer. This creates a significant safety risk, as it can give the illusion that reality has stopped or slowed down, potentially endangering human health and life.

Flicker is technically described in standards as voltage fluctuations that modulate the light amplitude or power output of a light source. The principle of determination of flickering severity has been given in IEC documents [8,9]. The method used to calculate the voltage quality index, called flicker severity (or flicker intensity), is complicated but widely used. The calculation method assumes that light flickering occurs as a result of the operation of incandescent lamps exposed to voltage fluctuations [10,11]. The proposed in standards flickermeter presents a model of a complex system consisting of human brain and eye and an incandescent lamp, which renders possible estimation of the flickering phenomenon independent of the character of voltage fluctuations and the source of the disturbances (Figure 1). Luminous flux variations (flickering) of incandescent light sources has been assumed as voltage variation indicator. Model of incandescent lamp functions as a demodulator, at the output of which signal is proportional to luminous flux variations (③ in Figure 1). Modeling of the reaction of human brain and eye has been based on ergonomic data (Rashbass and Koendrink model of ergonomic data). The results of the experimental investigations have made possible presentation of a thesis about similarity between the sensitivity of human eye to light stimuli and frequency characteristics of a four-pole filter (of band 0.05 to 35 Hz)(④). Interference is analyzed from the point of view of harmfulness for human beings. For this reason, the influence of the brain waves α (98 – 10c/s) in the form of a filter has been taken into account, which is model of the reaction of human eye to a change of luminous flux of an incandescent lamp, whereas the reaction of human brain to a light stimulus was modeled by a quadrator and an integrating system. The course thus transformed represents instantaneous flickering level (⑤). Because of a random character of the flickering phenomenon, two statistical factors P_{st} and P_{lt} are to be determined (⑥). Short term flickering severity indicator P_{st} is determined by means of a function of a cumulative probability of obtaining of instantaneous flickering values CPF, that is a curve of orderly probabilities which does not exceed definite values of the flickering levels in the respective time, for a recording period of the course under investigation equal to 10 minutes. $P_{st} = 1$ [*p.u.*] corresponds to the flickering visibility threshold, which must not be exceeded in order to avoid psychic discomfort of the observer. Long term flickering severity indicator P_{lt} is determined for a 2h time window from twelve successive values P_{st}. The IEC 61000-4-15 standard [9] summarizes the research supporting the IEC 61000-3-3 standard [8] for flicker and establishes a measurement method (Figure 1). In order to check the quality of power supplied by the supplier, the international standard EN-50160 [12] is used. This standard sets a limit for the P_{lt} parameter for light flicker, which is 1 for 95% of measurements taken each week.

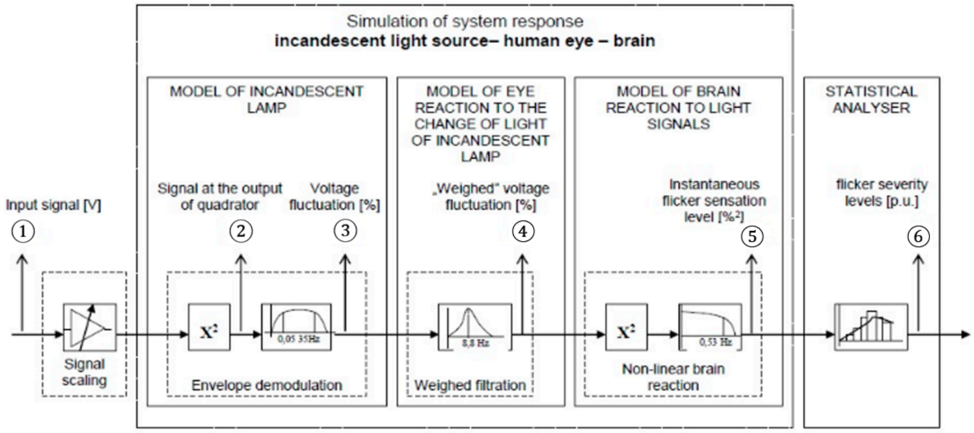

Figure 1. Functional diagram of the flickermeter [13].

In [13] an analysis of voltage changes causing light flicker in the onshore power grid of the Metallurgical Works is presented. The measurement were carried out in the supply lines of an electric motor for supplying the rolling mill of rated voltage equal to 6 kV. Short-term flickering severity indicator P_{st} didn't exceed the severity level during the experiment (Figure 2). Figure 3 shows the course of the instantaneous flicker sensation level [14] along with the corresponding cumulative probability function [15] for the 10-minute period in which the highest P_{st} value occurs.

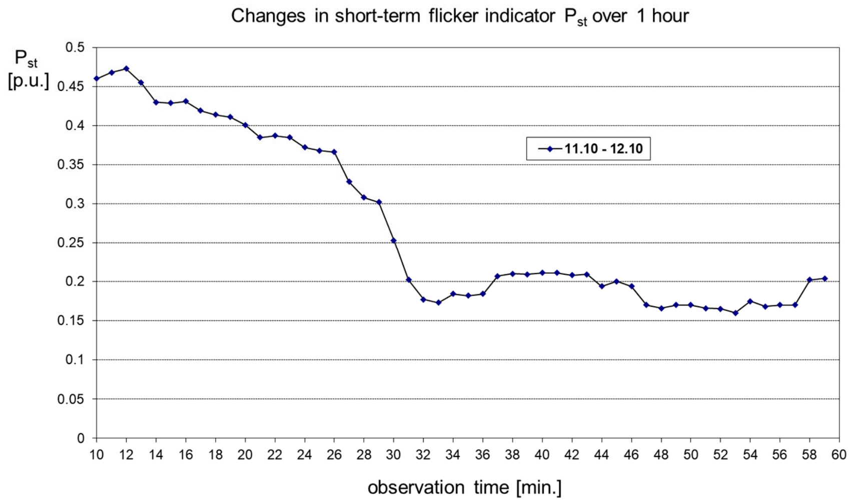

Figure 2. The short-term flicker severity indicator measured in the industrial supply line of rolling mills [16].

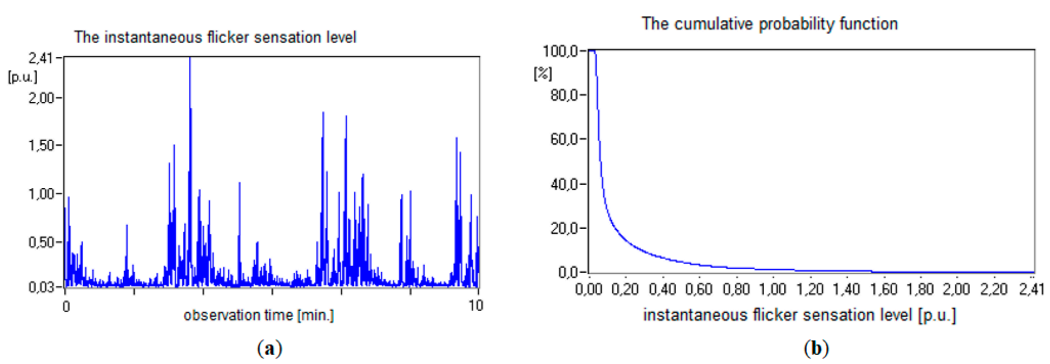

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Figure 3. The instantaneous flicker sensation level measured in the industrial power system: (**a**) supplying the rolling mill motors; (**b**) the corresponding cumulative probability function; P_{st}=0.46 [p.u].

The flicker effect of light emitted from different lamps depending on the actual mains voltage varies considerably depending on the design of the specific lamp. Therefore, various methods based on signal processing techniques has been presented in the literature for source detection [17].

However, these traditional lamps are being replaced with energy-saving lamps. At the beginning of the 21st century, in addition to new developments of compact fluorescent lamps (CFL), light-emitting diode (LED) lamps appeared on the lighting market.

The purpose of developing the IEC standards and P_{st} flickermeter was to create a tool for assessing voltage fluctuations in power supply to avoid visible lamp flicker and complaints from electricity consumers. Determining the P_{st} value is based on a 60 W light bulb. Since P_{st} was developed at a time when incandescent bulbs were the most common light source, modeling light fluctuations based on voltage fluctuations made sense because there was a relationship between supply voltage fluctuations and light fluctuations.

However, to estimate the flicker intensity of LED lamps, a new approach must be used. It has already been noted that the use of existing standards to assess the effects of flickering light in relation to its various sources is cumbersome and not always clear. The flicker severity index should no longer be a measure of the light flicker with those energy-efficient lamps. Instead of determining voltage fluctuation indicators, an assessment method was introduced based on measurements of the light intensity produced in the lamp. This approach is included in the technical report [6,18]. The IEC-TR-61547 standard describes a flickermeter that uses changes in light as a direct input signal, unlike the original IEC flickermeter which takes voltage as an input signal and models the light of a 60 W incandescent lamp. A new short-term flicker indicator P_{st}^{LM} has been introduced, which is a measure of flicker defined in the same way as P_{st}, taking light intensity as the input signal.

The IEEE 1789 standard [18] introduces two factors used to assess flicker, flicker index F_i and flicker percent F_p illustrated in Figure 4, which take into account the effects of both voltage fluctuations and source properties, includes all visual and non-visual flickering light effects. F_p determines and characterizes the relative variability of light amplitude, i.e., it is a measure of the depth of flicker modulation. F_i is a lesser-known measure that takes into account the different shapes or duty cycles that periodic lighting waveforms can have. It includes flicker percentage, waveform, and duty cycle, which refers to the percentage of time in a single cycle.

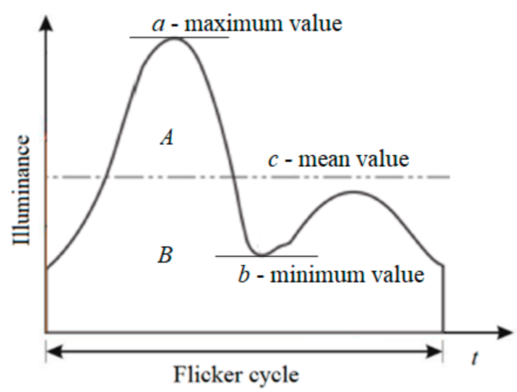

Figure 4. Elements of the light intensity curve used to determine the F_i and F_p coefficients.

Mathematical relationships describing flicker indicators:

$$F_p = 100\% \frac{a-b}{a+b} \; [\%] \tag{1}$$

$$F_i = \frac{A}{A+B} \; [-] \tag{2}$$

where:

A – surface area for the area above the average value during one flicker cycle,

B – surface area for the area below the average value during one flicker cycle,
a – maximum voltage value recorded during flickering cycle,
b – minimum voltage value recorded during flickering cycle.

Considering the flicker frequencies f_{flick}, the standard [18] recommends the limits of the flicker percent F_{p_b} defined by relations (3) and (4). Equation (3) refers to f_{flic} frequencies below 90 Hz, while (4) is for frequencies above this threshold. Flicker percent values F_p determined for a given light source that are lower than the corresponding F_{p_b} values can be considered acceptable.

$$F_{p\_b} = 0.25 \cdot f_{flick} \tag{3}$$

$$F_{p\_b} = 0.08 \cdot f_{flick} \tag{4}$$

With respect to the standards [8,9], the main difference is that the F_p and F_i coefficients describe the behavior of the supply voltage together with the characteristics of the light source itself.

The article presents exemplary results of flicker tests, relating mainly to LED lamps, selected from many test specimens of various light sources: LED lamps, CFL fluorescent lamps and halogen lamps. The influence of the distance from the light source on the intensity of flicker is also shown. Additionally, the effects resulting from various parameters of the DC power supplies used for LED lamps were presented. Measurements were performed in accordance with the recommendations of the standard [18]. The subject of the research was the flickering of light from sources powered by uninterrupted mains voltage, and their aim was to demonstrate whether the design of a modern light source itself may be the cause of the flickering effect.

2. Materials and Methods

The diagram of the developed measurement system is shown in Figure 5. Using a photodiode ① type ams Osram BPW21 [19] in the application system, measurements of the light produced in the tested bulbs were performed. A voltage follower ② is connected to the AI_0 input of the NI USB 6008 multifunction data acquisition (DAQ) device [20]. The DAQ operates under the control of a PC running a dedicated application in the NI LabVIEW environment. For the best results, tests were performed in complete darkness with no other light-emitting sources. This was achieved by using a rectangular box measuring 30x30x100 cm, which was constructed in such a way as not to allow light into the interior of the housing. The photodiode ① is placed on one side of the box, and the individual light sources under test ③ are mounted on the opposite side. For safety reasons and to obtain stable power supply conditions for the tested light sources, an ST (230/230 V) isolating transformer was used. Additionally, the voltage on the light source is measured in a voltage divider circuit (resistors R2 and R3) connected to the AI_2 and AI_6 inputs of the DAQ device.

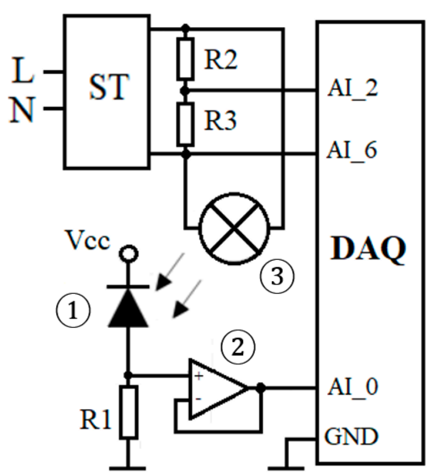

Figure 5. Diagram of the measurement system.

The characteristic of the conversion of light intensity E to voltage U, formed in the developed system with the participation of resistance R1, determined and recorded using a DAQ device, is

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shown in Figure 6. It was determined using the reference flux meter Voltcraft LX-10 [21]. The maximum output voltage value of 4.55 V corresponds to approximately 1000 lx. Using the voltage values measured in the developed system, the illumination intensity values can be reconstructed based on the relationship (5), as a polynomial interpolation of the inverse relationship E=f(U) to that shown in Figure 6.

$$E = 16.161U^2 + 143.61U + 0.4401 \quad (5)$$

The flicker indicators (1) and (2) for each tested bulb were determined using a dedicated program developed in the NI LabVIEW environment.

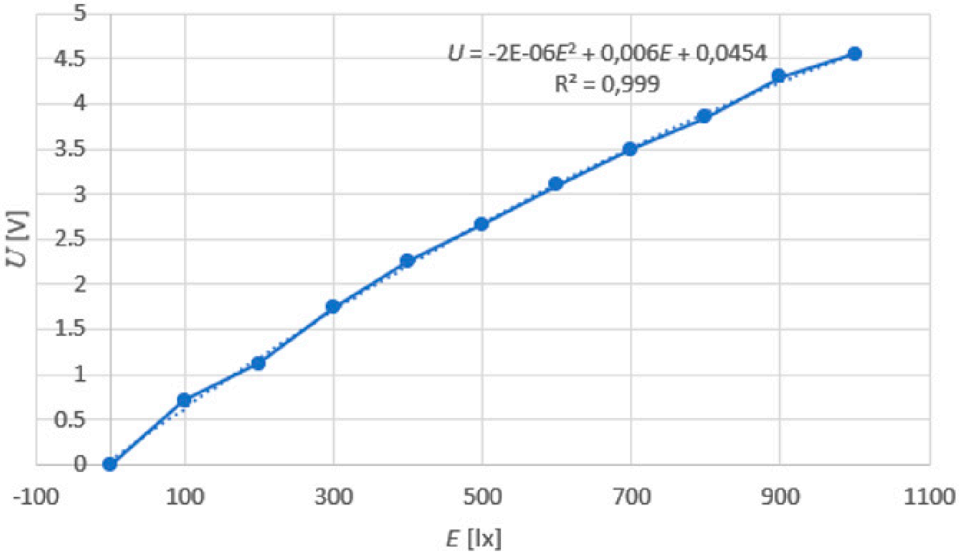

Figure 6. The characteristics of measurement system.

Modern, compact light sources were selected to test the flicker effect: LED lamps, fluorescent lamps and halogen lamp (Table 1 in Section 3). The largest group studied are LED lamps. It contains light sources from different manufacturers, with different properties, but with similar luminous fluxes. When selecting bulbs, it was considered that they represented different price ranges, bulb shapes and terminal types.

The first group of modern light sources, most represented in the research (18 items), is LED lighting (Figure 7a,b). This technology has become the most popular and rapidly advancing in recent years, as demonstrated by the fact that the luminous efficiency of standard LED sources typically ranges from 100 to 120 lm/W, with the latest LED chips achieving 180-200 lm/W. The advantage of this technology is its long operating time (up to 25 years). The disadvantages of this group include the relatively high cost of their production in comparison to the other tested groups.

The second group of tested bulbs included two compact fluorescent lamps (CFLs) (Figure 7c). They are the first light sources that began to replace traditional bulbs. Fluorescent lamps offer a good service life, estimated at 6-8 years of use, and additionally provide luminous efficacy at an average level of 70 lm/W, with fluorescent lamp-type sources available with almost 100 lm/W efficiency. The disadvantages of this group of sources include the emission of UV radiation, the effect of light flicker, and the spectral distribution of light unfavorable to the human eye.

In the third type of light source, a single halogen bulb was tested (Figure 7d). Halogens offer a longer operating time than traditional light sources, but much shorter than fluorescent lamps. The great advantage of this type of lighting is the potential lack of flicker and the favorable spectral distribution of the generated light, similar to sunlight, as well as the lack of UV radiation characteristic of fluorescent lamps. The disadvantage of halogens is low luminous efficiency, which is on average about 15 lm/W, and a high level of thermal radiation.

An additional group of tested light sources are integrated LED modules with an external constant current power supply.

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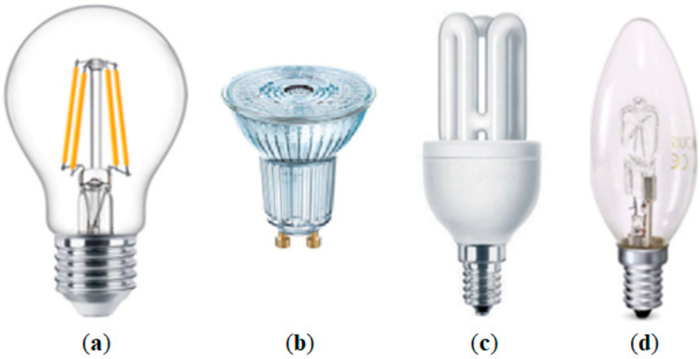

Figure 7. View of examples of popular light sources with E27, GU10 or E14 terminals: (**a**), (**b**) LED bulbs; (**c**) fluorescent bulb; (**d**) halogen bulb.

At this point, it is worth recalling that the light intensity (illuminance) E [lx] is a measure of how much light falls on a given surface, while the luminous flux Φ [lm] indicates the amount of light emitted by a light source.

3. Results

The tests were carried out in a room free from other light sources, although the measuring box was closed for each measurement to eliminate any influence of other light sources and ensure appropriate measurement accuracy. All measurements were carried out with a delay of 15-30 minutes in order to obtain stable temperature conditions of the tested light sources.

3.1. Flicker Studies

Figure 8 shows the waveforms recorded in the developed system for the light emitted by two exemplary LED light sources along with a description of their basic properties.

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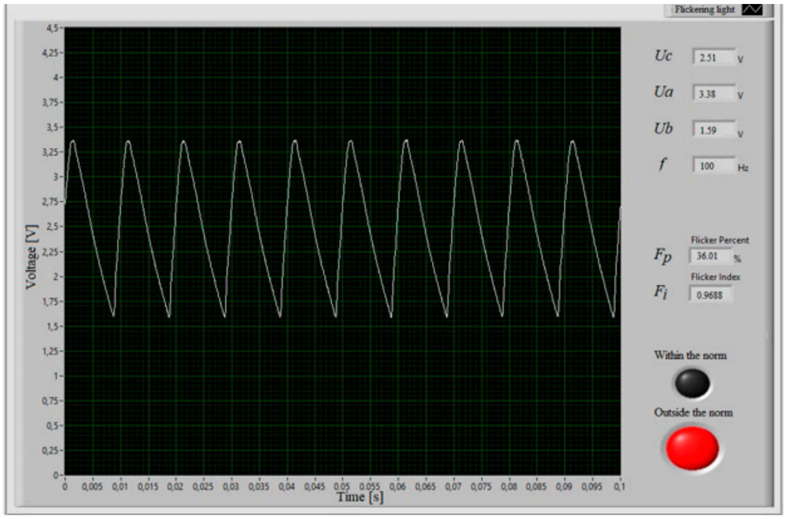
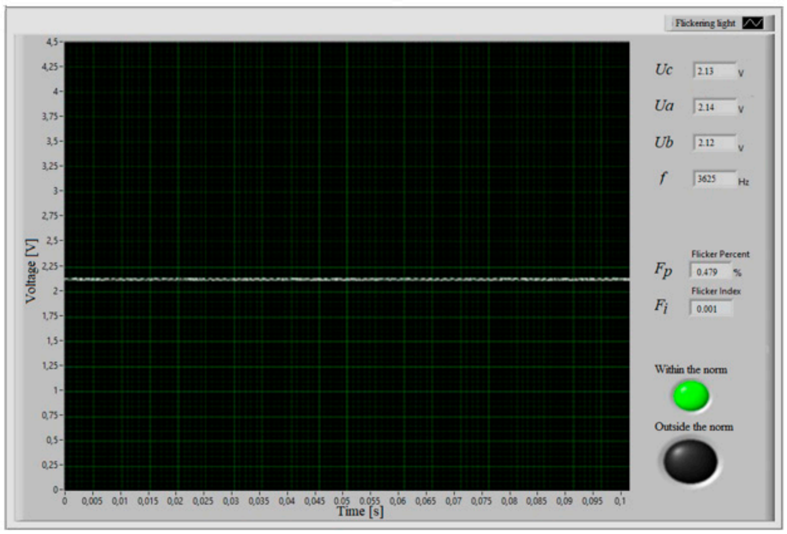


(a)



(b)

Figure 8. Examples of light waveforms recorded in the LabVIEW application, generated by: (**a**) Polux LED E27; (**b**) Tungsram LED E27.

Table 1 presents basic features of the tested light sources. These are examples of lamps currently available on the market, among which LED lamps are the "first choice" of users. In addition to different LED lamps (18 initial items in Table 1), tests were carried out on 2 fluorescent lamps and 1 halogen lamp. Table 2 contains results obtained for individual tested light sources. The numbering used in Table 1 to designate individual light sources is consistent with the numbering used in Table 2. The voltage designations (Ua, Ub and Uc – maximal, minimal and mean voltage, respectively) correspond to indexes a, b, c in Figure 4. The flicker frequencies f_{flick} of all tested light sources were above 90 Hz, hence the formula (4) was used to determine the F_{p_b} limits. F_p values exceeding the recommended limits are marked in bold in Table 2.

Table 1. Designations and basic properties of the tested bulbs.

No.	Manufacturer and type	Nominal power P [W]	Luminous flux Φ [lm]
1	Polux Platinum LED E27 G45	5.5	480
2	Tungsgram LED E27 G45	4.5	470

3	Philips CorePro LED luster E27 G45	5.5	470
4	Philips Master Value LED E27 A60	3.4	470
5	Philips Master LED bulb E27 A60	12	806
6	Philips CorePro LED bulb E27 A60	5.5	470
7	Kanlux Apple LED E27 A60	8	800
8	Osram Retrofit LED E27 G125	6.5	806
9	Philips Hue White E27	9	806
10	IKEA SOLHETTA LED bulb E14 G45	2.2	200
11	Elitecho B35G LED E14	4.8	470
12	Osram Parathom E14	4	470
13	LumiLed GU10	3	270
14	No name (China) LED GU10	1	105
15	Osram LED Value LED GU10 PAR16	4	230
16	Osram Parathom PRO LED GU10 PAR16	3.4	230
17	Philips Hue White Ambiance LED GU10	5	350
18	Philips Hue White LED GU10	5.2	400
19	POLUX Gold2 mini FST2 fluorescent E14	6	315
20	Philips Genie Hg fluorescent E14	8	425
21	Pila Halogen E14 P45	42	630

Table 2. The results of measurements of the light emitted by the tested bulbs and the values of the determined coefficients.

No.	U_c [V]	U_a [V]	U_b [V]	f_{flick} [Hz]	F_p [%]	F_i [-]	F_{p_b} [%]
1	2.51	3.38	2.21	100	**36.01**	0.097	8
2	2.13	2.14	1.59	3635	0.47	0.001	290.8
3	3.49	3.51	3.47	3525	0.58	0.001	282
4	1.33	1.35	1.31	100	1.34	0.002	8
5	3.41	3.48	0.00	100	**100.00**	0.009	8
6	3.42	3.47	3.36	100	1.6	0.003	8
7	2.12	2.17	2.06	2166	2.66	0.006	173.28
8	2.02	2.22	1.85	100	**9.28**	0.024	8
9	2.49	2.71	2.21	100	**10.10**	0.029	8
10	0.90	0.94	0.84	6950	5.43	0.012	556
11	1.12	1.13	1.11	3274	0.91	0.002	261.92
12	0.89	0.91	0.87	100	2.00	0.003	8
13	3.66	3.67	3.65	3107	0.27	0.001	248.56
14	2.33	2.53	0.73	100	**65.89**	0.175	8
15	2.21	2.30	2.11	8118	4.33	1.011	649.44
16	3.15	3.19	3.10	100	1.46	0.003	8
17	2.11	3.97	0.71	2019	69.79	0.157	161.52
18	2.32	2.34	1.90	2054	10.10	0.002	164.32
19	1.10	1.20	0.94	100	**11.94**	0.028	8
20	4.04	4.26	3.68	100	7.35	0.018	8
21	1.13	1.34	0.91	100	**18.97**	0.052	8

The developed measurement system and the procedures for determining the flicker coefficients are also used in further tests described in the following subsections.

3.2. Study of the Influence of DC Power Supply Properties

The aim of this part of the research was to assess whether the properties of the DC power supply intended for cooperation with the LED lamp have an impact on the quality of the generated light.

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The tests utilized the same recessed LED Arkos Swap S lamp (5 W, 640 lm), mounted in a suspended ceiling. The lamp was powered successively by two different DC power supplies: a 350 mA DC power supply QH-40LP20-36x1W from QiHan Power Co. Ltd., China and a 350 mA DC power supply TCI Maxi Jolly from Telecomunicazioni Italia S.R.L., Italy.

Table 3 contains the measurement results and the values of the coefficients determined in the developed measurement system.

Table 3. Measurement results of emitted light and values of determined coefficients for tested bulbs powered from two different DC power supplies.

DC power supply	*Uc* [V]	*Ua* [V]	*Ub* [V]	*f* [Hz]	F_p [%]	F_i [-]
QH (China)	2.40	3.24	1.70	100	31.34	0.087
TCI (Italy)	2.23	2.25	1.22	3396	0.85	0.001

3.3. Flicker Tests for Different Distances from the Light Source

Tests were conducted with a selected light source to determine how the distance between the measuring photodiode and the flickering light source affects the flicker level. The study was performed using halogen Piła Halogen E14 bulb. A very interesting relationship was observed here: although the voltage amplitude from the light measurement system was much greater at a distance of 10 cm than at 100 cm (0.48 V for 10 cm and 0.21 V for 100 cm), the flicker rates increased significantly at the distance 100 cm (F_p=12.58 % and F_i=0.037 for 10 cm, and F_p=18.97 % and F_i=0.051 for 100 cm, respectively).

Table 4. Measurement results of emitted light and values of determined coefficients for tested bulbs at different distances from the measuring photodiode.

Distance [cm]	*Uc* [V]	*Ua* [V]	*Ub* [V]	*f* [Hz]	F_p [%]	F_i [-]
10	3.84	4.32	3.36	100	12.58	0.038
100	1.13	1.34	0.91	100	18.97	0.052

4. Discussion

The conducted research largely confirms the current knowledge about the tested light sources. Starting with fluorescent light sources (CFL), guided by the manufacturer's reputation, both the higher quality source (Philips Genie) and the lower quality (and cheaper) source (Polux Gold2) generated obvious classic flickering with a frequency of 100 Hz, but it is worth noting that the better quality source generates lower flickering level. The representative of the next group of light sources - halogens, also in line with expectations, generated flickering with a frequency of 100 Hz, which confirms the typical way of flickering for sources of this type.

LED light sources are the most interesting and currently the most important group of lighting devices. During the research, this group showed a whole spectrum of different results that are subject to interpretation, but after examining this group it cannot be clearly stated that there is a clear relationship between LED technology and specific effects related to flickering. A number of the tested sources indicated the presence of flickering effects, often very intense, but a large number of the tested sources did not show any flickering.

During the study, measurements of the same light source were carried out at two different distances of the light source from the measuring photodiode to analyze the differences obtained in the results of flicker measurements. An example of a flickering light bulb was selected and measurements were taken at distances of 10 cm and 100 cm. The measurement Table 4 shows the test results for the halogen lamp, but the measurement results for the LEDs and CFLs were similar to those of this group. At first glance, analyzing the graphical course of flickering, one could say that the flickering effect decreases with increasing distance, because the flicker amplitude drops

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significantly, but in fact, the flickering effect intensifies, as shown by the measurement results. Both the percentage flicker index F_p and the flicker index F_i increased as the distance of the measuring photodiode from the light source increased (at a distance of 100 cm they increased by approximately 50 % compared to the value at a distance of 10 cm). There is one conclusion - the distance of the observer from the source of flicker has a significant impact on the values of flicker indicators.

The conducted research has shown the importance of selecting a DC power supply, supplying the light source with voltage of appropriate quality, for the generation of flickering light. Using the same light source, powered from two different DC sources, light of different quality was obtained. In the case of the QH power supply, the source generated large flicker with the worst possible properties - high amplitude, low frequency. When using the TCI power supply, the flicker amplitude was negligible and the frequency was very high, over 3 kHz. This example confirms that the generation of flickering can be caused not only by the light source itself or LED technology, but also by the power source - the controller/power supply.

5. Conclusions

The conducted studies have shown that the flickering effect of light generated in modern lamps can also occur under stable voltage conditions in the supply network. Depending on the manufacturer and type of lamp, this flickering has different intensity, in different frequency ranges. The methods presented in IEC standards [8,9] do not apply to the description of the flickering properties in these conditions.

The research concerned understanding the mechanism of the phenomenon of flickering light generated from various sources powered by electricity. Thanks to the construction of a stand based on optoelectronics and a modern DAQ measurement device, as well as using the measurement algorithm developed as part of the research in the NI Lab VIEW environment, observations and research on this interesting phenomenon were carried out. The most important observation may be formulated as follows:

- The flickering effect is a common phenomenon in modern light sources. Flicker occurs in each of the studied groups of light sources. The first group tested were fluorescent lamps, which, according to the assumptions, generate constant flickering at a frequency twice as high as the frequency of the power supply. Flicker is a characteristic feature of fluorescent lamps, which has been confirmed by research. Studies of the second group of light sources, i.e., halogen sources, also confirmed the predictions. They generate light similarly to the sources from the first group, with a flicker frequency twice as high as the supply frequency. The research results of the first two groups were not very surprising due to the fact that these technologies have been known for a long time, and at the same time their principle of operation. The most interesting tested group turned out to be LED technology sources, as some models of sources from this group did not show the flickering effect, but at the same time a representative of this group had the worst flicker factor of all the tested sources (item 5 in Table 2). In this group, the general conclusion is ambiguous, because it should be stated that LED technology may be associated with the appearance of a flickering effect, but this is not the rule. The presence of the flickering phenomenon is mainly related to the low price of the light source, but there are also exceptions to this rule. To sum up, to a greater or lesser extent in each group, examples of light sources exhibiting the flickering effect were found.
- Another element of the research were the differences in the intensity of flickering for close and far distances of the photodiode from the light source. At first glance, it seems that the flicker effect decreases with increasing distance, but this only decreases the flicker amplitude, which gives the false impression of less flicker. In fact, moving the photodiode further away from the source showed that flicker rates increase significantly with distance, despite the smaller amplitude. This results from the method of calculating the flicker coefficients, i.e., the quotient of the amplitude and the sum of the extreme values of the light curve.
- As expected, the flickering phenomenon occurs more often in relation to sources categorized as cheap, but it does not exclude products from producers described as reputable due to their

 doi:10.20944/preprints202409.0249.v1

higher quality and price. Interestingly, one of the worst results, i.e., with the highest F_i and F_p coefficients, was obtained by a product from the Philips and Osram brands, a representative of the premium light sources. It is also worth noting that the more expensive sources, despite the flickering effect, mostly met the IEEE recommendations [6,18], which means that reputable manufacturers usually calculate and design the production of light sources in such a way that to be healthy for users. Therefore, the decision to purchase (usually wholesale) a specific type of light source should be preceded by an assessment of its properties, at least on the basis of the quality declaration provided by the manufacturer.

It should be mentioned that the indicators from the IEC 61000-3-3 standard, P_{lt} and P_{st}, quoted in the work characterize the flicker effect caused only by voltage fluctuations at the source, and the coefficients used in the work to determine the level of flicker, F_i and F_p, result from both voltage fluctuations and properties of a particular light source.

In the developed measurement system, flicker coefficients are designated in time windows related to the current flicker frequency. It is an easy task to determine the coefficients for following time windows and this way to determine the course of coefficients related e.g., to the varying conditions of the supply voltage. The elaborated measurement and data processing system enables estimation and recording time-varying coefficients, e.g., in accordance with the procedures recommended by the IEC in [8,9].

Author Contributions: Conceptualization, R.M. and B.P.; methodology, R.M. and D.W.; software, R.M. and D.W.; validation, J.M., B.P. and R.M.; formal analysis, J.M.; investigation, D.W. and R.M.; resources, B.P and R.M..; data curation, R.M. and B.P.; writing—original draft preparation, R.M. and D.W; writing—review and editing, R.M.; visualization, D.W., R.M. and B.P.; supervision, J.M.; project administration, R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data is contained within the article or supplementary material. Dataset available on request from the authors

Conflicts of Interest: The authors declare no conflicts of interest.

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