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New Flicker Weighting Curves for Different Lamp Types Based on the Lamp Light Spectrum

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Abstract— Flicker is a kind of annoyance of the human eyes. This is due to the fact that the human eyes are sensitive to the light color and light intensity, which vary under flicker conditions. The light color depends on the light spectrum. How the light spectrum varies under flicker is the interesting problem. In this paper, the lamp light spectrum of the incandescent lamp and the fluorescent lamp is presented. Based on the lamp light spectrum under flicker, a frequency domain flicker measurement proposal is described in this paper.

Index Terms— flicker, light spectrum, flicker response, lamp-eye-brain system, weighting curve

I. INTRODUCTION

LIGHT flicker is the noticeable light intensity variation of the lamp caused by the voltage fluctuations in the electric power system. The amplitude of the voltage fluctuation should be less than 10% of the nominal voltage [1]. The flicker frequency of interest is lower than 35Hz. The main sources of the flicker are arc furnaces and welding machines. Nowadays flicker is also caused by wind farms. The UIE/IEC flickermeter is world wide used to evaluate the flicker level. The input of the UIE/IEC flickermeter is the modulated voltage. By using a statistical calculation, the final output of the UIE/IEC flickermeter is the short term flicker level indicator P_{st} and the long term flicker level indicator P_{lt} . In the UIE/IEC flickermeter, there is an important lamp-eye system simulator, called the weighting filter [2] [3]. The weighting filter simulates the flicker response of the 230V 60W incandescent lamp as a first order low pass filter. The combined flicker response of the lamp-eye system is simulated as a transfer function.

The lamp-eye simulator is important in the flicker measurement because flicker is a kind of annoy of the human eyes caused by the light variation resulting from the voltage fluctuations. Since flicker is a kind of sensation of the human

eyes, it is important to know the structure of the vision system of the human being. The function of human eyes is like a camera [4]. Comparing the human eye to a camera (see Fig.1), the cornea acts as the cover of the lens. The pupil, which is the aperture on the center of the iris, acts like the aperture of a camera. Both the crystalline lens and the vitreous act as the lens of a camera. The retina acts like the film of a camera. When the human eyes look at an object, the light rays reflected from the object first pass the cornea. Then the light rays are bent by passing the pupil, which also can affect how much light rays are allowed to enter the human eyes. After passing the crystalline lens and the vitreous, the light rays are focused on the fovea, the most sensitive part of the retina. At the retina, the light signal is converted to an electrical impulse signal and sent to the brain by an optic nerve.

Fig.1 The camera (left) and the human eye (right) [4]

The size of the pupil varies for two causes: changes of the ambient light intensity and changes in viewing distance as part of the near triad (the near reflex). The flicker phenomenon causes a continuous action of the dilator and the sphincter muscles [5]. This also is the main reason why human beings feel annoyance under flicker. When people look at the light or the lighting or reflecting surfaces of the objects, the color and brightness are two important features that people notice. The light color depends on the light spectrum. The light brightness depends on the light intensity.

For simplicity, it is assumed that the average eye-brain response to flicker is identical for all people. Then the flicker level can be evaluated by examining the light variation level. Each lamp type has a specific light spectrum and light intensity. If the lamp light spectrum variation under flicker is known, a weighting factor, that represents the lamp-eye spectrum sensitivity under flicker, can be found by combining the light spectrum variation with the human eye spectrum sensitivity.

In this paper, section II gives the spectrum measurement results of two lamp types. Section III shows the spectrum weighting curves of different lamp types. Section IV gives a

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proposal how to evaluate the flicker level in the frequency domain.

II. SPECTRUM MEASUREMENT

The human eyes are mainly sensitive to two factors: light color and light intensity [6]. The color of the lamp light depends on the spectrum of the lamp light. These are different for different lamp types because of different working principles.

Two lamp types are tested in this work: a 230V 60W incandescent lamp and a 230V 11W energy saving lamp. The lamp light spectrum is tested under normal voltage and flicker voltage. The required voltage is generated by a programmable power source. The corresponding light spectrum of the lamp is measured by a spectrometer through an optical fiber sensor. The measured sensitivity range of the spectrometer and the optical fiber sensor matches the visible light wavelength (380nm – 750nm). This spectrometer can capture the spectra by the speed up to 1000 full spectra/s. It is fast enough to catch the spectrum variation under flicker. The measurement set-up is shown in Fig.2.

Fig.2 The lamp spectrum measurement set-up

A. The normal spectrum of different lamp types

First, a stable 230V voltage was given to the tested lamps. The lamp spectrum was measured by the spectrometer. Fig.3 and 4 show the spectrum of the 60W incandescent lamp and the 11W energy saving lamp. The light intensity of the wavelengths of the incandescent lamp increases continuously from 390nm to 590nm and then continuously decreases. The highest light intensity of the incandescent lamp is around 590nm. For the energy saving lamp, it can be noticed that a few specific wavelengths have relative high light intensity because of the specific spectrum of the discharge in the lamp tube. Other wavelengths have almost a constant light intensity. The highest light intensity of the energy saving lamp appears around 550nm. This difference between these two lamp types is because of the different working principles [7].

B. The light spectrum variation under flicker

For the lamp light, the light intensity of each wavelength varies with the voltage variation under flicker conditions. Since the spectrometer can capture 1000 full spectra per second, the lamp light spectrum variation is measured by using this spectrometer. As an example, a flicker voltage with 2Hz modulation frequency and 10V modulation amplitude was applied to the tested lamp. A lamp spectrum was measured during 5 sec by using the 1000Hz sampling frequency. Fig.5 and 6 show the light spectrum variation of a 60W incandescent lamp and an 11W energy saving lamp under the 2Hz flicker.

This measurement gives us the 3-dimension figures. The X axis is the wavelength. The Y axis is the light intensity. The Z axis is the time. From Fig.5 and 6, we can see that the fundamental frequency of the lamp light spectrum is 100Hz. This is due to the fact that the lamp light depends on the electrical power consumed by the lamp. The fundamental frequency of the electrical power is 100Hz. The light spectrum also shows the obvious amplitude modulation with the modulation frequency of the flicker voltage.

Fig.3 The light spectrum of a 230V 60W incandescent lamp

Fig.4 The light spectrum of a 230V 11W energy saving lamp

Fig.5 The 3-D light spectrum of a 230V 60W incandescent lamp with a 2Hz flicker voltage

Fig.6 The 3-D light spectrum of a 230V 11W energy saving lamp with a 2Hz flicker voltage

C. The wavelength contribution of different lamp types under flicker

For the incandescent lamp and the fluorescent lamp, the wavelengths have a different contribution to the light intensity variation under the same flicker conditions (both modulation amplitude and frequency are same). Due to this different contribution, both the light color and the light intensity change under flicker. Thus, the human eye can feel annoyance under flicker. If each wavelength is observed along the time axis, there are many harmonic components inside it. The Fast Fourier transfer (FFT) is used to extract the signal with the flicker frequency. For comparing the light intensity variation between different lamp types, the relative light intensity variation value is used. It is calculated by

$$L_{re_s} = \frac{\text{light intensity variation of the flicker frequency}}{\text{light intensity of the lamp under normal voltage}} * 100 \quad (1)$$

Where L_{re_s} is the relative light intensity variation value of each wavelength in %

A flicker voltage with different modulation frequencies (from 0.5Hz – 25Hz) and 10V modulation amplitude was applied to the tested lamp. Fig.7 shows the light spectrum contribution of the 2Hz modulation of a 230V 60W incandescent lamp. Comparing Fig.7 to the Fig.3, it can be noticed that the biggest light intensity contribution is around 540nm instead of 590nm presented in the Fig.3. The shape of the light spectrum contribution is also different to the shape presented in the Fig.3. As showed in equation (1), the relative light intensity variation of each wavelength can be low even though the absolute light intensity variation value is high. Under a certain flicker frequency, the light intensity variation contribution of different wavelength is different.

Under the same flicker frequency, the spectrum contribution of different lamp types is different. Fig.8 shows the light spectrum contribution of the 2Hz modulation to a 230V, 11W energy saving lamp. This is again due to the fact that different lamp types have different working principles. Comparing Fig.8 to Fig.4, the spectrum contribution to the modulation of the energy saving lamp has relative similar same shape as the lamp spectrum under normal voltage. The highest light intensity contribution appears at 545nm, the same as the energy saving lamp under normal situation.

For a single wavelength, the light intensity variation decreases when the flicker frequency increases. This is the same conclusion as in [8] (see Fig.9).

Fig.7 The light spectrum contribution to a 2 Hz flicker of a 230V 60W incandescent lamp

Fig.8 The light spectrum contribution to a 2Hz flicker of a 230V 11W energy saving lamp

Fig.9 Light intensity variation versus flicker frequency of a 230V 60W incandescent lamp for wavelength 545.14nm

III. WEIGHTING CURVE OF DIFFERENT LAMP TYPES

The lamp spectrum is different for different lamp types. Each wavelength has different contribution under flicker. In 1924, the CIE gave a standard photopic luminosity curve to show the human eye sensitivity to the light during daytime. This curve is shown in Fig.10 [9] – [11]. This curve shows that human eyes are most sensitive to the wavelengths around 555nm. If we know how the human eye responds to the lamp light variation under flicker, we can weight the wavelength contribution curve with the CIE standard photopic luminosity curve. Based on the measured results of Fig.7 and 8, Fig.11 and 12 show the weighting curves of the 230V, 60W incandescent lamp and the 230V, 11W energy saving lamp for a 2Hz flicker respectively. Fig.11 shows that the peak weighting value of the incandescent lamp is around 555nm. Furthermore, there is a small hollow point around 550nm. The peak weighting value of the energy saving lamp is around 545nm (see Fig.12).

The weighting factor for each flicker frequency should be the sum of the weighting factor of each wavelength for the corresponding flicker frequency f_m . Since the spectrometer totally records 68 wavelengths for each measurement, the weighting filter for each flicker frequency should give the sum of 68 items. The weighting factor for each flicker frequency can be calculated by:

$$W(f_m) = \sum_{i=1}^{68} W_i(f_m) \quad (2)$$

Where i is each wavelength

$W_i(f_m)$ is the weighting factor of each wavelength for the flicker frequency f_m

$W(f_m)$ is the weighting filter value of the flicker frequency f_m

By using the data of Fig.11 and 12, the weighting filters of these two measured lamp types for 2Hz flicker are calculated. The weighting factor of the incandescent lamp is 214. The weighting factor of the energy saving lamp is 31.9. The lamp-eye weighting factor of the energy saving lamp is lower than the lamp-eye weighting filter of the incandescent lamp. Thus,

the conclusion can be drawn that the energy saving lamp is less sensitive to the flicker than the incandescent lamp. This is also found in [7].

Fig.10 CIE standard photopic luminosity curve

Fig.11 The weighting curve of 230V 60W incandescent lamp for a 2 Hz flicker

Fig.12 The weighting curve of 230V 11W energy saving lamp for a 2 Hz flicker

IV. FREQUENCY DOMAIN FLICKER MEASUREMENT PROPOSAL

In the UIE/IEC flickermeter, the flicker level is evaluated by demodulating the modulated voltage signal and weighted with the lamp-eye-brain simulator (the weighting filter and a non-linear variance estimator [2]). Finally the short term flicker level indicator P_{st} and long term flicker level indicator P_{lt} are obtained by using a statistical calculation. To implement this measurement, it takes a long time to get the statistical results: 10 minutes measurement to obtain the P_{st} value and a 2 hours measurement to get the P_{lt} value. In [12], a new P_{st} value is calculated by using a weighting filter in frequency domain. This can reduce the flicker measurement time.

In this paper, a new method to evaluate the flicker level is proposed. It can be faster and easier. The input of this new flickermeter is still the modulated voltage. Since the power consumed by the lamp is proportional to the voltage square, the modulated voltage is squared to represent the information of the power consumed by the lamp. By using FFT, the amplitude of each frequency component inside the voltage square waveform is found. C_m is defined as the amplitude of each frequency component within the range of interest (0 – 35Hz). The subscript m represents the different frequencies. As derived in section III, there is one weighting factor for each flicker frequency. Thus, the instantaneous flicker level can be calculated by:

$$F_{in} = \sum_{m=0}^{35} C_m \times W(f_m) \quad (3)$$

Where m is frequency of interest (0 – 35Hz)

$W(f_m)$ is the weighting factor of the flicker frequency

f_m

F_{in} is the instantaneous flicker level

This instantaneous flicker level F_{in} indicates the relationship between the voltage variation and the light variation. The scheme of flicker measurement in frequency domain is shown in Fig.13.

Fig.13 The scheme of flicker measurement in frequency domain

V. CONCLUSIONS

Since the lamp light spectrum might vary under flicker conditions, two lamp types' light spectrums under flicker are measured. The measured results are presented in this paper. The results show that the lamp light spectrum is different for different lamp types because of the different working principles. For the same flicker frequency, different wavelengths give different contributions. For a single wavelength, the light intensity variation decreases when the

flicker frequency increases. By weighting with the CIE standard photopic luminosity curve, the weighting curve and weighting factor of a 230V 60W incandescent lamp and a 230V 11W energy saving lamp are obtained. A proposal about a new flicker measurement method is also described in this paper. More lamp light spectrum measurements and a further verification of the new flickermeter proposal will be done in the future. Furthermore, the different contribution from the light color variation and light intensity variation under flicker will be compared in the future work.

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VIII. BIOGRAPHIES

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Wil L. Kling (M'95) was born in Heesch, the Netherlands in 1950. He received the M.Sc. degree in electrical engineering from the Technical University of Eindhoven, The Netherlands, in 1978. From 1978 to 1983 he worked with Kema and from 1983 to 1998 with Sep. Since then he is with TenneT, the Dutch Transmission System Operator, as senior engineer for network planning and network strategy. Since 1993 he is a part-time professor at the Delft University of Technology and since 2000 he is also a part-time professor in the Electric Power Systems Group at the Eindhoven University of Technology, the Netherlands. He is leading research programs on distributed generation, integration of wind power, network concepts and reliability.

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