LIGHT FLICKER CAUSED BY INTERHARMONICS

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ABSTRACT

In certain circumstances, superimposed interharmonics in the supply voltage can lead to oscillating luminous flux and cause light flicker. This phenomenon can be observed with filament lamps as well as with fluorescent lamps.

Different items are dealt with in this paper:

Presentation of some experimental results: determination of the sensitivity curves for different types of lighting devices, concept of gain factor.
Definition and measurement of an equivalent P_{st} *for fluorescent lamps flicker.*
The IEC short-term flicker severity value P_{st} *is the "unit" of measure for the flicker perceived by the classical flickermeter. This measurement is strictly related to filament lamps. However, it is interesting to show how this concept can be extended and applied for the analysis of the flicker of fluorescent lamps caused by interharmonics.*
Analysis of the specific case of fluorescent lamp flicker caused by 175 Hz ripple control signals.

EXPERIMENTAL STUDY OF FLICKER CAUSED BY INTERHARMONICS

This section is dedicated to the study of the effects of interharmonic voltage superimposed voluntarily or not to the supply voltage on several types of modern lighting devices (mostly electronic).

Flicker caused by interharmonics can be observed with filament lamps as well as with fluorescent lamps. However, the mechanisms and the involved frequency range as well as the amplitudes are quite different.

The light output of a filament lamp is dependent on the temperature of the filament, which in turn is directly related to the power dissipated in the lamp (or the RMS voltage). When the applied voltage is a pure sinusoidal wave, the luminous flux is composed of a steady-state average component and a double supply frequency component, which can not be detected by the human eye.

When a single interharmonic is superimposed, the electrical power and the luminous flux contain, beside the above mentioned double frequency component, side band frequencies to the fundamental. The average component of the luminous flux is modulated in amplitude with a modulation frequency equal to

$$f_M = \left| f_0 - f_{ih} \right| \qquad (1)$$

Where f_0 is the fundamental frequency (50 or 60 Hz)
f_{ih} is the interharmonic frequency

It appears that when $f_{ih} \leq 2 f_0$ and more particularly for f_{ih} around the fundamental frequency ($f_0 \pm 15$ Hz), this modulation causes sufficient RMS voltage fluctuations in order to generate light flicker. In any case, this kind of flicker should be detected by the UIE-IEC flickermeter (cf. [2]: IEC 61000-4-15).

On the other hand, the light output of a fluorescent lamp is strongly dependent on the average power dissipated in the lamp. This one is related to the "ignition" angle, i.e. the delay necessary for the supply voltage to reach the arc voltage, after zero-crossing (depending on the lamp geometry and the physical properties of the plasma). Any cause that will have as effect the jitter of the ignition angle will produce flicker. Among them are fluctuations in the voltage waveform caused by interharmonics. A detailed analysis of the phenomenon shows that [5] :

$$f_M = \left| f_{ih} \,\mathrm{MOD}\, (2f_0) - f_0 \right| \qquad (2)$$

The human eye is most sensitive for disturbances (flicker) caused by interharmonic frequencies corresponding to the minima of the sensitivity curves, they can be noted as follows:

$$f_{ih} = (f_{hi} \pm (10 \rightarrow 15))\ \text{Hz} \qquad (3)$$

Where f_{hi} = the odd harmonic frequencies.

The differences between the four types of tested devices appear evidently in the following graph.

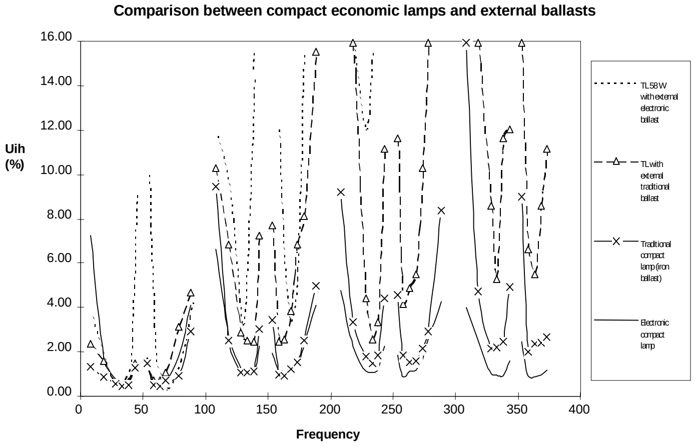

Figure 1: Sensitivity curves for different types of devices

THE GAIN FACTOR CONCEPT

Context of the experiments

The goal was to determine a correlation between a visible disturbance (flicker) and its cause: the interharmonic frequencies present in the supply voltage of the lighting devices.

Since the sensitivity curves rely on a factor of human perception, which may vary considerably from person to person, it is interesting to develop a different kind of experiment, which considers the information issued by an electronic eye (that is a photodiode[1]). The gain factor will permit the quantification and a comparison of the sensitivity of the different lighting devices in a reproducible and systematic manner [1].

A classification of the material will be realized, based on the results of the calculations of the gain factor.

Definition

It is verified experimentally for all lighting devices that the relation between the relative luminous flux variation and the corresponding voltage fluctuation is fairly linear, in the usual voltage fluctuation range. Consequently, for a given modulation frequency, the gain factor is defined as follows:

$$G.F. = \frac{\left(\frac{\Delta\Phi}{\Phi}\right)}{\left(\frac{\Delta U}{U}\right)} \qquad (4)$$

With for practical purposes :

- $\Delta\Phi$: The difference between extremes of the average value of the luminous flux. The average value is calculated on 10 ms, with a sliding window.
- Φ: The average value of the luminous flux.
- ΔU: the difference between the extremes of the peak value of the rectified supply voltage.
- U: the average value of the peak value of the rectified supply voltage.

The more the ($\Delta\Phi$ / Φ) factor is important for a given (ΔU / U), the more the gain factor will rise. This means that the gain factor is proportional to the sensitivity of the lamp.

The human eye can not detect luminous flux fluctuations superior to 30 Hz. Therefore, the fluctuations of the average luminous flux have been considered.

The fluctuation of the voltage peak values seems to be the factor most strongly related to the production of flicker in the case of discharge lamps.

Measurement results and comments

In the presence of a disturbance, the luminous flux is also modulated at f= f_M as well as the peak and the average values of the supply voltage. The RMS value is usually little or not influenced by the interharmonics superior to 100 Hz. This explains the absence of flicker in filament lamps for f_{ih}>100 Hz because its lighting is proportional to RMS voltage (cf. measuring principle of flickermeter).

The gain factor varies depending on the injected interharmonic frequency, but depends little or not on the disturbance level (for the usual levels). In order to establish valid comparisons between the devices, it is necessary to fix frequencies and, less important, to fix disturbance levels

In general, all the tested devices have an important gain factor, that is an important sensitivity, for “critical” interharmonic frequencies inferior to 100 Hz. Above 100 Hz, a classification of the different devices can be made, depending on the sensibilities.

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[1] The bandwidth of the photodiode as well as its chromatic filter permits to obtain perception characteristics nearly identical to the human eye.

Table 1 : Gain factor for different interharmonic frequencies (test level: U_{ih}= 4.4 % * U_n) and for different types of device

	65 Hz	165 Hz	260 Hz
Traditional ballast	0.75	0.3	0.05
Electronic ballast	0.3→0.7	<0.05	<0.05
Traditional compact lamp	1	0.35	0.3
Electronic compact lamp	0.75→0.9	0.65→0.9	0.6→0.8

In general, compact fluorescent lamps (CFL) are very sensitive to all critical frequencies and thus can not be used in places where stability and quality of light are required.

Most external electronic ballasts have minor sensitivity above 100 Hz. They can thus offer a partial solution to the most visible problem caused by the interharmonics: the flicker of lighting devices.

EQUIVALENT P_{ST}

Perception of interharmonics by the UIE-IEC Flickermeter

The flicker is the subjective impression of fluctuating luminance, which *for filament lamps are caused by the modulation of the RMS supply voltage*.

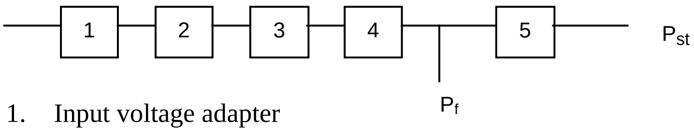
The determination of the P_{st} (see below) by the UIE-IEC flickermeter is based on the measurement of the fluctuation of the RMS supply voltage.

Interharmonic frequencies below the second harmonic (100/120 Hz) cause a significant modulation of the RMS supply voltage. In consequence, they are well perceived by the UIE-IEC flickermeter. For interharmonic frequencies above the second harmonic, it does not matter because the modulation of the RMS voltage tends to zero when the interharmonic frequency increases.

→ Flicker caused by interharmonics is not necessarily detected by the UIE-IEC flickermeter: it will be detected only for low frequency interharmonics (see above), but surely not for frequencies higher than 2 f_0 . The flicker caused by interharmonics is only well detected for filament lamps.

P_{st} and P_f

The IEC flickermeter calculates a disturbance limit (P_{st}=1) and a sensitivity limit (P_f=1), in order to quantify the disturbance caused by voltage modulation on a filament lamp [3].



1. Input voltage adapter
2. Square low demodulator
3. Low pass and weighting filter
4. Variance estimator
5. Statistical evaluation (P_{st})

Figure 2: UIE-IEC flickermeter

- The filter included in block 3 weights the voltage fluctuation according to the lamp and human visual sensitivity.

- The P_f value is delivered at the output of the block 4. The P_f represents the visual perception of the luminous flux modulation of a filament lamp (60 W/230 V). Value "1" *means the perceptibility limit* for a representative observer in test conditions.

- The P_{st} determination method is based on statistical analysis of the P_f. The value "1" *means the disturbance limit [3]*. Each lighting device filters differently the interharmonic frequencies. In conclusion, each device would require a different model of the flickermeter (block 2 & 3).

The determination of an equivalent P_{st} would allow quantification of the disturbance caused by interharmonics on every type of lighting device and thus to compare efficiently the performances (immunity to interharmonics) of the devices.

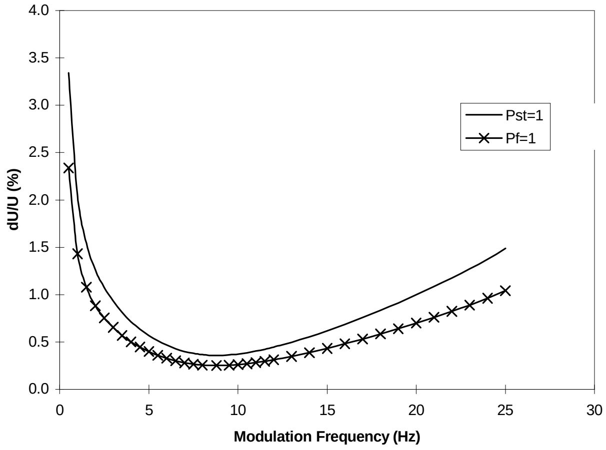


Figure 3: Sinusoidal modulation (ΔU/U) for Pf=1 and Pst=1 with a 60 W filament lamp

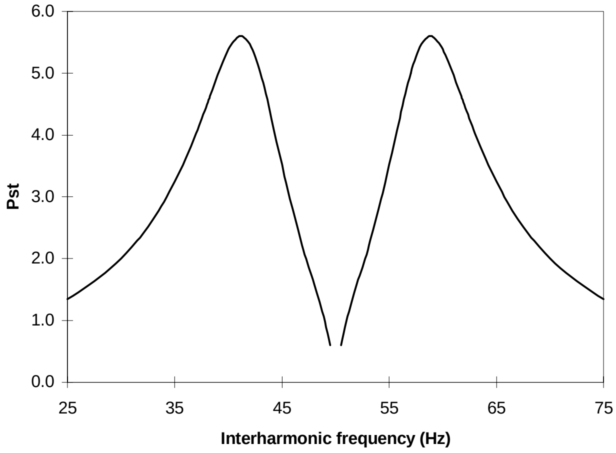


Figure 4: Pst for 1% interharmonic with 60 W filament lamp

Remarks: - A constant disturbance of the voltage which caused a P_{st}=1 is fully visible because the P_f is then greater than one.

- For a given modulation frequency, the P_{st} is linearly proportional to ΔU/U.

Determination of the equivalent P_{st} (P_{st_eq})

For an incandescent lamp, it is well known that there is a linear relationship between the luminous flux fluctuation and the flicker measurement P_{st}.

On the other hand, the perception of the flicker produced by any kind of lighting devices is the same as the one produced by the reference incandescent lamp, provided that the luminous flux modulations are identical. This has been verified by introducing luminous flux records in a simulator of the IEC flickermeter [4]. It appears that the maximal error on the calculated values of P_{st_eq} is ± 10%.

Consequently, under the assumption of sinusoidal luminous flux modulation, the equivalent P_{st} relative to a particular lighting device can be defined by:

$$P_{st\_eq} = \frac{\left(\frac{\Delta\Phi}{\Phi}\right)}{\left(\frac{\Delta\Phi}{\Phi}\right)_{ref}} \tag{5}$$

$\left(\frac{\Delta\Phi}{\Phi}\right)_{ref}$ = Luminous flux modulation of the reference filament lamp for P_{st}=1 at the considered modulation frequency.

$\left(\frac{\Delta\Phi}{\Phi}\right)$ = Luminous flux modulation of the lamp being tested.

Introducing $\left(\frac{\Delta U}{U}\right)_{ref}$, the voltage supply modulation of the reference filament lamp for P_{st}=1 at the considered modulation frequency (cf.Figure 3), we get:

$$P_{st\_\acute{e}q} = \frac{\left(\frac{\Delta\Phi}{\Phi}\right)}{G.F._{ref} * \left(\frac{\Delta U}{U}\right)_{ref}} \tag{6}$$

$G.F._{ref}$ = Gain factor of the reference (230/60W) filament lamp at the considered modulation frequency (cf.Figure 5).

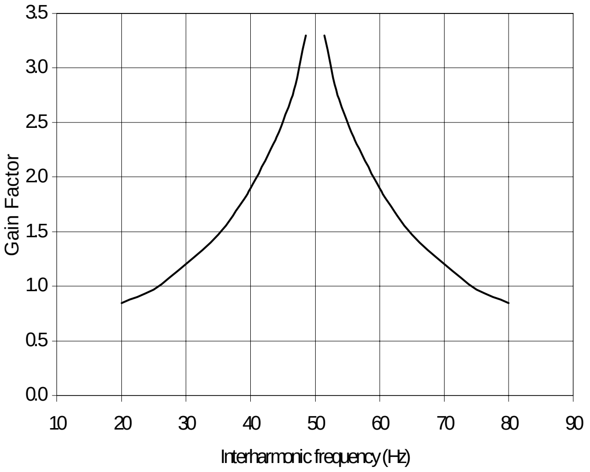
The gain factor of the reference filament lamp (230V / 60W) was experimentally determined:

An immediate application of this definition is the determination of the percentage of interharmonics which cause Pst=1 for a given lamp:

$$U_{ih-Pst=1}(\%) = \frac{G.F._{ref}}{G.F.} * 0.5\left(\frac{\Delta U}{U}\right)_{ref} \tag{7}$$

$G.F.$ = Gain factor of the lamp being tested.

Figure 5: Gain factor of a 60 W filament lamp

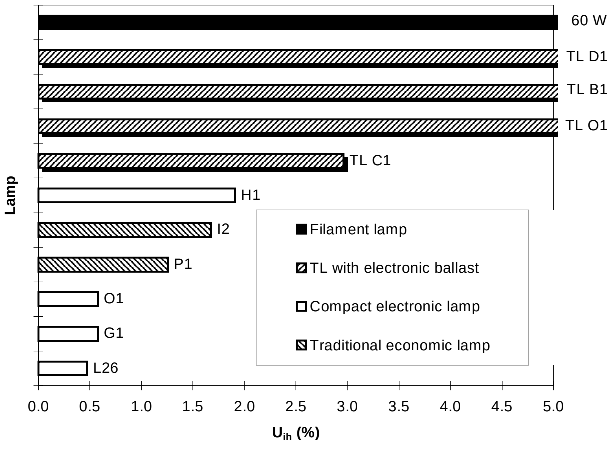


Numerical example

- Type of lamp: economic electronic lamp
- Interharmonic frequency: 135 Hz → Modulation frequency : f_M = 15 Hz
- G.F.$_{ref}$ (Figure 5) : 1.5

- $(\Delta U/U)_{ref}$ (Figure 3) = 0.617	- G.F.= 0.75	cf. (4)
- $\Delta U/U$ (experimental) = 8.82 %	- P_{st_eq} = 7.16	cf. (6)
- $\Delta\Phi/\Phi$ (experimental) = 6.62 %	- $U_{ih\text{-}Pst=1}$ = 0.43 %	cf. (7)

Figure 6: $\Delta U/U$ (%) for $P_{st\_eq=1}$, $f(U_{ih})$ = 35 Hz



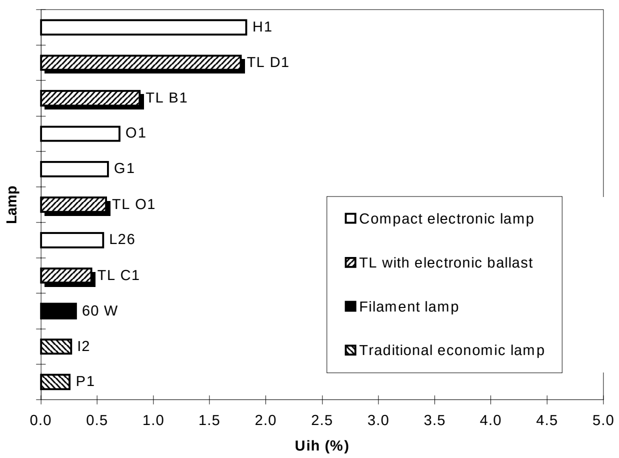


Figure 7: $\Delta U/U$ (%) for $P_{st\_eq=1}$, $f(U_{ih})$ = 260 Hz

Conclusions

- The results have been validated by comparison with the sensitivity curves on Figure 1 (Bear in mind that the limit of sensitivity curve corresponds to P_f=1).

- The determination of the equivalent P_{st} permits, based on the existing “flicker unit”, to quantify the disturbance caused by interharmonics on every type of lighting devices.

- This method permits an electronic determination of the sensitivity curves without the intervention of a human observer.

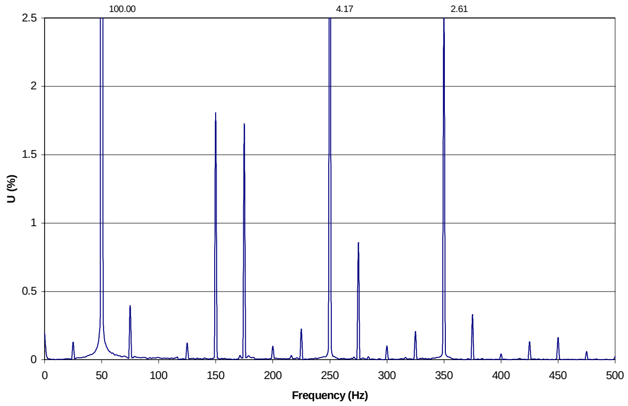
FLICKER CAUSED BY RIPPLE CONTROL SIGNALS

Ripple control signals represent a particular case where the emission of interharmonic frequencies (f=175, 180, 183.3, 283.3, etc. - U_{ih} = 1 to 5 %) on the power network is deliberated.

The Figure 8 shows that besides the main ripple control emitted at 175 Hz (1.35 %), other interharmonics are generated by intermodulation with the harmonic frequencies during the emission of the ripple control signals.

Measurements have been carried out on low voltage networks that feed offices buildings, where the voltage is deformed by harmonics generated by the numerous non linear charges. The tests show that "important" interharmonics can be generated, even if measured levels respect the norm EN 50160 [6].
It is also established that the level of intermodulated interharmonics varies depending on the harmonic deformation of the voltage.

Figure 8: FFT of the voltage during an emission of ripple control signal (U_{ih}=1.7 %, f(U_{ih})= 175 Hz)



Ripple control signals have generally little amplitude, but can cause flicker on sensitive lighting devices like economic lamps and TL's with an iron ballast. Disturbances are often observed in offices equipped with old lighting devices (iron ballast). TL's with electronic ballasts are almost always insensible. Differences in sensitivity between different products of the same type can occasionally be observed.

For the relighting of buildings, the choice of the lighting devices is based upon esthetic and most of all economic criteria such as the price of the equipment and its energy consumption. The choice made never takes into account a possible sensitivity to ripple control signals emitted on the supply network.

This ignorance of the problem provokes more and more often surprises and dissatisfaction of the electrical fitters.

The European standardization on the domain of lightning equipments does not foresee guidelines for the protections of the consumers [8].

The problem is however well known. The IEC 61000-2-2 standard [7] specifies to the product committees, the compatibility levels of equipment to public power system disturbances. The specified level is for ripple control signal between 2 and 5%.

CONCLUSIONS

An obligation of a minimum immunity level to interharmonics on the normative level is needed. The product standard for lighting equipments should contain requirements for immunity to interharmonics.

In case of problems, it would then be possible to determine the responsibilities of the distributors and manufacturers.

The development of a testing procedure permitting reproducible results that are independent of the human perception is necessary. Such as procedure has been proposed in this paper.

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