LIGHT FLICKER CAUSED BY INTERHARMONICS

M. De Koster - E. De Jaeger – W.Vancoetsem

LABORELEC
Tel.: +32 2 / 382 02 62 Fax: +32 2 / 382 06 49 E-Mail: Emmanuel.DeJaeger@Laborelec.be
Rodestraat, 125 - B-1630 Linkebeek - BELGIUM

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.

1. 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). The limit of sensitivity is defined as the maximum level of injection (for each frequency) for which no light flicker can be perceived by the human eye.

Two types of lighting devices were tested: *traditional TL’s equipped with external ballast and compact economic lamps*:

- The external ballasts were of two types: electronic and iron (magnetic).
- The compact lamps were of two types: traditional economic lamps (equipped with magnetic ballast) that switch on as an ordinary fluorescent lamp and economic electronic lamps.

The tested lamp was placed in a darkened room. The flicker was observed on three different backgrounds: gray, black and white. It is known that the perception of flicker by the human eye on the different colors varies with the flicker frequency.

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

$$f_M = \left| f_0 - f_{ih} \right| \qquad \text{Where} \quad f_0 \text{ is the fundamental frequency (50 or 60 Hz)} \qquad (1)$$

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] :

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

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

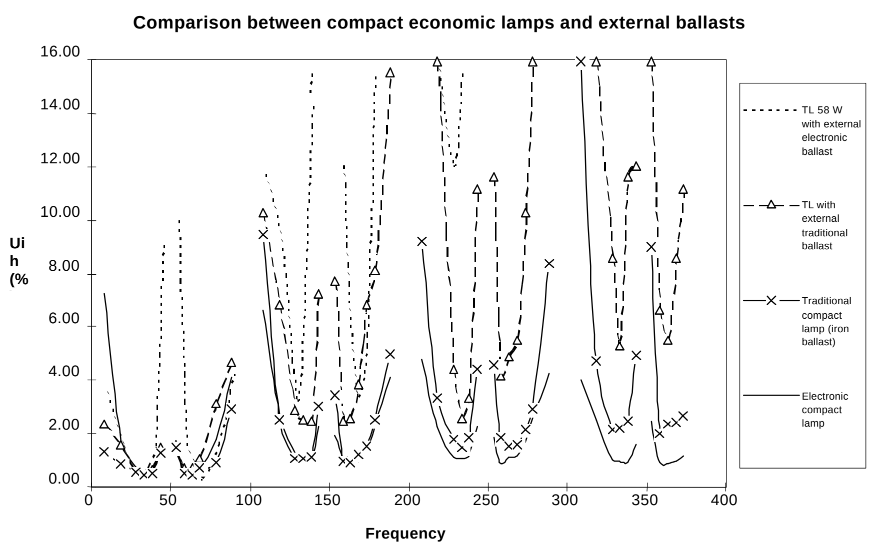

Figure 1
Sensitivity curves for different types of devices

The 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:

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

Where f_{hi} = the odd harmonic frequencies.

It can also be noted that the sensitivity around the odd harmonic frequencies diminishes for almost all the tested devices when the harmonic rank increases (H3, H5, H7,...).

For interharmonic frequencies below the second harmonic, all the devices show an important sensitivity.
For example, the electronic ballasts appear to be very sensitive between 30 and 70 Hz, but filter better the interharmonic frequencies between 130 and 170 Hz. They can even be considered insensitive to frequencies superior to 170 Hz. However, The compact electronic lamps remain sensitive for higher frequencies.

2. The gain factor concept

2.1. 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.

2.2. 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:

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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.

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

With for practical purposes (cf. Figure 2):

- $\Delta\Phi$: The difference between extremes of the average value of the luminous flux. The average value is calculated on 10 ms, with a sliding window, in steps of 2 ms.
- Φ: The average value of the luminous flux, calculated on the whole record (1 s).
- ΔU: the difference between the extremes of the peak value of the rectified supply voltage on the whole record (1 s).
- U: the average value of the peak value of the rectified supply voltage on the whole record (1s).

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 values of average and RMS voltage are calculated on a window of 10 ms, sliding with a step of 2 ms. 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.

2.3. Measurement results and comments

Without any disturbance, the luminous flux produced by a lamp is composed of a direct and an alternative part. The latter has a frequency of 100 Hz for a filament lamp and for the lamps with traditional ballasts. For compact electronic lamps, and external electronic ballasts it goes up from 30 to 40 kHz, slightly modulated at 100 Hz. This explains the better quality of the light provided by electronic devices.

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. The selected frequencies for the tests were 35, 65, 135, 165, 260 and 340 Hz.

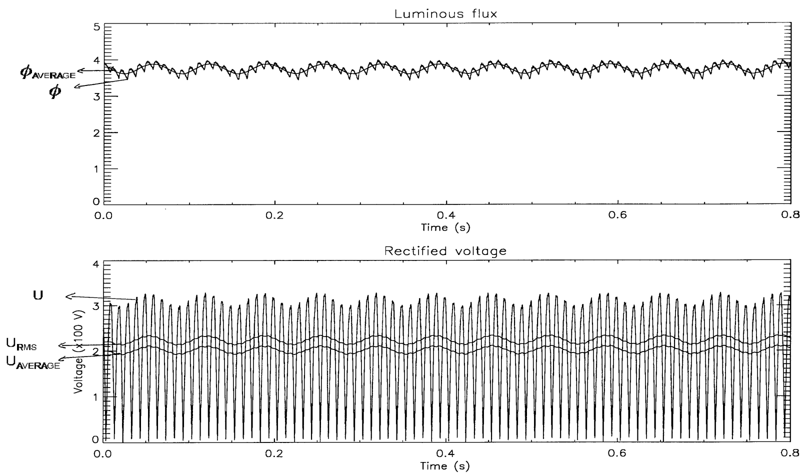


Figure 2
Electronic compact lamp; interharmonic 65 Hz, 4.4 %

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.

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.

3. Equivalent P_{st}

3.1. 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*.

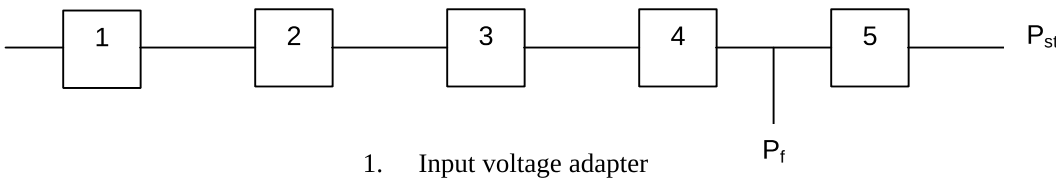
The determination of the P_{st} (see below) by the UIE-IEC flickermeter is based on the measurement of the fluctuation of the RMS supply voltage.

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.*

3.2. 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 [2].



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

Figure 3
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 [2]*. 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.

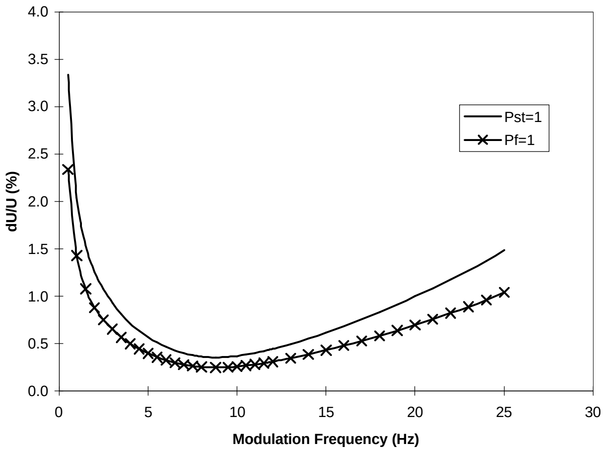


Figure 4
Sinusoidal modulation (ΔU/U) for P_f=1 and P_{st}=1 with a 60 W filament lamp

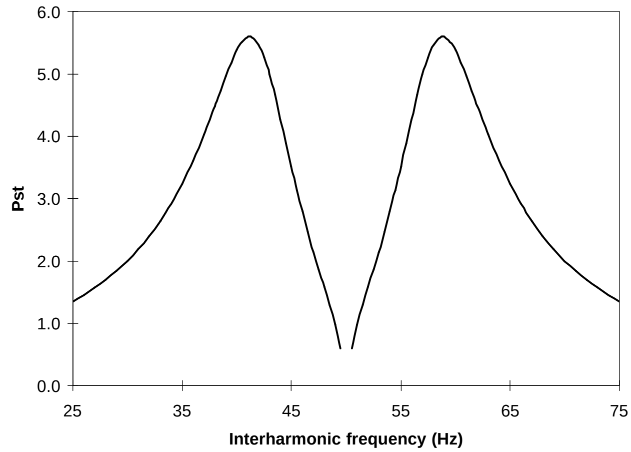


Figure 5
P_{st} for 1% interharmonic with 60 W filament lamp

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.

3.3. 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 4), we get:

$$P_{st\_éq} = \frac{\left(\frac{\Delta\Phi}{\Phi}\right)}{G.F._{ref} * \left(\frac{\Delta U}{U}\right)_{ref}} \qquad (6)$$

$G.F._{ref}$ = Gain factor of the reference (230/60W) filament lamp at the considered modulation frequency (cf. Figure 6).

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

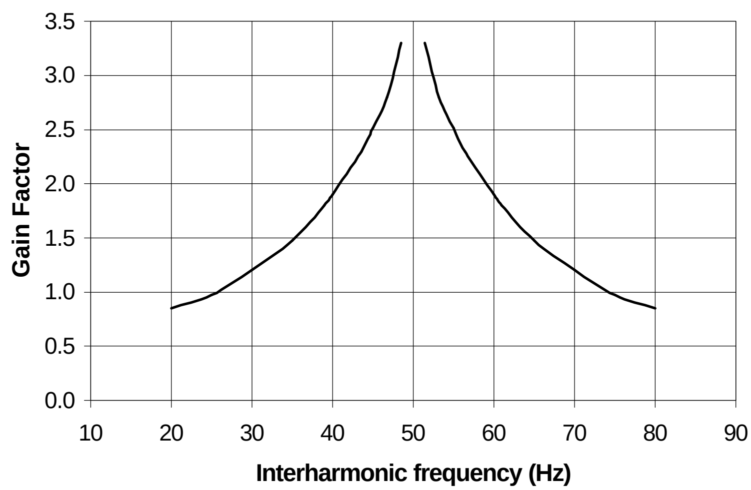


Figure 6
Gain factor of a 60 W filament lamp

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

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

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

Numerical example

- Type of lamp: economic electronic lamp
- Interharmonic frequency: 135 Hz → Modulation frequency : f_M = 15 Hz
- G.F.$_{ref}$ (Figure 6) : 1.5
- $(\Delta U/U)_{ref}$ (Figure 4) : 0.617
- ΔU/U (experimental) = 8.82 %
- ΔΦ/Φ (experimental) = 6.62 %

- G.F.= 0.75 cf. (4)
- P_{st_eq} = 7.16 cf. (6)
- $U_{ih-Pst=1}$ = 0.43 % cf. (7)

Tests have been realized on different lighting devices in an integrating sphere, usually used in photometry.

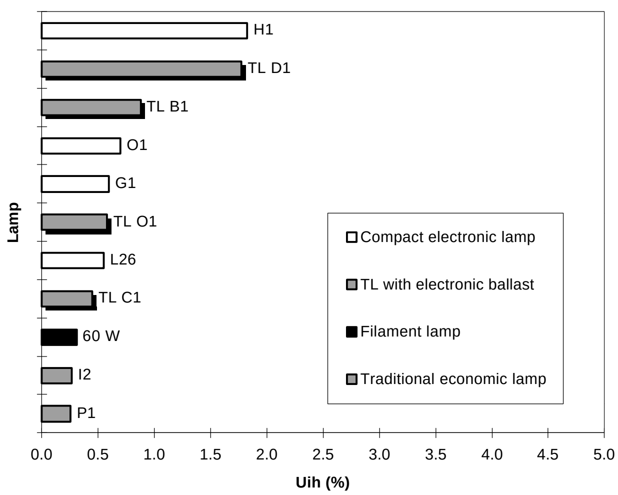


Figure 7
ΔU/U (%) for $P_{st\_eq=1}$, $f(U_{ih})$ = 35 Hz

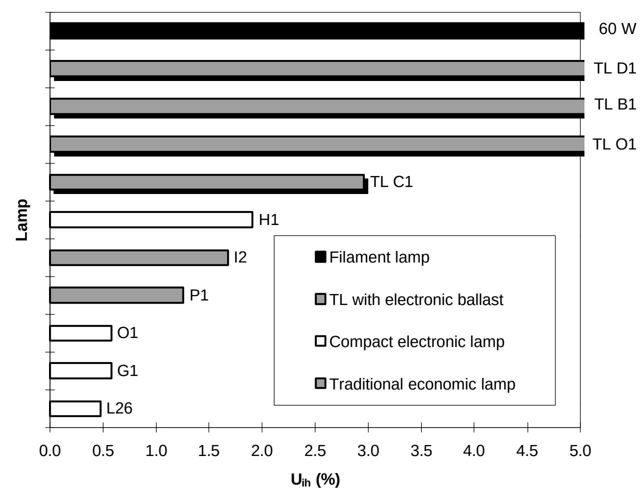


Figure 8
ΔU/U (%) for $P_{st\_eq=1}$, $f(U_{ih})$ = 260 Hz

3.4. 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.

4. 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.

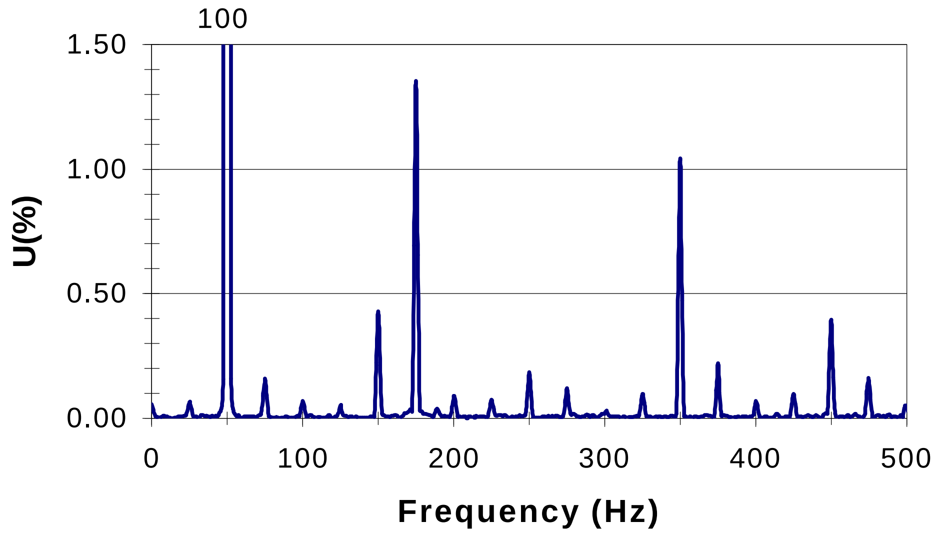


Figure 9
FFT of the voltage during an emission of ripple control signal (U_{ih}=1.35 %, f(U_{ih})= 175 Hz)

The Figure 9 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. These additional frequencies above the second harmonic can be neglected while other frequencies are not always without effect.

4.1. Conclusions

Ripple control signals have generally little amplitude, but can sometimes cause flicker on very 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.

5. References

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