The influence of non-uniform sampling in the IEC flicker metering

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ABSTRACT

This paper studies the influence of non-uniform sampling on the power line flicker estimation. A digital non-uniform sampling MATLAB flickermeter model is considered. The model is fully compliant with the CEI/IEC 61000-4-15 standard and is tested within mains frequency variations 50Hz +/- 2.5Hz. The normalized flickermeter response and the flickermeter classifier are tested according to the IEC standard recommendations. The results indicate that the most sensitive point 8.8Hz is influenced within the standard error +/- 0.05 and only the last testing point exceeds the prescribed standard error.

Keywords: flicker; flickermeter, non-uniform sampling, power quality, powerline signal processing;

1. INTRODUCTION

The Power Quality (PQ) measurement is a contemporary topic in the modern electricity service. The European regulations encourage power suppliers to supply the energy according to the recently developed standards, guaranteeing the citizen’s health and the compliance of the used devices [1,2]. The PQ measurement encompasses several factors - the level of: voltage, current, total harmonic distortion, flicker, voltage dips and swells etc. One of them and probably the most interesting is the flicker. The flicker is the visual phenomenon, which causes changes in the luminance of lamps and, above certain threshold, unpleasantly and annoyingly affects the human vision system. In other words, the flicker is the “impression of the unsteadiness of visual sensation inducted by a light stimulus whose luminance or spectral distribution fluctuations with time” [2]. Moreover, it may give mental and psychological discomfort in some individuals, or even hazardous stroboscopic effects [1,2,3]. The most severe sources of flicker are the devices having strong and rapid variable voltage consumption and reactive power fluctuations i.e. arc furnace, wind turbines, refrigerators, rolling mills, arc welders, railway stations etc. The flicker origin is slow mains voltage variations and depends on the voltage fluctuation and frequency changes. From a signal processing point of view, the flicker origin is a mains amplitude modulated waveform. The voltage fluctuation is the index of modulation; the frequency changes are the modulating frequencies, the mains is the carrier [1,2].

The flicker metering approach is an amplitude demodulation, filtering of the demodulated signal according to the human eye-brain perceptibility model, a short term (10min) and a long term (2h) statistical analysis [1,2,3]. Generally, the power quality analyzers should encompass not only flickermeter, but also other PQ parameters. From an engineering point of view, in order to measure some of them accurately a non-uniform sampling is required. For example, the accurate total harmonic distortion (THD) measurement needs Fourier analysis within a strict signal period. The International Electrotechnical Commission (IEC) power quality standard allows mains frequency variation. Therefore, in order to obtain high accuracy in TDH measurement through keeping exact number of samples within a mains period during the standard frequency mains deviation a non-uniform sampling is demanded. On the other hand, the flickermeter needs strict signal processing and its digitalizing is a subject to uniform sampling. Hence, combining a THD meter and flickermeter in a single device requires two different Analogue to Digital Conversions: uniform and non uniform. Performing only one ADC gives engineering and market advantages. Measuring THD outside the strict mains signal period is logically inaccurate. Therefore, the study of the influence of the non-uniform sampling on the flickermeter with varying mains frequency at hand, regarding combining a THD meter and a flickermeter through a single ADC, is logically defined. Despite the IEC flickermeter standard describes no flickermeter behaviour during the mains frequency variation, several relevant publications appeared [4,5]. Paper [4] describes the flickermeter response to the most sensitive point 8.8Hz. According to these results if the mains frequency changes the flickermeter keeps the short time flicker estimation equals to 1, +/-5%. Another paper [5] gives draft to test the flickermeter in mains frequency variation.
conditions. This paper also concerns the most sensitive point 8.8Hz. To our best knowledge, previous works concerning the influence of the non-uniform sampling on the total flickermeter response and classifier test, in standard mains variation, do not exist. The main contributions of this work can be summarized as follows:

- A study of a non-uniform sampling digital flickermeter model within IEC standard mains voltage and frequency deviation.
- The results indicate that the absolute flickermeter response and the flickermeter classifier tests exceed the IEC flickermeter standard accuracy boundaries at the last test point.
- Taking into consideration the total number of tested points, the ratio between the tested points within and outside the IEC flickermeter standard error boundaries is: 35/36 (the flickermeter response for rectangular voltage fluctuations), 36/37 (the flickermeter response for sinusoidal voltage fluctuations) and 6/7 (the test classifier test).

The reminder of the paper is organized as follows: Section 2 presents the flickermeter algorithm in certain details. Section 3 describes our motivation and modeling approach. Section 3 presents the obtained results and provides related discussions. Finally, section 4 concludes this paper with some final remarks.

2. BACKGROUND AND PROBLEM FORMULATION

2.1 Flicker and flickermetering description

The contemporary PQ standard imposes strict requirements on the powerline suppliers. The monitoring devices require more signal processing algorithms. One power quality indicator is the flicker. The first IEC standard that regulates the flicker effect appeared in 1999. Next, several amendments were issued [2,6,7].

![Image 1](image1.png)

**Figure 1. Functional diagram of flickermeter acc. to IEC 61000-4-15 [6,7]**

IEC recommends a diagram for analogue flickermeter device. Recent publications turned the flickermeter into a fully digital device (fig.2) [8].

![Image 2](image2.png)

**Figure 2. Diagram of fully digitalized flickermeter [8]**
The flickermeter standard describes the light fluctuations caused by the incandescent lamps. This standard is being developed and is a subject to high research activities, in part due to the EU policy for use of energy efficient lamps. Figure 1 shows the flickermeter block diagram according to the International Electrotechnical Commission (IEC) [6,7]. The device consists of several blocks: a quadratic converter – it is used as an amplitude demodulator; a high pass filter 0.05Hz – it removes the constant component; a low pass filter removes the doubled mains frequency components; a weighting filter – a band pass filter, which models the device frequency response to sinusoidal voltage fluctuations of a standard incandescent lamp. The following quadratic converter and low pass filter model the fatigue effect of luminous flux changes. All three blocks (the weighting filter, the quadratic converter and the low pass filter) represent a statistically obtained lamp-eye-brain human reaction. The output of the second low pass filter is called instantaneous flicker sensation. The IEC standard has strict requirements for the total amplitude characteristic or i.e. normalized flickermeter response of the aforementioned blocks [6,7]. This response is calculated for two different input stimuli: sinusoidal and rectangular voltage fluctuations.

![Figure 3. Normalized response for sinusoidal and rectangular voltage fluctuations acc. to IEC 61000-4-14, 230V lamp, 50Hz system.](image)

Figure 3 shows those responses for 230V, 60W lamp 50Hz system. The figure gives the border level of input voltage fluctuations for maximal instantaneous flicker sensation equal to one (the reference human perceptibility threshold). Next, an on-line Cumulative Distribution Function (CDF) estimator or the flickermeter classifier performs statistical analysis for 10 min data interval [6,7 (table 1 and table 2)]. The result is the short-term flicker evaluation Pst. According to the IEC standard at certain rectangular input the Pst output should be 1+/- 5%.

### 2.2 Motivation and problem formulation

Figure 3 describes our substantial model challenge as a part of a complex power quality meter. As it was mentioned above, the PQ defines a number of parameters. One of them exemplifies the total harmonic distortion. It is well known that, in order to measure accurately the harmonic levels, the harmonic spectra should be determined within a strict input signal period. On the other hand, the PQ standard allows certain mains frequency variations. Hence, in order to keep the number of samples within a period during mains frequency variation, the sampling frequency should be changed (see fig.4). Therefore, a non-uniform sampling should be assured - both sampling periods for different mains periods (T1, T2) are different (t1 ≠ t2), but the number of samples within a period is a constant (see fig.5). The mains frequency change is defined by the slew rate as:

\[ F_{sweep} = \frac{(f_{\text{max}} - f_{\text{min}})}{T_{\text{sig}}} \]  

(1)

where \( f_{\text{max}} \) is the maximum frequency, \( f_{\text{min}} \) is the minimum frequency within the period of observation \( T_{\text{sig}} \). In [5] a normal slew rate 0.005Hz/s was reported. In our simulations if we consider the minimum frequency and the slew rate as arguments, the maximum frequency can be determined as:

\[ f_{\text{max}} = T_{\text{sig}} \cdot F_{sweep} + f_{\text{min}} \]  

(2)
Taking into consideration the 10min IEC standard observation interval, 0.005Hz/s slew rate and \( f_{\text{min}} \) (the lowest frequency value allowed by the standard), the possible standard frequency deviation is 47.5Hz – 50.5 Hz. According to the digital signal processing principles the change of sampling frequencies causes change in filter frequency characteristics. This addresses the normalized flickermeter response and the flickermeter classifier in terms of using the same non-uniform ADC.

\[
\text{err} = \xi - \xi'
\]

where \( \xi \) is the rectangular or sinusoidal input value tabulated by the IEC standard, \( \xi' \) is the rectangular or sinusoidal input value obtained after the simulation achieving instantaneous flicker sensitivity equal to one. According to the IEC, if the \( \text{err} \) is within +/- 5%, the flickermeter standard accuracy is achieved.

Figure 4. Our PQ metering approach

If a such PQ system employs a common AD converter, a problem for maintaining the accuracy characteristics might occurs. On the other hand, from engineering, ecological and market price point of view, exploiting a common ADC is better decision. The purpose of this work is to study the distortion of flickermeter characteristics - the tests for normalized response for sinusoidal and rectangular voltage fluctuations and the classifier. Furthermore, this paper will reveal the possibilities to use the IEC recommended flickermetering techniques in the non-uniform sampling conditions.

### 3. SIMULATION RESULTS

A flickermeter MATLAB model was created and verified according to the CEI/IEC 61000-4-15 standard [4,6]. The flickermeter characteristics: the normalized flickermeter response for sinusoidal voltage changes; the normalized flickermeter response for rectangular voltage changes and the test specification for flickermeter classifier are obtained within the recommended absolute error +/-5%. The flickermeter is designed for 230V, 50Hz and 60W incandescent lamp. According to [5] the maximum frequency slew rate is 0.005Hz/s. Hence, the considered mains frequency variation at the flickermeter model input, for 10 min observation time, is 47.5Hz – 50.5Hz (fig.6). The samples within a single
period are kept exactly 50. Therefore, the sampling frequency variation, within 10 min observation interval, is: 2375Hz – 2525Hz. The analogue to digital converter is modeled with 16-bit resolution.

![Figure 6. Mains frequency changing, maximum slew rate 0.0069Hz, 10 min period](image)

The flickermeter model is tested according to the IEC standard input stimuli and the change of normalized flickermeter response for sinusoidal and rectangular voltage fluctuations is studied. Furthermore, the classifier behaviour is tested under the same non-uniform sampling circumstances. Thus, a complete flickermeter test for non-uniform sampling frequency is performed. Figure 7 shows the absolute error of the normalized flickermeter response for sinusoidal voltage changes. The solid line represents the standard response error in uniform sampling mode. The “+” line depicts the error from the standard response in non-uniform sampling mode. It has been observed that in the uniform sampling mode the flickermeter model is within the standard error +/-5%. Whereas, in non-uniform sampling mode the model has inconsistence in the last testing point – 33.33Hz of the modulating component, or 4000 sinusoidal changes per minute.

![Figure 7. Absolute error in flickermeter response for sinusoidal input voltage fluctuations, acc. to the IEC standard test for non-uniform and uniform sampling frequency](image)

Figure 8 shows the absolute error of the normalized flickermeter response for rectangular voltage changes. Similarly to the previous one, the solid line representing the uniform sampling frequency result gives excellent results within the IEC standard error. The non-uniform sampling result, the “+” line, suggests again that the last testing point has bigger error. Figure 9 describes the behaviour of the CDF classifier under the IEC standard classifier test specification conditions. The solid line (uniform sampling test) gives standard error complete within the standard error. On the other hand, the dashed line, presenting the non-uniform sampling test gives the same inaccuracy in the last tested point. It is obvious that the bigger error in the flicker meter response, gathered from the blocks before the classifier trends similarly the classifier accuracy. Considering the total number of testing points for normalized flickermeter response and classifier test we could summarize that due to the non-uniform sampling, the total relative degradation is about 3% for the flickermeter response and about 14% for the classifier tests.

![Figure 8. Absolute error in flickermeter response for sinusoidal input voltage fluctuations, acc. to the IEC standard test for non-uniform and uniform sampling frequency](image)
4. CONCLUSIONS

From an engineering point of view, some complex power quality device implementations may require non-uniform sampling frequency. This paper suggested comparison between non-uniform and uniform sampling frequency in fully digital flickermetering. The normalized flickermeter response for sinusoidal and rectangular mains voltage fluctuations and flickermeter classifier for a MATLAB flickermeter model was tested according to the ICE standard recommendations. The absolute error, the difference between measured and inferred standard value, for uniform and non-uniform sampling frequency was determined. In contrast to the uniform sampling flickermeter behaviour, the non-uniform sampling one deteriorates the last testing point in all model tests, exceeding the prescribed IEC standard error. This work can successfully assist power quality device engineering solutions.

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REFERENCES