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Matlab based flickermeter

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Abstract – **Voltage flickers are one of the most important parameters of power quality. It deserves a special attention because people sense it directly through visible light flicker. The IEC 61000-4-15 gives the guidelines and specifications for the development of devices for measuring voltage flicker. In this paper all the building blocks of such model are described in detail. With the help of the simulation algorithm using the software package Matlab Simulink a Flickermeter was created and compared with commercial device.**

I.   INTRODUCTION

Power quality is a complex concept that can be defined as a characteristic of electricity at a certain point in the power system in comparison with the reference technical parameters [1, 2]. Power quality, along with the reliability and continuity of electric power supply, is a component of increasing importance in the distribution of electricity. Due to the growing share of wind power flickers are becoming increasingly important quality parameter. [3, 4]. Ideally, the voltage is at all times and at all points a pure sinusoidal with rated frequency and magnitude. Due to the nature of the power system and a number of disorders that can occur in it, the voltage over time to a greater or lesser extent deviates from that ideal situation.

Each variability of voltage causes the variability of the electric lightning. If such variability is visible by a human eye then this voltage variation is called voltage flicker or just flicker. It is one of the quality parameters present in power systems since the beginning of the production and distribution of electricity, but has been neglected in comparison with other parameters such is a voltage dip or transient, since flickers typically do not create technical difficulties and direct property damage, but its emphasis is on the impact on people. Lately, the effect of power quality on people and equipment have been given increasing attention, and a number of international standards and recommendations have been proposed in order to standardize power quality measurements, planning and control. [5, 6]

In 1986. International Electrotechnical Commission (IEC) issued a standard IEC 868 "Flickermeter functional and design specifications" which is the first standard that defines the design and performance of the instrument for measuring flicker (IEC flickermeter). Over time, the IEC has made several updates of that standard, and in 1997 it altered its designation in order to fit into the global IEC numbering scheme. Last official version is called the IEC 61000-4-15, and was released in 2003 [6].

II. IEC FLICKERMETER

IEC standard defines the short-term and long-term flicker severity (P_{ST} and P_{LT}) which are generally recognized universal numbering system expressing negative effects that cause flicker in humans and are the basis of almost all of today's considerations associated with flickering. A classic application of the device to measure flicker offered in commercially available devices is primarily intended for and directed toward direct physical measurement and evaluation of the existing situation regarding the strength of flicker in certain points of the power system.

Over time a number of different flickermeters were developed. One of the most popular is one based on the level of interference caused to humans from flicker based on the equivalent 10 Hz voltage flicker that causes the same level of interference. Equivalent 10 Hz flicker ΔV is calculated on the basis of the frequency spectrum from 0.1 to 30 Hz using the following formula:

$$\Delta V = \sqrt{\sum_n \left(a_n \, \Delta V_n \right)^2} \qquad (1)$$

where: a_n – human sensitivity to flicker frequency n, ΔV_n – present amount of voltage fluctuation of frequency n.

In the beginning of 1980's the International Union for Electroheat (UIE) proposed a protocol for measuring flicker based on chain model lamp-eye-brain. This protocol is the basis of today's modern flickermeter that uses the simulation of the variability of light intensity of ordinary bulbs and simulation that such stimuli causes to the human eye and brain. Based on this principle, the first flickermeter standard IEC 868 was adopted. In 1997 IEC 868 has been replaced by currently valid standard IEC 61000-4-15, which is basically the same as IEC 868. Block diagram of IEC flickermeter chain model of lamp-eye-brain is shown in Figure 1.
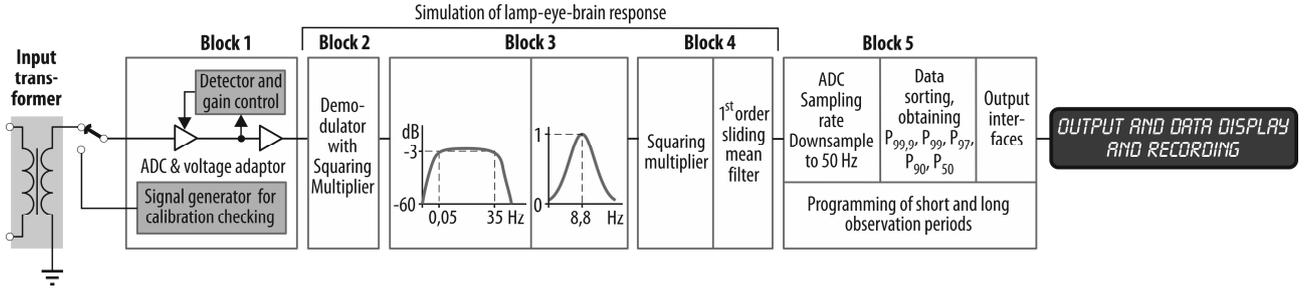
Fig. 1. *Block diagram of flickermeter based on modelling of bulb-eye-brain chain (according to the IEC 61000-4-15*

IEC Flickermeter measures the level of interference that cause flicker in humans regardless of the form of flickering, their periodicity and frequency of occurrence. The level of the interference is expressed as short-term flicker strength P_{ST} which is defined in 10 minute period, and as long-term strength P_{LT} which defines the 120 minute period.

IEC Flickermeter and flicker severity index P_{ST} and P_{LT} today represent by far the mostly used and widely accepted mean to express numerically negative effects that flicker cause in humans. IEC Flickermeter consists of 5 functional blocks which will be described in detail and simulated in Matlab Simulink software package. Practical implementation of the described algorithms have been done using MATLAB XPC platform.

A. Block 1 – Voltage adaptor

Voltage adaptor normalizes the input voltage of flickermeter so that the average effective value of the modulated voltage power frequency (50 Hz) at the outlet of the adapter is always at a constant reference value regardless of the level of the input voltage. Normalization is done by expressing the relative input voltage relatively to its time-averaged effective value Vsr, where it is important not to change the relative voltage fluctuations that participate in creating flicker. For this reason, the averaging period must be one second.
This is achieved in a way that the input signal is divided with its effective value in one second intervals calculated with the help of a block (RMS discrete). After that, the signal is divided by two to obtain a unit signal value at the output of the block 1.

B. Block 2 – Squarring demodulator

Task of the square demodulator (engl. squaring demodulator) is a separation of voltage fluctuations from voltage waveform. Sine power voltage that is amplitude modulated by flicker modulation function can be described by the following mathematical expression:

$$u(t) = V_{50}[1+m(t)]\cos(\omega_{50}t) \qquad (2)$$

that after a voltage adapter (block 1) takes the form:

$$u(t) = V'_{50}[1+m(t)]\cos(\omega_{50}t) \qquad (3)$$

where: V_{50} - instantaneous peak of 50 Hz supply voltage, V'_{50} - instantaneous peak of 50 Hz input voltage to block 2, $m(t)$ - amplitude flicker modulation of the supply voltage.

To extract the amplitude modulation from such waveform there are numerous methods, while standard IEC 61000-4-15 for this purpose uses square demodulation method. Square demodulation is performed in such a way that the input signal is squared. As a result the following waveform is obtained:

$$u(t)^2 = \frac{V'^2_{50}}{2}[1+2m(t)+m(t)^2][1+\cos(2\omega_{50}t)] \quad (4)$$

After removing the DC component and sine components of the double supply voltage frequency, following signal components remain:

$$u(t)' = V'^2_{50}m(t) + \frac{V'^2_{50}}{2}m(t)^2 \qquad (5)$$

As discussed voltage fluctuations rarely amount to more than a few percent $m(t) << 1$, neglecting the second member in the expression for $u(t)'$ is considered as acceptable approximation.

$$u(t)' \cong V'^2_{50}m(t) \qquad (6)$$

Described mathematical method in signal processing is performed by squaring and filtering. In this block only the squaring of the signal is performed, while filtering is performed in block 3.

C. Block 3 – Weighting filter

Demodulation filter consists of a high-pass filter of a first-order and a low-pass filter of a sixth order. Removal of the DC component according to the IEC standard is done with the help of a high-pass filter of the first order

32

with a -3 dB cut-off frequency in $\omega_{cH} = 2\pi\ 0.05$ s^{-1}, whose transfer function is as follows:

$$F(s)_H = \frac{s}{s + \omega_{cH}} \qquad (7)$$

Removal of sinusoidal component of dual power frequency is done using low-pass Butterworth filter of the 6-th order with a -3 dB cut-off frequency on $\omega_{cL} = 2\pi\ 35$ s^{-1}, whose transfer function is as follows:

$$F(s)_L = \frac{1}{1 + b_1\left(\dfrac{s}{\omega_{cL}}\right)^1 + \ldots + b_5\left(\dfrac{s}{\omega_{cL}}\right)^5 + \left(\dfrac{s}{\omega_{cL}}\right)^6} \qquad (8)$$

where filter coefficients are:
b_1=3.863703305156275 b_2=7.464101615137757
b_3=9.141620172685645 b_4=7.464101615137759
b_5=3.863703305156276

Different voltage fluctuation frequencies of the same amplitude are causing different changes in the intensity of light bulbs. Also, the human eye and brain are not perceiving equally the same changes of light intensity at different frequencies. Standard defines the weight evaluation of this filter on the basis of tests carried out on the sine voltage fluctuations and 60W/230V/50Hz filament lamp. The limit is set when 50% of the total number of people tested noticed the fluctuation. The transfer function of the weighting filter is defined by the IEC standard and in Laplace's field it looks like this:

$$F(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2} \cdot \frac{1 + \dfrac{s}{\omega_2}}{\left(1 + \dfrac{s}{\omega_3}\right)\left(1 + \dfrac{s}{\omega_4}\right)} \qquad (9)$$

Standard defined constants are:
k=1.74802, λ=2π×4.05981, ω_1=2π×9.15494,
ω_2=2π×2.27979, ω_3=2π×1.22535, ω_4=2π×21.9

D. Block 4 – Squaring and smoothing

This block consists of a squaring block and low-pass filter of the first order. Squaring simulates nonlinear perception of flicker in the human brain. Smoothing or low-pass filter simulates the memory effect in the brain. The corresponding filter is derived as 1st order sliding mean filter with a time constant of 300 ms, which corresponds to cut-off frequency ω_L=3.333 s^{-1}. Therefore, the low-pass Butterworth filter with a first-order is used, and its transfer function in the Laplace's area looks like:

$$F(s) = \frac{1}{1 + \dfrac{s}{\omega_L}} \qquad (10)$$

Output from block 4 is the value that gives us a value of the Instantaneous Flicker Sensation (IFS), which is then used in the statistical analysis to derive estimates of sensation flicker in the long periods of time.

All so far mentioned filters are implemented in software package Matlab Simulink. The coefficients of the transfer function in the numerator and denominator are obtained by calling functions such as:
[b, a] = butter (1,0.5305 * 2 * pi, 'low','s');
whose arguments are filter order, cut-off frequency, filter type and an indication that it is Laplace or *s* domain. Since the objective is digital implementation, the filter coefficients must be defined in the *z* domain, which is also easily obtained by calling the function for bilinear transformation e.g.: [num,den] = bilinear (b,a,Ns); Function arguments are filter coefficients in *s* domain, and sampling frequency. The selected sampling rate Ns = 2000 Hz. In order that an output value from block 4 (instantaneous flicker sensation PIFS) has a unit value it must be multiplied by a constant K = 1238400 [7].

The output from this block is the value that gives us a judgment of the Instantaneous Flicker Sensation (IFS). As the used filter is low-pass filter whose upper cutoff frequency is less than 1 Hz, down-sampling can be performed. The chosen frequency is 50 Hz, which is adapted to the requirements for statistical analysis, and it is also the lower limit allowed by the standard.

E. Block 5 –Statistical analysis

For information about the instantaneous flicker sensation, short term flicker severity value P_{ST} and long term severity value P_{LT} are calculated. Index P_{ST} is defined for 10-minute period and the P_{LT} index for 120-minute period. The indexes are relevant for assessing the level of flicker impact on people. The unit values of these indexes corresponds to the intensity of flicker which sees 50% of people exposed to its action, and in the case of application of the reference light source (60W, 230V/50 Hz 120V/60Hz; incandescent lamps). A value of 1.0 or more represents the flicker in which the observer feels interference.

Short-term flicker severity P_{ST} is calculated on the basis of the probability distribution function of the instantaneous sensation flicker P_{IFS} in 10 minute period according to the following formula:

$$P_{ST} = \sqrt{a_1 P_{99,9} + a_2 P_{99} + a_3 P_{97} + a_4 P_{90} + a_5 P_{50}} \qquad (11)$$

Where constants are: a_1= 0.0314, a_2=0.0525, a_3=0.0657, a_4=0.28, a_5=0.08. $P_{99,9}$ is value of instantaneous sensation

flicker P_{IFS} that 10 minute period has not been exceeded in 99.9 % of the time. Defined in the same way are the values of P_{99}, P_{97}, P_{90}, and P_{50}. Interval of ten minutes was chosen because it is short enough that the load whose operating cycle of operation is long can be characterized in detail (e.g. arc furnace), and also it is a long enough period so that there is no effect of short-term variations. Proper implementation must take all samples in 10 minutes, with the sampling rate of 50 Hz, which means 30000 samples. Afterwards, the samples are sorted to obtain percentile data. For example, the value of P_{50} is exactly at half of the sorted array. The index of long-term strength flicker P_{LT} is calculated for 120 minutes on the basis of the last 12 values of short-term flicker severity, according to the following:

$$P_{LT} = \sqrt[3]{\frac{\sum_{i=1}^{12}\left(P_{ST\,i}\right)^3}{12}} \qquad (12)$$

In this section, the response of flickermeter has been tested for the sine voltage of 50 Hz, which is modulated by voltage fluctuations as defined by standard (calibration signals). The result of the test parameters P_{ST} and P_{LT} must be exactly 1. The Fig. 2. shows the amplitude of voltage fluctuations in blue and flicker severity in red.
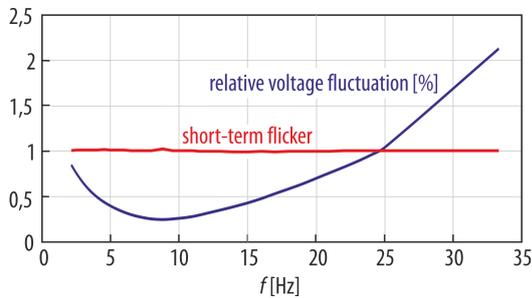

Fig. 2. Amplitude of voltage fluctuations and short-term flicker severity index

According to this standard flickermeter works correctly if the index of instantaneous intensity flicker $P_{ST}=1\pm0,05$.

III. TESTING OF THE MODEL

The simulation model has been implemented on an industrial PC with Real Time OS. Voltage was measured using AD card NI PCI 6024. Comparison was carried out with a commercial device Metrel MI 2292 Power Quality Analyzer. Measurements were carried out in actual operating conditions for period of 36 hours, and the result is shown in Fig. 3.
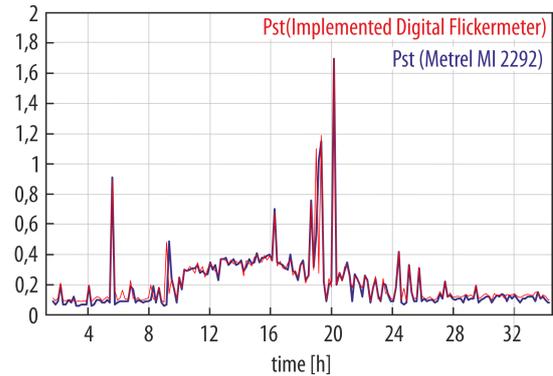

Fig.3. Comparative results show P_{ST} with Implemented Digital Flickermeter and Metrel MI 2292

II. CONCLUSION

Flickermeter has been realized according to IEC 61000-4-15 and implemented on an industrial PC. Testing was performed using the calibration signals whereby Flickermeter satisfied the prescribed accuracy of ±5%. A comparison was also performed using the commercial device for measuring flicker with very good agreement of results.

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