Digital Filter Simulation for Development of Digital Flicker Meter

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Abstract
The number of the non-linear equipments connected to the electrical energy distribution system is rising continuously. These equipments generate harmonic currents and voltages in the network impedances and they are added to the base signal deforming the value and the shape of the main voltage. The distorted voltage increases electrical strain and temperature load of the equipment connected to the network. Moreover some of the disturbances can be dangerous not just for the equipments but for the people as well through the lights causing weariness, irritableness, etc. This special, dangerous on people effect is called flicker.

Key words
flicker, Fourier analysis, digital filtering, complex transfer function, Z-transformation

1. Introduction

The main topic of this article is the flicker effect caused by the voltage and current fluctuations to the human body, defining its measure and future development of a measurement system for objective and exact measurement of the flashing effect of the electrical networks. The novelty of this project - unlike the analogue flicker-measurement systems available on the market - is based on a new digital method which raises a bunch of new development issues.

Equipments connected to the electrical system (non-linear characteristical) generate harmonic current and voltage hence the value of main voltage is distorted, the use of the electrical equipments is increased, thermo-emission and faults in application are induced.

For the sake of adequate operation, the electrical equipments connected in networks furthermore the incandescent lamps need constant effective voltage

However, high-capacity engines, transformers or impedances cause voltage fluctuation almost in all cases.

Fluctuation phenomenon imperceptibly influences the human body and its environment. The consequence of cyclical, fast voltage fluctuation is the so-called flicker. The flicker is the sequence of flashing lamp impulses. High-capacity factories, for instance, affect the electrical network variously. These factors support the appearance of flicker.

The flicker has serious influences on human body especially on our sight: eyes can get tired more easily. In addition, it can easily cause headache as well. The method of the fluctuation measurements is determined by the International Standard CEI IEC 61000-4-15 Electromagnetic Compatibility (EMC) [2].

2. The disturbing effect of the flicker

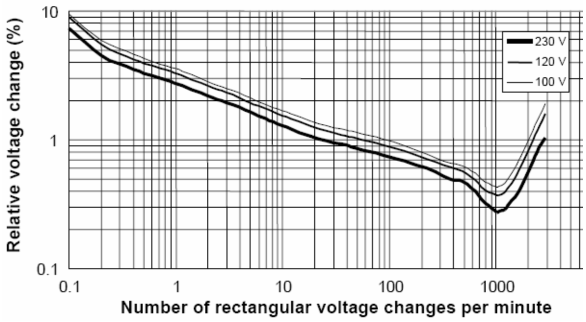

Figure 1. CEI IEC 61000-3-3 flicker sensory graph [3]

Determination of the flicker's disturbing effect is a complex problem, because the exact measurement of the human body's sensitivity practically unavailable. medical and engineering professionals have worked out the function representing and simulating the sensitivity of people's eye-brain system.

According to researches and observations on human beings and animals, people are especially sensitive to 8,8 Hz voltage fluctuation. Consequently, it is determined by standard that main voltage cannot contain any such frequency components

3. Digital flicker meter

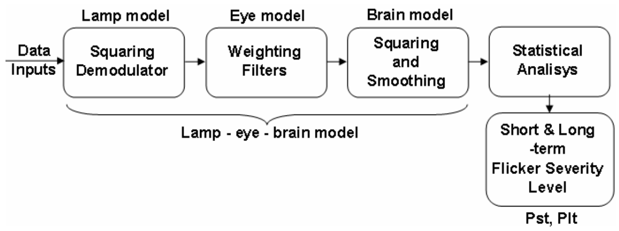

Figure 2. Simplified block diagram of a flicker meter according to IEC 61000-4-15 [2]

During the research the relevant international standards had to be taken account (International Standard CEI IEC 61000-4-15 EMC). Our development team examined the flashing effect, flicker detection curve, structure of an analogue flicker measurement system and certain equipments (three flicker meter) used for monitoring of quality of electrical energy. A special attention was paid to the structure and function of equipments which can implement the measurement of the flicker.

Digital implementation, mentioned above, was our most important goal. The implementation of digital modules –suited for the latest expectations- had to be fulfilled. There were many options during the development process. The representation of previous and current results and future prospects of the research can be found in this full paper.

The most complex and challenging part of this work was development of the cascade module of the central filter which is responsible for simulation of lamp-eye-brain response. The mentioned central module means one of the crucial components of flicker measurement system. If this central module is developed, the signal transformational part of measurement equipment will be ready to process the sampling analogue signal according to the required standards. Thus on the output of filter cascade module signal sequences of $P_f(t)$ are resulted.

This is apparent: we should approximate the analogue filter system of the central module in a digital way.

There were two ways for approximating the central module:

1) With a special filter cascade module according to an analogue implementation
2) Searching the Z equivalent of Laplace-transformation required in standard (Actually, it means the transplantation of the continuous time domain to the discrete-sampling one).

A. *The digital implementation of filter cascade module*

The central block can be modelled by a special, complex transfer function (defined by physicians, biologists, physics and engineers). Digital approximation is based on this transfer function. In other words it is suitable for substituting the analogue filter cascade. Therefore our work is reduced for approximation of this filter cascade given by the following Laplace-transfer function.

$$A(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2} \frac{1 + \frac{s}{\omega_2}}{(1 + \frac{s}{\omega_3})(1 + \frac{s}{\omega_4})} \qquad (1)$$

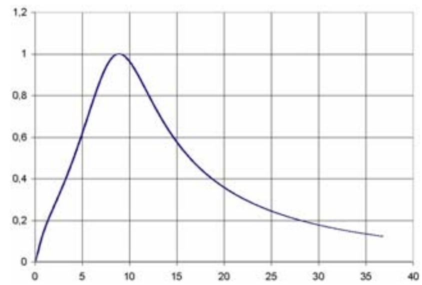

Figure 3. The complex (Laplace) transfer function (amplitude – frequency diagram)

Transfer function broken into four parts:

$$A_1(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2} \qquad (2)$$

$$A_2(s) = 1 + \frac{s}{\omega_2} \qquad (3)$$

$$A_3(s) = \frac{1}{1 + \frac{s}{\omega_3}} \qquad (4)$$

$$A_4(s) = \frac{1}{1 + \frac{s}{\omega_4}} \qquad (5)$$

(These sub-transfer functions were not only used in digital process but in the Z-transformation as a base formula.)

This part of the project was divided into three phases. We created a new analysing, simulating software for all voltage phases. Besides, we also developed a new calibration method for reliable and accurate definition of any kind of faults of the developed system.

During the calibration method we developed a model according to the required standard so that complex filtering processes could be avoided by Fourier-, and inverse Fourier analysis. On one hand we applied this method in order that we could avoid complex filtering and on the other hand we wanted to build reference points in our system. The final result $P_{st} = 1$ confirmed the correct function of the calibration method.

In the first step we created a simulator application in which we inspected the complex transfer function defined in the standard. We divided this function by mathematical way and created an application in which we studied sub-transfer functions. We also created a program for drawing the sub-transfer functions on the screen. For this purpose we used a special custom generated waveforms (all the signals had 1 V amplitude and 1–35 Hz frequency), representing the transfer functions itself. These functions are weighted outputs of this special input waveform.

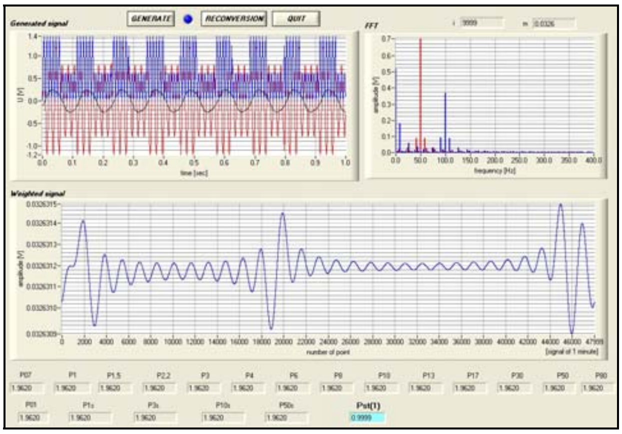

Figure 4. Calibration software for flicker meters

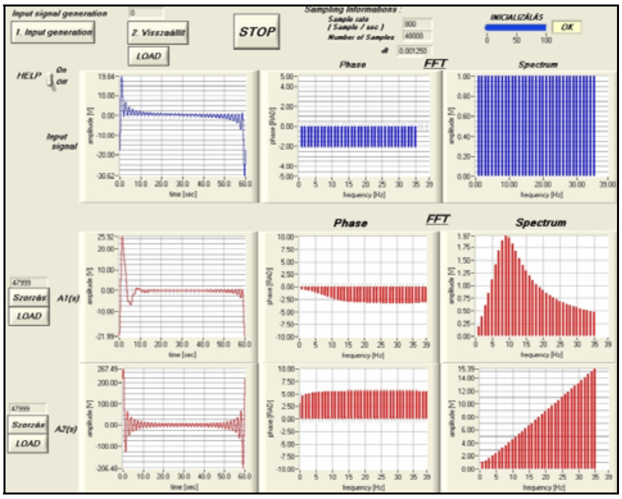

Figure 5. Simulation software for approximating sub-transfer functions

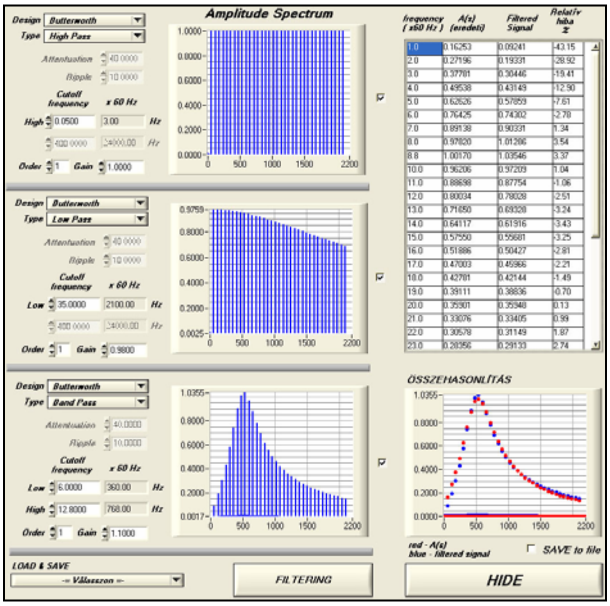

Figure 6. Approximation of transfer function with digital filter cascade

In the second step we approximated all the four sub-transfer functions with digital Butterworth filters. This approximation gave very accurate results in three cases but one. Sub-transfer function could not be approximated with a digital IIR filter. So it was obvious that we needed another method to solve this problem.

In the third phase we defined a cascade of three IIR digital filters according to the analogue implementation. We developed a special application for approximating the complex transfer function. At the end we found the proper approximation of the complex transfer function. So we created the most important part of the flicker-measurement system. The lower frequency component (1-4 Hz) of the transfer function could not be well-approximated. Thus further development will be needed. Henceforth a Z-transformation method will be used.

B. Modelling of transfer function with Z-transformation

The formula of Laplace-transformation refers to continuous time domain. However, during digital process only sampling signals can be taken into account. The other method of modelling the central filter cascade is the transformation of Laplace-transfer function. Consequently, the complex transfer function should be transformed into discrete transfer function in Z-domain. One of the applicable methods of transformation is the use of bilinear Z-transformation.

Formula needed for Z-transformation:

$$s = \frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}} \qquad (6)$$

A simulation software was developed for studying the transformed transfer function. Of course we had to face lots of problems. One of these derives from a pecualirity of Z-transformation. Digital filtering can be regarded as a special iterational process where not only input signal plays a significant role but the output signal as well.

Generally speaking, the accuracy of transformation influences the stability of filtering in a great extent.

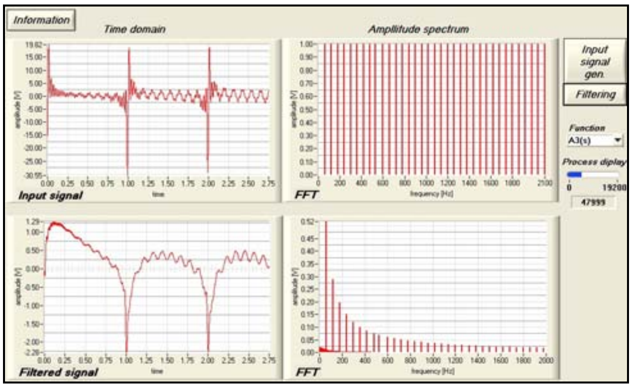

Figure 7. Simulation software for representing transfer function

We developed several solutions for transformation.

1) We attempted to transform the complex transfer function without any simplifications.Whereas, we could not represent this given function in graph. Extreme results were created in the simulation.

2) We attempted to Z-transform the four divided sub-transfer functions to find faults then to represent these in graph. Henceforth the discrete sub-transfer function was compared to Laplace-transfer function. As a result of it we could see that three in four cases there was relative error under 0.5%. The second-degree sub-transfer function could not be represented, either.

The main procedures of the Z-tranformation and the applied principles of programming is represented in the next part. One of the simplest transfer functions ($A_4(s)$) is chosen for analysis. Of course the other three transfer functions can be developed and programmed similarly.

1) As a first step the formula (6) should be substituted to $A_4(s)$ function. Henceforth, it should be reduced to the adequete expression.

$$U_{ki}[n] = \frac{a_0}{b_0} U_{be}[n] + \frac{a_1}{b_0} U_{be}[n-1] + \frac{b1}{b_0} U_{ki}[n-1] \quad (7)$$

where:

$$a_0 = 1 \quad (8)$$

$$a_1 = 1 \quad (9)$$

$$b_0 = 1 + \frac{2}{\omega_4 T} \quad (10)$$

$$b_1 = 1 - \frac{2}{\omega_4 T} \quad (11)$$

2) In the program two arrays should be defined for the temporary storing of input and output signals. The program should be developed with the help of a given transversal model.

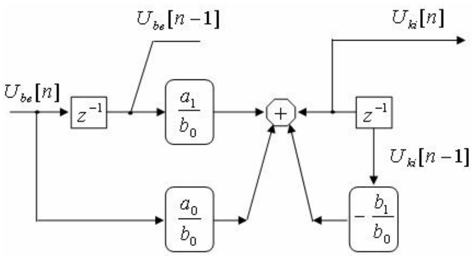

Figure 8. Transversal model

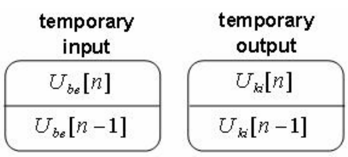

Figure 9. Temporary input and output arrays

According to our observations the Z-transformed second-degree member of the transfer function causes the main problem. As a conclusion it is apparent we should search another method for the simulation of the central block.

4. Conclusion

The research and development supported by the Regional University Knowledge Centre of Mechatronics and Logistics System includes the information technology and the electrical engineering science as well. Tools of information technology are used to solve problems of energy network systems diagnostics, particularly hardware and software development of the measurement and analysing system. Digital method of flicker definition can be considered as a novel in the everyday industrial use, as the most of available at the market procedures use the analogue method. The research work is continued, this paper presents the results achieved so far.

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