

Arduino - Matlab based flickermeter

Realization and verification according to IEC 61000-4-15 standard

Mansour S. Hashad,

AbdulRahman Mohamed, Saad al-Sheikh

Department of Electrical and Electronic Engineering

Higher Institute of Engineering and Technology -

Tripoli, Libya

ms_hashad@hotmail.com

abdo90ly@gmail.com

so.magic89@gmail.com

Abstract— The paper presents the construction, principle of operation and implementation of the flickermeter according to IEC 61000-4-15 standard. Based on these recommendations, a specific laboratory instrument was designed using Matlab software as well as Arduino hardware. Flicker is one of the most important power quality aspects caused by RMS voltage fluctuation in the electrical power system. A harmful phenomena could be occur in certain cases due to voltage fluctuation; it is annoying to human eyes, causes discomfort, and in extreme cases can even lead to an attack in epileptic patients. The verification procedure has been demonstrated as well. The main purpose of this paper is to present all the information needed to understand and design own instrument e.g. in the laboratories of the institutes by engineers, students and all interested in this subject.

Keywords— *power quality, flicker, flickermeter, simulation, voltage fluctuation, Matlab, Arduino, DSP.*

I. INTRODUCTION

According to the international energy and electronics vocabulary, the phenomenon of voltage fluctuation is a series of changes of root-mean-square value or waveform envelope [1]. Flicker phenomenon is a consequence of voltage changes, perceived subjectively as fluctuation of the luminous flux, the luminance or spectral resolution of which is subject to change over time.

The amplitude of the fluctuations, the frequency spectrum and duration of RMS changes are the main causes of flicker phenomenon.

The effects of flicker have been neglected for a long time in comparison with other phenomena such as a voltage dip or transient, since flickers typically do not create property damage, but their impact are on people; which can range from minor irritation by physiological malaise to serious health risk. In fact, it has been observed that some critical fluctuation can lead to epileptic seizures for those who have a tendency to do so [2]. The epileptic seizures phenomenon was noticed during video games watching. Apropos, in 2015 BBC- Arabic press release- has published the following news: "Twitter has deleted two adverts that an epilepsy treatment charity has described as irresponsible. Twitter published on its internet portal two short videos containing fast and repetitive tints of flashing colors,

and the executive vice president of the Epilepsy Action Foundation on epilepsy treatment said: the Twitter two ads were dangerous for photosensitive epileptic patients" [3].

The fluctuation of light intensity negatively affects also on the healthy people; their work quality, and other symptoms such as damage to eyesight, headache, nervousness, and last but not least a depression. This is why there a need for defining and measuring flickers [4].

Flicker –therefore- is one of the most important power quality aspects. The great impact produced by the light flicker phenomenon has led the International Standard Committees to fix very restrictive limits.

Despite of fact that in everyday utilization of electrical network; the flicker levels are generally low; however the malaise caused by them can be noticeable. Unfortunately authors have no information published by GECOL (General Electric Company of Libya) on flicker levels; therefore one cannot objectively assess the situation in Libya. One guesses the levels of flicker are exceedingly high.

The amplitude modulation of a voltage signal -as the carrier wave- it is nothing but flicker voltage signal. Its frequency ranges from 0,005Hz to 33Hz (a maximum spectral response ranges between 8 and 10 Hz).

According to UIE-IEC standard there are two defined parameters for qualitative assessment of the flicker severity, namely: short-term flicker Pst and long-term flicker Plt. The term of "flickermeter" means a device designed to determine the parameter Pst.

The procedure for determining Pst is very complex and requires a digital signal processing according to the given mathematical model, also there are specific memory requirements and number of bits in the A/D converter etc.

The flickermeter requirements are listed in IEC-61000-4-15 standard as well as the IEC 1000-3-3 standard. In 2016 Department of Electrical and Electronic Engineering (Higher Institute of Engineering and Technology - Tripoli) put forward a concept of developing a computerized flickermeter. The objective of this paper is to outline the most essential outcomes

of the device development project, which used an A/D converter located in an Arduino board, and the computing software was devised with help of MATLAB software.

II. STRUCTURE OF DIGITAL FLICKERMETER

The development of the digital flickermeter are based on standards [4][5][6] and papers [1][2][7][8], the block diagram of the flickermeter is shown in Fig. 1.

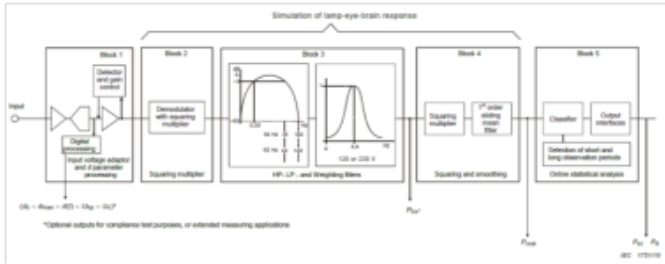


Fig. 1. Block diagram of the IEC flickermeter [4].

The general concept of the proposed laboratory instrument is introduced in Fig. 2.

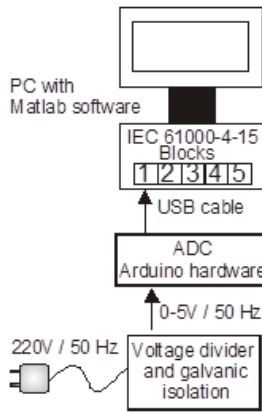


Fig. 2. General concept of proposed measuring instrument.

Specific blocks of the proposed measuring instrument provide the following functionality:

A. Voltage divider

The measurement set is connected to the measured object by resistance divider or/and isolation transformer.

The measuring signal is fed through the divider to the A/D converter on Arduino card (if it is fed without galvanic separation; utmost attention must be paid during measurement runs to the issues of safety and power the PC with a separating transformer as well as connecting PC chassis to PE).

B. A/D signal converter

The Arduino ADC cannot be used to measure AC signal directly (bipolar signal) because, the acceptable range of analog input is 0-5 V. In this case an additional circuit to make signal offset equal to 2.5 V was designed. This circuit is a bipolar to unipolar signal converter presented in Fig. 3.

The output signal of operational amplifier is the sum of input signal and offset; then it is shifted to 0-5 V.

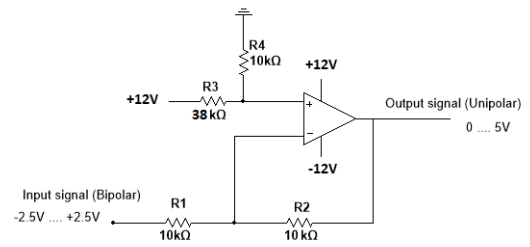


Fig. 3. A bipolar to unipolar signal converter.

Both signals (i.e. input and output) are shown in Fig. 4.

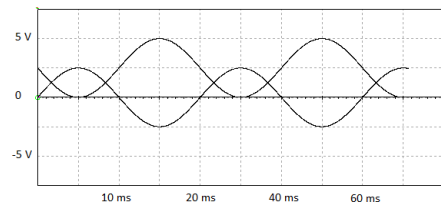


Fig. 4. The original and shifted signals.

The Arduino board with Atmega328P-PU microcontroller has six analog unipolar inputs with 10-bit ADC, which means 1024 different levels. Now suppose that the range of measured V_{ac} signal varies from -350V to +350V, this yields a resolution of 0.684V; namely 0.297% of the RMS voltage value.

Although It is acceptable –especially- for laboratory purpose, one can improve the measurement resolution twice (ie. 0.149%) if will measure the rectified signal. In the previous version of designed and tested own flickermeter has been used a professional Data Acquisition card, type: a PCI-DAS 1602/16 of „Computer boards” manufacture, located in a PC environment. The card allows synchronous block signal sampling. The length of input data vector is 600kS with sampling frequency $f_s = 1$ [k Samples/s]. The low-pass filter with stop band edge frequency equal to or less than Nyquist frequency ($f_N = f_s/2$) used as anti-aliasing filter. Fig. 5 presents the anti-aliasing filter; designed as 2nd order Bessel low pass filter with frequency response characteristic shown on Fig. 6.

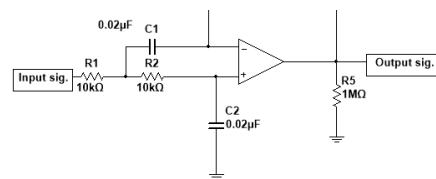


Fig. 5. 2nd Order Bessel Low Pass Filter.

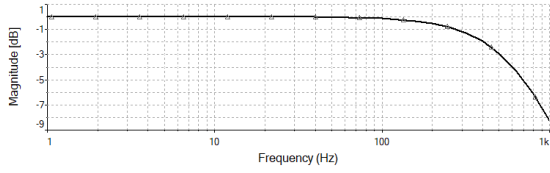


Fig. 6. Frequency response of anti-aliasing filter.

The designed flickermeter is working offline; this means the data processing stage starts only after digital data sampling is finished.

The data are fed into the PC memory (Matlab workspace) either directly or read from a previously saved file on a hard drive. One also can call MATLAB software as a computational engine by writing “C” program.

The data acquisition has to be realised in a synchronous mode with fixed sampling rate. This can be reached by using Simulink External Mode simulation. Data samples are sent to “Workspace” block. Provided data are accessible by m-code file when it is called from Matlab command line. Let the “SDane” is the name of input voltage vector saved to Workspace with sampling time $T_p = 1$ [ms].

The input voltage data vector has to be sampled with fixed sampling time T_p , this is very important because all transfer functions need to be converted from continuous to discrete time. To do that, the Matlab function $c2d(sys, T_p)$ is used.

C. Block 1: amplification detector and regulator

This block provides reference of voltage waveform over time to average root-mean-square value of one minute.

D. Blok 2: square demodulator

This block offers demodulation of measured signal, being a waveform envelope of system voltage. This block is made up of a series connection of squarer and band filter of boundary frequencies of $f_L=0.05$ [Hz] (Butterworth filter first order) and $f_H=35$ [Hz] (Butterworth filter sixth order).

E. Block 3: weighing filters

This block is made up of two filters with transfer function described as:

$$F(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2} \times \frac{1 + s/\omega_2}{(1 + s/\omega_3)(1 + s/\omega_4)}$$

Where:

$$k = 1,74802$$

$$\lambda = 2\pi 4,05981$$

$$\omega_1 = 2\pi 9,15494$$

$$\omega_2 = 2\pi 2,27979$$

$$\omega_3 = 2\pi 1,22535$$

$$\omega_4 = 2\pi 21,9$$

It is a characteristic for incandescent lamps of 60W fed with 230v.

F. Block 4: non-linear brain reaction

This block provides simulation of non-linear brain reaction to flicker sensation. The block is made up of a multiplying unit squaring instantaneous values to simulate the non-linear eye-brain perception and a low-pass first grade filter to simulate the storage effect in the brain.

G. Block 5: statistical analysis of output signal

Based on the output signal of block 4, the flickermeter computes statistical indicators Pst (short-term flicker indicator). Specific flickering levels are developed on the basis of CPF (cumulated probability function). For this purpose max and min values were divided into 100 levels with line interpolation and pseudo-zero section was applied.

III. MATLAB PROGRAM CODE

Fully functional simple version of code program is illustrated as given below. The name of file is optional according to choice e.g. “msflickermeter.m”.

```

%Digital filter coefficients
f = 50; %Hz
fp = 1000; %samples per second
Tp=1/fp ;
T=1/f ;
%Block Nr 2
[DB1,DA1]=BUTTER(1,(.05*2/fp),high');
[DB2,DA2]=BUTTER(6,(35*2/fp));
%Block Nr 3
k=1.74802;
la=2*pi*4.05981 ;
w1=2*pi*9.15494 ;
w2=2*pi*2.27979;
w3=2*pi*1.22535 ;
w4=2*pi*21.9 ;
a12=1;
a11=2*la ;
a10=w1.^2 ;
b10=0 ;
b11=k*w1 ;
a22=1/(w3*w4);
a21=(1/w3)+(1/w4) ;
a20=1 ;
b20=1 ;
b21=1/w2 ;
m1=[a12 a11 a10];
l1=[b11 b10];
m2=[a22 a21 a20];
l2=[b21 b20];
[l,m]=series(l1,m1,l2,m2);
[B3B1,B3A1]=c2dm(l1,m1,Tp,'zoh');
[B3B2,B3A2]=c2dm(l2,m2,Tp,'zoh');
%Block Nr 4
l4=[1];
m4=[0.3 1];
[B4B,B4A]=c2dm(l4,m4,Tp);
%%Digital Signal Processing%%
%Prepare data
lpno = round (fp / f);
lpkt =lpno * fix(length(SDane) / lpno);
Okresow = lpkt / lpno;
SDane = SDane(1:(Okresow * lpno));
U =reshape(SDane,lpno,Okresow);
U = sqrt(sum(U.^2)/lpno) ;

```

```

Uodn = mean(U);
clear U;
%% Demodulator %%
SDane = 100 * SDane / (1.4143 * Uodn);
SDane = (0.1 * SDane).^2;
SDane = filter(DB2, DA2, SDane);
SDane = filter(DB1, DA1, SDane);
%% Blok03 %%
SDane = filter(B3B1, B3A1, SDane);
SDane = filter(B3B2, B3A2, SDane);
%% Blok04 %%
SDane = SDane.^2;
SDane = filter(B4B, B4A, SDane);
SDane = SDane / (0.0323 * 249);
SDane(1:20000) = [];
%% Blok05 %%
%% Cumulative Parabolic Function
%% And Short Term Indicator Pst
podzial = 100;
[a b] = hist(SDane, podzial);
sig = sum(a);
s = fliplr(cumsum(fliplr(a)));
CFL = 100 * s / sig;
CFL = [CFL, 0];
b0 = 3 * b(1) - 3 * b(2) + b(3);
Smax = [b0, b];
%% [80% ]%%
p80 = pert(80, CFL, Smax);
%% [ 50% ]%%
p50 = pert(50, CFL, Smax);
%% [ 30% ]%%
p30 = pert(30, CFL, Smax);
%% [ 17% ]%%
p17 = pert(17, CFL, Smax);
%% [ 13% ]%%
p13 = pert(13, CFL, Smax);
%% [ 10% ]%%
p10 = pert(10, CFL, Smax);
%% [ 8% ]%%
p8 = pert(8, CFL, Smax);
%% [ 6% ]%%
p6 = pert(6, CFL, Smax);
%% [ 4% ]%%
p4 = pert(4, CFL, Smax);
%% [ 3% ]%%
p3 = pert(3, CFL, Smax);
%% [ 2.2% ]%%
p2_2 = pert(2.2, CFL, Smax);
%% [ 1.5% ]%%
p1_5 = pert(1.5, CFL, Smax);
%% [ 1% ]%%
p1 = pert(1, CFL, Smax);
%% [ 0.7% ]%%
p0_7 = pert(0.7, CFL, Smax);
%% [ 0.1% ]%%
p0_1 = pert(0.1, CFL, Smax);
%% %%% %%% %%% %%% %%% %%% %%% %%% %%% %%%
p50s = ((p30) + (p50) + (p80)) / 3;
p10s = ((p6) + (p8) + (p10) + (p13) + (p17)) / 5;
p3s = ((p2_2) + (p3) + (p4)) / 3;
p1s = ((p0_7) + (p1) + (p1_5)) / 3;
% Pst is equal to =
pst = (0.0314 * p0_1 + 0.0525 * p1s + 0.0657 * p3s + 0.28 * p10s + 0.08 * p50s).^0.5
pack;

```

The file with restricted name “pert.m” should be created and located in the same working directory. The program code of this file is given next:

```

function a = pert(w, C, S)
idx = find(C == w);
if ~isempty(idx)
    pointer = idx(1);
    a = S(pointer);
return;

```

```

end
idx = find(C > w);
pointer = idx(end);
y2 = S(pointer);
x2 = C(pointer);
idx = find(C < w);
pointer = idx(1);
y1 = S(pointer);
x1 = C(pointer);
x = w;
a = (y2 - y1) * (x - x1) / (x2 - x1) + y1;
% End of function pert()

```

IV. DEVICE CALIBRATION

The standard [4] defines a set of signals to test the instrument. Each flickermeter should be tested, with a regular series of rectangular voltage changes given in Table I.

TABLE I. TEST SPECIFICATION FOR FLICKERMETER CLASSIFIER

Changes per minute	$\frac{\Delta V}{V} \%$
1	2.72
2	2.21
7	1.46
39	0.905
110	0.725
1620	0.402

In each case given in the Table I, the short term indicator P_{st} should be 1.00 ± 0.05 .

To carry out the test; samples of modulated signal have to be already transferred to Matlab-Workspace memory, and then m-code file can be invoked by typing the file name in command line: “msflickermeter” then press “Enter” key .

A waveform for selected signal with amplitude 311v and frequency 50Hz, modulated with rectangular waveform of frequency with 39 (changes/min), and relative amplitude $\frac{\Delta V}{V} \% = 0.905$ is shown in Fig. 7.

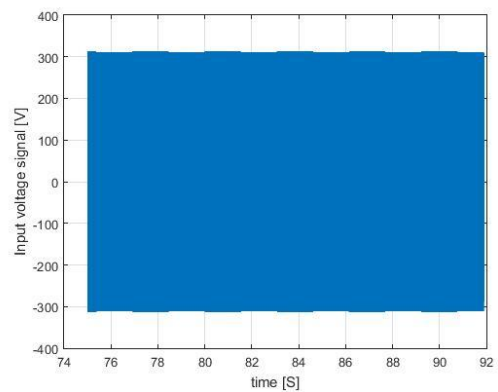


Fig. 7. Fluctuating input voltage.

To recover the voltage fluctuation an amplitude demodulation of input signal is making by block 2. The demodulated signal is presented in .Fig. 8.

In Fig.9 and Fig.10 are shown the output signals of block 3 and block 4 respectively.

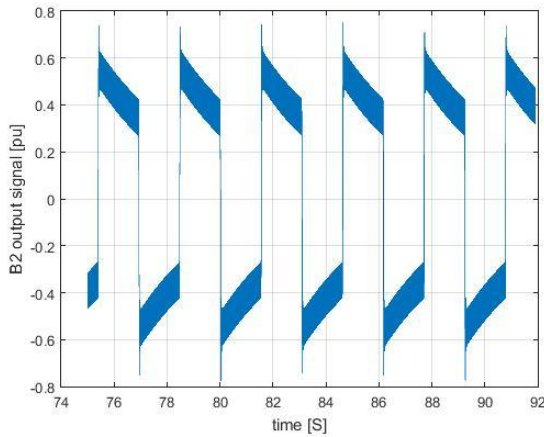


Fig. 8. Demodulated voltage fluctuations (B2 output).

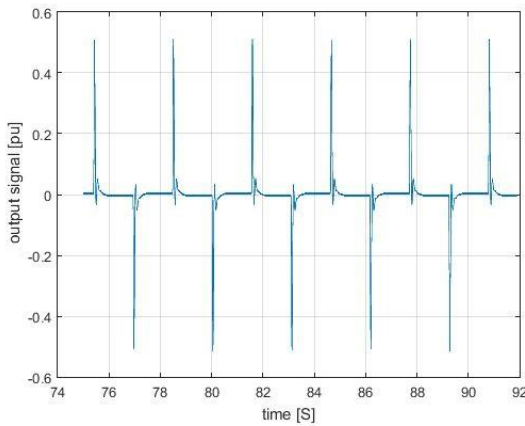


Fig. 9. Weighted voltage fluctuations (B3 output).

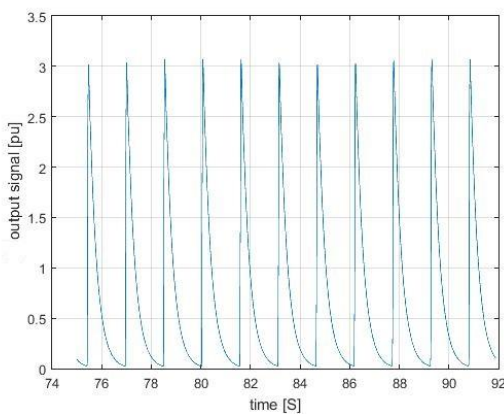


Fig. 10. Flicker level as a time-varying function (B4 output).

The cumulative probability function obtained by subdividing the amplitude of the flicker level signal into a hundred classes is presented in Fig. 11.

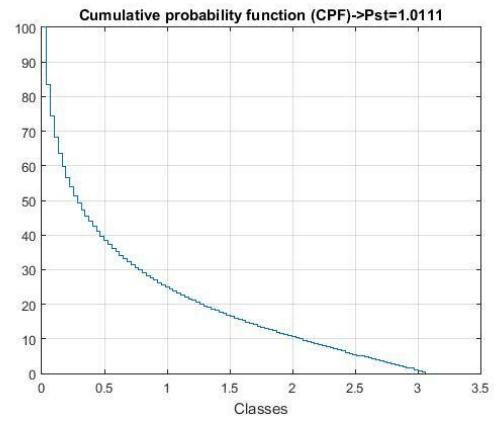


Fig. 11. Cumulative probability function (B5 output).

V. CONCLUSIONS

The presented above concept of digital flickermeter fulfills all requirements outlined in the standard [4], and corresponds to analogue flickermeters. Errors obtained during calibration of the device do not exceed 5%.

It has to be noted that the digital flickermeter described in this paper is designed for Laboratory of electrical engineering department purpose and can be used for additional voltage system analysis such as; relative dc, dmax voltage changes and long term flicker indicator (P_{lt}). The long term flicker indicator is defined in standard [4] as mathematical equation:

$$P_{lt} = \sqrt[3]{\frac{\sum_{i=1}^N P_{st}^3(i)}{N}}$$

Where N is the number of the measuring P_{st} during the observation interval. To determine P_{st} indicator ten minutes observation interval is required, and 2 hours to determine the P_{lt} (i.e. N=12 measurements of P_{st}).

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