

## A SIMPLE METHOD OF THD FACTOR MEASUREMENT

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*Abstract: The paper deals with a method of THD factor measurement with using watch filtration of the fundamental frequency. The proposed application enables to identify main frequency changes of evaluated signal what improves the effectiveness of filtration. Results of the simulation studies and laboratory experiments proved usefulness of suggested solutions for measurement of THD factor. It let design a prototype of measuring device based on the proposed method.*

*Keywords: THD factor, PLL, watch filtration*

### 1 INTRODUCTION

One of basic factors determining quality of electric energy is THD factor (Total Harmonic Distortion) defined in [1], which evaluates voltage distortion from sinusoid course. The proposed method of THD measurement is based on the application of filtration by which fundamental frequency and distortion (interpreted as higher harmonics) are extracted from the evaluated signal. Then, the value of THD factor is calculated as the ratio of RMS value of signal distortion  $U_D$  to RMS value of fundamental frequency  $U_1$  what leads to the following modification of definition:

$$THD = \frac{\sqrt{\sum_{h=2}^{40} U_h^2}}{U_1} \Rightarrow THD = \frac{U_D}{U_1} \quad (1)$$

where:

$U_h$  - amplitude or RMS value for  $h^{\text{th}}$  harmonic,

$U_1$  - amplitude or RMS value for fundamental frequency,

$U_D$  - RMS value of the distortion determined in frequency domain (eq.2) or time domain (eq.3):

$$U_D = \sqrt{\sum_{h=2}^{\infty} U_h^2}, \quad U_D = \sqrt{\frac{1}{T} \int_0^T u_D^2(t) dt} \quad (2,3)$$

$u_D(t)$  - time course of the signal after fundamental frequency was extracted.

Most of the methods used for THD measurement both in frequency and time domain require the complicated realization procedures and rather expensive equipment. The proposed method, based on the watch filtration (described in [2]), seems to be simpler and cheaper solution of THD factor measurement. Moreover, depend on local conditions of energy network, the fundamental frequency can be different from normative value 50 Hz and can change within a limited range (according to [1] permissible range of changes: -6÷+4%). To assure appropriate efficiency of filtration, it seems to be necessary to use actual identification of fundamental frequency of evaluated signal.

It was suggested the method of THD factor measurement with using watch filtration of fundamental harmonic of the signal.

### 2 DESCRIPTION OF METHOD AND HARDWARE FOR THD FACTOR MEASUREMENT

Watch filtration is based on monitoring and identifying and then filtering out of the fundamental frequency of input signal. This is realised by phase-locked loop PLL which makes possible to generate clock signal  $f_{\text{clock}}$  for switched-capacitor (SC) filter which, in turn, depends on the input signal:  $f_{\text{clock}} = 100 \cdot f_1$  ( $f_1$  - fundamental frequency). In this way, stop-band (or pass-band) is tuned up. Thanks to it, when appropriate damping is applied, output signal from filtering system contains higher harmonic frequencies interpreted as deformation of the main signal  $u_D(t)$ . In similar way but with using pass-band filtration the first harmonic (fundamental frequency) signal  $u_1(t)$  is obtained.

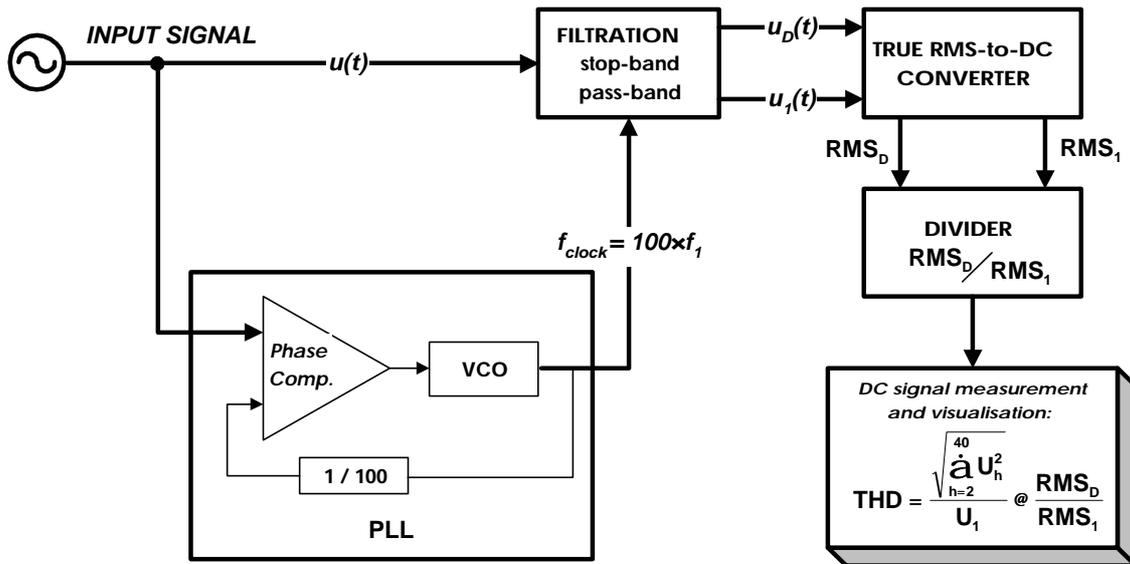


Figure 1. Block scheme of the proposed instrument.

Figure 1 presents the block diagram of a prototype instrument for THD factor measurement in which:

- Filtration block - based on notch, elliptic SC filter with the centre frequency set by external clock signal which depends on main signal frequency, used for:
  - rejection of the fundamental frequency in the main signal - distortion signal  $u_D(t)$  obtained from stop-band filtration,
  - evaluation of the fundamental frequency - first (fundamental) harmonic signal  $u_1(t)$  obtained from pass-band filtration
- PLL - phase-locked loop which enables to watch and capture main frequency of input signal, used for controlling of the centre frequency in SC filter
- True RMS-to-DC converter - used for evaluation of the root-mean-square value of distortion ( $RMS_D$ ) and first harmonic ( $RMS_1$ ) as DC signals
- Divider block - hardware evaluation of the quotient  $RMS_D / RMS_1$
- Measurement and visualisation block - measurement of DC signal proportional to instantaneous value of THD factor and visualisation of the obtained results

### 3 SIMULATION STUDY

In simulation study on the model system with the watch filtration, particular attention was paid to verification of usefulness of suggested solutions for measurement of THD factor. One of key parameters which influences work of the system is the attenuation at  $f_1$  of SC filter, which is devised to eliminate fundamental frequency from the signal. For simulation purposes a special model of the notch filter with tuning of the centre frequency was drawn up, presented in [4].

In simulation experiments, effectiveness of notch filtration was tested for the 4<sup>th</sup> order elliptic filter with following parameters:

- ⇒ stop-band attenuation:  $R_S \geq 40$  dB,
- ⇒ pass-band ripple:  $R_P \leq 0.25$  dB,
- ⇒ bandwidth:  $\Delta f_s = \{0.127 \cdot f_s, 0.26 \cdot f_s, 0.38 \cdot f_s\}$ .

Above parameters correspond with characteristics of typical low cost, easy accessible elliptic SC filters (for example LMF family).

The basic way for the verification was a test by monoharmonic sinusoidal signal with frequency 50 Hz and amplitude 2 V. For the clock frequency  $f_{clk} = \text{const}$  attenuation of the filter exceeds 40 dB. In the case of watch filtration an effective damping of the stop-band filter depends on stability of clock frequency  $f_{clk}$  given by PLL unit. Figure 2 presents the spectrum of output signal (after filtration) in which is seen blurring of the spectral line for 50 Hz what resembles a modulation effect. This results from instability of the clock signal frequency  $f_{clk}$  and then ambiguous determination of the centre frequency for SC filter.

\* between the cut off frequencies, where  $f_s$  is the centre frequency of the filter

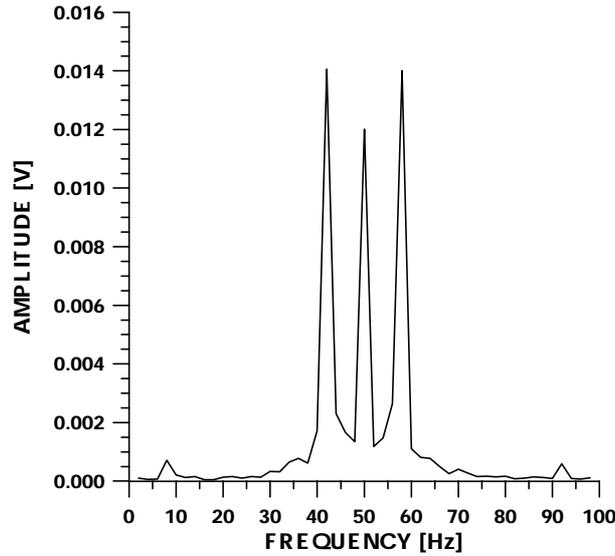


Figure 2. Spectrum after filtration of monoharmonic signal (50 Hz and amplitude 2 V).

This is caused by activity of PLL system, which oscillates all the time around frequency  $f_1$ , identified for the input signal. Level of these oscillations depends on the time constant  $T_{RC}$  of the loop filter found at the VCO input, what was illustrated in Table 1.

Table 1. Results of simulation study.

BANDWIDT H $Df_z$	ATTENUATION $R_s$ [dB]					
	$f_{clk} = \text{const}$	$T_{RC} = 1[\text{ms}]$	$T_{RC} = 5[\text{ms}]$	$T_{RC} = 10[\text{ms}]$	$T_{RC} = 20[\text{ms}]$	$T_{RC} = 50[\text{ms}]$
$0.127 \cdot f_z$	42.1	32.4	34.8	37.4	32.3	31.7
$0.26 \cdot f_z$	48.7	33.3	35.1	<b>39.4</b>	34.4	31.9
$0.38 \cdot f_z$	41.3	34.6	34.2	38.9	33.6	32.9

On the basis of presented results a condition of optimal damping in the watch filtration was formulated as follows:

$$T_{RC} \approx 0.5 \cdot T \tag{4}$$

where:  $T$  - period of the input signal.

Besides, simulation study led to the conclusion that with given parameters of the loop, the filters of too narrow stop-band should not be used. Of course, using filters with large bandwidth ( $\Delta f_s = 0.38 \cdot f_s$ ) lets increase oscillations of clock frequency ( $T_{RC}$  less than in eq.4, what causes better dynamics of the loop) but it affects the selectivity of filtration, especially unfavourably in the pass-band filter.

According to above remarks a hardware prototype of measuring device was designed with two elliptic SC filters (stop-band and pass-band) of bandwidth  $\Delta f_s = 0.26 \cdot f_s$ , tuned from the PLL circuit of time constant  $T_{RC} = 10$  ms.

#### 4 VERIFICATION OF MEASUREMENT FEATURES

A lot of experiments were done, among others by using triangular and rectangular test signals of frequency 50 Hz and amplitude 2 V. Effectiveness of the filtration was proved by frequency spectra for output signals, presented in Figure 3. There were also marked in this figure theoretical values of amplitudes of particular harmonics, which result from distribution of triangular and rectangular signals into Fourier series. In the spectra of both signals after filtration, it was also seen effect of blurring in the vicinity of fundamental harmonic  $f_1 = 50$  Hz, analogous to that in Figure 2. Measured value of THD factor for the triangular course was 12.3 % (error at level 1.2%\*) and for rectangular: 48.3 % (error at level 2.7%\*).

\* percent of theoretical value (calculation limited to the 40<sup>th</sup> harmonic)

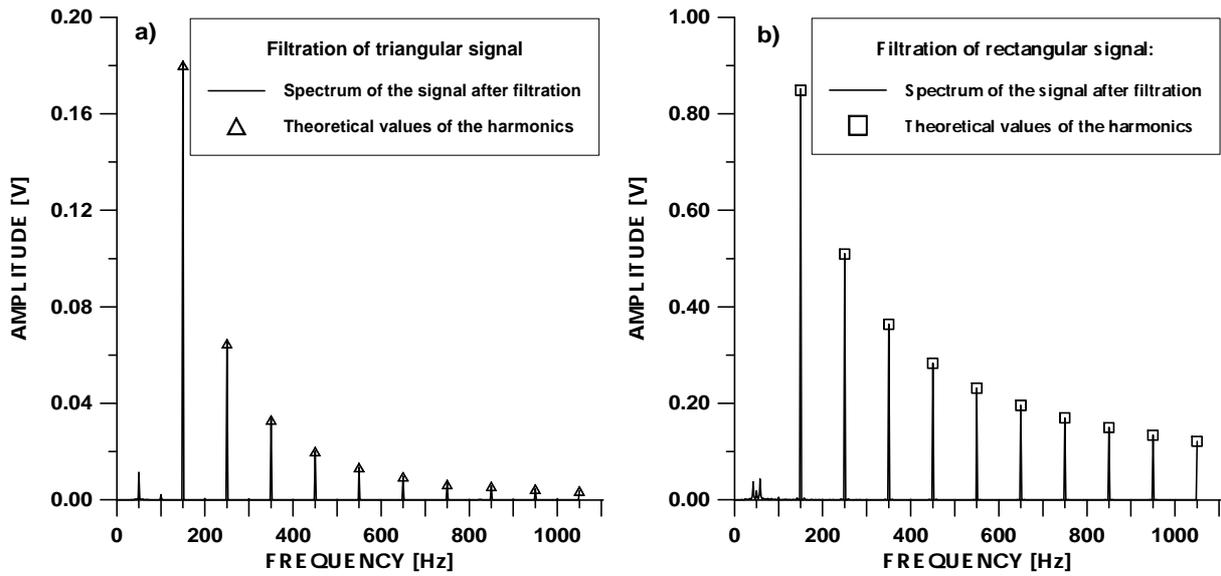
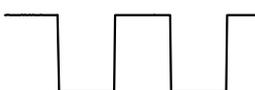


Figure 3. Spectrum and theoretical values for signal after filtration: a) triangular, b) rectangular.

Results from the prototype device were compared with measurements obtained from HA-2000 (Harmonalyzer™ by Amprobe Instrument®) for several signals, shown in Table 2. Accuracy of HA-2000 is declared as  $\pm 1\%$  of reading + 3 LSD for fundamental frequency  $60 \pm 0.1$  Hz [5]. Testing signals 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> have been taken as voltage transients from the standard lamp dimmer (incandescent bulb: 60 W/230V).

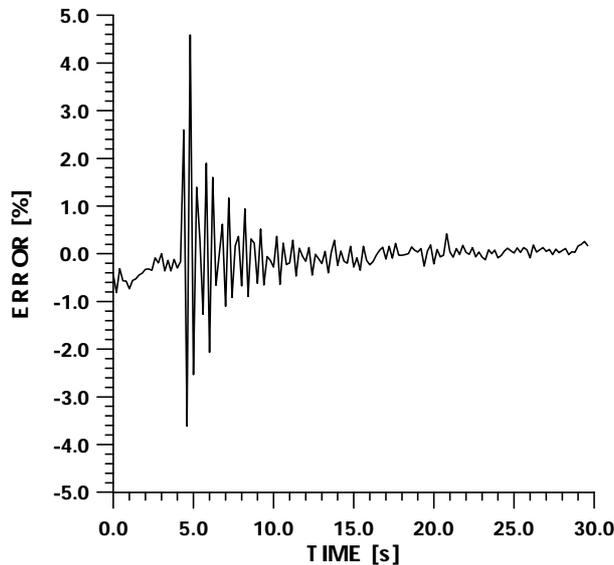
Table 2. Results of laboratory experiments (fundamental frequency: 50 Hz).

SIGNAL	THD <sub>1</sub> [%] (HA-2000)	THD <sub>2</sub> [%] (PROTOTYPE DEVICE)	ERROR [%] $\frac{THD_2 - THD_1}{THD_1} \cdot 100$
1 	12.40	12.28	-0.98
2 	46.10	48.38	4.95
3 	7.90	7.63	-3.36
4 	26.20	26.67	1.81
5 	51.40	47.93	-6.31

Difference between indications of both instruments is larger for signals with the high THD value (i.e. the 2<sup>nd</sup> and the 5<sup>th</sup> transient). It leads to the conclusion that prototype instrument operates worse in case of signals with high content of harmonics.

From the other side, accuracy of HA-2000 is declared for 60 Hz power systems and all tests were performed for signals of 50 Hz main frequency. For example theoretical value of THD for rectangular course is 47.03 % (limited to 39<sup>th</sup> harmonic) what gives an error at -1.98 %.

Figure 4 presents the time course of THD error during rapid change-over of the main frequency value from 50 Hz to 45 Hz for triangular signal. This kind of test led to verify effectiveness of the watch filtration: all error values are lower than  $\pm 5\%$  (demanded in [3]), even while the main frequency is switched-over. The maximum range of main frequency changes was also tested. It amounts from 30 Hz to 80 Hz.



**Figure 4.** Time course of THD error during rapid change-over of the main frequency value (from 50 Hz to 45 Hz) for triangular signal.

## 5 CONCLUSIONS

First results proved the proposed method to be right and correct for nonsinusoidal, periodical signals. All the tests confirmed that watch filtration applied in the prototype device enables to measure THD factor of input signals with error lower than maximum value determined in standard [3], i.e. 5% of measured value. Presented solutions let design a cheap, easy-to-use, precise enough device for THD factor measurement. However, it is also under consideration applying the conception of watch filtration into DSP systems to improve the resolution of A/D converters, synchronised by PLL. It will be possible to make final conclusions when thorough analyses have been made. Research on improvements of the prototype device is still in progress.

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