UDC 519.65
DOI: 10.32626/2308-5916.2025-28.22-27

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FEATURES OF CALCULATING THE SIGNAL'S DISTORTION IN AN ELECTRONIC SYSTEM

The preence of interfering loads in low, medium, and high voltage networks leads to an increase in harmonic distortion and asymmetry of transmission levels. Economic reasons make it difficult to install harmonic measurement devices throughout the entire system. Instead, harmonic measurement equipment could be installed in selected sections of the network, covering only a fraction of the blocks. These devices can then be used to estimate harmonic current injection. This article presents a method to determine the optimal parameters for installing harmonic voltage measurement devices. A key characteristic of programs for calculating the harmonic coefficient is the sensitivity threshold, which is primarily determined by rounding errors. A numerical experiment was conducted to analyze the dependence of the harmonic distortion coefficient on the parameters of the computational process. Based on the ADC configuration, the device's limitations for experimentally determining the harmonic distortion coefficient are simulated. The error that occurs due to rounding when determining the harmonic coefficient of a function is also investigated. For a given number of digits ADC, the value of the sensitivity threshold for the harmonic coefficient significantly exceeds the analytically obtained value of the absolute error.

Key words: *harmonics, harmonics sources, harmonic distortion sources, identification methods.*

Introduction. When calculating the harmonic coefficient, it is necessary to consider factors that affect the reliability of the results. The complexity of the situation can be evaluated by noting that the harmonic coefficient is on the order of tenths or hundredths of a percent. A key characteristic of programs for calculating the harmonic coefficient is the sensitivity threshold, which is primarily determined by rounding errors.

To estimate the sensitivity threshold, it is necessary to determine the spectrum and harmonic coefficient for a «pure» sinusoidal signal. It is known in advance that all higher harmonics and the harmonic coefficient in this case are equal to zero. Authors of the works partially investigated similar problems [1, 2].

1. Estimating the sensitivity threshold of harmonic coefficient calculation programs. It is also advisable to study the harmonic signal, on which a constant component is superimposed. It is clear that, in this case, the harmonic coefficient should also be zero. But due to rounding errors, the harmonic coefficient is nonzero. This value determines the sensitivity threshold. The characteristic of the distortion of a periodic harmonic signal is the harmonic coefficient [3], which is determined by the formula

$$k_{\Gamma} = \sqrt{\sum_{i=2}^{n} y_i^2} \Big/ y_1 . \qquad (1)$$

Here y_i are the spectral components of the harmonic signal.

The value of the sensitivity threshold for the harmonic coefficient is affected not only by rounding errors when using the fast Fourier transform [1, 4], but also by rounding associated with finding the trigonometric functions sin *x*, cos *x* using standard programs.

The main factors influencing the harmonic coefficient are very clearly visible. Using a computational experiment, it is possible to obtain the dependence of the sensitivity threshold of the harmonic coefficient on the number of discrete samples *N* per period (Fig. 1) for single and double-precision calculations.

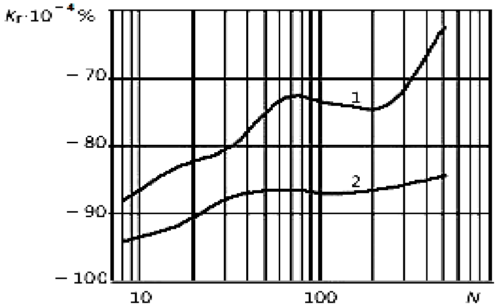

Fig. 1. *Dependence of the sensitivity threshold of the harmonic coefficient on the number of samples per period, (1 – single precision calculation; 2 – double precision calculation)*

The harmonic coefficient reaches the value $(0{,}4\div8)\cdot10^{-4}$ %. in the case of single precision research. Switching to double precision reduces this value to $(2\div6)\cdot10^{-5}$ %. In this case, lower harmonic distortion values are achieved with a smaller number of discrete points per period. The exact value of the harmonic coefficient is zero in all cases.

The value of the harmonic coefficient changes almost twenty times for single precision with an increase in the number of discrete samples per period from 8 to 512. The influence of the number of discrete points on the harmonic coefficient value is much smaller in the case of double calculation accuracy. It changes almost threefold.

Raising the sample size N increases the sensitivity threshold. This nature of the change in dependence is quite natural and can be explained.

According to the Nyquist theorem [5], the obtained value of the harmonic coefficient for a «pure» sinusoid is reliable with a minimum number of samples, which is equal to two. In fact, the sinusoidal signal samples formation occurs through level quantization. The consequence of using the discrete Fourier transform to process such a signal is the appearance of higher-order harmonic components in its spectrum, which is confirmed by the increase in the sensitivity threshold with an increase in the number of discrete samples.

The dependence obtained in the process of the computational experiment can be represented by the following empirical formula (2)

$$\Delta k_{\Gamma} = 2\frac{N}{\log_2 N}\delta^*. \quad (2)$$

Where δ^* is the relative unit rounding error, Δk_{Γ} is the error in calculating the harmonic coefficient.

2. Dependence of the harmonic coefficient sensitivity threshold on the ratio of the amplitude to the constant component. The error that arises due to rounding when determining the harmonic coefficient for the function is also investigated.

$$y(x) = a + b\sin x \quad (3)$$

where b is the amplitude value.

The calculation results show that with an increase in the constant component a, the conditions for calculating the harmonic coefficient deteriorate. This is caused by the increase in rounding error. The patterns of error changes affecting the value of the harmonic coefficient for different values of b / a are shown in Fig. 2.

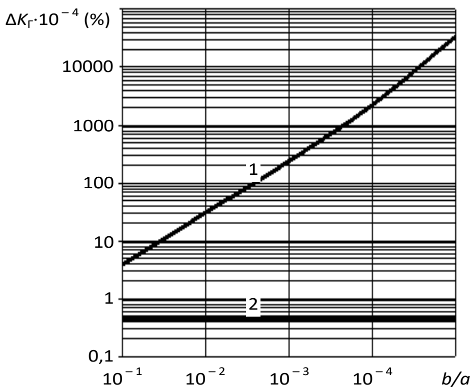

Fig. 2. *Dependence of the sensitivity threshold on the harmonic coefficient on the ratio of the amplitude to the constant component (1 – single precision calculation; 2 – double precision calculation)*

The study of the discrete Fourier transform for different ratios between the variable and constant components of the signal allows for assessing how the number of bits in binary numbers used by the computing system affects the sensitivity threshold during the estimation of the harmonic coefficient.

Really, let $b/a = 1/2^S$. Then it can be stated that only $l - s$ bits participate in the representation of the variable component, where l is the maximum number of binary digits.

Let the harmonic coefficient be determined by formula (1), and the unit relative error of discretization for a given number of binary digits is

$$\delta_1 = 1/2^l \; . \tag{4}$$

The ratio (5) gives the relative error

$$\delta_{k_\Gamma} = \frac{\Delta k_\Gamma}{k_\Gamma} . \tag{5}$$

We can write for minor changes Δy_i in the spectral components from the actual values y_i

$$\Delta k_\Gamma = \sum_{i=1}^{n} \frac{\partial k_\Gamma}{\partial y_i} \Delta y_i \; . \tag{6}$$

It is obvious that for $i = \overline{2,n}$

$$\frac{\partial k_\Gamma}{\partial y_i} \Delta y_i = \frac{1}{k_\Gamma} \left(\frac{y_i}{y_1} \right)^2 \delta y_i \; . \tag{7}$$

If $i = 1$, then

$$\frac{\partial k_\Gamma}{\partial y_1} \Delta y_1 = -k_\Gamma \delta y_1 \; . \tag{8}$$

Where $\delta y_i = \Delta y_i / y_i$, $i = \overline{1,n}$.

Then, to find the relative error, we have

$$\delta_{k_\Gamma} = \frac{\sum_{i=2}^{n} y_i^2 \delta y_i}{\sum_{i=2}^{n} y_i^2} - \delta y_i \; . \tag{9}$$

Let $\delta y_i = 1/2^l$, $i = \overline{1,n}$. Then, the absolute error in calculating the harmonic coefficient, which arises due to inaccuracy in determining the values $\delta = \left| \delta_{k_\Gamma} \right|$ of the spectral components, is determined from the relation

$$\delta = \frac{2}{2^l}. \tag{10}$$

For a given number of discharges, the value of the sensitivity threshold for the harmonic coefficient significantly exceeds the analytically obtained value of the absolute error.

This is explained by the fact that in the process of processing a level-quantized signal using the discrete Fourier transform, higher-order harmonic components appear in the spectrum. In addition, when calculating the harmonic coefficient using the fast Fourier transform, an error accumulates.

Conclusion. The numerical experiment was conducted to study the dependence of the harmonic coefficient on the parameters of the computational process. The dependences of the harmonic coefficient on the number of discrete samples per period and the ratio of variable to constant components of the harmonic signal were obtained.

An evaluation was performed to determine how the calculation error relates to the sensitivity threshold for the harmonic coefficient.

Analytical studies and numerical experiments show that the detectable minimum harmonic coefficient reaches 10-3%. Additionally, the device's maximum capacity for experimentally measuring the harmonic coefficient using an ADC was simulated.

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ОСОБЛИВОСТІ РОЗРАХУНКУ СПОТВОРЕННЯ СИГНАЛУ В ЕЛЕКТРОННІЙ СИСТЕМІ

Наявність заважаючих навантажень у мережах низької, середньої та високої напруги призводить до збільшення гармонійних спотворень та асиметрії рівнів передачі. Економічні причини ускладнюють встановлення приладів вимірювання гармонік по всій системі. Натомість, обладнання для вимірювання гармонік можна встановити на окремих ділянках мережі, охоплюючи лише частину блоків. Ці пристрої потім можна використовувати для оцінки інжекції струму гармонік. У цій статті представлено метод визначення оптимальних параметрів для встановлення приладів вимірювання гармонійної напруги. Ключовою характеристикою програм для розрахунку гармонічного коефіцієнта є поріг чутливості, який в першу чергу визначається помилками округлення. Було проведено числовий експеримент для аналізу залежності коефіцієнта гармонійних спотворень від параметрів обчислювального процесу. На основі конфігурації АЦП моделюються обмеження пристрою для експериментального визначення коефіцієнта гармонійних спотворень. Також досліджується похибка, що виникає через округлення під час визначення гармонічного коефіцієнта функції. Для заданої кількості розрядів АЦП значення порогу чутливості для коефіцієнта гармоніки значно перевищує аналітично отримане значення абсолютної похибки.

Ключові слова: *гармоніки, джерела гармонік, джерела гармонічних спотворень, методи ідентифікації.*

Отримано: 29.11.2025