Investigation of the Effect of Harmonic Interference on the Error with Frequency Conversion of Energy Supply Systems on Water Transport Vehicles

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Abstract

The study substantiates the current scientific and technical problem of developing precision methods for measuring the parameters of electrical signals (usually harmonic voltages), which will allow to create a fairly simple control equipment with desired characteristics. The method of measuring the frequency (period) of a sinusoidal signal based on the conversion of voltage into the frequency of pulses is investigated. This method has pronounced filtering properties with respect to interference. In particular, if the interference is harmonic with a frequency multiple of the frequency of the measured signal, the error caused by interference is virtually absent.

Keywords

Error, electrical signal, power supply system, method, obstacle.

1. Introduction

Increasing the requirements for electricity quality indicators of energy supply systems of water transport vehicles requires improvement of methods and means of their control [1, 2]. However, the further development of such measuring instruments is largely constrained by the level of their technical characteristics (errors in measuring electricity quality indicators) at low cost. Today it is not economically necessary to use high-precision control equipment on water vehicles, which is constantly in harsh operating conditions [3, 4]. Therefore, a very important scientific and technical task is to develop precise methods for measuring the parameters of electrical signals (usually harmonic voltages), which will create a fairly simple and at the same time with the desired characteristics of the control equipment.

In this regard, there is an urgent scientific and technical problem in the field of monitoring the technical condition of energy supply systems of water transport: improving methods of synthesis of equipment for monitoring the technical condition of energy supply systems of water transport by reducing their errors in measuring the characteristics of electrical signals.

2. Investigation of the Effect of Harmonic Interference on the Error with Frequency Conversion

2.1. Literature Analysis

A significant number of publications are devoted to the problem of monitoring the technical condition of power supply systems of various technical systems [5–19].

Thus, the article [5] considers the method of monitoring the technical condition of electronic circuits that are part of power supply systems. In [6–9] the results of research of methods of synthesis

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CPITS-II-2021: Cybersecurity Providing in Information and Telecommunication Systems, October 26, 2021, Kyiv, Ukraine
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of the equipment of control of a technical condition of radio electronic systems of water transport vehicles are presented. However, in such works the estimation of errors of measurement of parameters of the electronic equipment at control of a technical condition is not resulted.

In the publications [10–14] the questions of functioning of modern electric and electronic systems are considered, the factors which essentially influence definition of their technical condition are allocated.

In [15–19] the results of efficiency of technical condition control of a power supply systems at operation of water transport vehicles and in the field of development of the digital control equipment are presented. However, in such works there are no results of research of influence of features of operation of the control equipment in the aggressive environment (sea and river environment) on an error of measurement of electric signals characteristics at control of a technical condition.

Thus, the most critical for the synthesis of equipment for monitoring the technical condition of energy supply systems of water transport are: the lack of results of estimation errors in measuring the characteristics of electrical signals; lack of results of evaluation of the influence of interference on the measurement error of the characteristics of electrical signals; lack of a reasonable universal method for measuring the characteristics of electrical signals with minimal errors under interference.

The results of the analysis of modern literature show the lack of universal methods for the synthesis of equipment for monitoring the technical condition of energy supply systems of water transport to ensure minimal errors in measuring the characteristics of electrical signals. Therefore, the topic of the article, aimed at studying the errors in measuring the characteristics of the electrical signal of the power supply systems of water transport vehicles, is relevant.

2.2. The Effect of Harmonic Interference on the Error with Frequency Conversion

The error with frequency conversion in the presence of a harmonic interference is determined by two factors: the sampling of the input voltage u_{inp} at its transformation into frequency and the errors caused by integration of frequency of pulses by the counter. Lets consider first the error due to sampling u_{inp} in the presence of a harmonic obstacle [4].

In the presence of a harmonic interference, the input voltage can be recorded as

$$u_{inp}(t) = U_x + U_p \sin(\omega_p t + \phi_p). \tag{1}$$

As a result of the integration of this signal over a period of time from t_{k-1} to t_k average value

$$\overline{U} = \frac{1}{t_k - t_{k-1}} \int_{t_{k-1}}^{t_k} \left[U_x + U_p \sin(\omega_p t + \phi_p)\right] dt = U_x + U_p \sin\left(\omega_p \frac{t_k + t_{k-1}}{2} + \phi_p\right) \frac{\sin\left(\omega_p \frac{t_k - t_{k-1}}{2}\right)}{\omega_p \frac{t_k - t_{k-1}}{2}}. \tag{2}$$

The second addition in this expression is equal to the average value of the harmonic interference in the interval from t_{k-1} to t_k. For a voltage to frequency converter with pulse feedback, this time interval is determined from the condition

$$\int_{t_{k-1}}^{t_k} \left[U_x + U_p \sin(\omega_p t + \phi_p)\right] dt = q, \tag{3}$$

where q is unit of quantization of the integral value (threshold of operation of the comparison device).

Performing the integration of expression (3), we obtain

$$\overline{f} = \frac{1}{t_k - t_{k-1}} = \frac{U_X}{q} + \frac{U_p}{q} \sin\left(\omega_p \frac{t_k + t_{k-1}}{2} + \phi_p\right) \frac{\sin\left(\omega_p \frac{t_k - t_{k-1}}{2}\right)}{\omega_p \frac{t_k - t_{k-1}}{2}}.$$

The right part of this expression, which determines the output frequency of the converter, can be represented as the sum of two applications: frequencies f_X, which depends on the value of the measured DC voltage U_X and some increase Δ_f, proportional to the average value of the periodic component in the range from t_k to t_{k-1}:

$$\bar{f} = f_X + \Delta f = f_X + f_m \, sin\left(\omega_p \frac{t_k + t_{k-1}}{2} + \phi_p\right) \frac{sin\left(\omega_p \frac{t_k - t_{k-1}}{2}\right)}{\omega_p \frac{t_k - t_{k-1}}{2}},$$

where $f_m = \frac{U_p}{q}$ is the frequency of the output pulses of the converter, which corresponds to the amplitude U_p of harmonic obstacle [13, 15, 17].

If the quantization unit is small enough (ie the conversion frequency is relatively high), then

$$\lim_{t_k - t_{k-1} \to 0} \frac{sin\left(\omega_p \frac{t_k - t_{k-1}}{2}\right)}{\omega_p \frac{t_k - t_{k-1}}{2}} = 1,$$

and the instantaneous frequency at the output of the converter can be recorded as

$$f\left(t_k\right) = f_X + f_m \, sin\left(\omega_p t_k + \phi_p\right). \tag{4}$$

From the comparison of expressions (2) and (4) it follows that with a small and constant quantization unit, a linear conversion of the measured voltage into a proportional value of the frequency of the output pulses is carried out.

Changing the frequency of the output pulses in the presence of a harmonic interference at the input of the converter means that in the output pulse sequence there is a temporary shift of pulses relative to the clock points due to the constant component of the input signal U_X, that is, there is a modulation of the pulse sequence [4, 12].

The difference between the average frequency $\bar{f}$ at interval $\left[t_k;\ t_{k-1}\right]$ and the instantaneous frequency value $f\left(t_k\right)$ represents the signal conversion error $u_{inp}\left(t\right)$ in signal $f\left(t\right)$:

$$\Delta_p = f\left(t_k\right) - \bar{f}.$$

The relative error due to the influence of harmonic interference is determined by the expression and is shown in Fig. 1:

$$\delta_p = \frac{\Delta_p}{f_m} = sin\left(\omega_p t_k + \phi_p\right) - sin\left(\omega_p \frac{t_k + t_{k-1}}{2} + \phi_p\right) \frac{sin\left(\omega_p \frac{t_k - t_{k-1}}{2}\right)}{\omega_p \frac{t_k - t_{k-1}}{2}}. \tag{5}$$

An approximate error value can be obtained by decomposing the input signal (2) into a Taylor series near the point t_k and be limited to the first members of the series. In this case, expression (3) is written as

$$\int_{t_k}^{t_k + \mathrm{T}} \left[U_x + u_{pk} + u'_{pk}\left(t - t_k\right)\right] dt = q, \tag{6}$$

where T is the current period of the pulse sequence at the output of the voltage-frequency converter;

u_{pk} and u'_{pk} is the value of the interference voltage and its derivative at the time t_k.

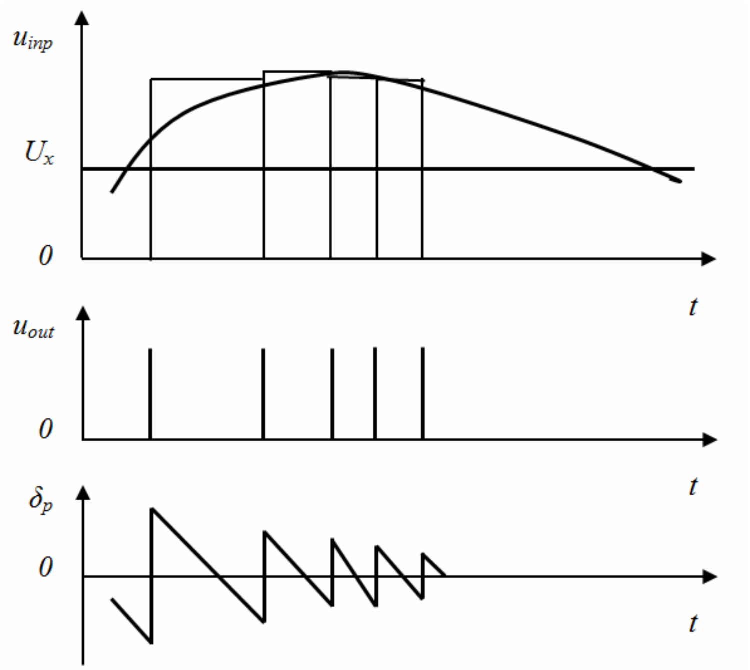

Figure 1: Analyze the effect of harmonic interference with frequency conversion

Performing the integration of expression (6), we obtain

$$\left(U_X + u_{pk}\right)T + \frac{u'_{pk}T^2}{2} = q\,. \tag{7}$$

Solving equation (7) with respect to the period, we find

$$T = \frac{1}{u'_{pk}}\left[-\left(U_X + u_{pk}\right) + T_0\sqrt{\left(U_X + u_{pk}\right)^2 + 2U_X u'_{pk}}\right],$$

where $T_0 = \dfrac{q}{U_x}$ is the period of pulsespassage in the absence of interference.

If the rate of change of the obstacle in the interval T is constant $\left(u'_{pk} = const\right)$, then the conversion error is determined by the expression (Fig. 2):

$$\Delta_p = \frac{u'_{pk}T}{2} = \frac{1}{2}\left[-\left(U_X + u_{pk}\right) + T_0\sqrt{\left(U_X + u_{pk}\right)^2 + 2U_X u'_{pk}}\right].$$

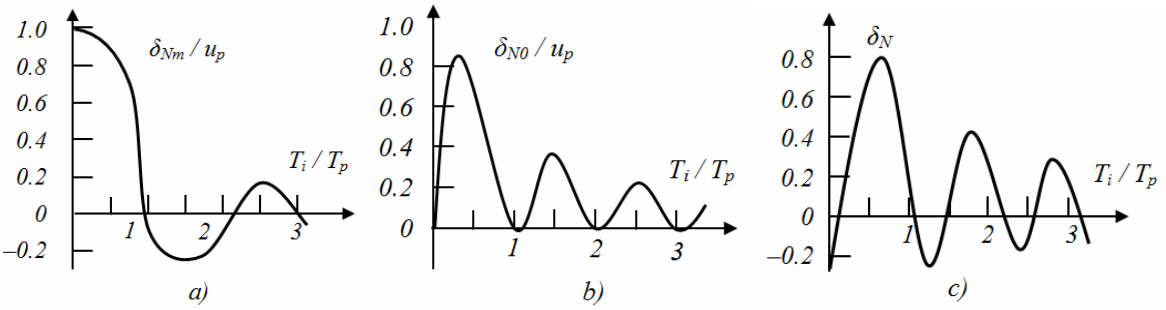

Figure 2: Dependence of the maximum error: (a) at zero initial phase; (b) at an arbitrary phase; (c) from the integration time

The final result of the measurement in the counting method of frequency measurement is the number of pulses N accumulated in the counter during T_i, that is, the result of the transformation can be represented as

$$N=\int_{0}^{T_i} f\left(t\right)dt\ .$$

Using the value (4), we obtain

$$N=N_X+\Delta N\ ,$$

where the first application: $N_X=f_X T_i$ is the desired measurement result, and the second appendix: $\Delta N=\frac{f_m}{\omega_p}\left[cos\,\phi_p-cos\left(\omega_p T_i+\phi_p\right)\right]$, is an absolute measurement error due to the action of interference.

Relative measurement error

$$\delta_N=\frac{\Delta N}{N_X}=\delta_{N_m}\,sin\left(\pi\frac{T_i}{T_p}+\phi_p\right), \qquad (8)$$

where $\delta_{N_m}=\frac{U_p}{U_X}\frac{sin\left(\pi T_i\,/\,T_p\right)}{\pi T_i\,/\,T_p}$ is the maximum value of the relative measurement error.

From expression (8) it follows that the relative measurement error is a periodic function that depends on the initial phase of the interference ϕ_p and the relationship of the interference period to the measurement time [11]. The dependence of the maximum value of the relative error on the measurement time is shown in Fig. 2, a. With the integer ratio of the measurement time to the interference period, the error is zero, regardless of the initial phase of the interference. If the measurement time is not a multiple of the interference period, then the initial phase ϕ_p has a significant effect on the measurement error.

The value of the initial phase of the interference, which corresponds to the maximum relative measurement error, is obtained from the condition $sin\left(\pi\frac{T_i}{T_p}+\phi_p\right)=1$, where of

$$\phi_p=\left(2k-1\right)\frac{\pi}{2}-\pi\frac{T_i}{T_p}\ .$$

If the initial phase of the obstacle $\phi_{p0}=0$, that is, if the start of the measurement is synchronized with the moment of transition of the interference voltage through the zero value, than error

$$\delta_{N_0}=\frac{U_p}{U_X}\frac{sin^2\left(\pi\frac{T_i}{T_p}\right)}{\pi\frac{T_i}{T_p}}\ .$$

The dependence of the measurement error at zero value of the initial phase is shown in Fig. 2, b.

At an arbitrary value of the initial phase of the obstacle ϕ_p relative error δ_N according to expression (8) is drawn to zero twice on the segment $T_i=T_p$. The first zero value of the error corresponds to the zeros of the function δ_{N_m} and takes place at $\left(T_i\,/\,T_p\right)_{01}=k\ \left(where\ k=1,\ 2,\ \ldots\right)$, and the second zero value corresponds to the condition $sin\left(\pi\frac{T_i}{T_p}+\phi_p\right)=0$, where of

$$\left(\frac{T_i}{T_p}\right)_{02}=\frac{\kappa\pi-\phi_p}{\pi}\ .$$

Graph of the dependence of the relative error at the value of the initial phase of the obstacle, not equal 0 or $\pi\,/\,2$, shown in Fig. 2, c.

3. Conclusions

When analyzing the error introduced by interference, when using the method of converting voltage into frequency when measuring electrical parameters, the estimates that characterize the averaging algorithm are fully applied, ie it has pronounced filtering properties with respect to interference. That means that this method is noise-proof.

The method of measuring voltage with intermediate voltage-frequency conversion is presented. The considered method of voltage measurement has the following advantages. It eliminates the dependence of the measurement result on the frequency of the studied signals, which ultimately leads to an expansion of the frequency range and increase accuracy, because the effect of instability of the frequency of the measured signals is eliminated. The measurement result also does not depend on the amplitude of the studied signals. Has a short measurement time, no more than one or two periods of the studied signals.

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