Measuring modules for the research of compensators of reactive power with voltage stabilization in MATLAB

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Abstract. A set of mathematical modules was developed for evaluation the energy performance in the research of electrical systems and complexes in the MatLab. In the electrotechnical library SimPowerSystems of the MatLab software, there are no measuring modules of energy coefficients characterizing the quality of electricity and the energy efficiency of electrical apparatus. Modules are designed to calculate energy coefficients characterizing the quality of electricity (current distortion and voltage distortion) and energy efficiency indicators (power factor and efficiency) are presented.There are described the methods and principles of building the modules. The detailed schemes of modules built on the elements of the Simulink Library are presented, in this connection, these modules are compatible with mathematical models of electrical systems and complexes in the MatLab. Also there are presented the results of the testing of the developed modules and the results of their verification on the schemes that have analytical expressions of energy indicators.

1. Introduction

Improving the quality of electricity and energy saving is one of the priority areas in the field of electrical engineering, consistent with the Energy Strategy of Russia for the period until 2030 and a number of branch programs. Undoubtedly, in the new electrotechnical projects, no special attention is paid to actual research results - improving the quality of current in electrical networks and the quality of voltage in consumers, studying the physical processes of energy exchange, and directing them to increase the coefficients of power and usefulness.

In the research and development of electrotechnical complexes and systems including electromagnetic and electromechanical devices, components of power electronics and microelectronics, a wide-scale method of mathematical modeling using the MatLab software was widely used. In the known works on mathematical modeling [1-3], the blocks of the electrotechnical library of the software MatLab and examples of working with these blocks are considered; in [4,5] examples of simulation of power circuits and control systems of power electronics devices, electric drives, power supply are shown; Individual blocks and modules of the Simulink library in the form of a workshop with illustrations of the simulation results. At the same time, both in the MatLab software itself and in the literature on modeling in this environment, there are not only mathematical blocks of calculators for power indicators of electrical systems, but there are no questions related to the calculation of energy quality and energy efficiency indicators. After reviewing and analyzing publications [6-8], and in the process of conducting an in-house study of the electrotechnical system

[9], there was a need for the development of specialized measuring modules based on the elements of Simulink Library. Therefore, to conduct a study of energy indicators, there is a need to develop specialized measuring modules based on the elements of Simulink Library.

The purpose of the work: the development of measuring modules designed to study the energy performance of electrical systems and complexes in the MatLab environment.

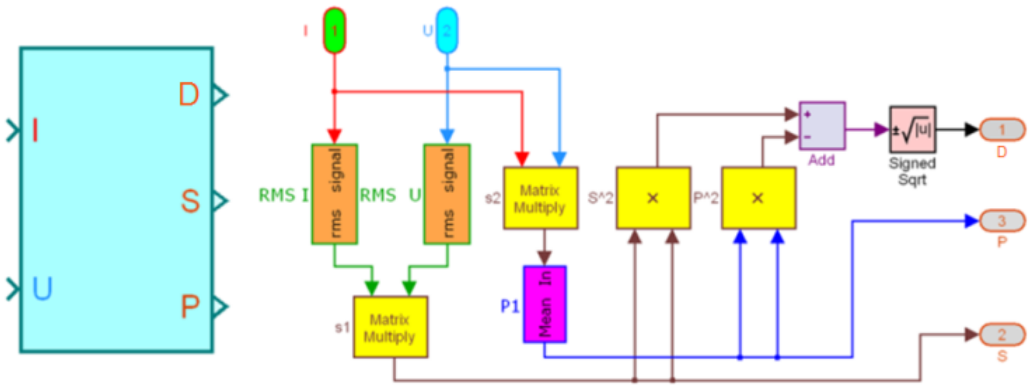
To achieve this goal, the following problems are set and solved in the work.

1. To develop mathematical models of specialized measuring modules and to propose a set of them that allows performing a comprehensive analysis of the energy indicators of electrical devices.

2. To test and test the measuring modules for simple, well-studied electrical circuits that have analytical expressions for energy indicators.

2. Measuring module of active, reactive and full power

The modules for calculation of active and reactive power available in the MatLab Sim Power Systems / measurements perfom calculation only with the first harmonics of current and voltage and are not intended for the researching the electrical devices with non-sinusoidal magnitudes. figure 1, a shows a specialized measuring module SPD, developed to determine the numerical values of the total S (VA), active P (W) and reactive D (var) powers, using for this purpose signals of instantaneous values from voltage and current sensors. The scheme of the calculator SPD is shown in figure 1, b.



a) b)

Figure. 1. The module of active, reactive and full power (a) and its expanded scheme (b)

The root-mean-square (RMS) values of voltage and current, taking into account their harmonic composition, are determined by the formulas:

$$U=\sqrt{\frac{1}{T}\int_0^T u(\theta)^2\,d\theta}\,; \qquad I=\sqrt{\frac{1}{T}\int_0^T i(\theta)^2\,d\theta}\,, \tag{1}$$

where $u(\theta), i(\theta)$ - instantaneous value of voltage and current, $\theta=\omega t$.

In the module (figure 1), the numerical value of the total power is determined according to the expressions (1), taking into account their distortions:

$$S=U\cdot I, \tag{2}$$

where U and I – the RMS values of voltage and current.

To determine the total power S, this method was used, because it allows simple and minimal error calculation of the numerical value for any form of current and voltage. To calculate the RMS values of current and voltage, the RMS block is applied. This block calculates the RMS value of the signal regardless of its form. Further multiplication of U and I values is performed by the Matrix Multiply block from the MatLab library.

The value of the active power P is obtained by calculating the mean (arithmetic mean) value of the total power using the Mean block.

$$P = \frac{1}{T}\int_0^T s(\theta)d\theta = \frac{1}{T}\int_0^T u(\theta)\cdot i(\theta)d\theta. \tag{3}$$

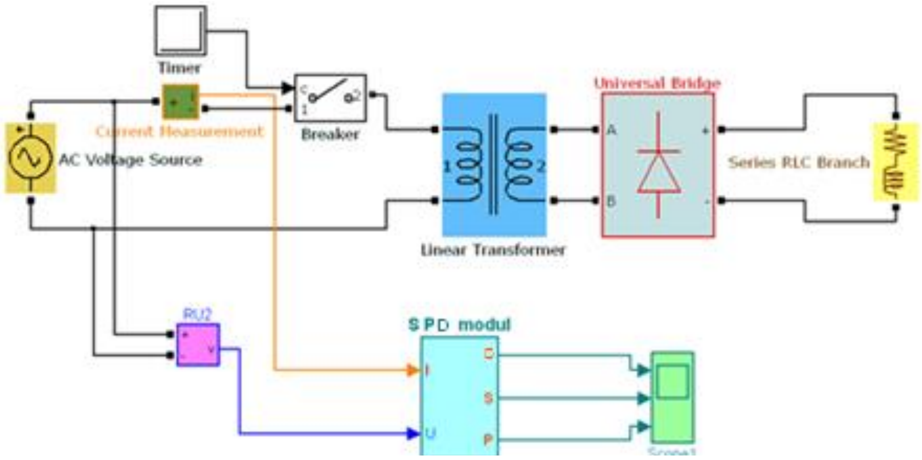
In accordance with [10], the components of the total power S are active P and reactive power D, related by the relation $S^2 = P^2 + D^2$ [10].

The calculation of the reactive power D in the measuring module SPD is realized by the formula

$$D = \sqrt{S^2 - P^2}. \tag{4}$$

The test model for the SPD measuring module in the MatLab is shown in Figure 2, a. It consists of a voltage source AC Voltage Source, to which a diode bridge rectifier with RL load is connected with a transformer. At a time t of 0.1c, the Breaker switch commutes the electrical circuit. The oscillograms of the output signals of the SPD module are shown in Figure. 2, b.

a)



b)

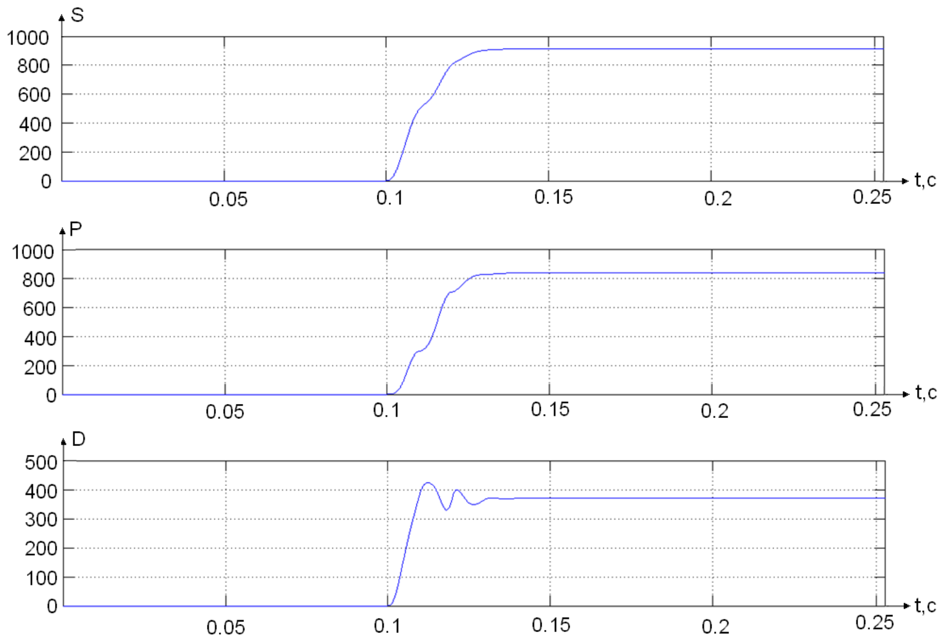
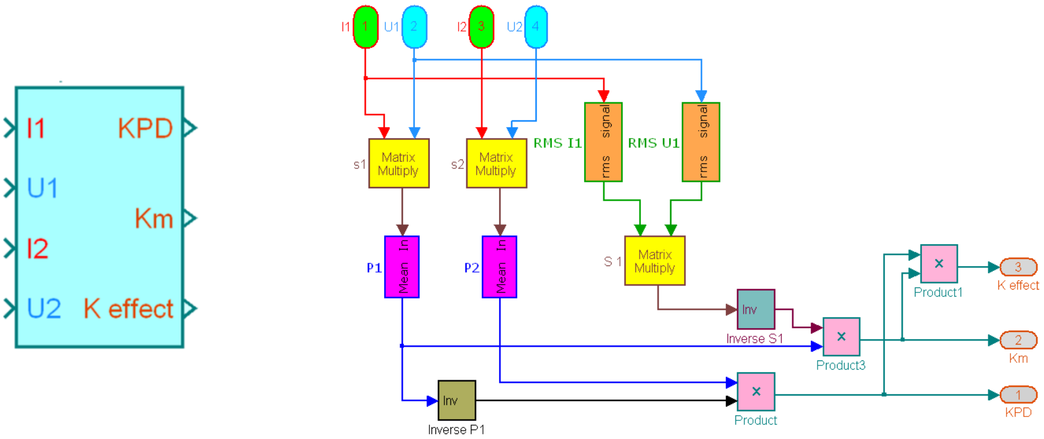


Figure 2. Test model of the measuring module SPD (a) and oscillograms (b) full (top), active (in the middle) and reactive (from below) capacities

3. The module for calculating the energy coefficients through the power

This module is shown in figure 3a. It is designed to calculate the main energy coefficients that characterize the efficiency of electricity consumption and use. These are the power factor Km, the efficiency and their product, called the power efficiency coefficient Ke of the system. The coefficient of power efficiency characterizes the efficiency of both consumption and use of electricity. To calculate the energy coefficients that characterizes the efficiency of electricity consumption and use. For calculation the energy coefficients are taken the instantaneous values are used from the current and voltage sensors at the input (I1 and U1) and at the output (I2 and U2) of the system (apparatus). The inputs of the module can be supplied as alternating voltage and current, or DC. The circuit of the module is shown in figure 3, b.



a) b)

Figure 3. The module for calculating energy coefficients through the power (a) and its expanded scheme (b)

The test model of the measuring module for calculating the energy indicators is shown in Figure 4. It consists of a single-phase voltage source AC Voltage Source, to which a bridge diode rectifier with an RL load is connected with a transformer.

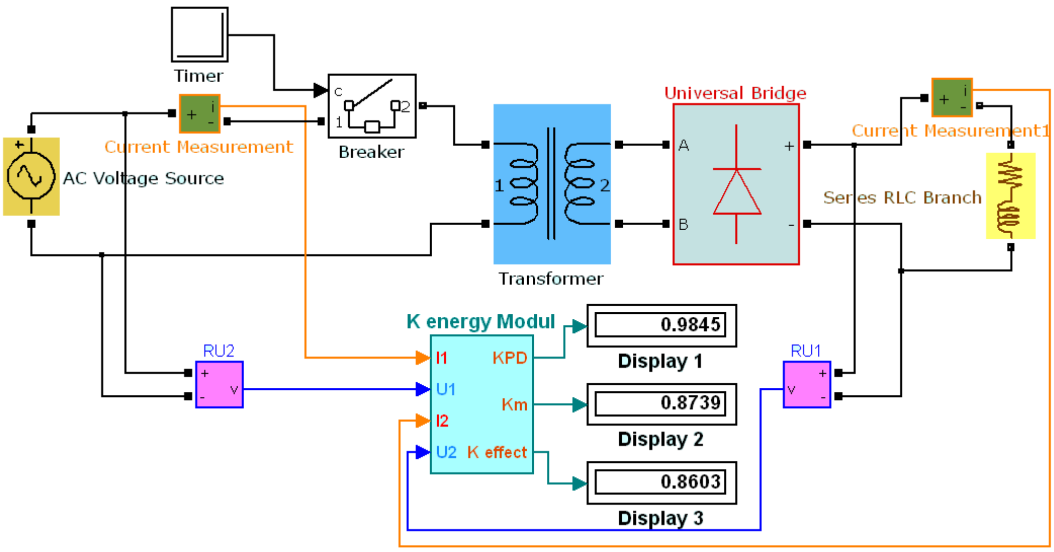


Figure 4. Test model for the energy calculation module

The module (Figure 3a) is well suited for calculating the energy coefficients in certain sections of the power grid. It is based on a method that takes into account all parameters of both input and output currents and voltages. The drawbacks of this module include the presence of four inputs necessary for calculating the efficiency.

The calculation of the efficiency is based on the formula

$$\eta = \frac{P_2}{P_1}. \quad (5)$$

Here P1 and P2 are the values of the active powers at the input and output.

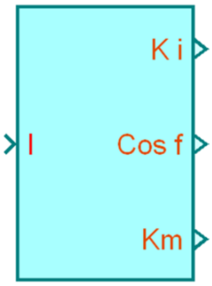
The computation of Km is carried out according to the formula:

$$Km = \frac{P_1}{S_1}. \quad (6)$$

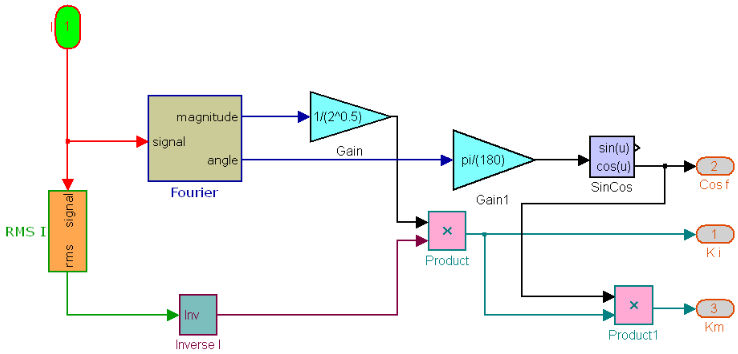
This method of calculating Km takes into account the non-sinusoidal voltage, phase shift and current distortion.

3) Module for calculating the power factor through the coefficients of distortion and phase shift the current

It should be noted that the input power factor of the system can be determined by another method through the form and phase of the current. This method is implemented in the module shown in figure 5, a. The expanded scheme of the measuring module composed of the MatLab Library Browser elements is shown in Figure 5, b. The main element here is the unit that performs the Fourier transformation and detects the necessary harmonic current, its amplitude and phase (Fourier). This unit in this scheme calculates the amplitude and phase of the first harmonic of the current.



a)



b)

Figure 5. The module for calculating the energy coefficients through points (a) and its expanded scheme (b)

The module (figure 5a) has only one input for the signal of the instantaneous value of the investigated current. This principle of block construction is convenient in the absence of nonsinusoidal supply voltage or neglecting the distortion of the shape of the voltage in view of their smallness, which is typical for high power sources.

The determination of the power factor by this method (via a current signal without monitoring the voltage signal) was made possible by the fact that the calculation in the MatLab starts from zero of the source voltage (in the three-phase circuit - from zero phase A voltage). This method has limitations with the non-sinusoidal form of the supply voltage.

The coefficient of current distortion is determined by formula (7) as the ratio of the effective value of the first harmonic of the current detected by the Fourier module to the effective value of the total current:

$$\nu = Ki = \frac{I_{(1)}}{I}. \quad (7)$$

This coefficient characterizes the percentage composition of the first current harmonic relatively to all harmonics of the current and tends to 1 as the harmonic composition improves.

The phase shift of current is calculated with the SinCos unit from the Angle signal of the Fourier module. And, finally, the power factor is determined by the formula

$$Km = \nu \cdot \cos\varphi, \tag{8}$$

from which it is possible to identify the reasons for the decrease of Km and direct measures or to eliminate distortions, or to compensate for the reactive component of current (reactive power).

This functionality of the calculation Km through the coefficients of distortion and phase shift the current (figure 5) favorably distinguishes it from the calculation Km through the power (figure 3).

4. Checking the accuracy of measuring the power factor in two ways n a bridge diode rectifier circuit operating on RL-load

In this experiment we measured the coefficient Km with two modules, which are shown in figure 3, a and figure 5, a. A model with two measuring modules and experimental results on digital indicators is shown in Figure 6, a, and the oscillograms of the investigated model in figure 6, b.

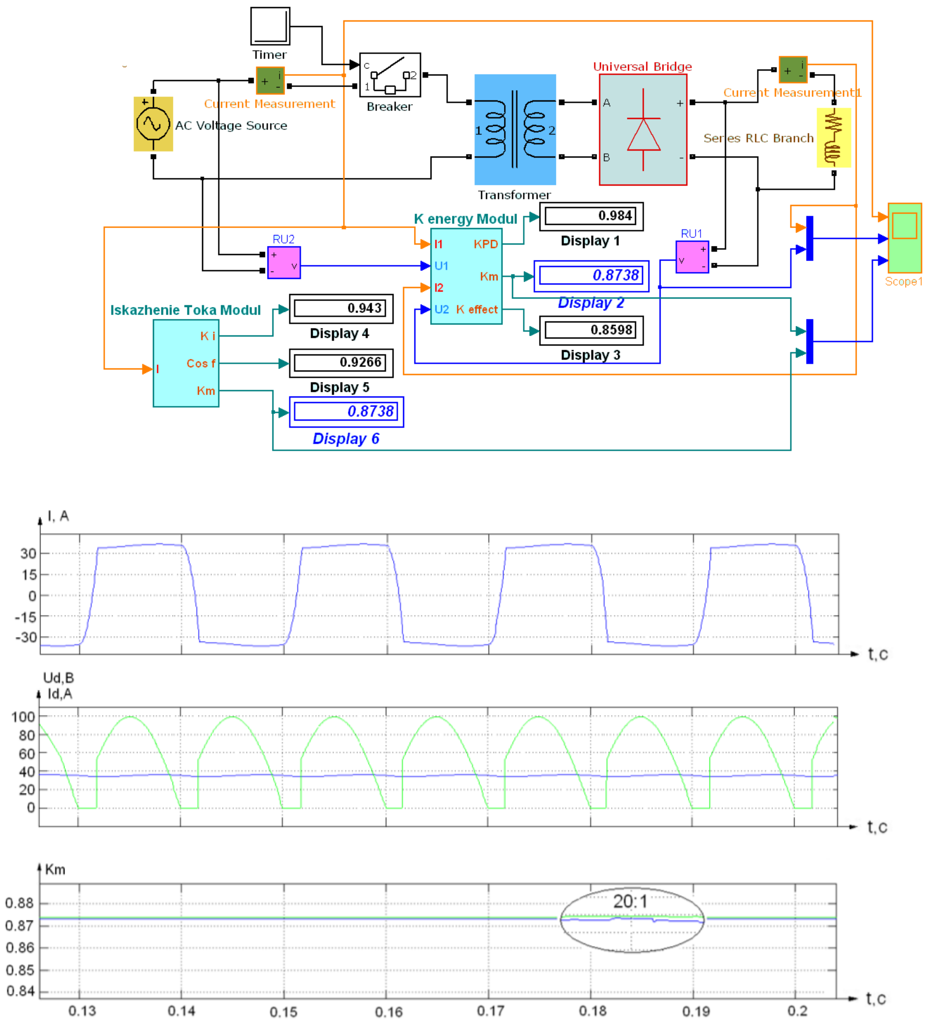


Figure 6. Model for comparative analysis of Km measurement by two modules (a) And oscillograms (b) of the input current (above), direct current and voltage (in the middle) and the overlap of two oscillograms from the outputs of the two power factor calculators (below).

A comparative analysis of the numerical experiment for determining the power factor by two methods using the developed modules is performed in the form of determining the relative error, the graph of which is shown in figure 7.

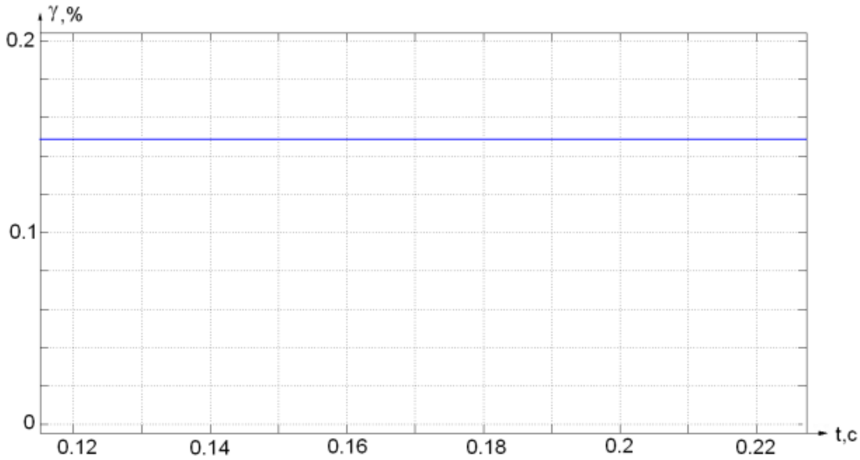


Figure 7. Time dependence of the relative error when comparing the results of measurements of the power factor by two units.

The relative error (figure 7) is only 0.15%, which made it possible to verify the high accuracy of the calculation of the designed modules.

5. The module for calculating the voltage distortion coeffcent

This calculator-evaluator (figure 8, a) is based on a method that, without spectral analysis of the voltage under investigation, allows to determine the sum of all higher harmonics and its percentage relatively to the first harmonic. The sum of the higher harmonics as a percentage of the first is a coefficient of the quality of the voltage, characterizing its non-sinusoidal nature, and is normalized by Russian GOST 13109-97 and international IEEE 519-1992 standards.

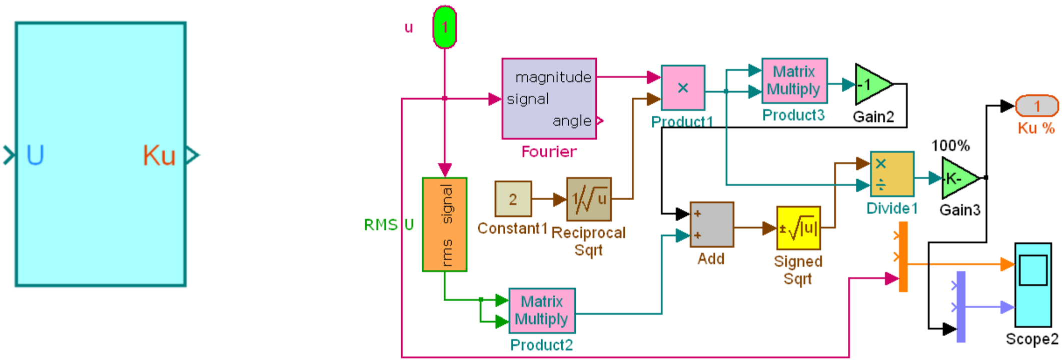
Voltage distortion coefficient

$$Ku = \frac{U_{\Sigma}}{U_1} 100\%, \quad (9)$$

here, $U_{\Sigma} = \sqrt{U^2 - U1^2}$ – is the RMS value of the sum of all higher voltage harmonics, which is determined by U and U1 are the RMS values of the voltage under investigation and its first harmonics.

It can be seen from expression (9) that when the harmonic composition of the voltage is improved, Ku tends to zero.

The expanded block scheme for calculating the voltage non-sinusoidal coefficient is shown in figure 8, b. The structure of its main elements includes the calculator of the RMS value, the calculator of the amplitude of the first harmonic of voltage, the multiplier and divider, the square root calculator. The check of the block in action is carried out in the simplest scheme shown in figure 9, a. In it, three voltage sources with different amplitudes and frequencies are connected seriesely and connected to the load, the voltage under test is illustrated by the oscillogram in figure 9b.



a) b)

figure 8. The module for calculating the voltage non-sinusoidal coefficient (a) and its detailed scheme (b).

a)

b)

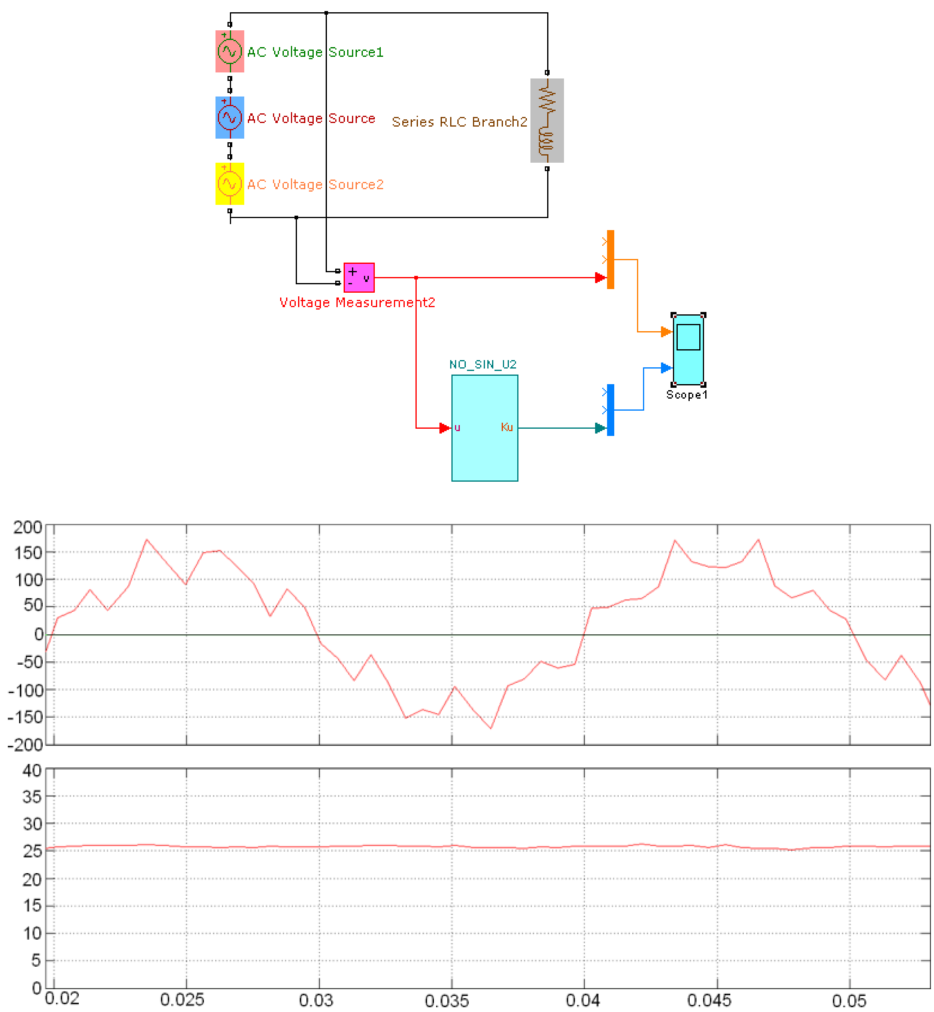


Figure 9. The scheme of the numerical experiment for determining the voltage non-sinusoidal coefficient (a) and the oscillogram (b) of the voltage under investigation (from above) and its non-sinusoidal coefficient (from below)

As a result of the numerical experiment, it is determined that the voltage distortion coefficient of the investigated voltage with a complex asymmetric form (the percentage of higher harmonics in the investigated voltage relatively to the first harmonic) is Ku = 25.2%.

6. Concluson

On vehicles with autonomous power stations, power of which is commensurable with the power of consumers (ships, diesel locomotives, etc.), the use of nonlinear ones, including valve devices, leads to distortion of the form of the supply voltage. For such power supply systems, when determining the power factor, the formula (6), taking into account the harmonic composition of both current and voltage, should be applied. At the same time, it is possible to individually determine the distortion of the current according to formula (7) and the distortion of voltage according to formula (9) and estimate the quality of voltage and current, and determine the phase shift of current, find out the cause that reduces energy efficiency and outline activities aimed at raising Km and Ke, using expressions (5) - (8) and computational modules constructed on their basis.

Thus, the above methods for determining Km and the modules constructed on their basis complement each other in the study of energy indices.

For researching the energy performance of electrotechnical complexes and systems in MatLab there are developed a set of specialized computational modules based on the elements of the Simulink Library.

The application in the mathematical models of electrotechnical complexes and systems of these modules allows:

1) to identify the main reasons for the reduction of electricity quality indicators, the efficiency of its consumption (generation) and usage;

2) to create a measuring base with a visual observation of the change in energy indicators in the process of performing research and searching for new technical solutions;

3) to develop new models and apparatus on the models, their modifications and exercise control over the effectiveness of their application.

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