AUTOMATING COMPUTATIONS FOR ELECTRIC CIRCUIT ANALYSIS WITH LABVIEW

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Abstract. The article considers the application of the theory of the complex variable function employing the LabVIEW graphical programming environment for automating the calculation of electric circuits. The software products have been created to implement the method of constructing the matrix of the system of linear algebraic equations by inspection for both the mesh current method and nodal potential method in electric circuits of direct and alternating current and voltage using a graphical programming environment, except for circuits with dependent sources. All developed programs can be converted into .exe files, with subsequent utilization on computers that do not have a program environment installed. These software solutions can help lecturers quickly generate solutions for new assignments, saving valuable time. Students can utilize these software products for self-control, further reducing their workload.

Key words: Complex Numbers, Nodal Analysis, Mesh Analysis, LabVIEW.

1. Introduction

Choosing software for technical projects is crucial to designing technical systems, especially those that automate measurements and control.

Intricate engineering projects often require more advanced tools than conventional programming languages and software packages can provide. These tools may lack adequate hardware support, limited integration with other programming languages, or require developers to possess extensive programming expertise to function optimally.

LabVIEW graphical programming environment (GPE) stands out as the preferred choice for several reasons compared to other software packages and programming languages that can be applied to solve similar tasks [1-3]. GPE offers various benefits, including modules for adapting the code of the most common programming languages, such as C, C++, Python, and others, making it an extremely flexible solution for projects that combine different technologies. Moreover, GPE delivers extensive device aid by utilizing numerous drivers, enhancing equipment linkage directly to software, streamlining data collection from diverse sensors, and enabling swift processing via specialized analytical or visualization tools. Most importantly, LabVIEW's intuitive graphical interface makes it easy to use, underscoring its unique status as a formidable, efficient mechanism for thorough automation and data handling.

2. Disadvantages

It is important to note that constructing systems of equations matrices for mesh and nodal methods by inspection applies only to the most straightforward schemes operating under direct current conditions, as described [4-8].

3. Goal

The aim of the paper is to create the software for automating electric circuit calculations based on the modified mesh current and nodal voltage methods for both alternating current and direct current, with an intuitive interface to save users time.

4. Nodal voltage method for alternating and direct currents

Complex numbers are integral to the field of electrical engineering. They enable accurate and convenient analysis of electrical phenomena and serve as the primary tool for describing alternating current (AC) and voltage in complex circuits. Electrical networks rely on complex numbers for calculations and are employed to model the behaviour of various electrical components.

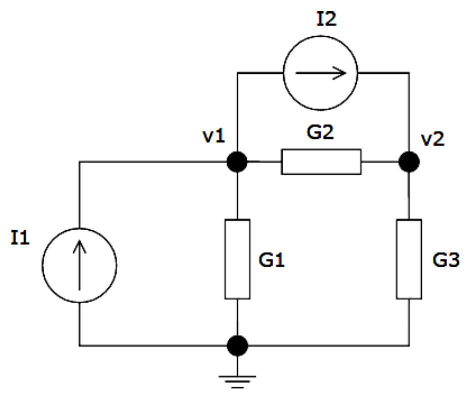

Fig. 1 The circuit with two nodes, v1 and v2, at direct current

If the circuit with independent current sources contains N non-resistive nodes (see Fig. 1), the matrix of the system of equations for calculating nodal voltages can be constructed by inspection, that is, without writing the equations of Kirchhoff's first law for each node [1]:

$$\begin{pmatrix} G_{11} & \cdots & G_{1k} \\ \vdots & \ddots & \vdots \\ G_{k1} & \cdots & G_{kk} \end{pmatrix}\begin{pmatrix} v_1 \\ \vdots \\ v_N \end{pmatrix} = \begin{pmatrix} i_1 \\ \vdots \\ i_k \end{pmatrix}, \quad (1)$$

where G_{kk} is the sum of conductances attached to the k-th node. $G_{kkk} = G_{kkk}$ are the negative sum of the conductances directly connecting the nodes k and jj, $k \neq jj$, i_k is the sum of all independent current sources directly connected to k node while the currents entering the node are considered positive, v_k is the unknown voltage at the k-th node.

The method of constructing the matrix of the system of equations by inspection, described in [4-6] for the simplest direct current (DC) circuits, can be generalized and effectively used for alternating current circuits. In this method, passive elements like capacitors and inductors can be represented in equations. Their impedance can be computed by formulas [4-6, 9]:

$$G_R = \frac{1}{R} \quad (2)$$

$$G_L = \frac{1}{ZL} = \frac{1}{jj\omega L} \quad (3)$$

$$G_C = \frac{1}{ZC} = \frac{1}{\frac{1}{jj\omega C}} = jj\omega C \quad (4)$$

$$G_{kk} = \sum_{i=1}^{nk_R}\left(\frac{1}{R_i}\right) + \sum_{i=1}^{nk_{CC}}\left(\frac{1}{ZC_i}\right) + \sum_{i=1}^{nk_L}\left(\frac{1}{ZL_i}\right), \quad (5)$$

where nk_R, nk_C та nk_L are the number of resistors, capacitors and inductors, respectively, which directly belong to the k-th node.

$$G_{kkk} = -\left(\sum_{i=1}^{nkkk_R}\left(\frac{1}{R_i}\right) + \sum_{i=1}^{n_{kkkCC}}\left(\frac{1}{ZC_i}\right) + \sum_{i=1}^{nkkk_L}\left(\frac{1}{ZL_i}\right)\right) \quad (6)$$

where $nkjj_R$, $nkjj_C$ та $nkjj_L$ are the number of resistors, capacitors, and inductors, respectively, that are common to the k-th and jj-th nodes.

As an example, we consider the circuit with resistances R1, R2, and R3, capacitors C1 and C2, inductances L1 and L2, and current sources AC1, AC2, and AC3 (Fig. 2). Our task is to determine the voltages at nodes 1, 2, and 3.

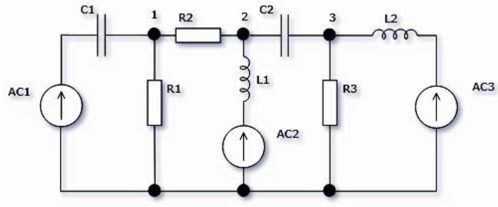

Fig.2 The circuit with three nodes at alternating current

Write down the equation matrix for the circuit mentioned in Fig. 2.

After solving the intricate system, attain the numerical values of the three indeterminate variables.

Solving a system of linear algebraic equations (SLAE) by the nodal voltage method for a three-node circuit with alternating voltage is relatively straightforward [7]. First, enter the nominal values of the resistances, inductances, and capacitances adjacent to nodes 1, 2, and 3 in the complex-valued array's R_(1..3), L_(1..3), and C_(1..3) cells. Next, enter the nominal values of elements common to the first and second, first and third, and second and third nodes in the R_1-2, L_1-2, C_1-2; R_1-3, L_1-3, C_1-3; and R_2-3, L_2-3, C_2-3 arrays, respectively. Finally, enter the voltage source values, frequencies, and phases for nodes 1, 2, and 3 in the A_(1..3), w_(1..3), and fi_(1..3) cells, respectively. The "Solution" array displays the calculation results.

$$\begin{bmatrix} \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{ZC_1} & -\frac{1}{R_2} & 0 \\ -\frac{1}{R_2} & \frac{1}{R_2} + \frac{1}{ZL_1} + \frac{1}{ZC_2} & -\frac{1}{ZC_2} \\ 0 & -\frac{1}{ZC_2} & \frac{1}{ZC_2} + \frac{1}{R_3} + \frac{1}{ZL_2} \end{bmatrix} \begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix} = \begin{pmatrix} i_1 \\ i_2 \\ i_3 \end{pmatrix} \quad (7)$$

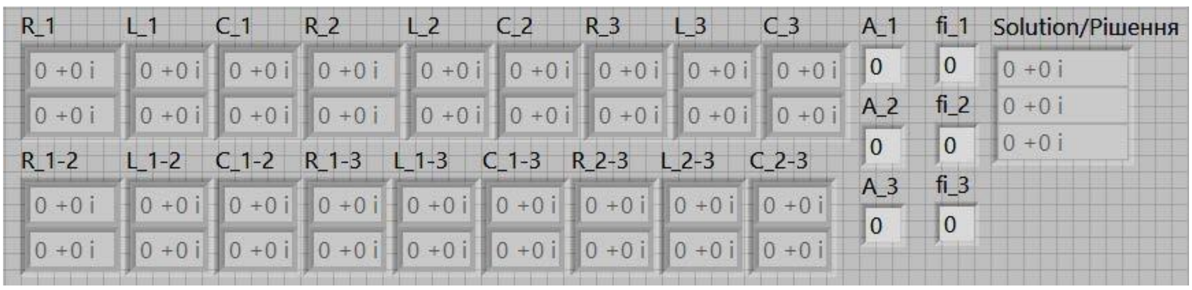

Fig. 3 Front panel for calculation of nodal potentials

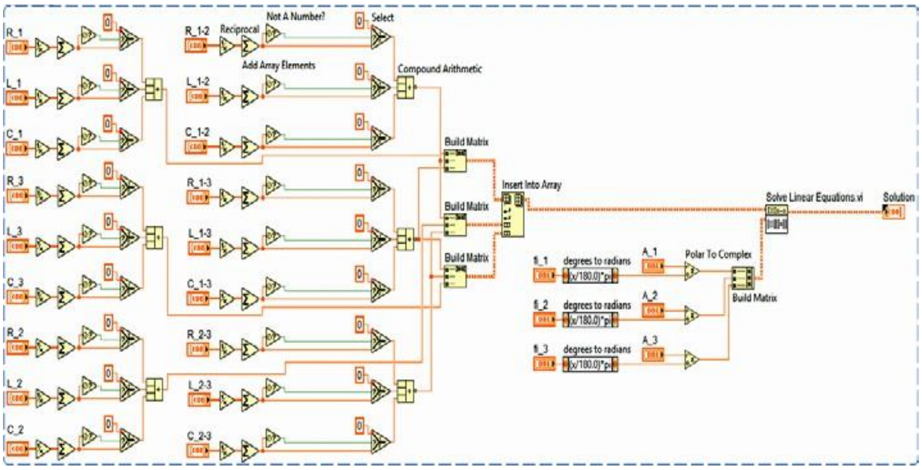

Fig. 4 Block diagram for calculation of nodal potentials

It is worth noting that this program is universal. It is suitable for calculating circuits at direct and alternating voltages and currents for 2 or 3 nodes circuits. We use complex number's real and imaginary parts at alternating voltage and only the real part at direct current.

We proceed with calculating several circuits that consist of three nodes. The first circuit only contains direct current sources, whereas the second includes alternating ones. You may refer to figures 5 and 6, which have been accurately filled with the relevant array information.

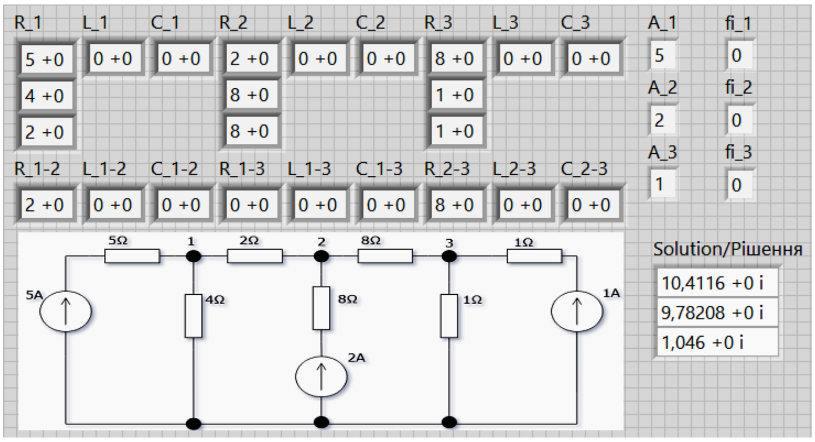

Fig. 56 The front panel for calculating nodal voltages at direct current

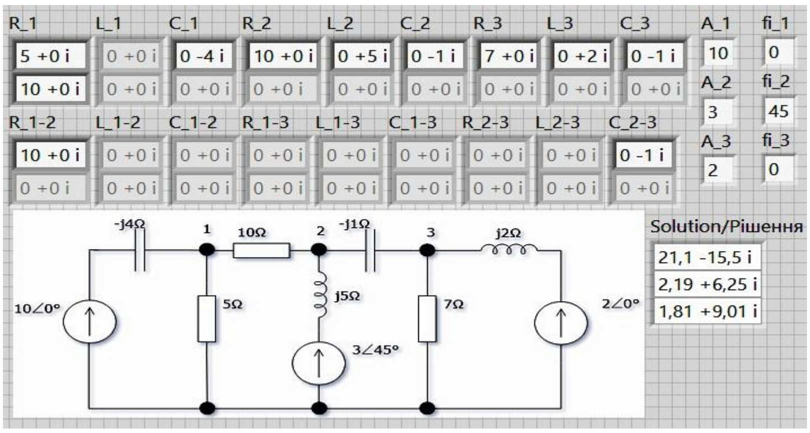

Fig. 6 The front panel for calculating nodal voltages at alternating current

1. Mesh current method for alternating and direct voltages

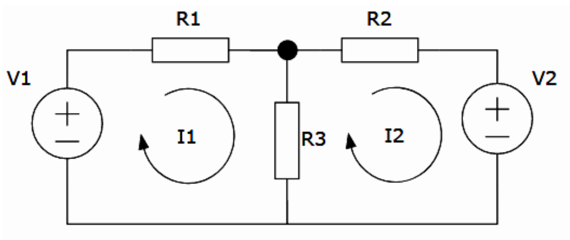

Fig. 7 The circuit with two mesh currents, I1 and I2, at constant voltage

If the linear resistive circuit contains only independent voltage sources, the matrix for the system of equations forcalculating mesh currents can be constructed by the inspection [4-5], that is, without writing the equations of Kirchhoff's second law in each circuit, as follows:

$$\begin{bmatrix} R_{11} & \cdots & R_{1N} \\ \vdots & \ddots & \vdots \\ R_{N1} & \cdots & R_{NN} \end{bmatrix} \begin{bmatrix} i_1 \\ \vdots \\ i_N \end{bmatrix} = \begin{bmatrix} v_1 \\ \vdots \\ v_N \end{bmatrix}, \tag{8}$$

where R_{kk} is the sum of resistances of the k-th mesh; i_k is unknown current in k-th mesh in the clockwise direction; v_k is the sum of voltages taken clockwise for all independent voltage sources in the $k-th$ mesh; at the same time, the voltage increase is interpreted as positive; $R_{kkk} = R_{kkk}$ is the negative sum of the resistances common to the meshes k and jj, $k \neq jj$. Let's form the matrix of the system of equations by inspection for circuits at alternating current and voltage. When analyzing circuits with alternating current, it's crucial to account for passive components like capacitors and inductors. To do this, one must express their impedances with formulas in [4-6, 9]:

$$ZR = R \tag{9}$$

$$ZL = jj\omega L \tag{10}$$

$$ZC = \frac{1}{jj\omega C} \tag{11}$$

$$ZR_{kk} = \sum_{i=1}^{nk_R}(ZR_i) + \sum_{i=1}^{nk_{CC}}(ZC_i) + \sum_{i=1}^{nk_L}(ZL_i) \tag{12}$$

where nk_R, nk_C, and nk_L are the number of resistors, capacitors, and inductors, respectively, which directly belong to the k-th mesh; $nkjj_R$, $nkjj_C$, and $nkjj_L$ are the number of resistors, capacitors, and inductors, respectively, that are common to the k-th and jj-th meshes.

$$ZR_{kkk} = -\left(\sum_{i=1}^{nk_R}(ZR_i) + \sum_{i=1}^{nk_{CC}}(ZC_i) + \sum_{i=1}^{nk_L}(ZL_i)\right), \tag{13}$$

Consider the circuit illustrated in Figure 8, where the resistances R1 and R2, the capacitances C1 and C2, and the inductances L1 are connected to alternating voltage sources AC1 and AC3. We aim to determine the values of the mesh currents I1, I2, and I3.

For the problem in Fig. 8, it is enough to consider the partial case of (11), i.e., the system of three equations. The matrix representing the system of equations in Fig. 8 can be described as follows:

$$\begin{bmatrix} ZR_1 + ZC_1 & -ZC_1 & 0 \\ -ZC_1 & ZC_1 + ZL_1 + ZC_2 & -ZC_2 \\ 0 & -ZC_2 & ZC_2 + ZR_2 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \tag{14}$$

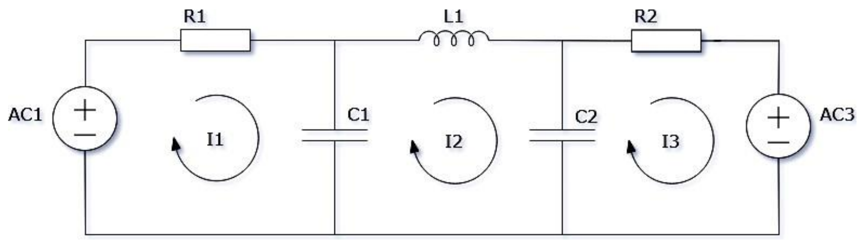

Fig. 8 The circuit with three meshes at alternating voltage

After solving the composed system, we obtain the three unknown mesh currents [7]. We can incorporate fields for entering source characteristics and indicating the system's solution on the front panel. Formula (13) is the way we find ZL_1. We connect array L_1, imaginary unit, and w_1 to the inputs of the function "Compound Arithmetic," select its multiplication mode, and get complex resistance ZL_1 at the output.

To determine the capacitive complex impedance ZC_1, we employ the formula (14).

The following algorithm has been devised for solving SLAE for the mesh method at alternating voltage for three mesh [4-6, 9]. The algorithm involves filling in the complex-value arrays R_(1..3), L_(1..3), and C_(1..3) with the nominal values of resistances, inductances, and capacities, respectively, that belong to the meshes I1, 12 and I3. Subsequently, the complex-value arrays R_1-2, L_1-2, C_1-2; R_1-3, L_1-3, C_1-3, and R_2-3, L_2-3, C_2-3 are filled with the nominal values of the elements that are common to the first and second, first and third, and second and third meshes, respectively. The sources from the meshes I1, I2, and I3 are then entered into cells A_(1..3), w_(1..3), and fi_(1..3), respec- tively. The solution is finally displayed in the "Solu- tion" array.

It is worth noting that this program is suitable for calculating electric circuits at direct and alternating voltage for two or three meshes.

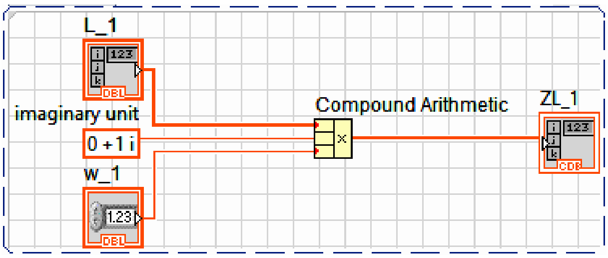

Fig. 9 Calculating inductive complex impedance ZL_1

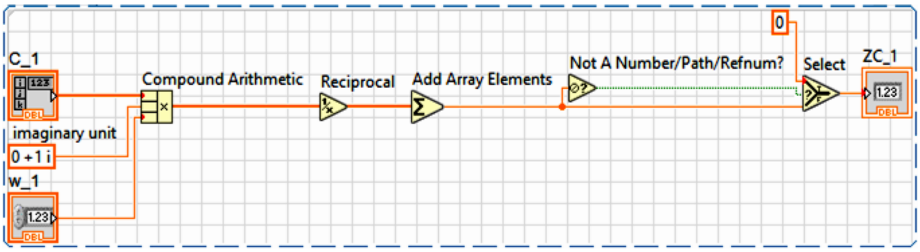

Fig.10 Calculating capacitive complex impedance ZC_1

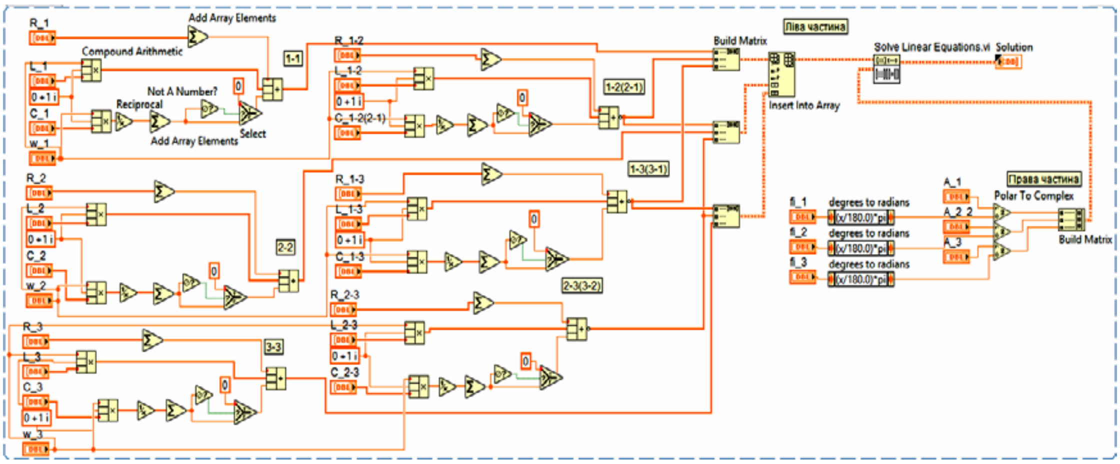

Fig. 11 Block diagram for calculating mesh currents at AC

We can take a look at two circuits with three meshes. The first circuit contains a DC voltage source and the second one an AC voltage source.

Engineers often need to calculate electric cir- cuits quickly. With the advent of modern technology and social media, students can easily share test and exam materials, frequently putting instructors in a po- sition where they need to compute multiple electric cir- cuits quickly. To keep up with the fast-paced academic environment, educators must revise assignments, which can be time-consuming. However, with their ex- pertise and knowledge, instructors can confidently tackle any challenge that comes their way. As demon- strated earlier, the software developed significantly simplifies and automates the calculation of electric cir- cuits, significantly reducing time and effort. Calculat- ing electric circuits involves entering the nominal val- ues of circuit elements and nodes in the corresponding fields. The rest operations, including outputting the re- sult, are performed automatically.

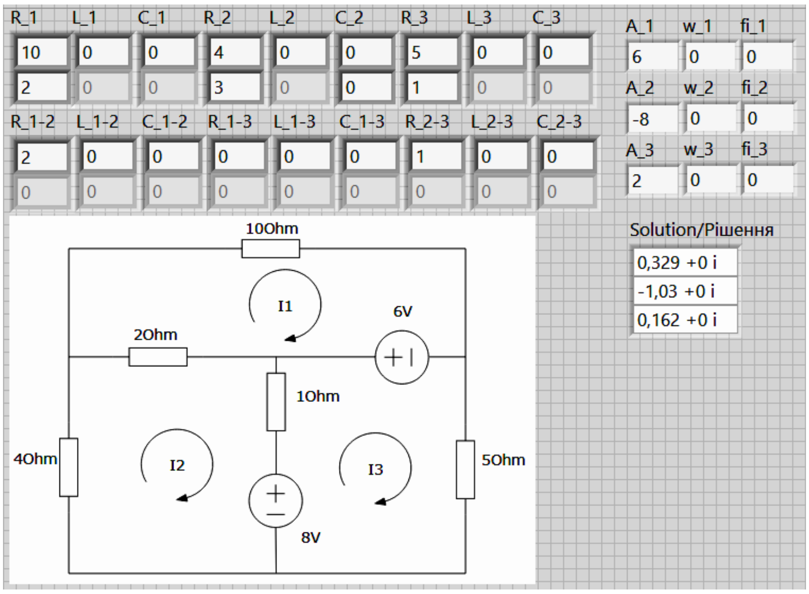

Fig. 127 Front panel for calculating mesh currents at DC voltage

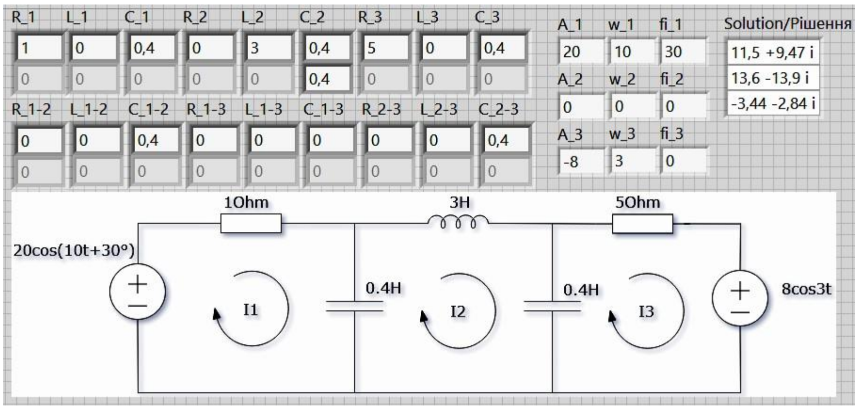

Fig. 13 Front panel for calculating mesh currents at AC voltage

The developed software does not require familiar- ity, even with the basics of programming in GPE. The chosen GPE has another advantage: developed programs can be compiled into executable.exe files and fulfilled on computers without LabVIEW installed. Since such prob- lems dominate textbooks, examples for calculating elec- tric circuits with three circuits and three nodes have been provided [1-4]. Nevertheless, the developed software can be utilized for more circuits and nodes.

7. Conclusions

In this work, the classical methods of circuit anal- ysis were improved. The contribution of paper can be summarized as follows:

1) We propose a modification of the classical method of mesh currents. The idea is to assign a certain voltage drop across each current source. To write down the Kirchhoff's current law for the current source. we de- rived the rule: the mesh current on the right from the pos- itive node of the current source minus the mesh current on the left equals the current of this source;

2) A similar modification is made for the nodal po- tential method. A current is assigned to each voltage source;

3) These modifications help to avoid ambiguity in the selection of meshes or nodes. In other words, in the mesh method, each "window" is a mesh for which Kirch- hoff's voltage law can be written. For the method of nodal potentials, each connection of three or more branches is a node for which Kirchhoff's current law is written;

4) The proposed modifications make the methods well algorithmized. This allows applying them to con- struct the matrix of the system of equations by inspection for all typical problems of both DC and AC currents and voltages;

5) The software was developed to automate the cal- culation in the field of circuit analysis. The developed software possesses an intuitive interface; to find the re- sults, it is enough to enter the nominal values of compo- nents and power sources;

6) This software can be configured to operate auton- omously without installing LabVIEW on a computer.

8. Acknowledgment

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9. Mutual claims of authors

The authors have no claims against each other.

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