DIGITAL TEST SYSTEM
OF RELAY PROTECTION AND AUTOMATIC DEVICES

Special software "GRAN Test System"
of the device "RTS-M"

User manual

Version 4.0

ABSTRACT

Digital testing system designed for setting up and testing of the relay protection and automatic devices along with the other electrical devices was developed. These devices can be made on both electromechanical and digital basis.

CONTENTS

INTRODUCTION

Digital testing system has two-level hierarchical structure. The upper level is based on a standard laptop computer (PC). On the lower level there is a special device (the "Device") which directly connects to the object that is tested. The connection between the lower and upper level manages through a USB port or serial data port RS-232.

For optimal functioning of the upper level there are requirements to the following features of the PC:

- CPU clock speed not less than 600 MHz;
- RAM not less than 128MB;
- resolution mode of the monitor is not less than 1024x768 pixels;
- presence of a USB port or serial COM port;
- operating System Windows 7 and higher.

On the upper level of the digital testing system, the following tasks are fulfilling:

- controlling of the lower-level device;
- specifying testing settings for the specific relay protection device;
- forming of the testing cyphergrams;
- representing of the testing results and managing their analysis;
- archiving of the testing results.

On the lower level the following tasks are fulfilling:

- performing primary processing of the testing cyphergrams;
- generating analog signals for the three currents and three voltages;
- controlling the state of discrete inputs of the tested device;
- time intervals registration.

This tutorial describes specific software for digital testing system which is installed on the upper level of the system - the PC.

1. TERMS AND BASIC REGULATIONS FOR OPERATING WITH THE PROGRAM INTERFACE

The program interface - a set of tools for operating the program. It consists of separate control elements and elements for displaying the information.

Click - to perform a single left-button mouse click. Click on a specific control element means that you first need to move the cursor to the selected item, then click left "mouse" button.

Double-click - to quickly press left "mouse" button two times, the interval between two clicks must be minimal.

Press the key combination - means first click the first key combination on the keyboard and while holding the key down, press the other button to perform the combination.

Activate the control element (select the control element, give it focus). This can be done by using the manipulator "mouse" or using the keyboard. First "mouse" cursor is led to a control element and then pressed the left "mouse" button. Use the keypad to select the desired control by pressing the TAB key or key combination <Shift +Tab> to move focus from the active element to the desired element. Pressing the key <Tab> leads to the selecting of the next element, <Shift+Tab> - to the previous one.

Move – to perform the move using the "mouse". To do this, you first need to move the cursor "mouse" to the element that is moved, then click left "mouse" button and while holding it down move the item to the desired position and release the "mouse" button.

Select a fragment - an operation designed to highlight a piece of text or a graphic image fragment. To select the fragment, you need to move the mouse cursor to the beginning of the selection, click left "mouse" button and while holding it, move cursor to the end of the selection and release the "mouse" button.

Icon - conventional graphical representation of a certain command, for example, the image for command of the window menu or image of the commands in the toolbar (Figure 1.1).

Window - a standard object of the WINDOWS system, in which the information is displaying (Figure 1.1) and which is the basis for other interface elements. There are several types of windows:

- main window;
- modal window;
- non-modal window;
- dialog window.

When you start the program the main window opens and other subwindows of the program may be opening. When you close the main window – you exit the program.

If you open a modal window, then the window gets focus and operations can be performed only in it, and to work with other windows of the program you need to close this window.

If the window is nonmodal, you can set the focus to another window without closing this nonmodal window.

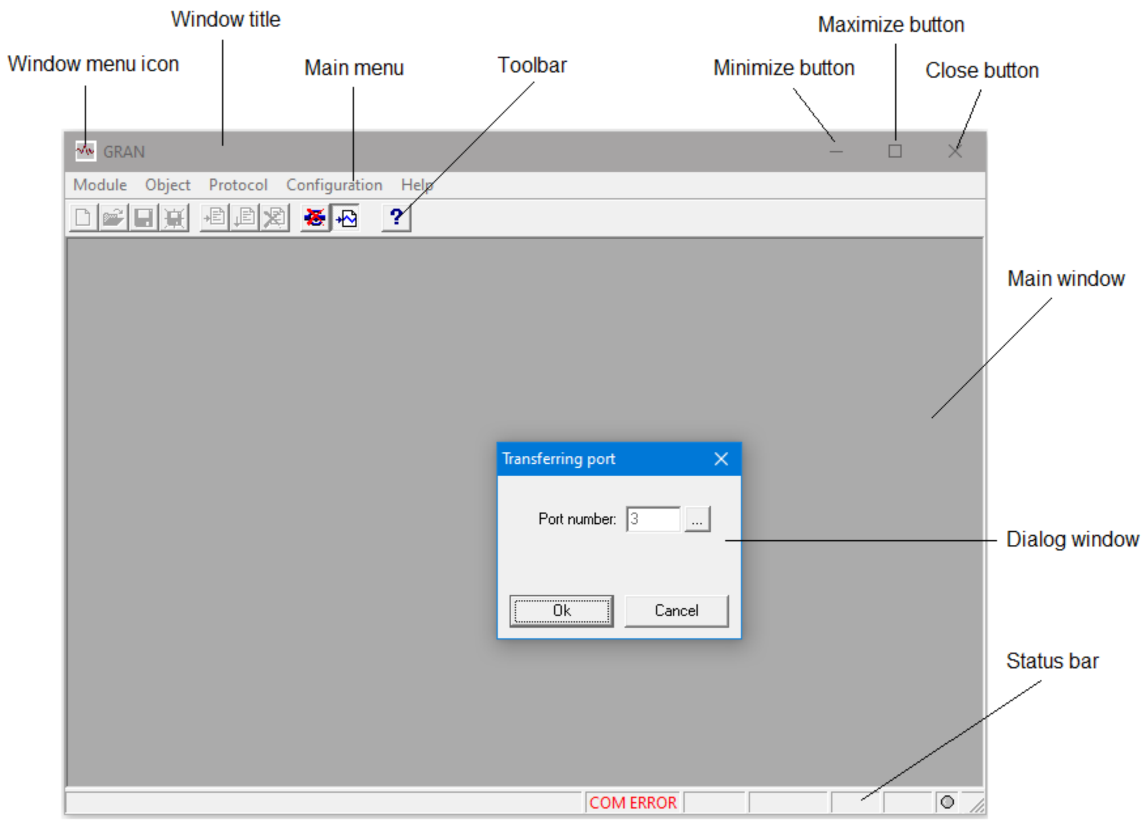


Fig.1.1. The main and dialog windows

Dialog windows are designed for setting or modifying certain parameters. Dialog windows are modal and contain the **"Ok"** and **"Cancel"** buttons pressing on which leads to closing the window and to confirming or cancelling the changes made (respectively the **"Ok"** or **"Cancel"** button).

Any window contains the title bar, which displays the name of the window; window control buttons on the right side of the title bar; menu of commands and client window part, which displays other interface elements. With the help of the command buttons you can minimize nonmodal window (minimize to the icon), maximize nonmodal window (maximize to the size of the screen), restore the original size of the nonmodal window, close the window and calling for help. These functions can be performed also by appropriate command of the menu, which is called up either by using the "mouse" by pressing the "Mouse" icon on the left side of the title bar, or by using the keyboard by pressing the key combination <**Alt+BackSpace**> .

With the help of the title bar, you can move window on the display. This operation also can be made by using the appropriate menu command.

If the window is nonmodal, you can resize it using the "Mouse" or menu command. To resize the window using the "mouse", you must bring the cursor to the border of the window (the cursor will change its shape), press the left mouse button and, keeping it pressed, move the cursor to the desired resizing.

Main menu - the set of menu items, each of which contains a submenu with a set of commands (Figure 1.2). Operation with the main menu can be done by using the "mouse" or using the keyboard. In order to select a menu item, you need to bring the cursor and click the left "mouse" button. Operation with the keyboard manages as follows. First press <**F10**> key, then by using the arrow keys select the desired item or the menu command and press <**Enter**>. In addition, some commands can be performed directly using keyboard shortcuts. If the command can be executed by pressing the shortcut, then the name of the key or key combination is displayed to the right of the menu items, for example "**Exit Alt + X**" (Fig. 1.2).

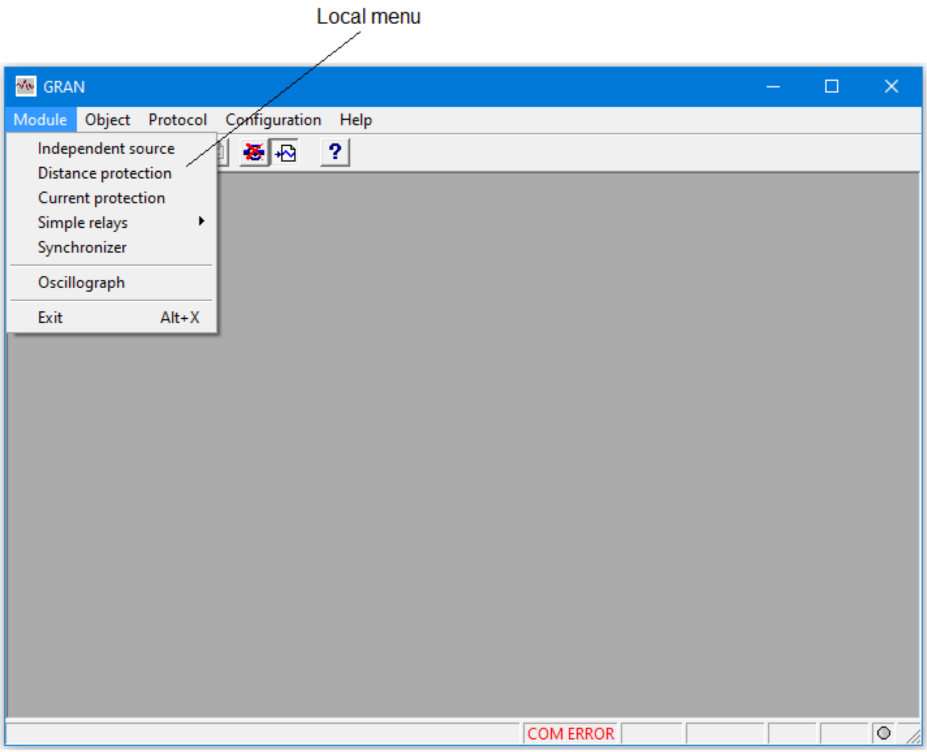


Fig.1.2. Submenu of the main menu

Local menu - set of commands related to the selected object. This menu is opened by pressing the right button "mouse". Cursor thus should be on the selected object. The structure and operation of the local menu is the same as of submenu of the main menu.

Toolbar - set of buttons with icons you can use to perform certain commands (Figure 1.1). Typically, it is the most used commands in the list of commands of the main menu.

Status bar - the area at the bottom of the window for displaying certain information.

Scrolling – sliding band. This is a standard Windows control element. There are vertical and horizontal scrolling (Fig. 1.3). Controls of the scrolling are slider and arrow keys. The slider indicates the relative position and may reflect the proportion of the visible box of information comparatively to the whole information. Moving the slider on the band allows the user to scroll through all the information. You can scroll the information in the window also by use of the arrow buttons. In this case, the scroll will be done discretely with a certain step. The arrows on the keys indicate the direction of the scroll. Scrolling can be performed with a major step rate, by clicking on the scroll bar between the slider and arrow button.

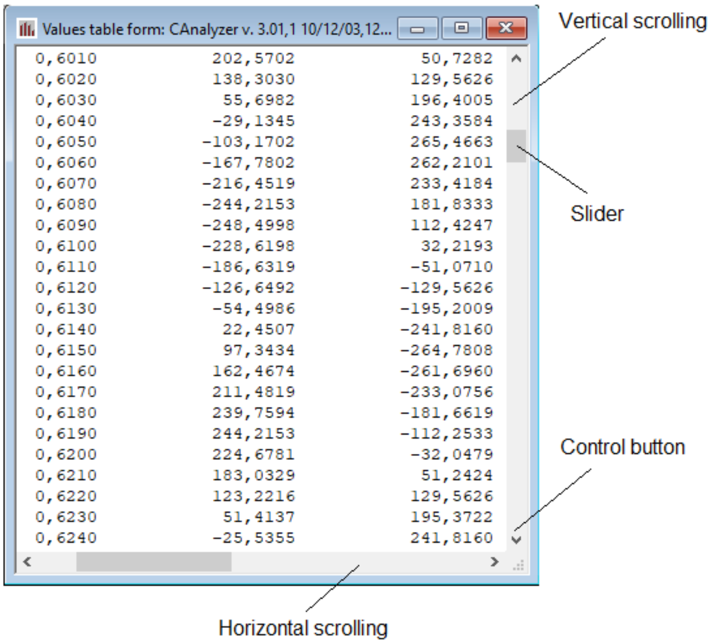


Fig.1.3. Vertical and horizontal scrolling

Bookmark page - designed for grouping by functional characteristics of controls and information displayed in the window. Only elements of the active (selected) page are displayed in the window. Switching to another page can be done by using of the "mouse" or keypad. With "Mouse" - you should bring the cursor to the desired tab and click on it. Switching with the keyboard is done by pressing a combination of keys, <**Ctrl+Tab**> up until the desired page will be selected.

Group field - designed to group a set of controls and elements of the information displayed in a window (Figure 1.4).

Editing field - a field in which you can display or edit a single line of text (see Fig. 1.4). To work with this field it is necessary to activate it. After activating you can enter the desired text or edit the existing one using keypad.

Displaying field – similar to editing field, but designed only to display the single-line text.

Button – element of control that is designed to perform a specific command. To perform the command you need to click on the button (see Fig. 1.4).

Independent checkbox – element of control (see Fig. 1.4) is designed to activate a particular mode. Activated checkbox is marked with the image "tick" and deactivated checkbox is clear. Mode change is done by clicking on the checkbox. This operation can also be performed using the keyboard. To do this, you first need to select the checkbox and then press <**Space Bar**>.

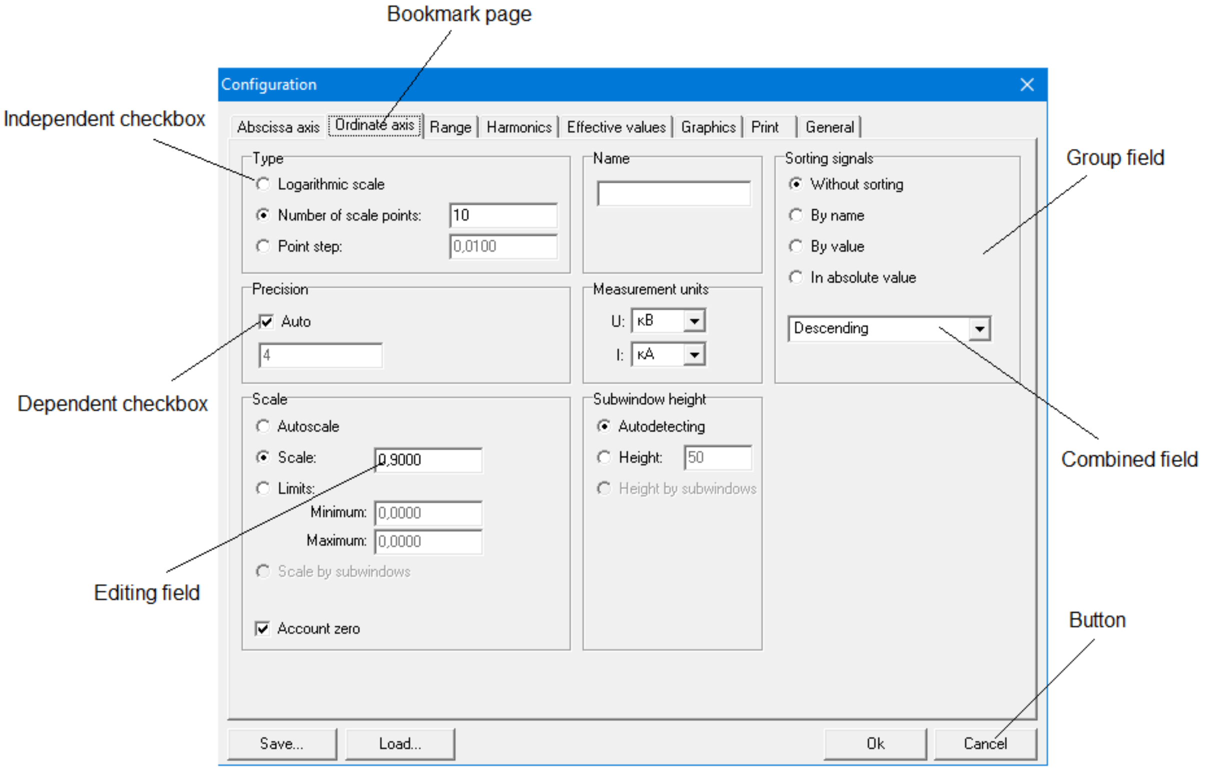


Fig.1.4. Dialog window with the elements of control and display

Dependent checkbox - element of control (see Fig. 1.4) is designed to activate a particular mode. Unlike independent checkbox dependent checkboxes are combined into a group of checkboxes. Among the group of checkboxes there can be only one active. To activate the checkbox you must click on it. Active checkbox is marked with the image "dot". Operation with keyboard is performed similarly as for the undependent checkbox.

Combined field - contains a display field and a list of defined single lines of text (see Figure 1.5). To select the desired text in the list you need to bring the cursor to the button with the image of the arrow and press the left mouse button - a list of texts will appear. From this list using the cursor you must select the desired text and then click left "mouse" button - the selected text will appear in the display field. Selecting with the keyboard accomplishes as follows: after activating the element press <**Space bar**>, a list of single lines of text will appear from which you must select the appropriate text by moving the cursor keys <Down Arrow> and <Up Arrow> and then pressing the <Enter> key.

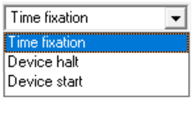
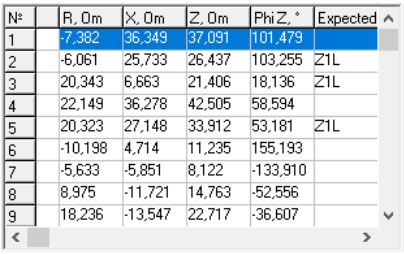


Fig. 1.5. The combined field

List box - the box that displays a list of single lines of text. Selecting the desired text is done similarly as in the combined field. If the list does not fit in the box, you can scroll through the list using vertical scrolling.

Datasheet - a field in which certain information is displayed in tabular form in the rows and columns of cells. Table cells can contain text information or elements of control (Figure 1.6). The information in the table cells can be edited or just read-only. To edit you must first activate the cell and then use the keypad to make the appropriate changes.



№		R, Om	X, Om	Z, Om	Phi Z, °	Expected
1		-7,382	36,349	37,091	101,479	
2		-6,061	25,733	26,437	103,255	Z1L
3		20,343	6,663	21,406	18,136	Z1L
4		22,149	36,278	42,505	58,594	
5		20,323	27,148	33,912	53,181	Z1L
6		-10,198	4,714	11,235	155,193	
7		-5,633	-5,851	8,122	-133,910	
8		8,975	-11,721	14,763	-52,556	
9		18,236	-13,547	22,717	-36,607	

Fig. 1.6. Datasheet

Cyphergram – digital record of the set of signals - currents, voltages, state of binary inputs and so on.

Subwindow of the signal display - separate fields of the window for displaying the signals.

For more information on working with the interface of Windows programs you can use help from the operating Windows system.

2. PROGRAM STRUCTURE

After starting the program on the screen of PC displays the main menu window (Figure 2.1).

Main menu which is located at the top of the window consists of the following paragraphs:

- *"Module"*. Allows you to generate three-phase systems of voltages and currents of different configurations depending on the test object. It is possible to work with the following modules: *"Independent source"*, *"Distance protection"*, *"Current protection"*, *"Simple relays"*, *"Synchronizer"*, *"Special Programs"*, *"Oscilloscope"*;
- *"Object"*. Allows you to record and download the file in which information is stored about the specific testing device of the relay protection. The file format depends on the type of module test;
- *"Protocol"*. Formation of the protocol with the results of the test of the device of relay protection. This protocol has defined form and can be stored in database or put to print;
- *"Configuration"*. Allows you to calibrate the voltage and current channels of the device, virtually connect (disconnect) "DEVICE" to a PC, to set the sharing port, set (cancel) autosave mode for the datafile of the object, to adjust the graphic parameters, to set the automatic formation of the test results, etc.;
- *"Help."* Allows the user to refer to the electronic version of this manual.

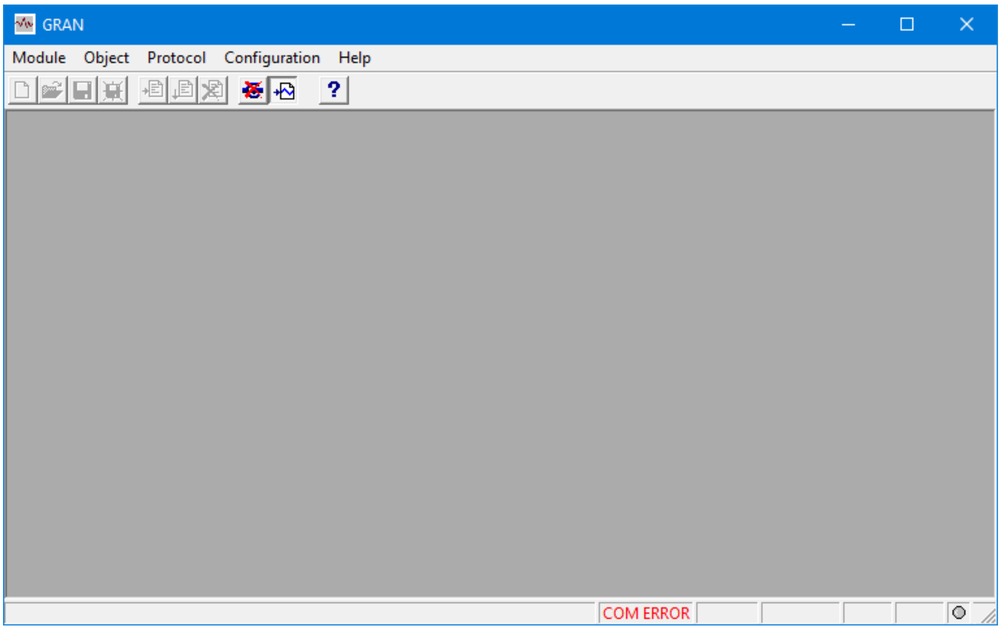


Fig.2.1. The main window of the program

Some of the main menu commands can be called directly from the toolbar

2.1. Module

For setting-up and testing of the devices of the relay protection the software provides different modules, which gives user the opportunity to form a three-phase system of voltages and currents of different shapes and to have a convenient interface for operating with the specific testing device. The module is displayed in the corresponding window. Each module consists of interconnected subsystems placed on separate tabs of the window.

After selecting the menu option *"Module"* on the PC screen appears the submenu with a list of modules that are implemented in the system (Fig. 2.2). Details of specific modules for testing of the relay devices are presented in the following chapters.

There are separate module *"Oscilloscope"* for analysis of the cyphergrams that were taken from various sources and are recorded in digital form in a specific format (as noted in detail in Chapter 9).

Executing of the last command *"Exit"* enables the completion of the work with the program.

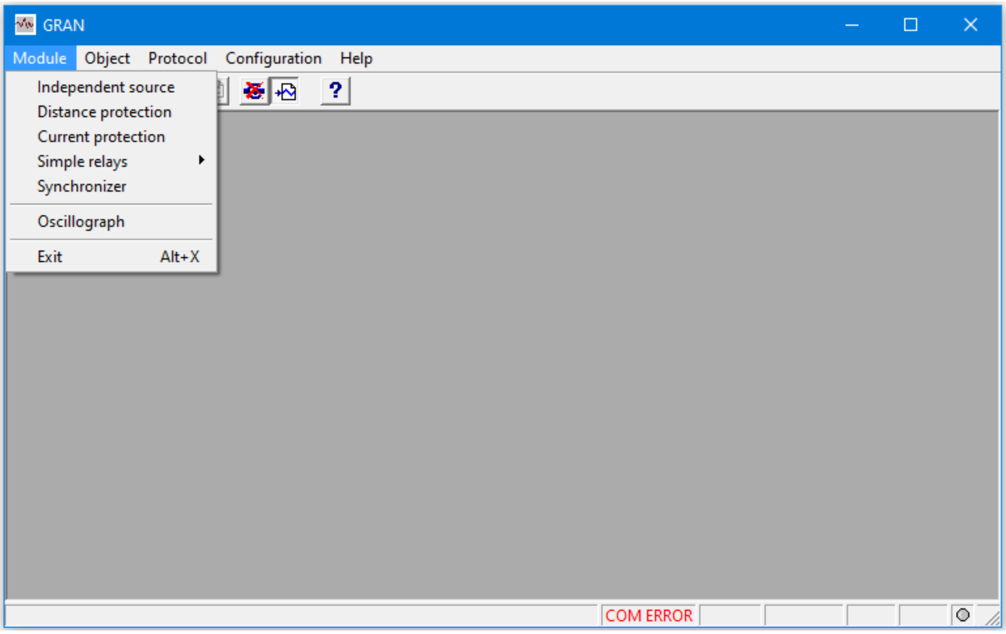


Fig.2.2. "Module" menu commands

2.2. Object

In this software under the object understands the number of files that stores information from all pages of the particular module.

Information for each object is stored in a file in a specific format, depending on the module:

- Module "Independent source" - *.gnr;
- Module "Distance Protection" - *.dys;
- Module "Oscilloscope" - *.tgr, *.cfg, *.fls, *.fa2, *.epk, *.fg;

- Module "Current protection" - *.ovc;
- Module "Simple relays" ("auxilliary relays" - *.smr);
- Module "Simple relays " ("voltage relays" - *.vtr);
- Module "Simple relays " ("current relays" - *.srr);
- Module "Simple relays " ("frequency relays" - *.frr);
- Module "Simple relays " ("power relays" - *.pwr);
- Module "Simple relays " ("differential relays" - *.dif);
- Module "Synchronizer" - *.syn.

Modules are mechanisms for creating separate objects (Figure 2.3). These mechanisms are implemented on separate pages of the module window. On each page can be formed different modes. These modes are stored in the object database.

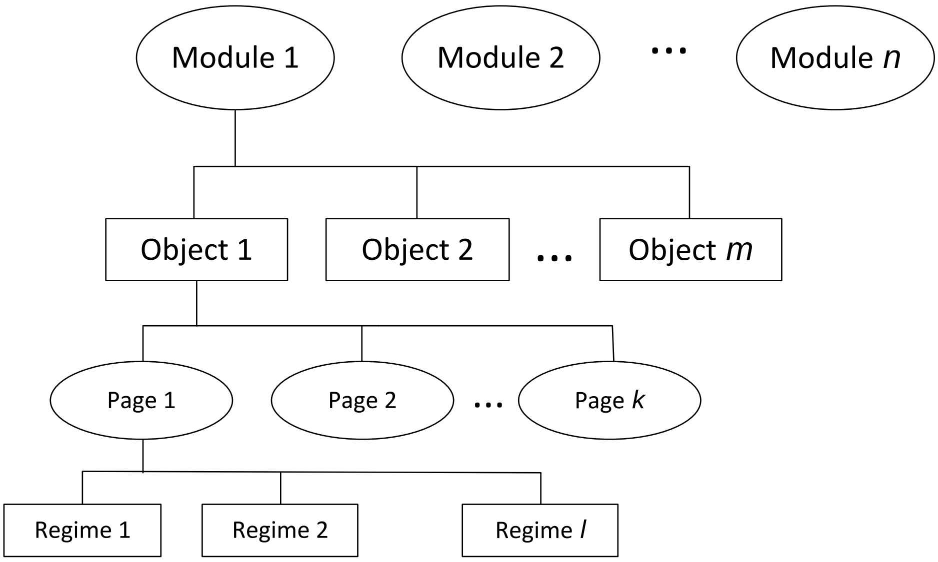


Fig. 2.3. The data structure of the object

The main menu item "Object" allows the user to work with database that contain the information for testing of relay devices. It is possible to create a new object, save object under his own or under a different name, download from the database previously created object (Figure 2.4). This menu item is available when activating the module. Menu "object" contains the following commands:

- *"New"**;*
- *"Download"**;*
- *"Save"**;*
- *"Save As."*

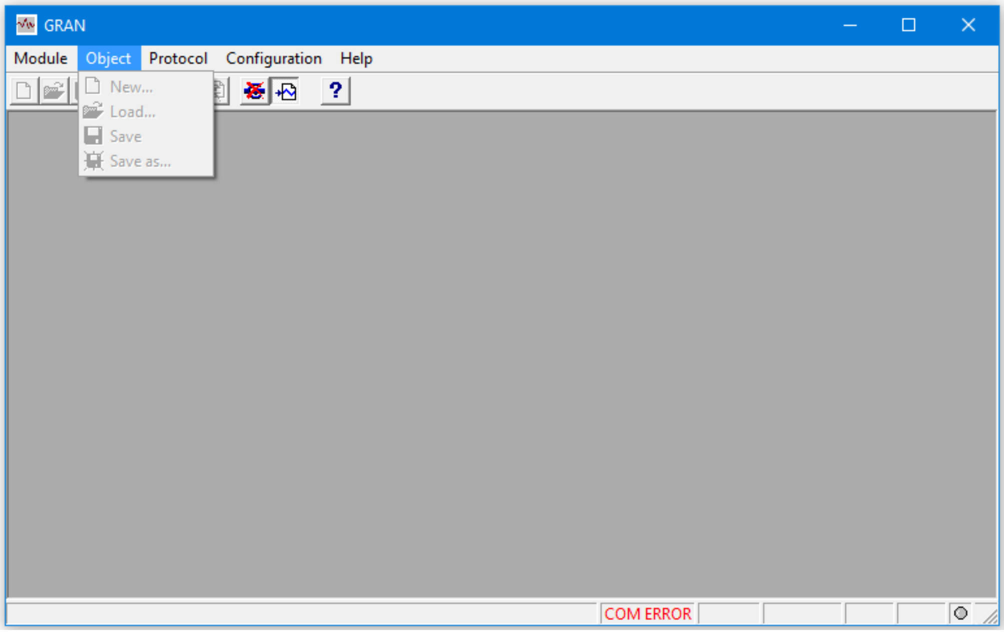


Fig. 2.4. Commands of the menu "Object"

The "*New*"  command is designed to create a new object in the module. After activating this command, the previous object would be closed. Parameters of the closing depends on the "Autosave" mode (see Section 2.5.10).

The "*Download*"  command is designed to load the object. After activating this command opens a dialog window in which you need to select the desired object. After downloading the name of the selected object will be displayed in the title bar of the main window (see Fig. 2.4). The structure of the title bar is: GRAN - <*module name*> [<*path and filename of the object*>]. The previous object will be closed. As in the previous case, parameters of the closing depends on the "Autosave" mode (see Section 2.5.10).

The "*Save*"  command is designed to record the object to a file with the name specified earlier. When writing new object the user must specify in the corresponding dialog window its location on the disk and name.

The "*Save As*"  command is designed to record the object with the new name.

Besides, the number of modules can operate with the information recorded in international format RIO and analog of XRIO format. In this case, the information is stored in files with the extension *.rio (*.xrio). To download the file in this format, in the dialog box of the file selection you need to choose the file type RIO or analog of XRIO. This dialog box opens when activating the command "*Download*".

The is a possibility to write to the database and read from it the information about the modes that were formed on the different module pages. To perform these operations, you must use commands in the menu "*Mode*" of the module window. There are the following commands:

- *"Save";*

- *"Save As";*
- *"Download".*

Remember that on some pages you can't save mode in the database. In this case, the menu item "Mode" is not available!

"Save" command is used to record information about the mode, generated on the active page into database. If this mode already exists, the entry will be made in the database with the same name that appears in the title bar of the module. The structure of the title bar is: *module name - the name of a page [mode name]*. Otherwise, a dialog box will appear where you must enter a name of the mode.

The "*Save As*" command is used to record mode with the new name.

The "*Download*" command provides the ability to load data from the database of the desired mode. After the executing of this command, a dialog box "*Mode list*" will appear (Figure 2.5).

All modes generated on this page are displayed in the window. After selecting the desired mode you have to click "**Ok**" button.

This window provides the ability to delete unwanted modes from the database. To do this, use the button "**Remove**".

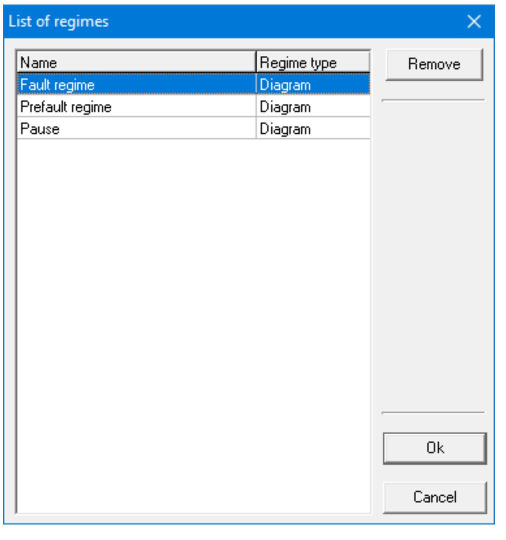


Fig. 2.5. Mode list

The menu item "*Close*" in the module window is designed to exit the module. Executing this menu item is similar to pressing the button in the upper right window of the module.

2.3. System message about the faults of the "DEVICE"

"DEVICE" has a self-diagnostic system that performs protective functions. After the detection of faults in the "DEVICE" by the self-diagnostic system, corresponding messages are transferred to a higher level to the user. These messages are displayed.

2.4. Protocol

The commands of this menu allow the user to create reports with information of the testing results. The form of the protocol is defined for each mode of the test of the particular device. After selecting the menu item "*Protocol*" a submenu opens (see Figure 2.6) with a list of commands that allow you to add new protocol to existing one (command "*Add*"), to display on the screen the protocols which were created in this testing session ("*Show*"), to remove the protocols which were created in this testing session (command "*Clear*") and load previously created and saved reports (command "*Protocol archive*").

Remember that user cannot make any changes to protocols!

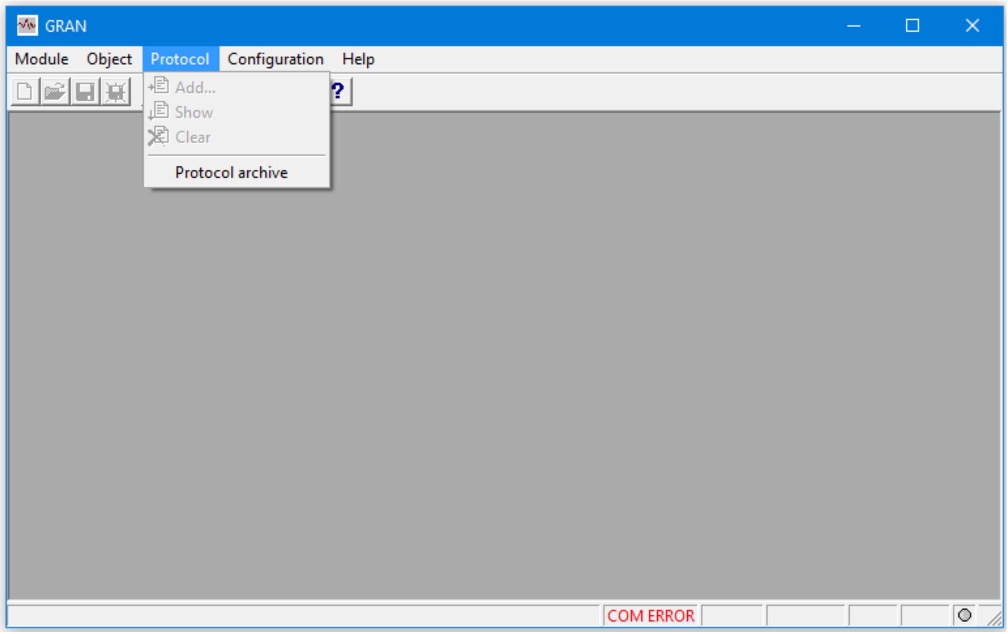


Fig. 2.6. Menu "Protocol" commands

After you click "**Add**" button a dialog box will appear on the screen, in which the user can add a comment that will appear in the protocol (Figure 2.7) and after clicking "**Ok**" button a new protocol will be created and added.

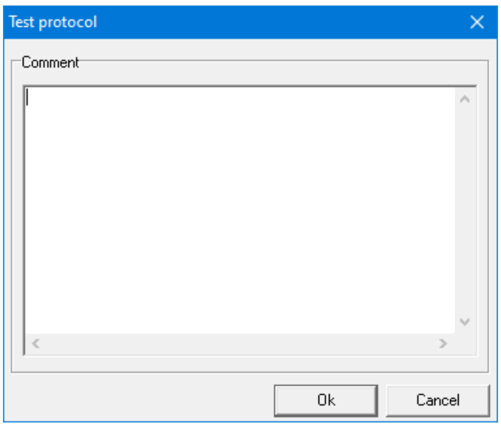


Fig. 2.7. Window for writing the comment during the making of protocol

The "*Show*" button allows the user to display protocols recorded in this test session in a separate window, in which user can view them, record to database or print.

After activating the command "*Clear*" the dialog window should appear where you are prompted to confirm this command, and after confirming, this protocol will be deleted.

After activation "*Archive protocols*" command a window will be displayed on the screen (Figure 2.8), which can display the report file. To display the desired protocol you must use the icon  - "*Download Protocol*".

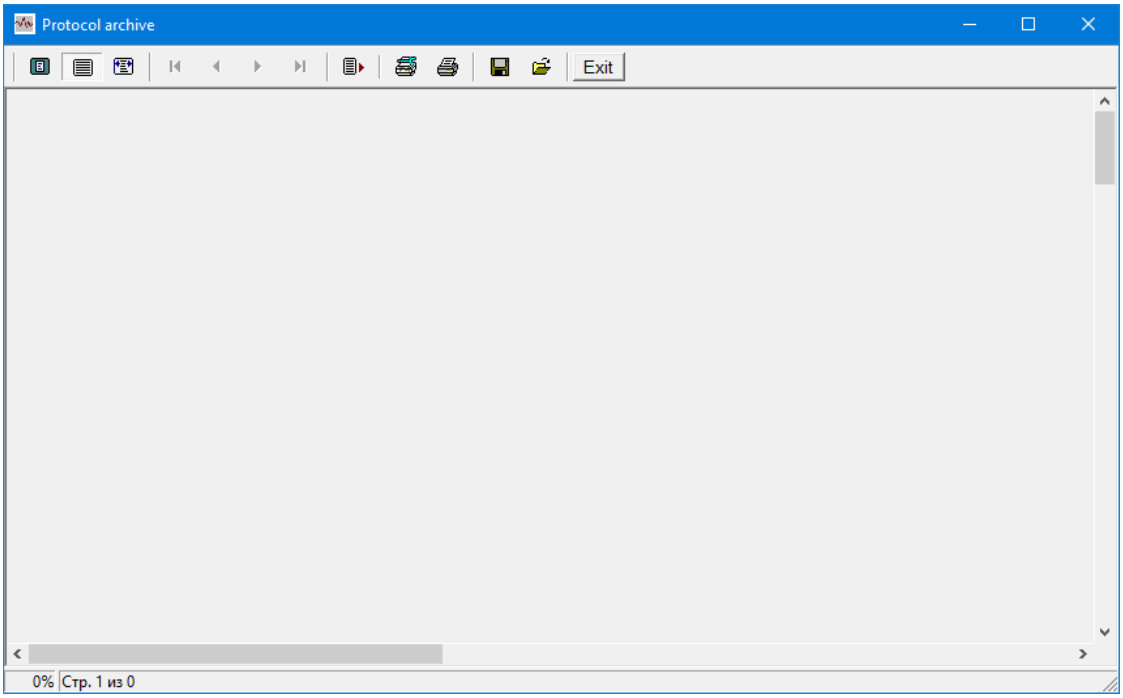


Fig. 2.8. Window for displaying protocols from the archive

The protocol of the results of operation of the device from the page "*Vector diagram*" from "*Independent source*" module, is given in Fig. 2.9 as an example.

Window "*Research of the protocol*" contains a toolbar with a set of the following commands:

-  - zoom to the window size;
-  - display the protocol on the screen without scaling;
-  - zoom to the window width;
-  - move to the first page of the protocol;
-  - move to the previous page;
-  - move to the next page;
-  - move to the last page;

- - move to page number;
- - print settings;
- - printing Protocol;
- - save protocol in a specified file;
- Exit - exit from the protocol.

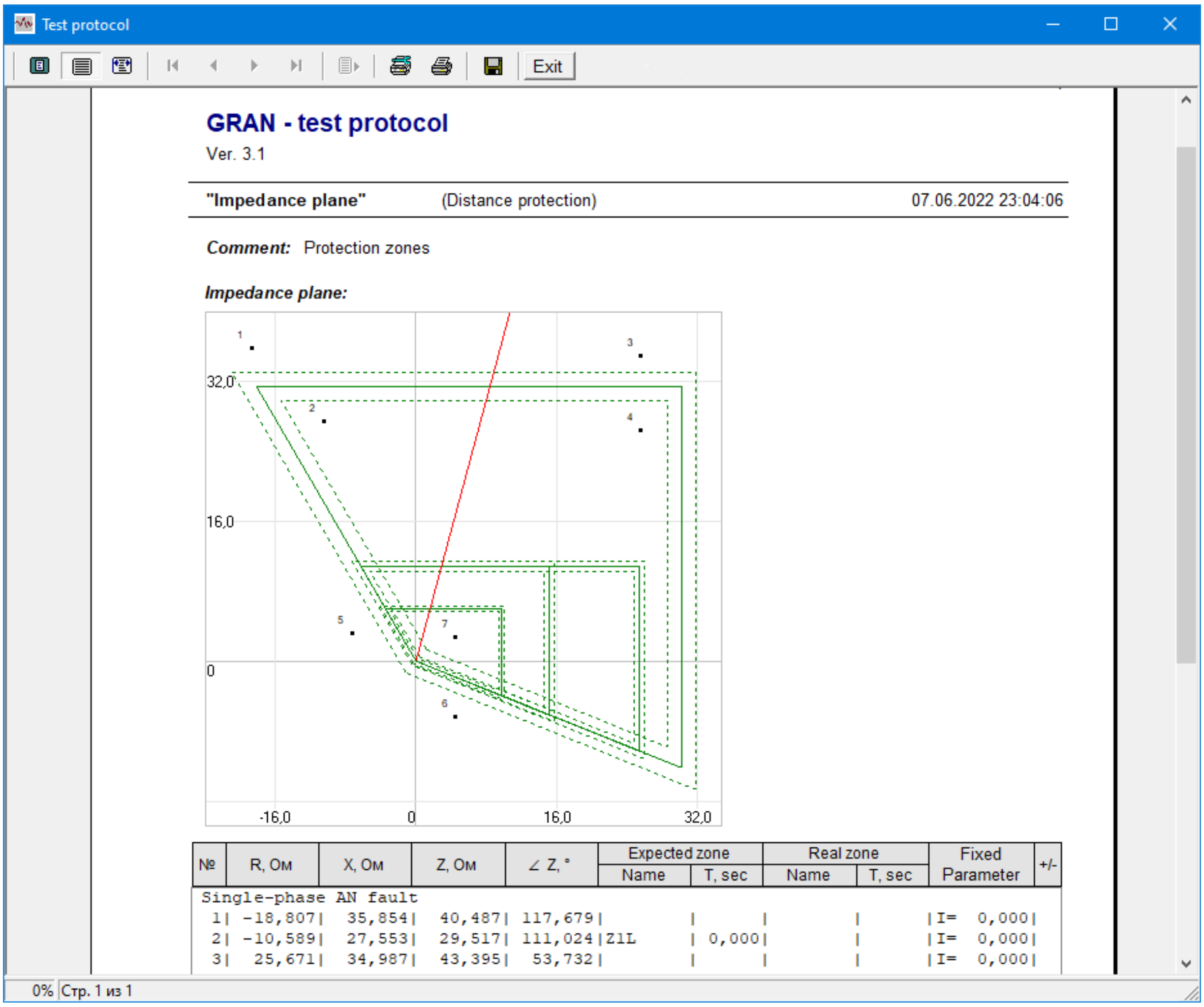


Fig.2.9. Example of protocol

Remember if the user did not save protocol to the file, then the protocol will be lost!

2.5. Configuration

Menu "*Configuration*" (Fig. 2.10) contains the following commands:

- *"Without connection (Connection)";*
- *"Transferring port";*

- *"Graphic";*
- *"Autosave";*
- *"Forming the result".*

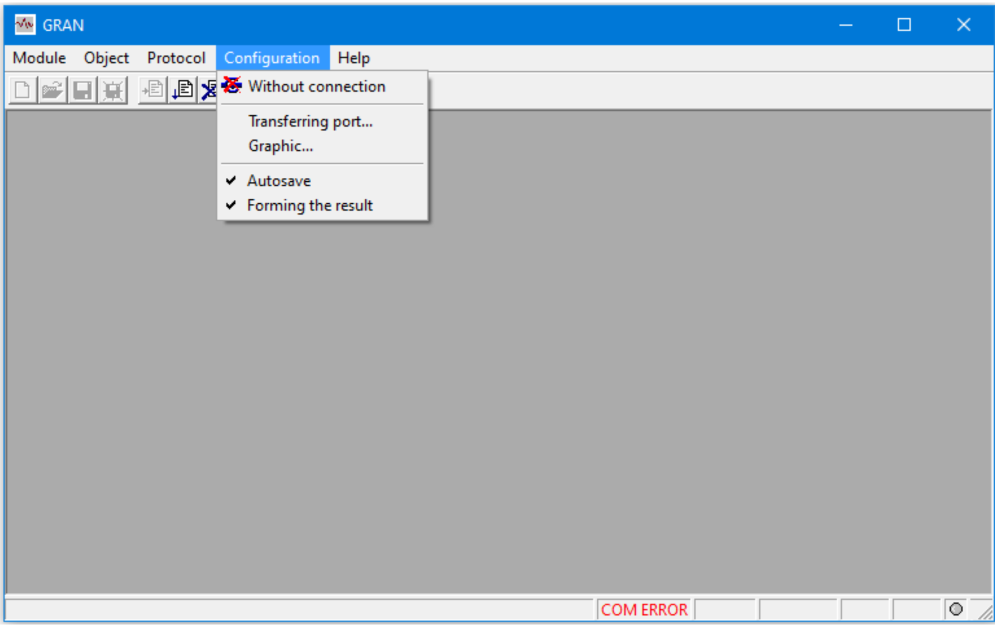
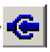


Fig. 2.10. Menu "Configuration"

2.5.1. Command for communication with the lower level device

The *"Without connection"*  *("Connection"*  *)* allows to virtually connect (disconnect) "DEVICE" to the PC. In " *Without connection*" mode, the PC operates in the offline mode.

If the "DEVICE" is not physically connected to the PC, is disconnected from the power source, connection line is physically damaged, is connected to unidentified COM port or virtual COM port, software of the "DEVICE" is not yet loaded, then it is impossible to switch to "*Connection*" mode.

In case when the number of COM port specified in the configuration is not initialized in Windows, the command is not available. In this case, you must set the required COM port number (see Section 2.5.2).

In the "*Without connection*" mode operating with the "DEVICE" is impossible.

2.5.2. The "Transferring port" command.

This command is designed to select the PC serial port to be used for communication with the "DEVICE".

After activating this command the following screen appears on a computer display (Figure 2.11).

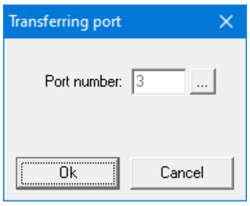


Fig. 2.11. Connection port selection window

In the "*Port number*" will be displayed the number of the selected port. To change the port number click the button to the right of the field. A dialog window will open with a list of available ports (Figure 2.12). You must select the required port and click "**Ok**". Connection between the PC and the "DEVICE" will be implemented through selected port.

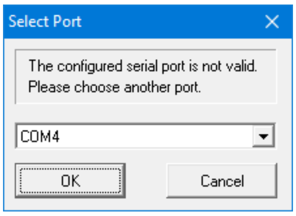


Fig. 2.12. A list of serial ports

2.5.3. The "Graphics" command

After activating this command the following window will appear on the display of the PC (Figure 2.13). To change the graphics settings you need to select the page "*Graphics*".

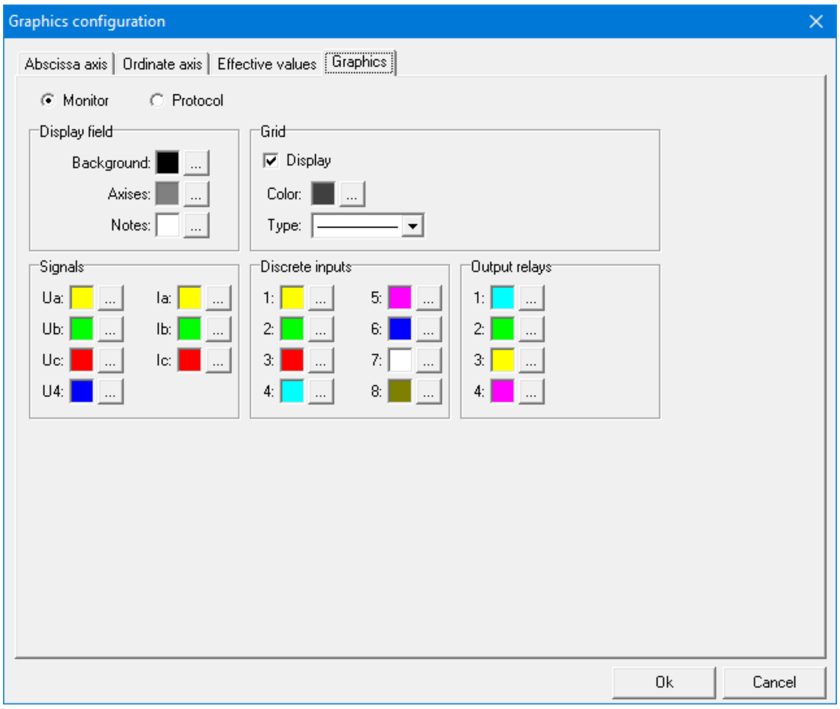


Fig. 2.13. Graphics settings window

On this page the user can change the color of background, axises, inscriptions of the vector diagram fields, cyphergrams; color and style of the grid, color of the signals and also colors which reflect changes in time of binary inputs and outputs states.

To change the color you need to press the button, located next to the pattern of colors. Default color palette will appear from which you can select the desired color. After finishing selecting the desired colors in the window (see Fig. 2.13) you must click on the "**Ok**" button. The selected colors will be used for further operations.

It is possible to specify separate settings for the graphics displayed on your PC screen and to output information in the protocol. For this purpose the appropriate switches are provided ("**Display**", "**Protocol**").

Remember, that "Graphics" page for different modules may have additional settings.

Operation with other pages of this window ("*Axis X*", "*Axis Y*", "*Common*") is described in detail in Section 9.2.4.1.

2.5.4. The "Autosave" command

Command allows you to set automatic data saving mode.

After activating this mode, when you close the testing mode or while the object module is loading from disk, the current information is automatically saved in the object with name that was defined earlier. If this information has not yet been saved, then before saving a standard dialog window opens where you define the name and location of the object.

If the "Auto Save" mode is not activated, then when you close the test module or when loading a new object from the disk, you have to confirm the saving of the information in the dialog window (Figure 2.14).

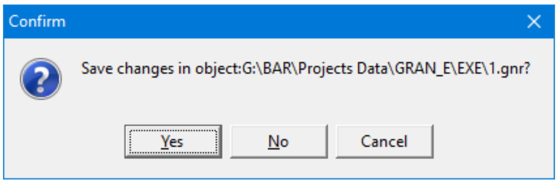


Fig. 2.14. Saving changes in the object

2.5.5. The "Forming the result" command

This command allows you to set (cancel) formation mode of the testing results.

In this software most of the modules has page "*Results*", which displays information about testing of the relay protection device. This page displays the change of coordinates mode (currents and voltages), and the possible triggering of digital input and output of the device. If the command is not activated then the test results are not formed. The last mode is useful in the case when the user does not need detailed test results, but only the information that is available on the page, and that can be stored in the test protocol (see Section 2.4).

2.5.6. The "Primary coordinates" command

The command is designed to setting currents and voltages mode in the primary coordinates. This mode is available in the following testing modules: "*Independent source*", "*Distance protection*", "*Independent frequency*". For transformation from secondary to primary coordinates the transformer ratios for current and voltage are used. These ratios are automatically calculated from the nominal primary and secondary values of current and voltage transformers respectively. These values are set on the page "*Configuration*" of the corresponding modules.

2.5.7. The "Secondary coordinates" command

The command is designed to setting currents and voltages mode in the secondary coordinates.

3. MODULE "INDEPENDENT SOURCE"

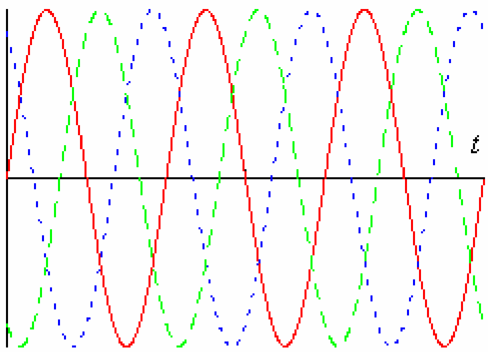
3.1. Terms

Module "Independent source" is designed for manual testing and adjustment of relay devices and other electronic devices of any degree of complexity.

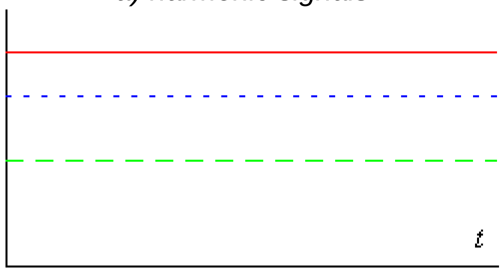
Using this module gives user the opportunity to test the operation of the tested device during generation of the signals of varying complexity by the "DEVICE":

- harmonic - values of phase currents and voltages are generated by the harmonic law with a given frequency;
- direct voltage and current - non harmonic signals of voltages and currents are generated;
- complex harmonic signals - values of current and voltage are generated with account of higher harmonic components and subharmonics;
- complex harmonic signals with account of aperiodic component - values of current and voltage are generated with account of higher harmonic components, subharmonics and aperiodic component;
- cyphergrams – various forms of currents and voltages which were formed by other digital devices or digital models and can be reproduced;
- complex modes - various forms of currents and voltages are worked out with consecutive operating in time of various combinations of all the above-mentioned signals.

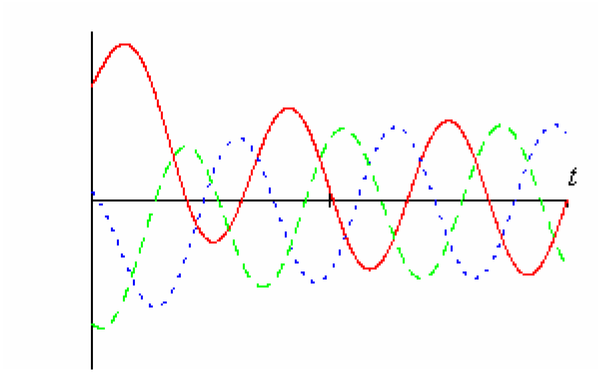
Figure 3.1 shows examples of different cyphergrams.



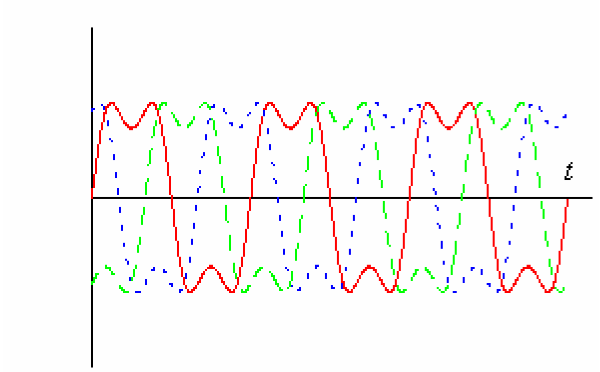
a) harmonic signals



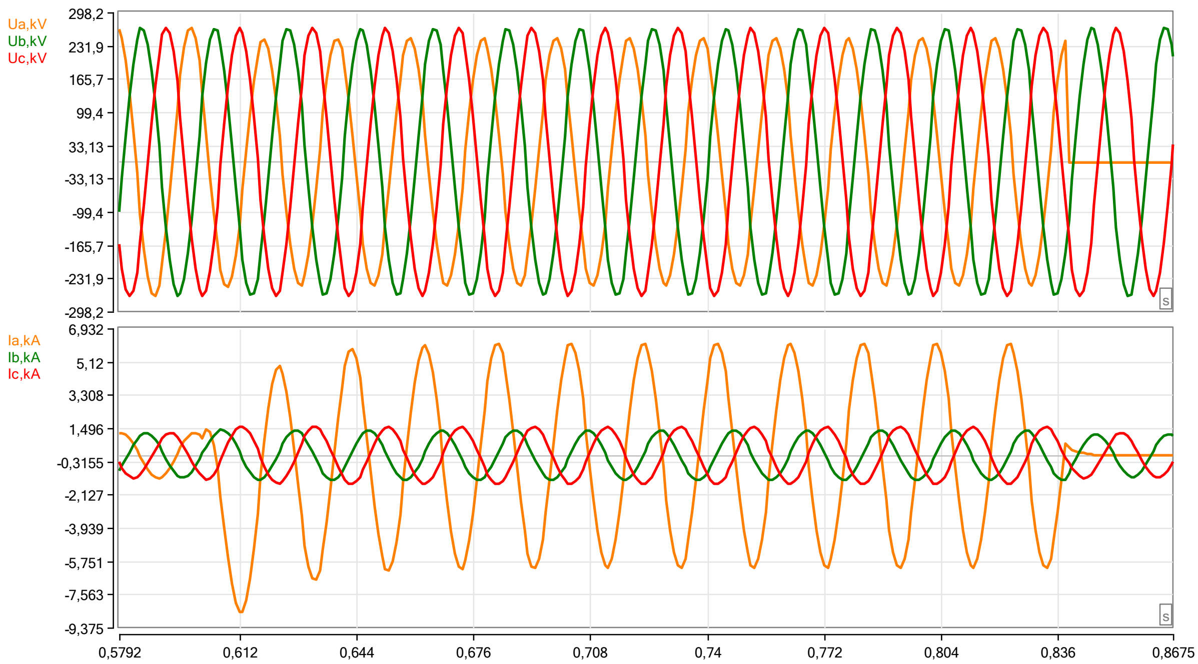
b) direct voltage or current signals



c) harmonic signals with aperiodic component



d) harmonic signals with higher harmonic components



e) Cyphergram recorded on a real substation by digital oscilloscope

Fig. 3.1. Examples of different types of signals

To organize such modes it is necessary to perform a number of preparatory operations. These operations are functionally separated and formed into separate pages. There are following pages:

- *"Configuration";*
- *"Vector diagram (alternating current)";*
- *"Vector diagram (direct current)";*
- *"Harmonics";*
- *"Cyphergrams";*
- *"The change of coordinates (for alternating current)";*
- *"The change of coordinates (for direct current)";*
- *"Complex regime";*
- *"Results."*

Information that is formed in the pages of the module can be recorded into the database to use it to adjust other devices of relay protection (see section 2.2).

3.2. The "Configuration" page

On the "Configuration" page sets the limiting settings of the tested device, the frequency of the alternating current, steps of change of coordinates mode (voltage, current, angle, frequency), as well as information for digital (discrete) inputs, output relays.

The overall look of the page "*Configuration*" is shown in Fig. 3.2. Here are the group fields "*Device*", "*Alternating current*", "*Direct current*", "*Discrete inputs*", "*Output relays*", "*Discrete inputs (Output relays) state*".

3.2.1. The "Device" field

In this field, the user writes a brief description of the device, which is being adjusted (tested).

In some edit fields, records the name of the power station (substation) on which the device is located, connection for which it is intended, for example, name of the electrical line, transformer, etc., the name of the device and the name of the user. This information, together with the results of the tests will be saved in the protocol.

3.2.2. The "Alternating current" field

For testing the alternating current devices you must specify the following information in the group field "Alternating current":

- F_{nom} - rated frequency of the harmonic signals of current and voltage;
- Δf - a step of frequency change - to organize the harmonic signals with alternating frequency;
- $U_{\text{nom.l}}$ - primary rated linear voltage;

- $U_{nom.ph}$ - primary rated phase voltage;
- $U_{nom.l}$ - secondary rated linear voltage;
- $U_{nom.ph}$ - secondary rated phase voltage;
- $U_{max\ ph}$ - the maximum value of the secondary phase voltage;
- I_{nom} - nominal value of the primary phase current;
- I_{nom} - nominal value of the secondary phase current;
- I_{max} - maximum value of the secondary phase current.

Remember that the maximum values of current and voltage are limited by technical capabilities of the "DEVICE". If the user sets higher value, it will be automatically reduced.

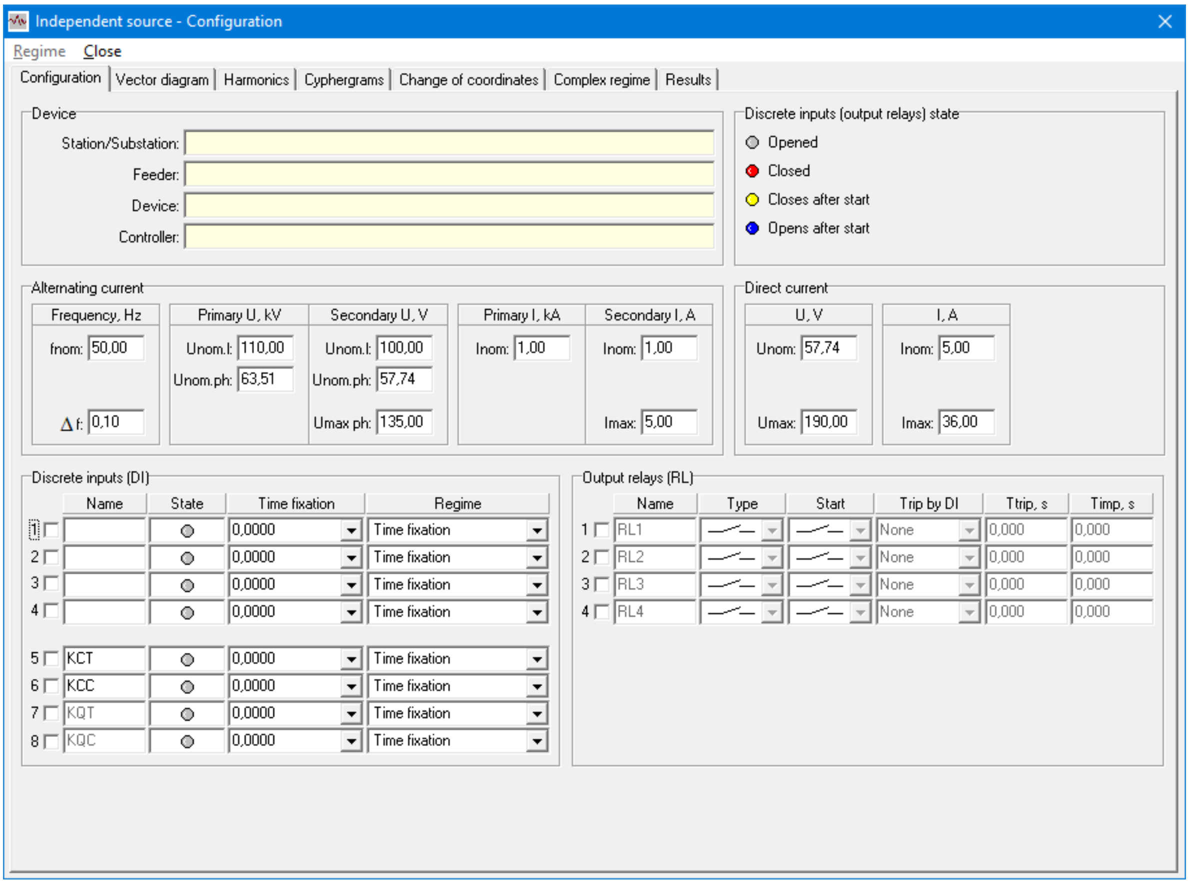


Fig. 3.2. The "Configuration" page of "independent source" module

3.2.3. The "Direct current" field

For testing the direct current devices you must specify the following information in the group field "*Direct current*":

- U_{nom} - nominal DC voltage;
- U_{max} - maximum value of DC voltage;

- I_{nom} - nominal DC;
- I_{max} - maximum value of DC.

Remember that the maximum values of current and voltage are limited by technical capabilities of the "DEVICE". If the user sets higher value, it will be automatically reduced.

In this case, on the PC screen will appear a warning window: "Value can not be greater than ...!"

The linear voltage is determined automatically if the nominal phase voltage is set: $U_{\text{nom.l}} = \sqrt{3} \cdot U_{\text{nom.ph}}$.

If the value of nominal linear voltage is set, then the value of phase voltage will be automatically calculated.

3.2.4. The "Discrete inputs" field

Information about binary inputs is specified in the group field "*Discrete inputs*". It is possible to process information for 8 binary inputs (see Fig. 3.2). Serial numbers of binary inputs on the "*Configuration*" page corresponds to physical inputs of the "DEVICE", to which the terminals of the tested relay device is being connected.

The following information is set for terminals of the device that is tested.

In the *first field* discrete input activates (deactivates). Activated duscrete input will be processed by the device. Only activate discrete inputs that will be used in the testing process.

In the *second field*, enters the name of the discrete input. This name will be recorded in the test protocols and on all other pages of this test module. The length of the name is not limited.

The *third field* shows the state of the discrete input.

In the *fourth field* enters mode of fixation of operation time of discrete input.

There are following possible modes of time fixation:

- Fixation of period of operation of discrete input from the moment when cyphergram is put from the "DEVICE" to the tested device. In this case, in field enters value "0";
- Fixation of period of operation with respect to pre-specified point in time. To do this in the edit field enters a time value, with respect to which will be made the time count of the triggering operation of the contact. If this contact will trigger before the specified time, then the negative value will be fixed;
- Fixation of period of operation with respect to the triggering moment of another contact. You must select the desired contact number from the list in the combined field (the list contains all activated contacts except this particular contact). If this contact triggers before the contact in respect of which we need to fix time of operation, but both contacts triggered during a given cyphergram, then the device will record negative time of operation.

Time diagrams that illustrate the three modes of fixation time for the triggering of the output contact of the device that is tested, are shown in Fig. 3.3.

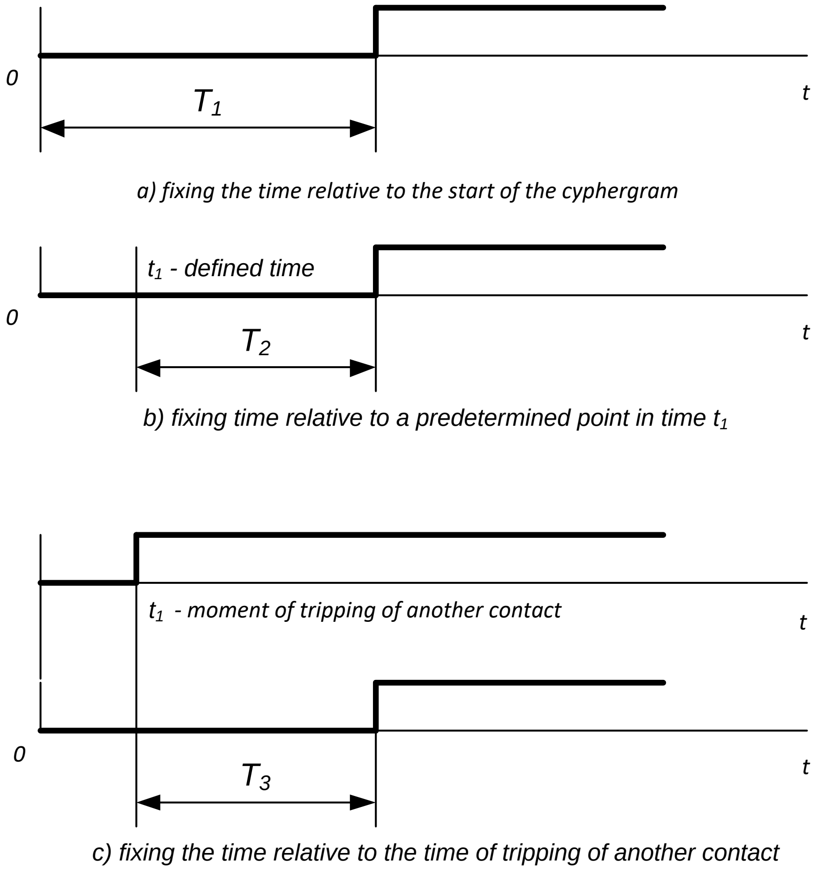


Fig. 3.3. Time diagrams of operation time fixation

In the *fifth field*, select the operating mode of the "DEVICE", depending on the contact triggering.

There are following modes:

- "*Time fixation*". In this mode the triggering of the contact will cause no influence on the operation of the "DEVICE". Only the time of triggering will be fixed according to a given in the fourth field mode of time fixation;
- "*Device halt*". In this mode after the triggering of the contact, operation of the "DEVICE" will stop completely;
- "*Device start*." After triggering of the contact, previously prepared cyphergram is launched. This is described in detail in Section 3.7.2.

3.2.5. The "Output relays" field

There are four output relays, which are used to control the "DEVICE" by external devices.

Information about output relays is specified in the group field "*Output relays*" (Figure 3.2). Serial numbers of output relays on the "*Configuration*" page corresponds to physical outputs of the "DEVICE".

For the operation of output relays the following information must be specified.

In the *first field* the output relay is activated. Activate only those output relay that will be used in the testing process.

In the *second field*, enters the name of the output relay. This name will be recorded in the test protocol and on other pages of the module "*Independent source*".

In the *third field* determines initial state of the output relay - closed or open-circuited (Figure 3.4). The state is selected from the list. Selected initial state immediately realizes physically in the "DEVICE" in case when there is connection.

a) the contact is open *б) the contact is closed*

Fig.3.4 State of output relay (contact)

In the *fourth field* determines the state of the output relay after start.

The *fifth field* sets mode when the output relay will switch opposite in the moment when the selected discrete input of the tested device will switch. Discrete input of the tested device selects from the list (the list contains only activated discrete inputs).

In the *sixth field* specifies the time which the output relay is in the opposite state of the initial.

In the *seventh field* specifies the time during which the output relay is in the opposite state of the initial, counting from the point in time specified in the sixth field.

3.2.6. Discrete inputs (Output relays) state

There is signalling for triggering of the contact of the tested device. Signalling is implemented with the help of image "light bulb" of the corresponding color.

In a group field "*Discrete inputs (Output relays) state*" (Fig. 3.2) the depiction of possible contacts state is shown. Depending on the character of operation the image can be:

- gray colour - contact opened;
- red colour - contact closed;
- yellow colour - contact closes after start;
- blue colour - contact opens after start.

3.3. The "Vector diagram" page

The "Vector diagram" page is designed to form the three-phase harmonic signals of voltages and currents, direct current signals and and to run complex cyphergrams.

General view of *"Vector diagram" (for AC)* page is shown in Fig. 3.5.

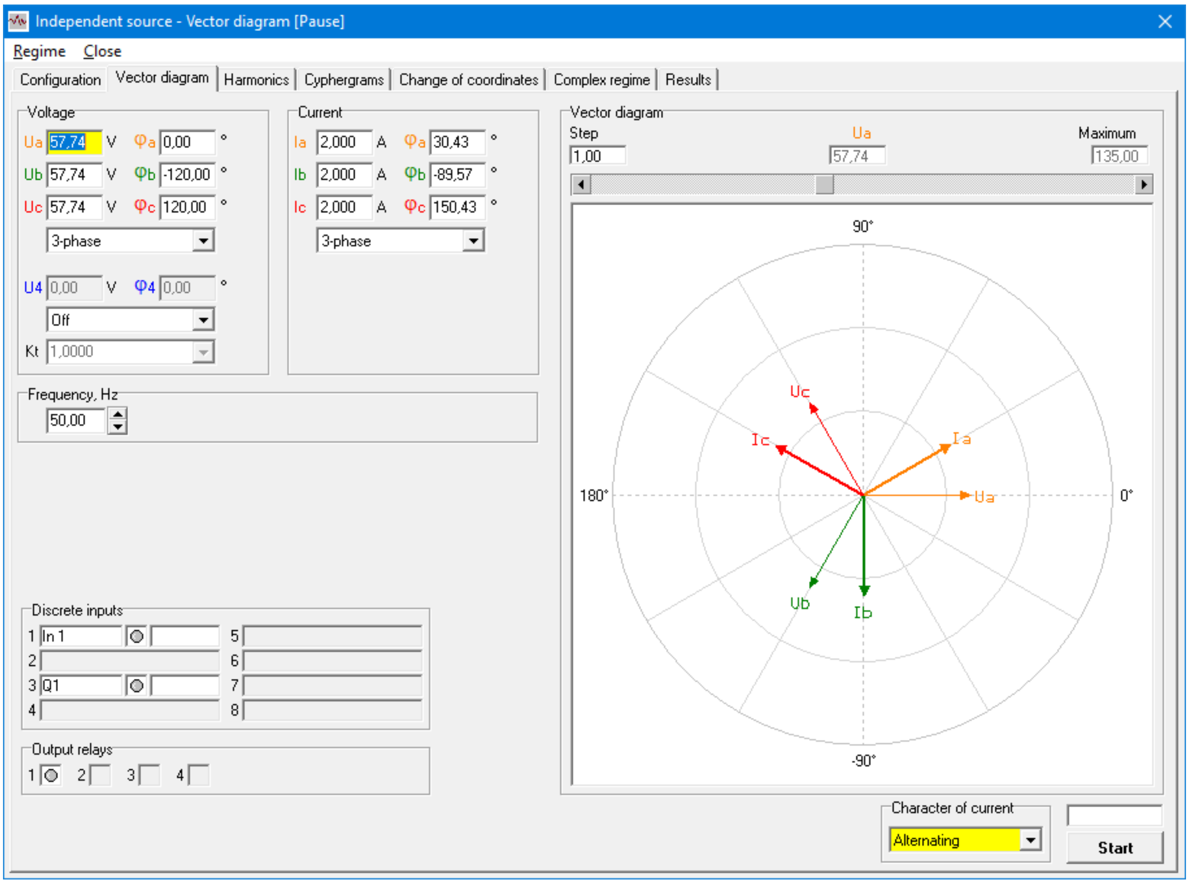


Fig. 3.5. The "vector diagram" page for AC

3.3.1. Formation of phase currents and voltages

On this page you can specify the coordinates of the AC as well as DC mode. Select the desired mode in a combined field "*Character of current*."

The values of currents, voltages, and their initial phases, you can specify using one of the following ways:

- using the keyboard. To do this, in the corresponding edit field you must enter the desired value. After moving to another field or after pressing the <**Enter**> button this value will be fix and will be displayed in the "*Vector diagram*" field by the relevant position of the vector. Remember that the values of currents and voltages will be limited by the maximum values which were specified in the "*Configuration*" page;
- using scrolling. With scrolling, you can smoothly change the value of a selected value (by moving the scrolling slider) or discrete (pressing the arrow keys). To select the appropriate value you must first activate this value. To do this, select the appropriate edit field - "Voltage" ("Current") – the field will be highlighted with yellow colour. Then above the scrolling (scrolling is located in the upper part of the '*Vector diagram*" page) appears the name of the value that can be changed. Above the scrolling are also two fields in which the step of the discrete value change is displayed (set in this field) and its maximum value (set in the "*Configuration*" page);

- directly acting on the corresponding vector shown in the vector diagram. To do this in the "*Vector diagram*" field put the cursor to the end of the desired vector (the cursor will change its shape), and click the left "mouse" button. Holding the left mouse "button", set the desired vector length. At the same time you can control the magnitude of the vector and its phase in the appropriate edit fields "*Voltage*" ("*Current*").

In addition to the values of phase currents and phase voltages user can control other parameters - linear voltages U_{AB}, U_{BC}, U_{CA}; difference of phase currents I_A-I_B, I_B-I_C, I_C-I_A; values of symmetrical components of voltages and currents, respectively *U1, U2, U0, I1, I2, I0*, and the values of active, reactive and total power in phases P_A, Q_A, S_A, P_B, Q_B, S_B, P_C, Q_C, S_C. To do this use a local field menu "V*ector diagram*".

On the "*Vector diagram*" page you can change the frequency of harmonic signals. Frequency values can be changed directly in the edit field and discretely by pressing the appropriate arrow buttons, located to the right of the field. Step of frequency change sets on the "*Configuration*" page.

3.3.2. Modes of the formation of phase currents and voltages

It is possible to set the mode of formation of currents and voltages. Desired mode is set in the combinate field (modes of change for voltage and current are set independently). There are following modes:

- "*Independent*". In this mode, you can independently change the magnitude and phase of each of the vectors of voltage (current);
- "*Three-phase*". This mode provides the ability to set the initial conditions for the symmetric mode. After changing any of the three vectors (in magnitude and phase) two other vectors are changed automatically - their size becomes the same as in the modified vector, and the corresponding phases shift on $\pm 120°$;
- "*Single-phase*". In this mode, initial conditions for all three vectors are the same both in magnitude and in phase. Changing any of the three vectors automatically causes a similar change in the other two vectors. All vectors changes in phase. This makes it possible for current circuits (with parallel connection of all outputs of current amplifiers) to increase the output current by three times;
- *"Two-phase mode (AB - C)."* In this mode, change of the voltage vector of phase A leads to an automatic change of the voltage vector of phase B. Vector of phase B changes in magnitude similar to the vector of phase A but its the phase is shifted by an angle 180°. After the change of the vector of voltage (current) of phase B the vector of voltage (current) of phase A changes similarly. The third voltage vector - phase C can be changed independently. For currents this mode is slightly different. The currents of phases A and B changes in phase and current of phase C changes independently. This makes it possible to test complex devices of the relay protection during simulation of two-phase short-circuit;
- "S*ymmetrical components*". In this mode, you can set the values of positive, negative and zero sequences of currents and voltages. The values of the components and their initial phases

can be specified in the relevant edit fields (after entering this mode the edit fields for phase values change into edit fields for symmetrical components), and also with the help of scrolling. In the "*Vector diagram*" field will be displayed phase values of current and voltage that correspond to specified values of symmetrical components and that will be generated by the "DEVICE". Remembered that the system provides automatic control of the phase values by the limits defined on the "*Configuration*" page. In case when user sets the value of one of the symmetrical components, that would increase the phase value over the allowable level, the system will ignore the change and leave the previous value;

- "*The power P and Q*". In this mode, the user can set the values of active and reactive power, which can generate a "DEVICE" to the tested device. After switching to this mode, in the edit fields where phase values or symmetrical components were set, you must enter values for active and reactive power. Power values are set independently for each phase. This mode has the following feature. If the mode "*P, Q*" is set in the field for phase voltages, then automatically in the field of phase currents sets the mode "*Independent*" and in reverse: if the mode "*P, Q*" is set in the field for phase currents, then automatically in the field of phase voltages sets the mode "*Independent*". If the power values are set in the fields for voltages, then for the specified powers and currents, the voltages will be calculated according to the equation: *P=Real(U·I), Q=Im(U·I)*. In the case when the power values are set in the field of currents, then automatically the calculation of currents, which correspond to the specified power and voltage values, take place. Power value can also be set with the help of scrolling. The "*vector diagram*" field represents the vector diagram of phase currents and voltages that correspond to the specified powers. As in the symmetrical components mode, the system provides automatic control of the values of phase currents and voltages. In case when user sets the value of power that will increase the value of phase voltage or current over the allowable level, the system will ignore the change and leave the previous value.

3.3.3. Start mode of the cyphergrams

After start cyphergrams are generated that corresponds to the harmonic signals (voltages and currents) formed on this page.

Remember that the signals that are shown on the page "*Vector diagram*" are presented in the format of effective values, and the "DEVICE" will generate harmonic signals in instantaneous coordinates by the following law:

$$\begin{aligned}
u_A &= \sqrt{2} \cdot U_A \cdot sin(\,2 \cdot \pi \cdot f \cdot t + \varphi_{AU});\\
u_B &= \sqrt{2} \cdot U_B \cdot sin(\,2 \cdot \pi \cdot f \cdot t + \varphi_{BU});\\
u_C &= \sqrt{2} \cdot U_C \cdot sin(\,2 \cdot \pi \cdot f \cdot t + \varphi_{CU});\\
i_A &= \sqrt{2} \cdot I_A \cdot sin(\,2 \cdot \pi \cdot f \cdot t + \varphi_{AI});\\
i_B &= \sqrt{2} \cdot I_B \cdot sin(\,2 \cdot \pi \cdot f \cdot t + \varphi_{BI});\\
i_C &= \sqrt{2} \cdot I_C \cdot sin(\,2 \cdot \pi \cdot f \cdot t + \varphi_{CI}),
\end{aligned} \tag{3.1}$$

where - U_A, U_B, U_C, I_A, I_B, I_C, φ_{AU}, φ_{BU}, φ_{CU}, φ_{AI}, φ_{BI}, φ_{CI} effective values of phase voltages, currents and their initial phases; f - the specified frequency, Hz; t - time, s.

Generation of harmonic signals is carried out by the "DEVICE" within a specified time, from the moment $t=0$.

To start the cyphergram of harmonic signals you need to click "**Start**" button - the "DEVICE" will generate a harmonic signal by equation (3.1). In generation mode the name of the button will change to "**Stop**" and will blink, and in the field above the button the time of generation will display.

Generation may be terminated as follows:

- by pressing the "**Stop**" button. After this, the generation of harmonic signal will stop and the field displays the total time of generation;
- by triggering of contact that is programmed in the "*Device halt*" mode (see Section 3.2.4).

In the "*Discrete inputs*" field reflects the real state of binary inputs (regardless of whether or not generation take place) by the corresponding signalling lamp. In addition, in the process of generation, also displays the time of the first triggering of appropriate binary input. Total time (from the start of the generation) is shown in green, and the relative - in red. For example, if value "*Time fixation*" in the configuration of the discrete input is different from zero, it will be fixed relative time red.

In the "*Output relays*" field displays their actual state. In addition, the user can control the state of the output relay by double "clicking" in the field with the image of signalling lamp of the corresponding output relay.

3.3.4. Formation of the direct current signals

To test the devices that run on direct current you must change the "*Vector diagram*" page to the mode of displaying DC. To perform this you must set mode "*Direct*" in the list of "*Character of current*" field on the page "*Vector diagram*" (see Fig. 3.5). After this the page "*Vector diagram*" takes the form (see Figure 3.6).

On this page you can specify values for direct voltages and currents similarly as for alternating current.

Sign of direct voltage and current sets in a field on the left side of the value of voltage or current. Remember: to change the sign of the value just double-click the appropriate box.

There are following voltages and currents mode changes that are set in the "*Mode change*":

- "*Independent*". In this mode, you can independently change the values of the three voltages (currents);
- "*A - B - C*" - three phase mode. This mode provides the ability to set the voltages (currents) for the symmetric mode. After changing any of the three voltages (currents), the other two values changes automatically - their values became the same as in the modified value;

- "*A - B*", "*C - A*", "*B - C*" - two-phase mode. In this mode, the change of the voltage A leads to an automatic change of voltage B. The voltage B alternates in magnitude similar to voltage A, but with the opposite sign. The third voltage C alternates independently. Similarly, voltage A changes after changing the voltage B. Changing of currents in this mode is somewhat different. Currents A and B alternate with the same sign, and the current C alternates independently. Similarly, changing of voltages and currents in modes *C - A*, *B – C* proceeds. For convenience, in this mode in separate fields, located below the "*Diagram*" field, values of voltage differences and the sum of the currents outputs.

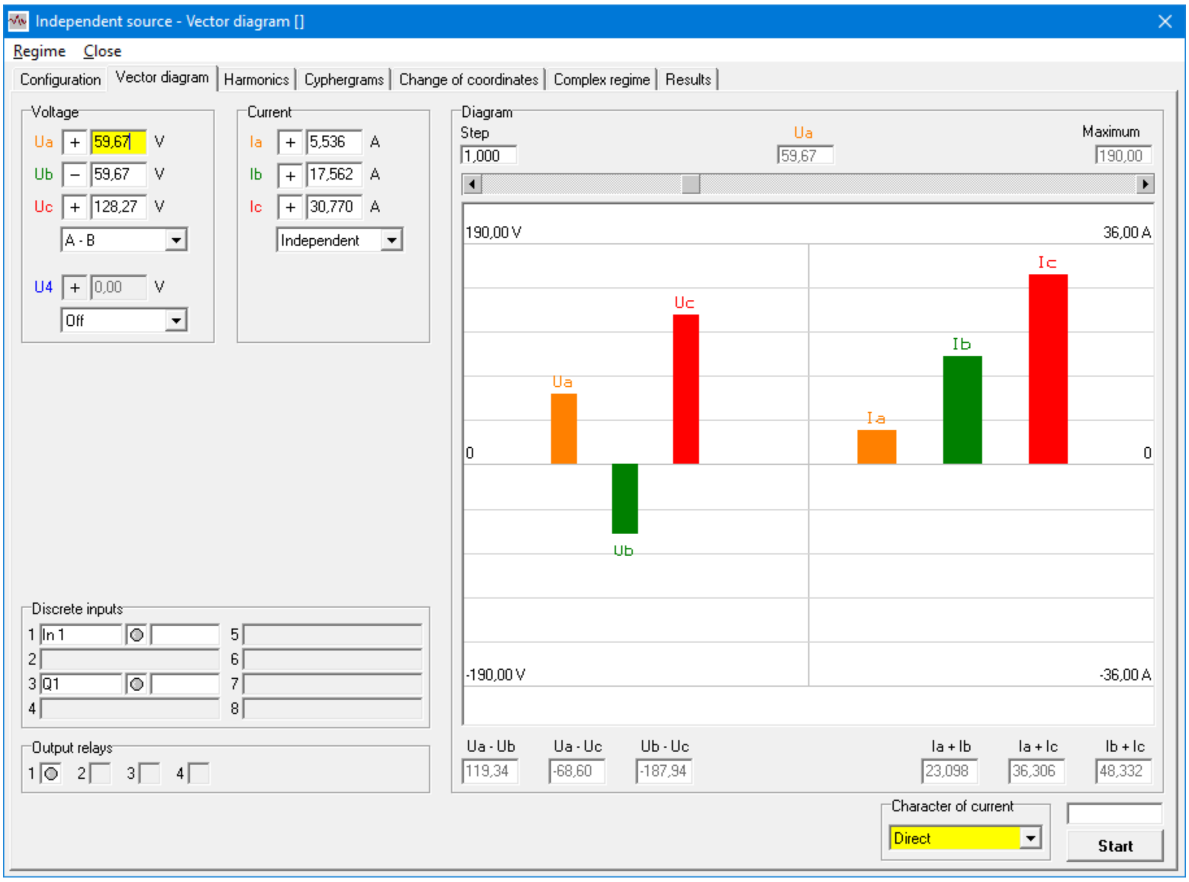


Fig. 3.6. The "Vector diagram" for DC

3.4. The "Harmonics" page

The "Harmonics" page is designed for the formation of complex harmonic signals, with account of the higher harmonic components, subharmonics and the aperiodic component.

The overall view of the page "*Harmonics*" shown in Fig. 3.7.

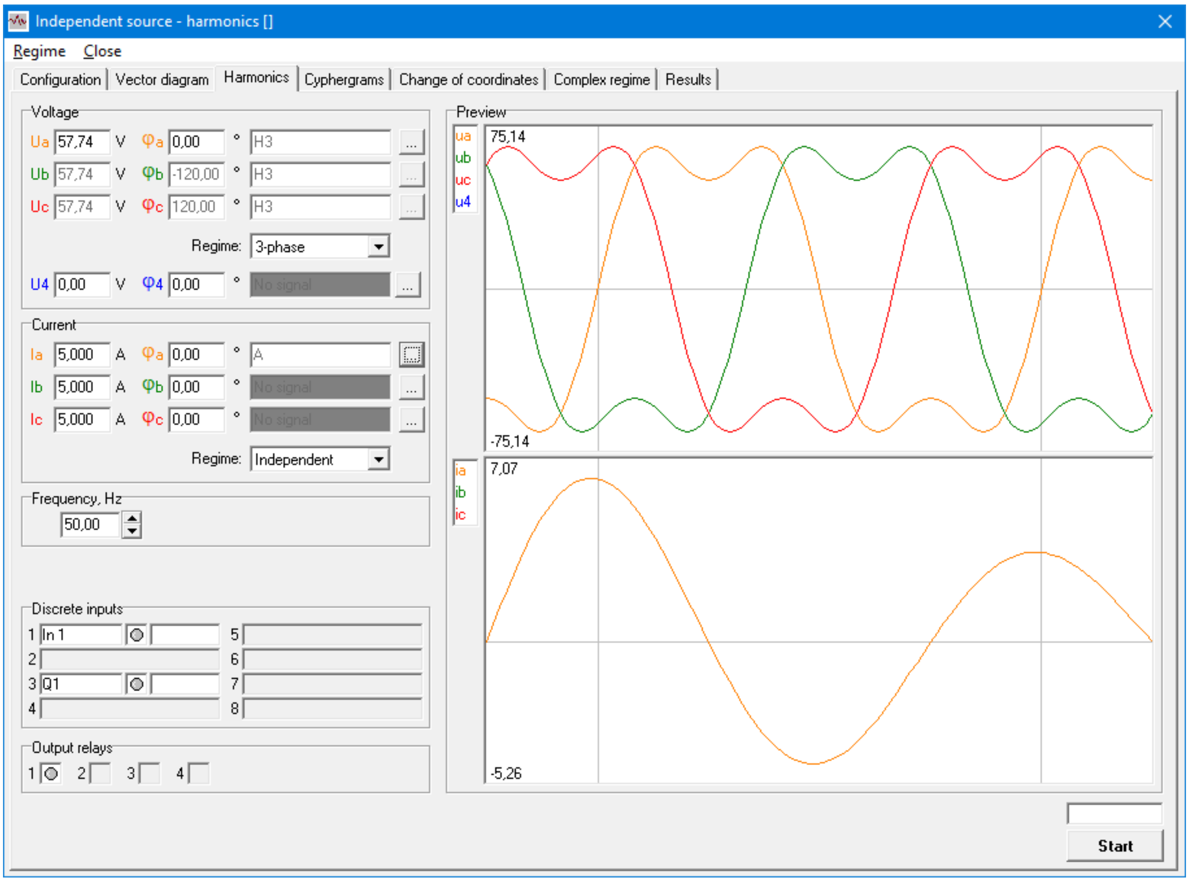


Fig. 3.7. The "Harmonics" page

3.4.1. Formation of phase currents and voltages

To form the harmonic components it is necessary to set in the "*voltage*" and "*current*" edit fields the effective values of corresponding voltages and currents, in relation to which shall be calculated higher harmonic components, the initial phases. Also you can choose from the library the desired form of the signal.

Change of the basic frequency of harmonic signal performs in the edit field "*Frequency*".

There are two modes of formation of the phase voltages and phase currents, which can be set in the "*Mode*" field:

- "Independent";
- "3-phase".

In independent mode, the maximum effective values of all three voltages, currents and their phases are set independently.

In 3-phase mode active windows are only for voltages and currents of phase A. If you change the effective value of voltage or current of phase A, the effective values of voltages and currents of phases B and C automatically shall be the same. After changing the initial phase of voltages and currents of phase A, the initial phase of voltages and currents of phases B and C are automatically transferred to the relative value of ±120˚ respectively.

To select the harmonic components from the library you must click the button in the "*Voltage*" and "*Current*" field - a dialog box appears (Figure 3.8).

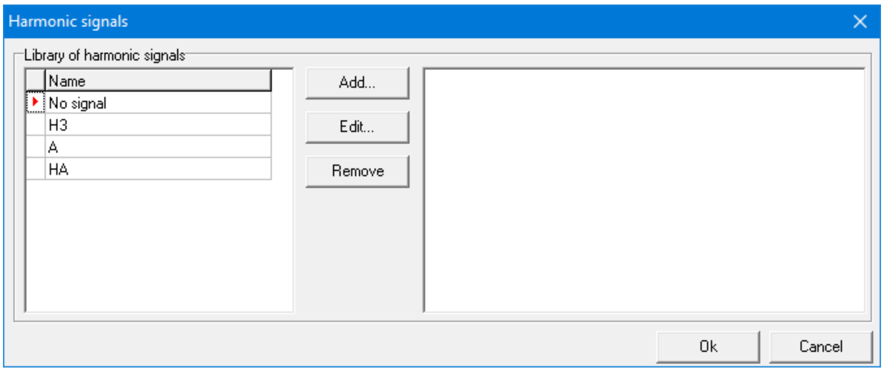


Fig. 3.8. Library of harmonic signals

This window contains list of the previously formed harmonic signals.

This library can be edited - create new signals, edit existing ones, delete unneeded. For this purpose function buttons "**Add**", "**Edit**", "**Remove**" are provided.

Remember there is an entry in the list "*No signal*" that can not be removed or edited. This entry is used when you want to set the zero level of voltage or current signal.

To select the desired signal you must select it from the list and click "**Ok**" button.

In the right part of the window displays a form of complex harmonic signal, selected from the list: green colour depicts the separate harmonic components, and other colour - the resulting signal.

3.4.2. Creating a new harmonic signal

In case when you want to create a complex harmonic signal and record it in the library, in a window (Figure 3.8) you must click "**Add**" button – a window will appear: "*Formation of the harmonic signal*" (Fig. 3.9).

In the edit field "*Name*" you must enter a name for the new signal. The name is required and must be unique.

Complex harmonic signal is formed by the expression as the sum of harmonic signals of higher harmonics, subharmonics and aperiodic component

$$a(t) = \sum_{i=1}^{n} (\sqrt{2} \cdot A_i \cdot sin(2 \cdot \pi \cdot f \cdot N_i \cdot t + Phi_i) \cdot e^{-k_i \cdot t}), \qquad (3.2)$$

where n – number of harmonics; A_i – value of i-th harmonic as a percentage of the value of the signal specified in the corresponding fields "*Voltage*", "*Current*" (Fig. 3.9); f – basic frequency (specified in the "*Frequency*" field on the "*Harmonics*" page (Fig. 3.9)); N_i – serial harmonic number relative to the basic frequency; t – time; Phi_i – initial phase of each harmonic; k_i – damping factor of aperiodic component.

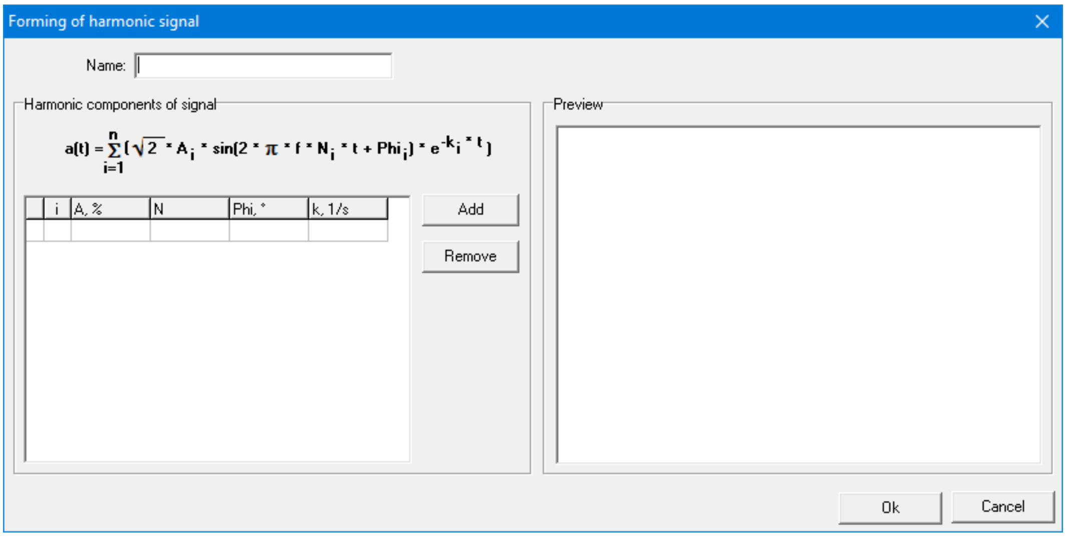


Fig. 3.9. Formation of the harmonic signal

To add a new component of the signal you must click "**Add**" button. In the list a new line will appear, in which the information about the component is set.

It is possible to delete the individual components of the signal. To do this, use the button "**Remove**".

During the formation of the signal in the "Sample" field will be displayed form of signal.

To form the signal without aperiodic component, you must assign damping factor k_i equal 0.

If you want to create a signal that contains only the aperiodic component, you must specify the following information:

- initial value of the aperiodic component, which is determined from the expression $A_i/\sqrt{2}$;
- serial number of harmonic $N_i = 0$;
- value of the initial phase $Phi_i = 90°$;
- damping rate of aperiodic component set with the appropriate value of the coefficient k_i.

If you want to create a subharmonic component, you must specify the sequence number less than 1. For example, to set the subharmonic frequency of 25 Hz at basic frequency 50 Hz, the N_i must be set to the value of 0.5.

An example of the formation of a complex harmonic signal shown in Fig. 3.10.

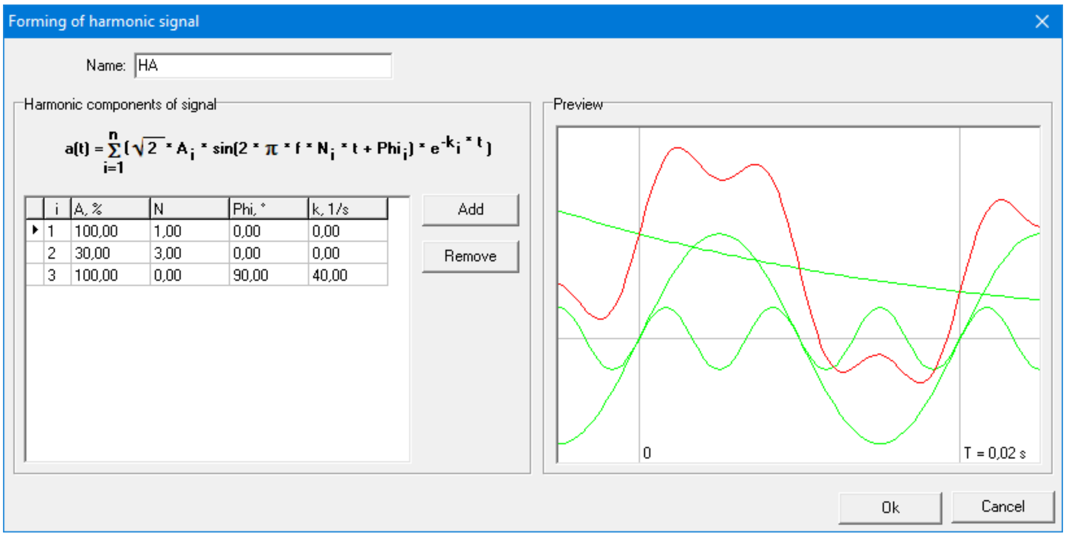


Fig. 3.10. An example of the formation of a complex harmonic signal

After completion of signal formation you must click "**Ok**" button (Figure 3.10) - a new complex signal is written to the library.

3.4.3. Running cyphergrams with complex harmonic signal

Running cyphergram that correspond to the complex harmonic signal, formed on this page is performed by pressing the button "**Start**" (Figure 3.7). After this, the information of the harmonic signal is loaded into the "DEVICE". The loading process is displayed in the dialog box. After downloading process completes, the "DEVICE" wil start generating the signal.

If the signal does not contain aperiodic component, the "DEVICE" will generate a signal until user deliberately stops the process, by pressing the "**Stop**" button or in the case of operation of discrete input that is configured in the "*Device halt*" mode (see Section 3.2.4).

If the signal contains aperiodic component, then after pressing the "**Start**" button, a dialog box opens in which you can specify period of generation of complex signal. By default, this period calculates as: $T = 3 \cdot \tau_i = 3 \cdot 1/k_i$, where k_i- minimum damping factor according to (3.2). User can adjust this period. Generation begins after pressing "**Ok**" button in this window. In this case, the signal will be generated over a period of time T. Signal generation can be stopped earlier by pressing "**Stop**" button or in case of binary input operation that is configured in the "*Stopping device*" mode.

3.5. The "Cyphergrams" page

The "Cyphergrams" page is designed to restore in real time by the "DEVICE" the form of currents and voltages that were formed in digital format by other digital relay protection devices or various digital models.

Overall view of the "*Cyphergrams*" page is shown in Fig. 3.11.

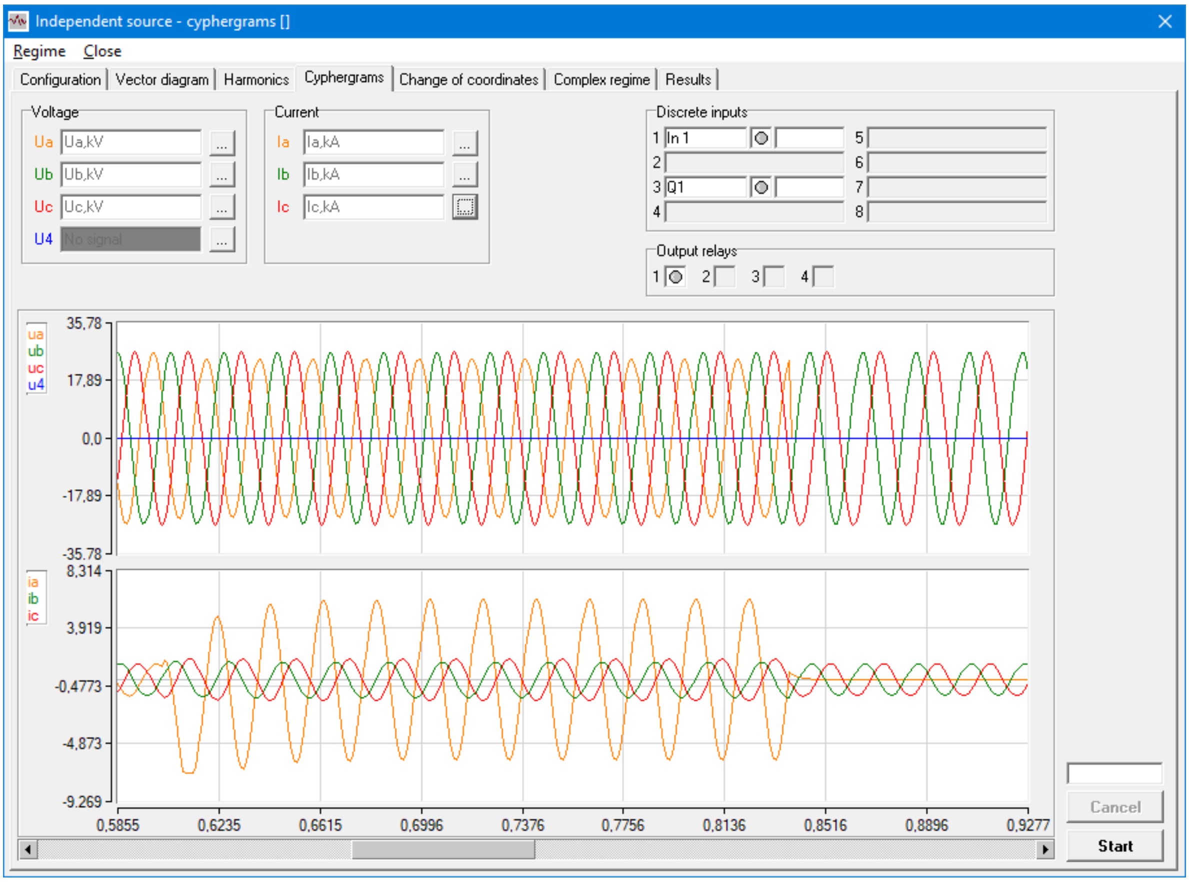


Fig. 3.11. The "Cyphergrams" page

3.5.1. Formation of phase currents and voltages

Formation of phase currents and voltages is performed in the corresponding fields "*Voltage*" and "*Current*" (Fig. 3.11). To do this, click the button to the right of the appropriate field. After this the "*Signal selection*" window will appear (Fig. 3.12).

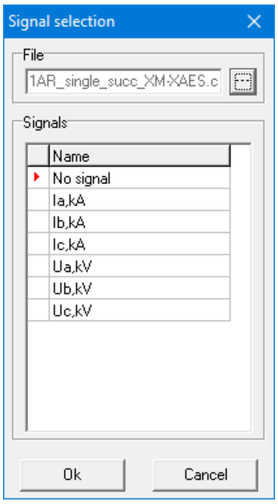


Fig. 3.12. Signal selection

In the "*File*" field user selects the file that stores the necessary information. To do this, click on the button to the right of the "*File*" field - a standard file selection dialog box appears (Figure 3.13).

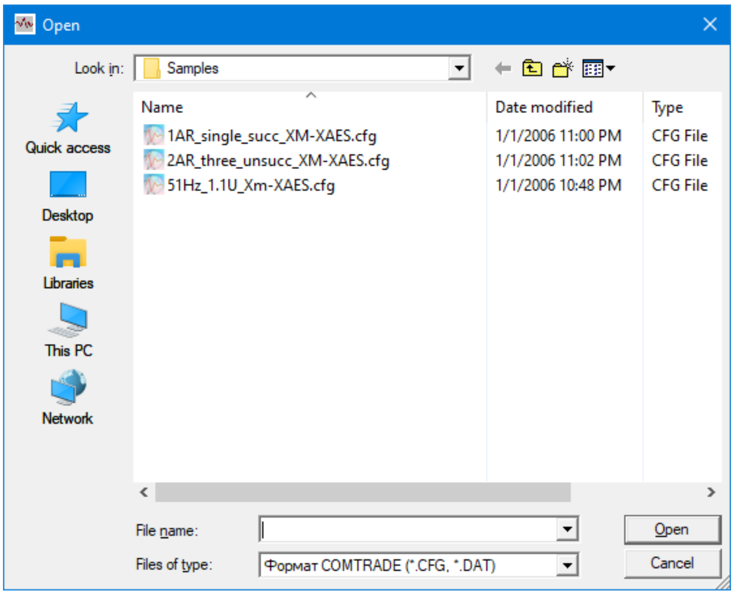


Fig. 3.13. File selection

After selecting the file (the system supports the COMTRADE format) in the "*Signal selection*" window in the "*Signals*" field (see Fig. 3.12) appears the list of signals that are stored in this file. From this list, select the appropriate signal and pressed "**Ok**" button. Information is read from the selected file. After the process of reading finishes, the name of the selected signal displays in the corresponding window field (Fig. 3.11), and graphic form of signal displays in the field, which is located at the bottom of the page.

In the "*Signal selection*" field (Fig. 3.12) is a line "*No signal*", activating which you can write zero signal level to the selected channel of voltage or current.

Based on the selected signals, mode coordinates forms which will be generated by the "DEVICE"

Remember that for each channel information can be read from different files where it can be recorded from different devices and with different sample rate.

Then in the displaying field you can perform the following operations with the selected signals: scaling, choosing a certain time periods, view instantaneous coordinates values etc. Choosing the appropriate command is performed from the local menu (Figure 3.14).

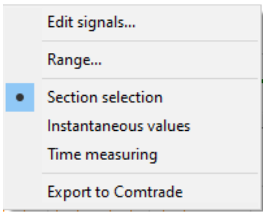


Fig. 3.14. Local field menu for displaying signals

The "*Edit signals*" command.

After launching command the following window will appear (Figure 3.15).

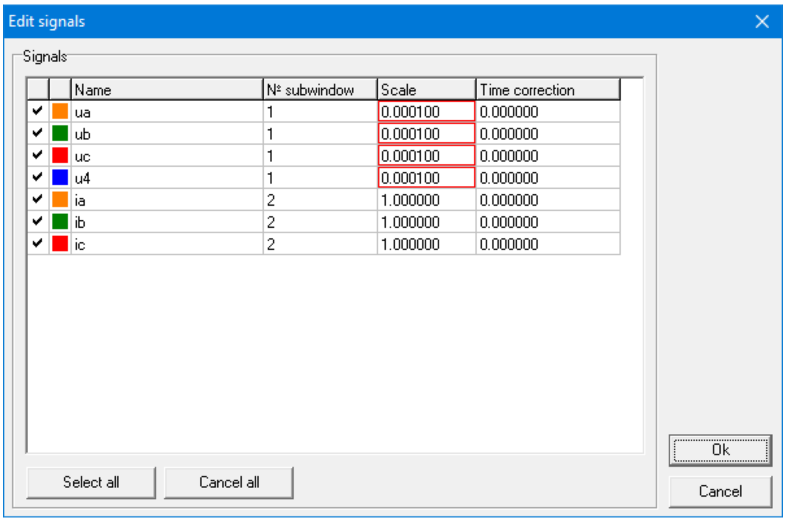


Fig. 3.15. "Edit signals" window

In this window you can change the scale of the coordinate mode – to do is in the "*Scale*" field, opposite of the desired coordinate you need to enter a scaling factor - all the values of this coordinate will be multiplied by the value of this factor. Remember that the values of the coordinates will be limited to the maximum values of voltage and current, which were specified on the "*Configuration*" page. Therefore it is necessary to scale these values.

You can also make a shift of coordinate mode by time. To do this, in the "*Correction of time*" field, opposite of the desired coordinate you need to set time offset in seconds - the given coordinate will shift for a specified amount of time with respect to the rest of the coordinates.

In the "*№ of subwindow*" field you can specify the number of subwindows, in which coordinates should display. By default, the first subwindow displays voltages, the second - currents.

In the first field there is an opportunity to select coordinates for display. By default all coordinates should display. Using the "**Select All**" and "**Cancel All**" buttons you can select or cancel displaying all of the coordinates. But at least one coordinate for display must always be specified. Otherwise, the following message window will appear (Figure 3.16).

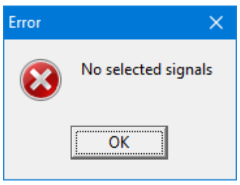


Fig. 3.16. Error message – appears in case when no signal is selected

Remember, selecting of coordinates in the "Edit signals" window (see Fig. 3.15) is only for display.The "DEVICE" will generate all signals with respect to scaling and to time correction.

After making changes click on the "**Ok**" button.

When you write cyphergram to the library of modes or launch generation process by pressing "**Start**" button – defined mode coordinates will be corrected considering changes made. After you reactivate the window "*Edit Signals*", in the "*Scale*" fields will be written value "1", and in the "*Time correction*" fields -"0 ".

The "*Range*" command.

With the help of this command (Figure 3.14) you can chose individual segments of cyphergram on a given range of display. After activating the command "*Range*", the PC screen will display following window (Figure 3.17).

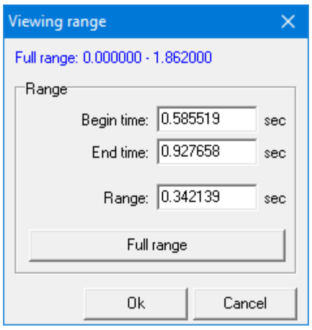


Fig. 3.17. Window of change of the time range of cyphergram

With the help of this window you can select the desired time range of cyphergram. To do this in the fields "*Start time (sec)*" and "*End Time (sec)*"you must enter the desired values of time range of cyphergram to display. If the user sets start time or end time that exceeds the cyphergram limits, the system will automatically restrict the values to a minimum or maximum values of the time range of cyphergram. To restore the full time range of cyphergram click on the "**Full range**" button. After making the changes click on the "**Ok**" button.

Remember, after saving cyphergrams to the library of modes or after pressing the "Start" button for generating cyphergrams, only selected segment of cyphergram will be saved!

The "*Select of the segment*" function

With the help of this function you can select a desired segment of cyphergram. To do this, after activation this function, use the "mouse" to select the desired segment directly from the field for cyphergram display.

Remember, that changing of range is also possible using the horizontal scrolling at the bottom part of the display. This is described in detail in Section 9.2.3.1.

The "*Instantaneous values*" function.

The use of this function allows you to view instantaneous coordinates of cyphergram.

After activating this function, you need to move the "mouse" pointer to desired location in the field with cyphergram and click on the left "mouse" button - a window will appear, that displays time and instantaneous coordinates of mode (Figure 3.18). Holding the left mouse "button", you can move the pointer along the time axis - instantaneous values of coordinates shall be displayed in the instantaneous values window. These values correspond to the pointer position.

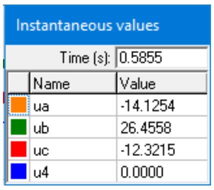


Fig. 3.18. Instantaneous coordinates values of cyphergram

The "*Export to Comtrade*" command saves developed cyphergrams to international format Comtrade.

3.5.2. Starting cyphergrams

Start is performed by clicking on "**Start**" button (Figure 3.11). After this, the information of the cyphergram loads into the "DEVICE". The loading process is displayed in the dialog box. This process can be stopped by pressing "**Cancel**" button in this window. After downloading, the name of the button "**Start**" changes to "**Run**". By pressing this button begins the process of generation of voltages and currents by the "DEVICE". Start of the cyphergram may perform multiple times.

Start of generation can also happen in the case of discrete input operation, if this input is configured in the "*Device start"* mode.

If you want to stop the process of generation you need to press the flashing button "**Stop**".

After completing the session you must click "**Cancel**" button – the cyphergram that previously was loaded into the "DEVICE" will be deleted.

3.6. The "Change of coordinates" page

The "Change of coordinates" page is designed to run mode of automatic change (increase, decrease) of mode coordinates - voltages and currents for determining, for example, the parameters of operation of the devices, test these parameters and compare them with the set values.

Total view of the page "*Change of coordinates*" (for alternating current) is shown in Fig. 3.19

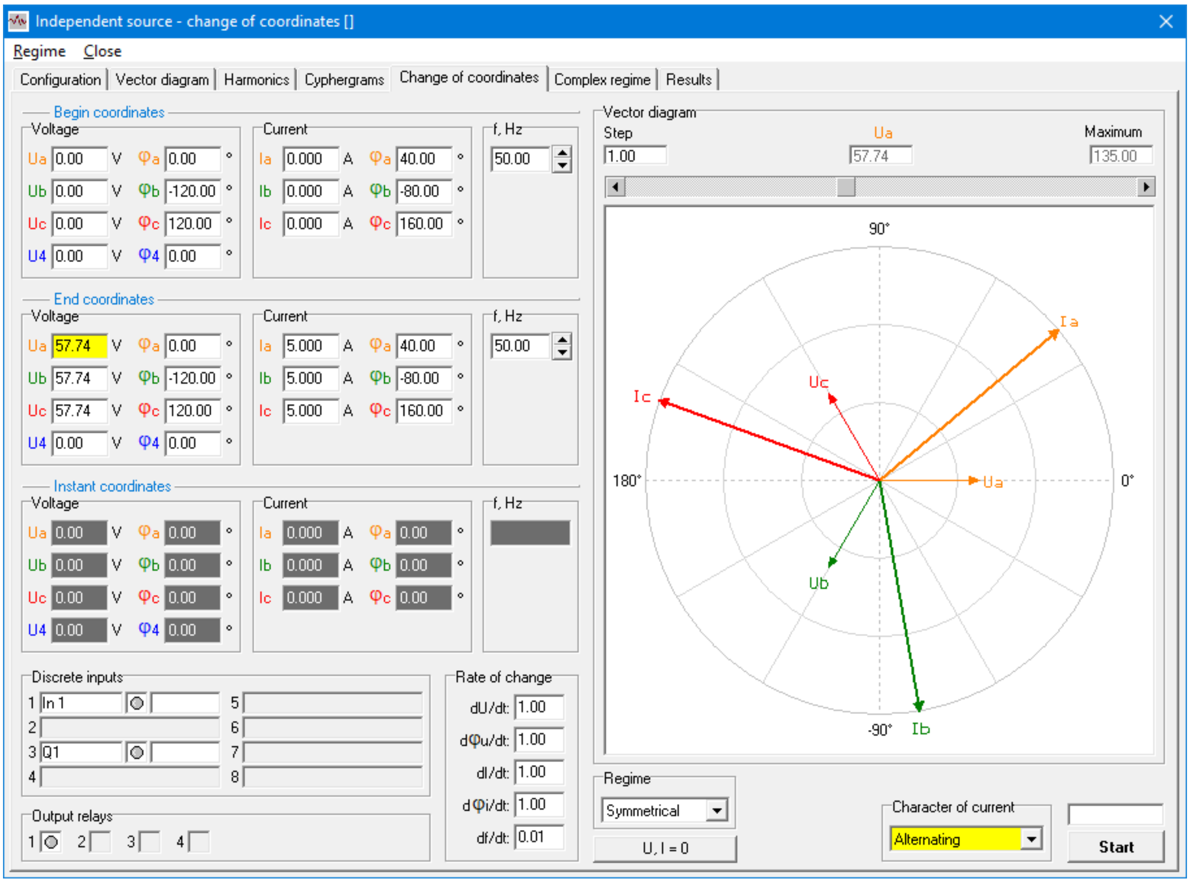


Fig. 3.19. The page "Change of coordinates" for alternating current

3.6.1. Formation of alteration of alternating voltages and currents

To run mode of automatic alteration of mode coordinates, you must set the start and end values of voltages, currents and their phase and frequency.

This information sets in corresponding fields: "*Start coordinates*" and "*End coordinates*". Information sets similarly as for "*Vector diagram*" page. This process is described in detail in Section 3.3.

In the "*Vector diagram*" box may display either vectors of start coordinates or end coordinates depending which field is active ("*Start coordinates*" or "*End coordinates*"). In the active field one of the coordinates is highlighted in yellow colour.

Formation of vector diagrams can be based on one of two modes:

- "*Independent*" - each vector of vector diagram of voltages or currents is formed independently;
- "*Symmetrical*" - change of one of the vectors leads to an automatic symmetrical change in the other two vectors.

The mode is set in the "*Change mode*" field. In addition, the possibility is provided to set zero values of currents and voltages. To do this, press the "**U, I = 0**" button - the values of vectors of voltages and currents of active field vector diagram became equal 0.

To set the rate of change of voltage and current, the field "*Rate of change*" is provided. In this field you can individually set the rate of change of voltage and its phase, respectively *dU/dt*, $d\varphi_u/dt$, rate of change of current and its phase *dI/dt*, $d\varphi_i/dt$, and the rate of change of frequency *df/dt*.

3.6.2. Formation of change of DC voltages and currents

To test the relay devices that are operating on direct current, you must set the mode "*Direct*", which selects from the "*Character of current*" field. The "*Change of coordinates*" field will look like shown below (Figure 3.20).

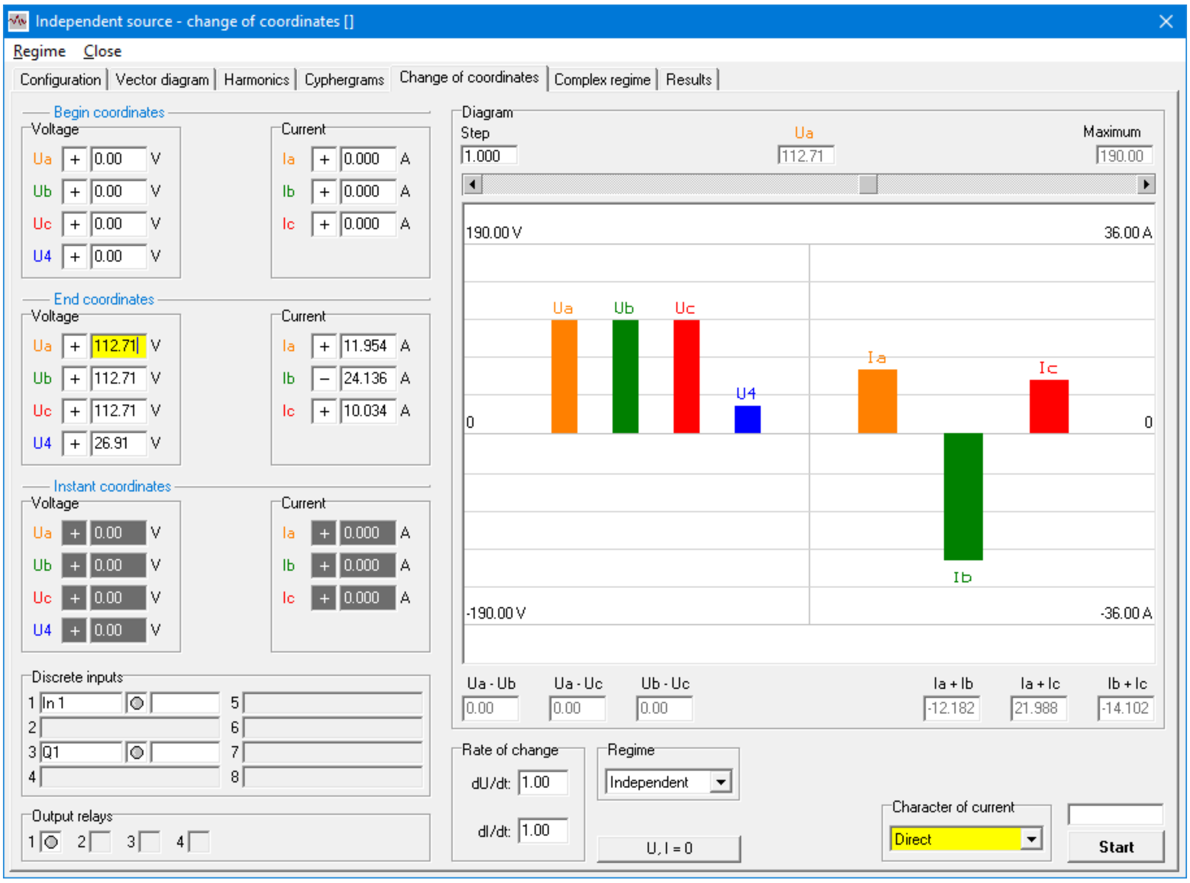


Fig. 3.20. The page "Change of coordinates" for DC

3.6.3. Running cyphegrams

To start generating process - press the "**Start**" button - the "DEVICE" starts generating alteration of voltages and currents. In generation mode the button text will change to "**Stop**" and will flash, and in the field above the button the time of generation will display.

Generation may be terminated as follows:

- by pressing the "**Stop**" button. After this, generation stops and the field displays the time, during which it took place;

- by operation of contact, that is programmed in the "*Device halt*" field (see Section 3.2.4).
- after voltages and currents reach their defined end value.

After start, in the fields "*Current coordinates*", "*Vector diagram*" (Figure 3.19) or "*Diagram*" (Figure 3.20) the process of changing the mode coordinates will display.

3.7. The "Complex regime" page

The "Complex regime" page is intended to form complex cyphergrams for complex testing of relay protection devices. Complex cyphergrams are forming on the base of simple cyphergrams, formed on pages "Vector diagram","Harmonics", "Cyphergrams", "Change of coordinates".

Complex regime can be formed for both alternating and direct currents. Selection is performed by dependent switches: "**AC**", "**DC**".

The overall look of the page "*Complex regime*" for alternating current is shown in Fig. 3.21.

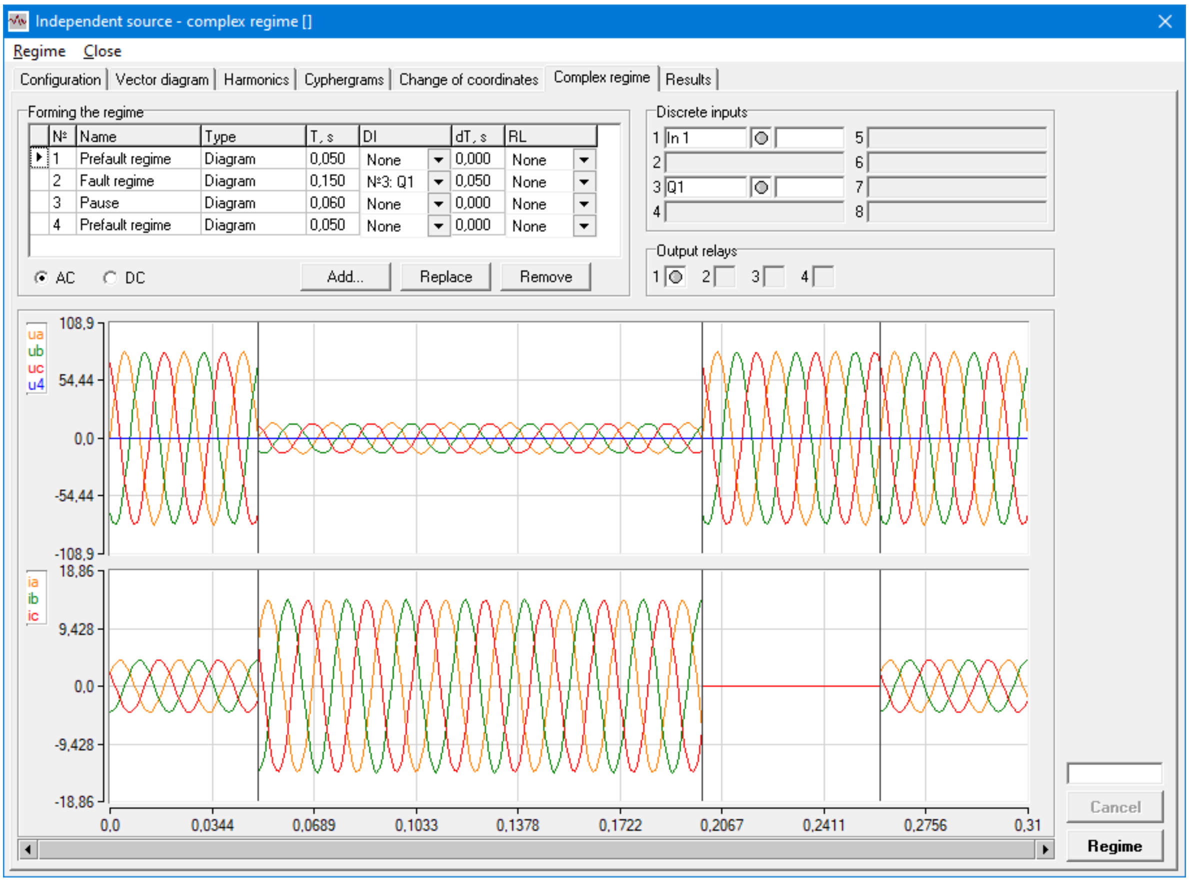


Fig. 3.21. The "Complex regime" page

3.7.1. Formation of the complex regime

Complex regime is created on the base of a library that stores simple modes, previously formed on the previous pages. Formation of a complex mode is performed in the "*Forming the regime*" field (Figure 3.21).

To add a simple mode from a library - click on the "**Add**" button – appears a window that contains a list of AC modes, that are in a library (Figure 3.22). If the complex mode specified as "**DC**", then the list will display only DC modes.

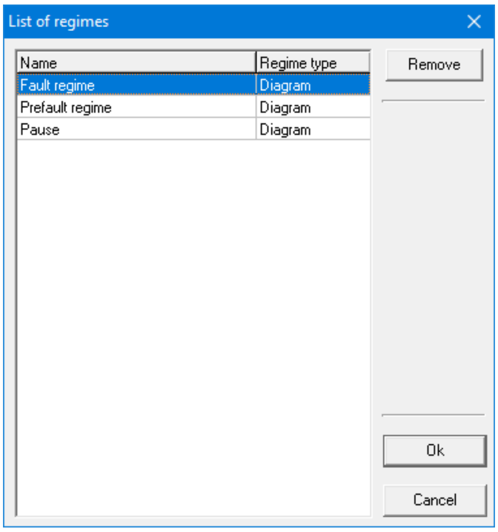


Fig. 3.22. List of modes

The "*Name*" field of the "*List of regimes*" window suggests mode names, and the "*Regime type*" field - the type of mode that corresponds to the page where it was formed: "*Diagram*" - "*Vector diagram"* page; "*Harmonics*" - "*Harmonics*" page; "*Cyphergarms*" - "*Cyphergarms*" page; "*Change of coordinates*" - "*Change of coordinates*" page.

From the list, you must select the desired mode and click "**Ok**" button. In the "*Forming the regime*" field (see Fig. 3.21) then appears a new line with the following information:

- serial number of simple mode - "*№*";
- name of simple mode - "*Name*";
- type of simple mode - "*Type*";
- time for which it must be implemented in this advanced mode - '*T, s*". After you select the simple mode, this position will display "0". Therefore, in this field you must enter a desired time value. Note, that for modes "*Cyphergrams*" and "*Change of coordinates*", the time is determined during the formation of these modes and it can not be edited;
- stopping simple mode when the defined contact "*DI*" operates. The contact selects from the list. If the user selects a contact from the list, then this simple mode will stop when this contact operates. If the contact did not operate during that time, then the simple mode should. If the user selects "*None*" from a list, then this simple mode stops after the timeout. The use of this mode allows you to simulate operation of the circuit breaker after the operation of relay protection;
- increasing time of generation in the simple mode - "*dT, s*" By default, the value of this field is "*0*". In case when you need to increase the generation time *T* of the simple mode, for

example, to simulate the actual time of closing or opening of the circuit breaker, you must specify the appropriate value in this field.

The information for the rest of the simple modes that build an advanced mode is entered similarly.

Remember that new mode will be added after selecting line.

To delete any simple mode from the advanced mode, you need to select the appropriate line with information about it and press "**Remove**" button.

Also the ability is provided to replace the selected simple mode for the other from the library. To do this, click "**Replace**" button.

Graphical form of the advanced profile is displayed in the corresponding field. In this field you can do various operations with an advanced mode, such as select individual time segments, view instantaneous values of coordinate etc. The choice of the desired operation performs in the local menu. Operations with this menu are described in detail in Section 3.5.1. The difference is in the implementation of the command "*Edit Signals*" – there are blocked fields "*Scale*" and "*Time correction*".

3.7.2. Launching the cyphergram of the complex regime

Launching the cyphergram of the complex regime is done by pressing the "**Regime**" button. After this, the complex regime loads to the "DEVICE". The loading process is displayed in the dialog box. The loading process can be stopped by pressing "**Cancel**" in this window. After downloading, the name of the button "**Regime**" changes to "**Run**". By pressing this button, the process of generation of voltages and currents by the "DEVICE" begins.

Start of generation can also happen in the case of discrete input operation if it is configured for the "*Device halt*" mode.

After the process of generation finishes, the name of the button again will be "**Run**" - the system is ready to re-generate cyphergram of the complex regime. Start can be performed repeatedly until you press "**Cancel**" button.

If you want to stop the generation when the time has not ran out, you press the flashing button "**Stop**".

After completing the session you must click "**Cancel**" button - loaded into the "DEVICE" cyphergram of advanced mode will be deleted.

3.8. The "Results" page

On the "*Results*" page in graphical form displays information about the process of generating voltages and currents as well as the state of selected binary inputs and outputs over the generation time. You can display the voltages and currents in instantaneous or effective values.

Information outputs on this page after testing mode, which was launched from any active page of the "*Independent source*" module - "*Vector diagram (AC and DC)*", "*Harmonics*", "*Cyphergrams*", "*Change of coordinates (AC and DC)*","*Complex regime (AC and DC)*", completes.

Operating with information in the display field is performed similarly as with the cyphergrams – you can select individual fragments of cyphergram, view the instantaneous values of currents and voltages at any point in time, record test results in a separate file etc.

Remember that test results will be formed on the page "Results" only if the command "Forming the result" in "Configuration" main menu is selected (see Section 2.5.11)!

4. MODULE "DISTANCE PROTECTION"

4.1. Terms

Module "Distance protection" is designed for adjusting and testing of distance protection devices, that are based on electromechanical, semiconductor or digital technology and can be both foreign and domestic manufacturers.

Using this module allows you to test practically all characteristics of distance protection - triggering zones of different levels with regard to acceptable errors, time triggering characteristics of levels, stability to higher harmonic components, reaction of relay protection devices to various perturbations of real electric networks, such as an asynchronous mode and swing, as well as some other characteristics.

After initializing the module, a window is displayed on the screen (Figure 4.1).

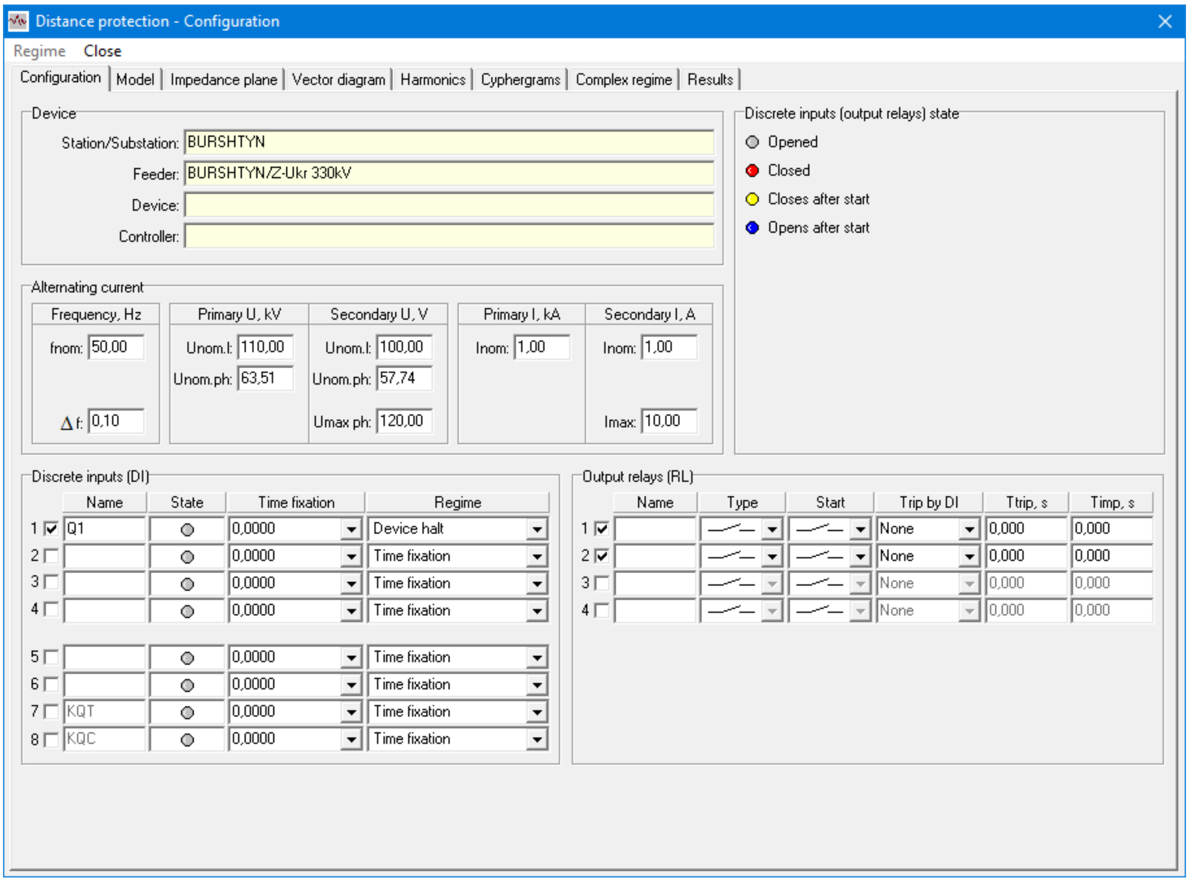


Fig. 4.1. Window of module "Distance protection"

The module "Distance protection" consists of individual functional blocks, placed on separate pages for optimum adjustment and testing of distance protection devices:

- *"Configuration";*
- *"Model";*

- *"Impedance plane";*
- *"Vector diagram";*
- *"Harmonics";*
- *"Cyphergrams";*
- *"Complex regime";*
- *"Results."*

4.2. The "Configuration" page

This page is similar to the page "*Configuration*" of module "Independent source" and were described in detail in Section 3.2. of this manual, with the exception of the implementation of direct current, which is non-available in this module.

4.3. The "Model" page

Overall view of "Model" page is shown in Fig. 4.2

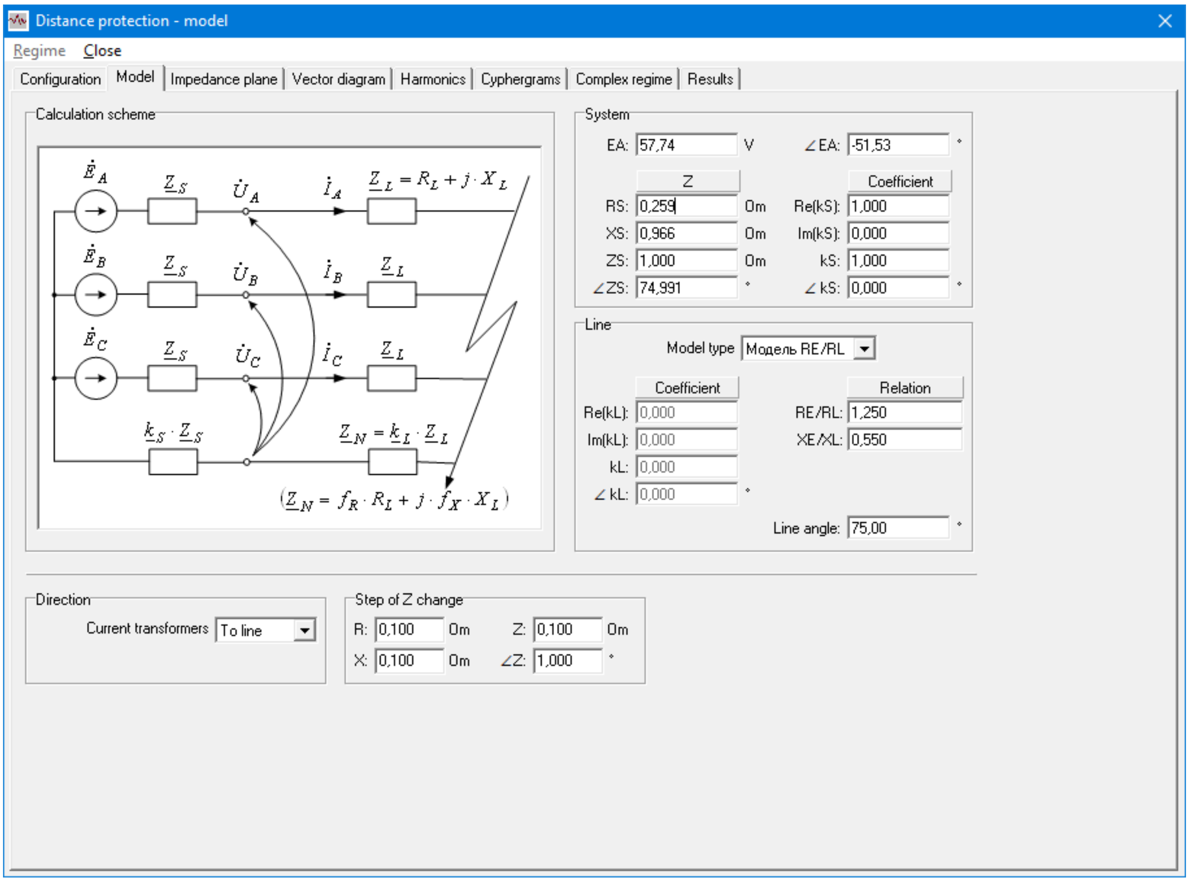


Fig. 4.2. The "Model" page of module "Distance protection"

On this page there are the following group fields:

- *"Calculation scheme"*;
- *"System"*;
- *"Line"*;
- *"Direction"*;
- *"Step of change of the resistance".*

In the *" Calculation scheme"* field, the model of the electrical network is shown. According to this model, formation of phase voltages and currents for various types of short-circuits faults take place. Features of a mathematical model of the electrical network are detailed in Section 4.4.

In the "*System*" field defines the value of phase electromotive force (emf) of the system and its initial angle for phase A. In phase B and C the values of emf automatically sets the same and the initial phase angles are shifted to -120° and +120° respectively. In the zero approximation (by default), the nominal phase emf is set as $100/\sqrt{3} = 57.74\ V$.

Also, sets parameters of *ZS* resistance and influence of the earth - the coefficient of grounding of the system *kS*. These parameters are set in the appropriate fields. You can specify the value in algebraic or exponential form.

In a group field "*Line*" the type of model defines - "*Model kL*" or "*Model RE/RL*". Selecting the right type of model is performed in a combined field "*Model type*". Features of these models are described in detail in Section 4.4.

In the same field, sets the information about the complex grounding coefficient of line *kL* (in algebraic or exponential form), when a model type "*Model kL*" were specified, or value ratios *RE/RL* and *XE/XL*, when a model type "*Model RE/RL*" were selected.

In the "*Line*" field defines the angle of maximum sensitivity of measuring resistance of distance protection. This information will be used on the page "*Impedance plane"*, where characteristics of the triggering zones of distance protection are reproduced. On the impedance plane at the specified angle the beam will be putted out through the origin.

In the "*Direction*" field sets the direction of current transformers of line, for which the testing or adjusting distance protection takes place. If the selected direction is "*In line*", the "DEVICE" would generate currents of three phases with an initial angle, that were calculated for a specific mode. If the direction is "*To busbar*", then the current generation will be done with the calculated initial angle shifted by 180°.

4.4. A model of the electrical network

For adjusting the relay protection devices, the following scheme of the electrical network were adopted (Figure 4.3).

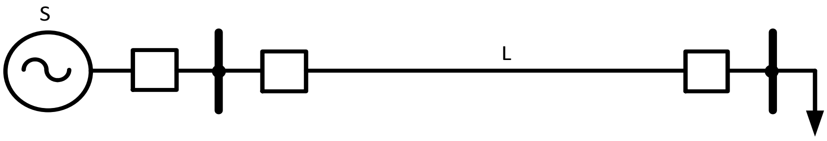


Fig. 4.3. Scheme of the electrical network

In the three-phase implementation for modeling of various types of short-circuit faults, the electrical network scheme shown in Figure 4.4.

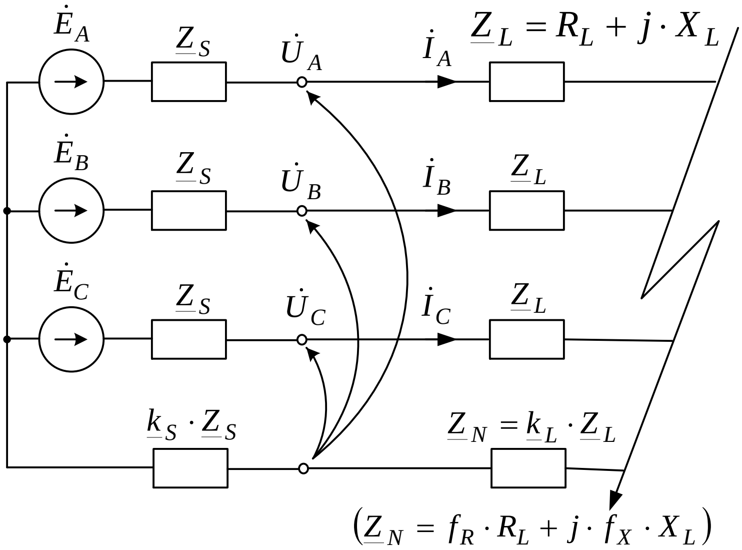


Fig. 4.4. Electrical network scheme for different types of short-circuit faults

In electrical network scheme, the following designations are adopted:

$\dot{E}_A,\ \dot{E}_B,\ \dot{E}_C$ – phase emf of the system;

$\dot{U}_A,\ \dot{U}_B,\ \dot{U}_C$ – phase voltages on the busbar of the substation (at the beginning of the line);

$\dot{I}_A,\ \dot{I}_B,\ \dot{I}_C$ – phase currents in the line;

$\underline{Z}_S$ – impedance of the system;

$\underline{k}_S$ – grounding coefficient of the system;

$\underline{Z}_L = R_L + j \cdot X_L$ –impedance to the site of short-circuit fault;

$\underline{k}_L$ – grounding coefficient of line;

$f_R = \frac{R_E}{R_L}, f_X = \frac{X_E}{X_L}$ – grounding coefficients of line for the model type $R_E/R_L,\ X_E/X_L$.

Grounding coefficient of line that has no taps $\underline{k}_L$, and when we can neglect the influence on it from other lines, is calculated by the expression

$$\underline{k}_L = \frac{1}{3} \cdot \left(\frac{\underline{Z}_{L0}}{\underline{Z}_{L1}} - 1 \right) = k_{LR} + j \cdot k_{LX}, \tag{4.1}$$

where $\underline{Z}_{L1}$, $\underline{Z}_{L0}$ - impedances of positive and zero sequences of the line.

Relationship between models $\underline{k}_L$ and R_E/R_L, X_E/X_L is carried out through the expressions

$$\underline{k}_L = \frac{\underline{Z}_E}{\underline{Z}_L} = \frac{R_E + j \cdot X_E}{R_L + j \cdot X_L} = \frac{f_R \cdot R_L + j \cdot f_X \cdot X_L}{R_L + j \cdot X_L},$$

or (4.2)

$$k_{LR} = \frac{f_R \cdot R_L^2 + f_X \cdot X_L^2}{R_L^2 + X_L^2}, \quad k_{LX} = \frac{R_L \cdot X_L \cdot (f_X - f_R)}{R_L^2 + X_L^2}.$$

To calculate the initial conditions of the currents and voltages in three phases, the parameter $\underline{Z}_L$ is set on the impedance plane. This parameter corresponds to the impedance from the location of protection to the place of short-circuit fault. (Figure 4.5)

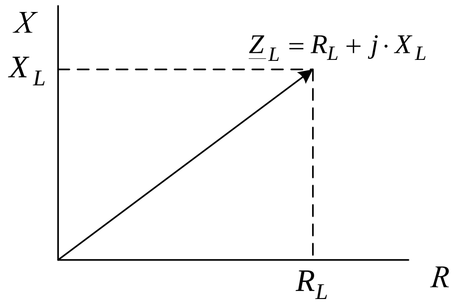


Fig. 4.5. Definition of parameter $\underline{Z}_L$

For the network model, a number of assumptions were carried out, the main ones are:

- emf of voltage source is alternates by the harmonic law with fixed preset frequency;
- emf amplitude of the three phases are equal;
- angle shift between the vectors of emf phases is constant and is equal 120 °;
- impedance$\underline{Z}_S$ of each phase is equal;
- during the simulation of various types of short-circuit faults, only the steady state is considered. The transition process is not considered, which is present, due to different initial conditions and the relations between network parameters;
- the influence of the latitude parameters of the line are not taken into account;
- Influence of the ground on the character of the processes during short-circuit condition is taken into account through the coefficients $\underline{k}_S$ for the system and for the line, in case model $\underline{k}_L$were adopted or through the relationships $f_R = \frac{R_E}{R_L}, f_X = \frac{X_E}{X_L}$ for model R_E/R_L, X_E/X_L.

If it is necessary to investigate the influence of higher harmonic components or influence of aperiodic component, you can use the page "*Harmonics*" on which you may form a signal of any degree of complexity. You can also use real cyphergrams, obtained from digital relay protection devices.

The user have the opportunity to select one of the following models:

- model of a determined system impedance $\underline{Z}_S$;
- model of a determined current;
- model of a determined voltage.

Model of a determined impedance most adequately corresponds to the network to which the relay protection device is adjusted.

Model of a determined current has the feature that the user can specify the desired level of current and simulate all kinds of short-circuit faults on any part of the line. The level of current will be equal to a determined value and will not exceed the maximum value that a "DEVICE" can generate even in case of the close short-circuit fault.

Model of determined voltage allows you to store a determined voltage for all kinds of short-circuit faults, regardless of the distance from the busbar to the site of the fault

Model type sets in the "*Impedance plane*" page. On the "*Vector diagram*" page the specified type of model only displays.

Remember that the values of phase voltages and currents obtained during the implementation of the elecrical network scheme will be limited by the characteristics of the "DEVICE". Apart from that, the restrictions may be imposed also by the user - on the page "Configuration".

4.4.1. Model of a determined impedance (ZS = const)

Three-phase short-circuit

On the vector diagram for this type of short-circuit, you can change the values of voltages and currents in all phases by the module and by the phase.

Determining the initial conditions:

$$\begin{aligned} &\dot{I}_A = \frac{\dot{E}_A}{\underline{Z}_S + \underline{Z}_L}; \quad \dot{I}_B = \frac{\dot{E}_B}{\underline{Z}_S + \underline{Z}_L}; \quad \dot{I}_C = \frac{\dot{E}_C}{\underline{Z}_S + \underline{Z}_L}; \\ &\dot{U}_A = \dot{E}_A \cdot \frac{\underline{Z}_L}{\underline{Z}_S + \underline{Z}_L}; \quad \dot{U}_B = \dot{E}_B \cdot \frac{\underline{Z}_L}{\underline{Z}_S + \underline{Z}_L}; \quad \dot{U}_C = \dot{E}_C \cdot \frac{\underline{Z}_L}{\underline{Z}_S + \underline{Z}_L}. \end{aligned} \tag{4.3}$$

Two-phase short-circuit (BC)

On the vector diagram the current of phase A ($\dot{I}_A = 0$) and the module of the voltage of the phase A ($|\dot{U}_A| = const$) can not change.

Determining the initial conditions:

$$\begin{aligned} &\dot{I}_A = 0; \quad \dot{I}_C = \frac{\dot{E}_C - \dot{E}_B}{2 \cdot (\underline{Z}_S + \underline{Z}_L)}; \quad \dot{I}_B = -\dot{I}_C; \\ &\dot{U}_A = \dot{E}_A; \quad \dot{U}_B = \dot{E}_B - \dot{I}_B \cdot \underline{Z}_S; \quad \dot{U}_C = \dot{E}_C - \dot{I}_C \cdot \underline{Z}_S. \end{aligned} \tag{4.4}$$

Similarly, the initial conditions for the two-phase short-circuit AB and CA are defined.

Single-phase short-circuit (AN)

On the vector diagram the currents of phases B and C can not change as by the module as by the phase ($\dot{I}_B = 0,\ \dot{I}_C = 0$).

Determining the initial conditions for the model $\underline{k}_L$:

$$\dot{I}_A = \frac{\dot{E}_A}{(1+\underline{k}_S)\cdot\underline{Z}_S + (1+\underline{k}_L)\cdot\underline{Z}_L};\quad \dot{I}_B = 0;\quad \dot{I}_C = 0;$$
$$\dot{U}_A = \dot{I}_A\cdot(1+\underline{k}_L)\cdot\underline{Z}_L;\quad \dot{U}_B = \dot{E}_B - \underline{k}_S\cdot\underline{Z}_S\cdot\dot{I}_A;\quad \dot{U}_C = \dot{E}_C - \underline{k}_S\cdot\underline{Z}_S\cdot\dot{I}_A; \tag{4.5}$$

Determining the initial conditions for the model $R_E/R_L,\ X_E/X_L$:

$$\dot{I}_A = \frac{\dot{E}_A}{(1+\underline{k}_S)\cdot\underline{Z}_S + R_L\cdot(1+f_R) + j\cdot X_L(1+f_X)};\quad \dot{I}_B = 0;\quad \dot{I}_C = 0;$$
$$\dot{U}_A = \dot{I}_A\cdot(R_L\cdot(1+f_R) + j\cdot X_L(1+f_X)); \tag{4.6}$$
$$\dot{U}_B = \dot{E}_B - \underline{k}_S\cdot\underline{Z}_S\cdot\dot{I}_A;\quad \dot{U}_C = \dot{E}_C - \underline{k}_S\cdot\underline{Z}_S\cdot\dot{I}_A;$$

Similarly, the initial conditions for the single-phase short-circuits BN and CN are defined.

4.4.2. The model of a determined current (*I* = const)

Three-phase short-circuit

In the model of a determined current for this type of short-circuit, the value of a determined (fixed) current is set in the impedance plane. As a result, the system phase currents will not exceed the set value. Only reducing of the current in phases is possible.

After the user sets the value of the impedance vector $\underline{Z}_L$ on the impedance plane, the effective value of current will be determined by the expression:

$$I_{real} \le \frac{U_{nom.ph}}{|\underline{Z}_L|}, \tag{4.7}$$

where $U_{nom.ph}$ - rated phase voltage of the system; $|\underline{Z}_L|$ - module of impedance vector, defined by the user on the impedance plane.

Determining the initial conditions:

$$\varphi_{\dot{U}_A} = \varphi_{\dot{E}_A};\ \varphi_{\dot{U}_B} = \varphi_{\dot{E}_B};\ \varphi_{\dot{U}_C} = \varphi_{\dot{E}_C};$$
$$\varphi_{\dot{I}_A} = \varphi_{\dot{U}_A} - \varphi_{\underline{Z}_L};\ \varphi_{\dot{I}_B} = \varphi_{\dot{U}_B} - \varphi_{\underline{Z}_L};\ \varphi_{\dot{I}_C} = \varphi_{\dot{U}_C} - \varphi_{\underline{Z}_L}; \tag{4.8}$$
$$|\dot{I}_A| = I_{real};\ |\dot{I}_B| = I_{real};\ |\dot{I}_C| = I_{real};$$
$$|\dot{U}_A| = |\dot{I}_A|\cdot|\underline{Z}_L|;\ |\dot{U}_B| = |\dot{U}_A|;\ |\dot{U}_C| = |\dot{U}_A|.$$

Two-phase short-circuit (BC)

In a model of a determined current for this type of short-circuit, the value of a determined (fixed) value of current is set on the impedance plane. After the user sets the value of vector of impedance $\underline{Z}_L$ on the impedance plane, the effective value of current will be determined by the expression:

$$I_{real} \le \frac{\sqrt{3} \cdot U_{nom.ph}}{2 \cdot \left|\underline{Z}_L\right|}, \tag{4.9}$$

where $U_{nom.ph}$ - rated phase voltage of the system; $\left|\underline{Z}_L\right|$ - module of impedance vector, defined by the user on the impedance plane.

Determining of the initial conditions:

$$\begin{gathered} \varphi_{\underline{Z}_C} = \varphi_{\underline{Z}_L}; \quad \left|\underline{Z}_S\right| = \frac{\left|\dot{E}_B - \dot{E}_C\right|}{2 \cdot I_{real}} - \left|\underline{Z}_L\right|; \\ \dot{I}_A = 0; \quad \left|\dot{I}_B\right| = I_{real}; \quad \left|\dot{I}_C\right| = I_{real}; \\ \varphi_{\dot{I}_B} = arg(\dot{E}_B - \dot{E}_C) - \varphi_{\underline{Z}_L}; \quad \varphi_{\dot{I}_C} = \varphi_{\dot{I}_B} - 180°; \\ \dot{U}_A = \dot{E}_A; \quad \dot{U}_B = \dot{E}_B - \dot{I}_B \cdot \underline{Z}_S; \quad \dot{U}_C = \dot{E}_C - \dot{I}_C \cdot \underline{Z}_S. \end{gathered} \tag{4.10}$$

Similarly, the initial conditions for the two-phase short-circuit AB and CA are defined.

Single-phase short-circuit (AN)

In a model of a determined current for this type of short-circuit, the value of a determined (fixed) current sets on the impedance plane. After a user sets the value of the impedance vector $\underline{Z}_L$ on the impedance plane, the effective value of current is determined by the expression:

$$I_{real} \le \frac{U_{nom.ph}}{\left|1 + \underline{k}_L\right| \cdot \left|\underline{Z}_L\right|}, \tag{4.11}$$

where $U_{nom.ph}$ - rated phase voltage of the system; $\left|\underline{Z}_L\right|$ - module of impedance vector, defined by the user on the impedance plane; $\underline{k}_L$ - grounding coefficient of the line.

Determining the initial conditions:

$$\begin{gathered} \left|\dot{I}_A\right| = I_{real}; \quad \varphi_{\dot{I}_A} = \varphi_{\dot{E}_A} - \varphi\left(\left(1 + \underline{k}_L\right) \cdot \underline{Z}_L\right); \quad \dot{I}_B = 0; \quad \dot{I}_C = 0; \\ \left|\dot{U}_A\right| = \left|\dot{I}_A\right| \cdot \left|(1 + \underline{k}_L) \cdot \underline{Z}_L\right|; \quad \varphi_{\dot{U}_A} = \varphi_{\dot{E}_A}; \quad \dot{U}_B = \dot{E}_B; \quad \dot{U}_C = \dot{E}_C. \end{gathered} \tag{4.12}$$

Similarly, the initial conditions for the single-phase short-circuits BN and CN are defined.

4.4.3. Model of determined voltage (*U* = const)

Three-phase short-circuit

The test voltage is defined by the user on the impedance plane, one that is limited by a determined network model emf of the system:

$$0 \le U_{\text{real}} \le E_A, \tag{4.13}$$

where E_A – emf of the system, the value of which is set in the "*Model*" page in the "*System*" field.

Determining the initial conditions:

$$\begin{gathered}\left|\dot{U}_A\right| = U_{real};\ \left|\dot{U}_B\right| = U_{real};\ \left|\dot{U}_C\right| = U_{real};\\ \varphi_{\dot{U}_A} = \varphi_{\dot{E}_A};\ \varphi_{\dot{U}_B} = \varphi_{\dot{E}_B};\ \varphi_{\dot{U}_C} = \varphi_{\dot{E}_C};\\ \varphi_{\dot{I}_A} = \varphi_{\dot{U}_A} - \varphi_{\underline{Z}_L};\ \varphi_{\dot{I}_B} = \varphi_{\dot{U}_B} - \varphi_{\underline{Z}_L};\ \ \varphi_{\dot{I}_C} = \varphi_{\dot{U}_C} - \varphi_{\underline{Z}_L};\\ \left|\dot{I}_A\right| = \frac{\left|\dot{U}_A\right|}{\left|\underline{Z}_L\right|};\ \left|\dot{I}_B\right| = \left|\dot{I}_A\right|;\ \left|\dot{I}_C\right| = \left|\dot{I}_A\right|.\end{gathered} \tag{4.14}$$

Two-phase short-circuit (BC)

The test voltage is defined by the user on the impedance plane, one that is limited by a determined network model emf of the system. It is assumed that for the two-phase short-circuit fault, the linear voltage value is specified -$\left|\dot{E}_B - \dot{E}_C\right|$. Thus the restrictions on the value of the specified voltage is determined by the expression

$$0 \leq U_{real} \leq \sqrt{3} \cdot E_A, \tag{4.15}$$

where E_A – emf of the system, the value of which is set in the "*Model*" page in the "*System*" field.

Determining the initial conditions:

$$\begin{aligned}&\dot{I}_A = 0;\quad \left|\dot{I}_B\right| = \frac{U_{real}}{2 \cdot \left|\underline{Z}_L\right|};\quad \left|\dot{I}_C\right| = \left|\dot{I}_B\right|;\\ &\varphi_{\dot{I}_B} = arg(\dot{E}_B - \dot{E}_C) - \varphi_{\underline{Z}_L};\quad \varphi_{\dot{I}_C} = \varphi_{\dot{I}_B} - 180°;\\ &\varphi_{\underline{Z}_C} = \varphi_{\underline{Z}_L};\quad \left|\underline{Z}_C\right| = \frac{\left|\dot{E}_B - \dot{E}_C\right|}{2 \cdot \left|\dot{I}_B\right|} - \left|\underline{Z}_L\right|;\\ &\dot{U}_A = \dot{E}_A;\quad \dot{U}_B = \dot{E}_B - \dot{I}_B \cdot \underline{Z}_S;\quad \dot{U}_C = \dot{E}_C - \dot{I}_C \cdot \underline{Z}_S.\end{aligned} \tag{4.16}$$

Similarly, the initial conditions for the two-phase short-circuit AB and CA are defined.

Single-phase short-circuit (AN)

The test voltage is defined by the user on the impedance plane, one that is limited by a determined network model emf of the system:

$$0 \leq U_{real} \leq E_A, \tag{4.17}$$

where E_A – emf of the system, the value of which is set in the "*Model*" page in the "*System*" field.

Determining the initial conditions:

$$\begin{aligned}&\left|\dot{U}_A\right| = U_{real};\quad \varphi_{\dot{U}_A} = \varphi_{\dot{E}_A};\quad \dot{U}_B = \dot{E}_B;\quad \dot{U}_C = \dot{E}_C;\\ &\dot{I}_A = \frac{\dot{U}_A}{(1 + \underline{k}_L) \cdot \underline{Z}_L};\quad \dot{I}_B = 0;\quad \dot{I}_C = 0.\end{aligned} \tag{4.18}$$

Similarly, the initial conditions for the single-phase short-circuits BN and CN are defined.

4.5. The "Impedance plane" page

It is possible to test the distance protection in two modes:

- by single determined point;
- by set of points.

Mode selection is performed in the "*Checking*" field.

In the "*Single point*" mode, characteristics for each individual set point are tested.

In the "*Point set*" mode, a complex test by the predetermined set of points is performed.

Overall view of the "*Impedance plane*" page for "*Single point*" mode is shown in Fig. 4.6.

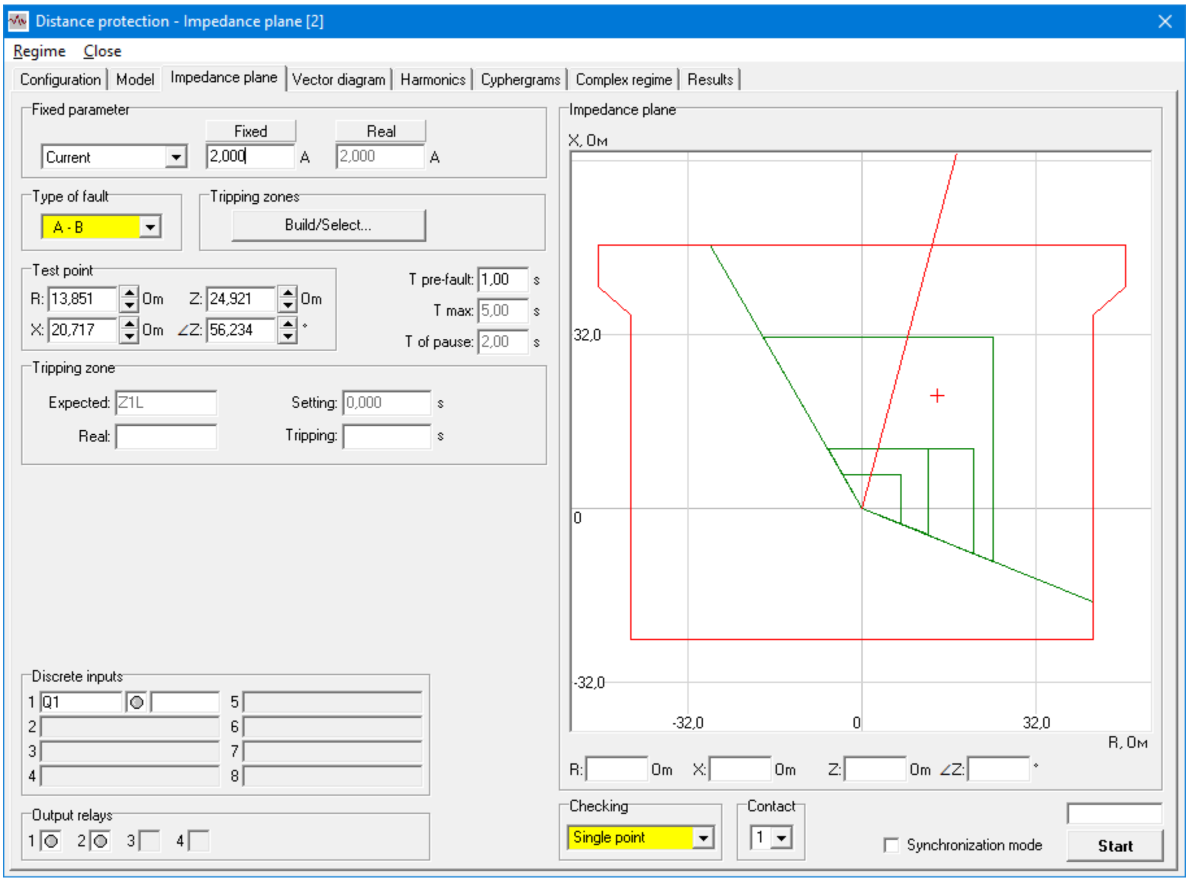


Fig. 4.6. The "Impedance plane" page of the module "Distance protection"

The page contains the following fields:

- *"Fixed parameter";*
- *"Type of fault";*
- *"Tripping zones";*
- *"Test Point";*
- *"Tripping zone";*

- *"Discrete inputs";*
- *"Output relays";*
- *"Impedance plane";*
- *"Checking";*
- *"Contact".*

4.5.1. The "impedance plane" field

In this field triggering zones of the distance protection displays. These zones can be build by the user, using a special editor program or the zone characteristics can be read in the RIO or analog of XRIO format.

Apart from zones, in the "*Impedance plane*", red line represents the angle of maximum sensitivity. The value of this angle is set in the "*Line*" field of the "*Model*" page.

In the absence of any information about the triggering zones of distance protection (zero initial conditions), in the field "*Impedance plane*" impedance plane outputs, with dimension along the axis of the display of active and reactive resistances equals ± 100 ohms.

On the impedance plane, a user can perform particular operations using the local menu (Figure 4.7). Operations are divided into groups. The first group includes operations that are realized using the manipulator "mouse". Cursor image depends on the selected operation. The second group includes operations that implement the selected function only once. The third group contains the command "*Autoscale*" after initialization of which, the image on the impedance plane is optimally scaled. Remember, that after the initialization of this command, operations such as "*Scale by frame*", "*Dynamic scaling*", "*Move*", "*Scale by coordinates*" and "*Previous scale*" are not available. The last group contains an operation that allows to display values of phase and linear voltages (currents), symmetrical components and powers on the impedance plane.

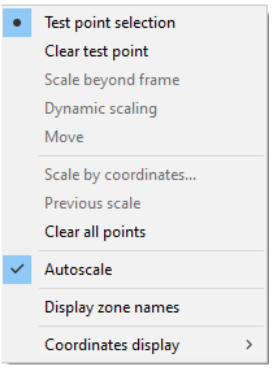


Fig. 4.7. Local menu of the "Impedance plane"

"*Test point selection*"

For testing the distance protection, on the impedance plane the user specifies the coordinates of fault point. For this purpose, user must bring the cursor on the impedance plane to the desired location and click the left "mouse" button. Coordinates of the cursor are displayed in the appropriate fields, located below the impedance plane. Coordinates of the selected fault point are shown in the "*Test Point*" field.

Also, the coordinates of fault point can be set by the keyboard in the "*Test Point*" field.

"Clear test point"

After selecting a fault point on the impedance plane and completing the test, that is after the launch of the device, the selected point locks on the impedance plane. and will be displayed in different color and shape, depending on the results of the test. After a series of tests a number of locked points can be excessive. To delete unnecessary points from the impedance plane and not include them to protocol of results, the command "*Clear all points*" is provided.

"Clear all points"

This command allows you to remove all test points.

"*Scale by frame*"

Activating this command allows the user to select the desired fragment on the impedance plane, that will display in a whole field "*Impedance plane*".

"Dynamic scaling"

This command allows the user to dynamically change the scale. Clicking the left mouse "button", you must move the cursor up or down on the impedance plane. During this, the scale of the impedance plane will gradually increase or decrease.

"Move"

This command allows the user to move the image on the impedance plane without changing the scale of the image. Clicking the left "mouse" button you must move the cursor on the impedance plane. This will cause the image to move. When you set the desired position of the image - release the left "mouse" button - the selected image locks on the impedance plane.

"Scale by coordinates"

This command allows the user to display the fragment with the specified coordinates on the impedance plane. After executing this command, the following window will appear on PC screen (Figure 4.8).

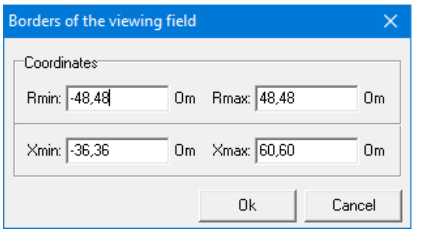


Fig. 4.8. Scaling by coordinates

In this window, in the corresponding fields the user must specify the coordinates of the borders of the fragment on the impedance plane and click on the "**Ok**" button – the fragment with specified coordinates will appear on the impedance plane.

"Previous scale"

The program has the possibility to store the previous scale and coordinates of the image of the impedance plane. If the user does not want to use the impedance plane after he made changes to it, he may activate this command - the impedance plane will be the same as it was before the last change.

"Autoscale"

If the mode "*Autoscale*" is active, then automatic scaling of the impedance plane performs, depending on the triggering zones and the placement of a locked point on it.

"Coordinates display"

After selecting this command, a submenu opens, that allows you to set the following display modes of coordinates on the impedance plane:

- *"Without display";*
- *"Phase voltages and currents";*
- *"Linear voltages and currents";*
- *"Symmetrical components of voltages and currents";*
- *"Powers".*

These coordinates correspond to the current vector diagram. Coordinates of voltages and currents are shown at the bottom of the impedance plane and the powers (in algebraic and exponential forms) - at the top. By default, the mode is set " *Without display*" - for which the coordinates are not displayed in the impedance plane.

4.5.2. The "Fixed parameter" field

In the "*Fixed parameter*" field the user sets the type of model - "*Model of determined resistance of the system*", "*Model of determined current*" or "*Model of determined voltage*" (see sections 4.4.1 - 4.4.3). The value of the fixed parameter depending on the model type also sets in this field. Desired type of model selects from the list, which is located in the left field.

After selecting the type of model in the field "*Determined*" you must enter the value of current (for model of determined current) or value of voltage (for a model of determined voltage). For the model of determined impedance in the field "*Determined*" displays the impedance value of the system, which were determined by the user on the page "*Model*" and is not available on the page "*Impedance plane*".

In the "*Real*" field, the real value of determined parameter displays, which may differ from the specified in case of the imposition of certain restrictions by the expressions (4.7), (4.9), (4.11) – for a model of determined current and by (4.13), (4.15), (4.17) – for a model of determined voltage.

4.5.3. The "Type of fault " field

In this field the user selects from the list the type of fault required for testing The possible types of short-circuit faults are: ABC, AB, BC, CA, AN, BN, CN. Depending on the selected type of fault, the corresponding mathematical model of the electrical network would be implemented (4.3) - (4.18).

4.5.4. The "Test Point" field

This field displays the coordinates of the test points on the impedance plane. Change of the coordinates can be made directly in the corresponding field or discreetly with a determined step by using the arrow keys. Step of change sets in the "*Model*" page. If you change the coordinates of a locked point, the image of this point moves on the impedance plane according to a given value.

4.5.5. The "Tripping zone" field

This field displays information about the expected tripping zone and actual operation of the distance protection device. These fields are not available to the user. In the "*Expected*" field – the name of the expected zone displays, depending on the test point.

Depending on the coordinates of the test point on the impedance plane, in the "*Expected*" field displays the name of the expected tripping zone, and in the "*Setting*" - the expected time of operation.

Remember, that the expected tripping zone is the selected zone with lesser operation time.

Operation time sets in the characteristics of the tripping zone. If the coordinates of the test point on the impedance plane does not fit in any of the specified zones of distance protection device, then the fields "*Expected*" and "*Setting*" will be empty.

After the completion of the test, in the fields "*Real*" and "*Tripping*" the actual triggering zone of distance protection and real time of operation of this zone will be displayed.

4.5.6. The "Contact" field

This field displays the number of binary input, which is connected to the tested device, and for which the analysis of its operation will be made. The selection is made from the list, which contains only initialized on the page "Configuration" binary inputs.

4.5.7. "Discrete inputs", "Output relays" fields

These fields are described in detail in the sections 3.2.4 - 3.2.6. of this manual.

4.5.8. Building (selecting) tripping zones

Selection of tripping zones or construction of new zones is performed by pressing the "**Select/Build**" button in the "*Tripping zones*" field. After pressing the button, a dialog box opens (Figure 4.9).

It is possible to construct characteristics of measuring detectors of distance protections, which have the form of ellipses and complex characteristics in the form of polygons with arcs - polylines.

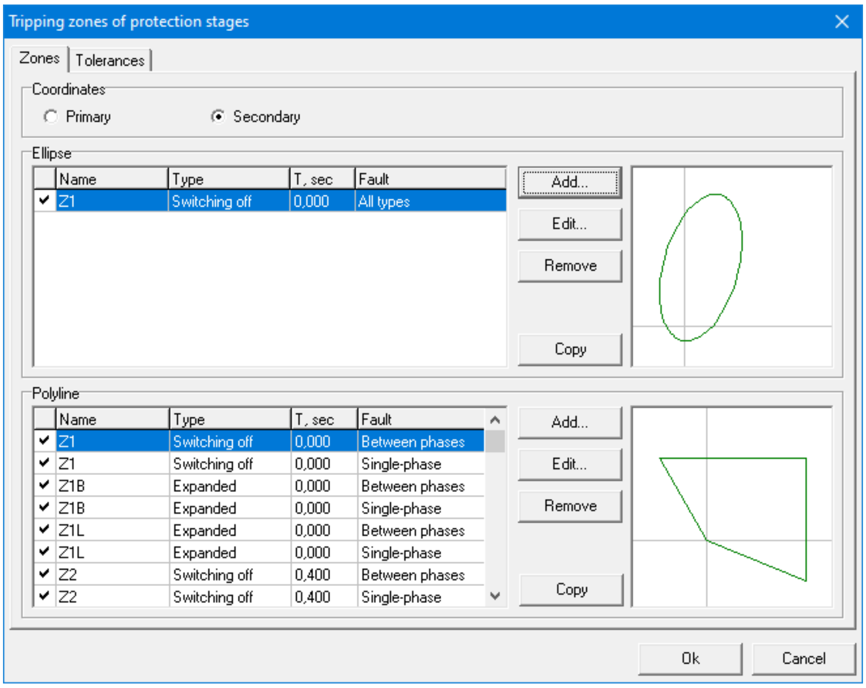


Fig. 4.9. Library of characteristics of measuring detectors of distance protections

To build the triggering zone in the form of ellipse you need to click "**Add**" button in the "*Ellipse*" field – the following window will appear (Figure 4.10).

To build an ellipse you need to write the following information in the "*Parameters*" field:

- *"Name"* - the name of the tripping characteristic of distance detector, under which it will be stored in the library;
- *"Calculated resistance, ohm"* – calculated triggering value of distance detector. This value corresponds to the angle of maximum sensitivity;
- "*Angle of maximum sensitivity,* °" – value of the angle of maximum sensitivity;
- "*Shift, %*" - defines shift of an ellipse in the opposite to angle of maximum sensitivity corner of the quadrant of the complex plane;
- "*Relation between ellipse sides, in relative units*" - defines the aspect ratio of the sides of an ellipse. If this ratio is set 1, we obtain the triggering characteristic of distance detector in shape of a circle;

- "*Tripping time, sec*" – Sets the operation time of the appropriate stage of protection;
- "*Type of fault* " - provides an opportunity to define for which kind of fault this measuring detector of distance protection is designed for - single-phase, multiple-phase, or for all types of protection. Fault type is selected from the list;
- "*Zone type*" – defines type of zone that is selected from the list. There are following types of zones: for opening, expanded, for launching, non-opening;
- "*Relative impedance tolerance,%*" - defines tolerance for impedance, with which the distance detector can operate;
- "*Absolute impedance tolerance, Ohm*" - defines absolute tolerance for impedance;
- "*Relative time tolerance, %*" - defines the tolerance for time, with which the distance detector can operate;
- "*Absolute time tolerance +. sec*" - defines absolute tolerance for time towards a possible increasing, with which the distance detector can operate;
- " *Absolute time tolerance -, sec"* - defines absolute tolerance for time towards a possible reduction;
- " *Circuit type*" - defines the type of line which displays characteristics of distance detector;
- "*Circuit color*" – defines the color of display of characteristics of distance detector.

During the building of characteristic, its form displays in the "*Preview*" field.

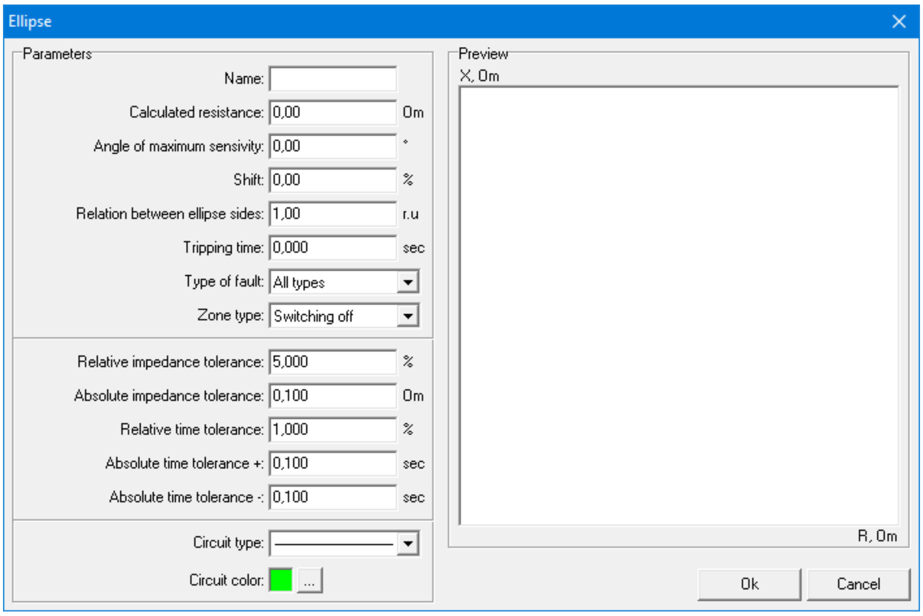


Fig. 4.10. Building of triggering characteristics of distant detector in the form of an ellipse

Example of building of the ellipsoidal characteristic of distance detector is shown in Fig. 4.11.

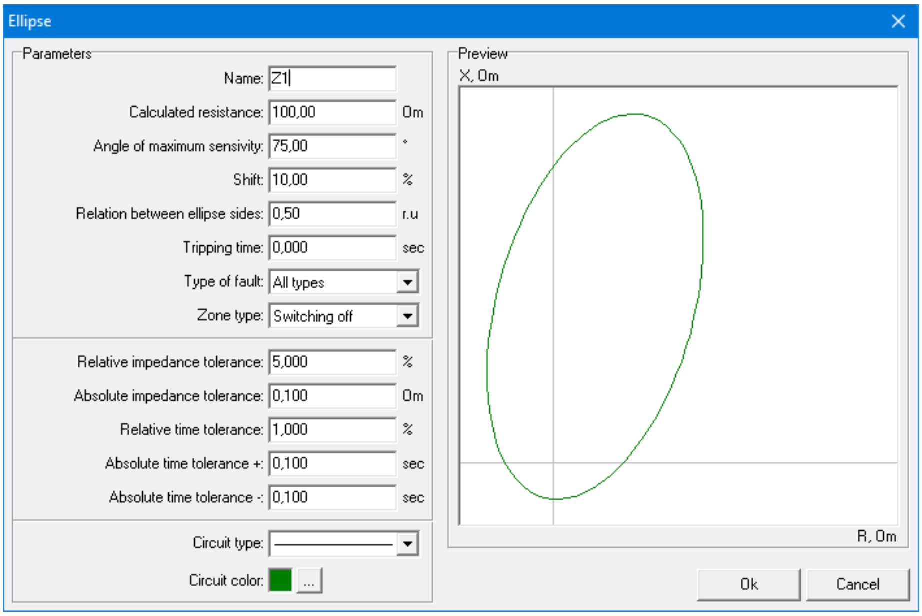


Fig. 4.11. Example of building of ellipsoidal characteristic

If you need to build a characteristic in form of a polygon, then click on the "**Ok**" button in the "*Polyline*" field (see Fig. 4.9) - a window will appear on PC screen (Figure 4.12).

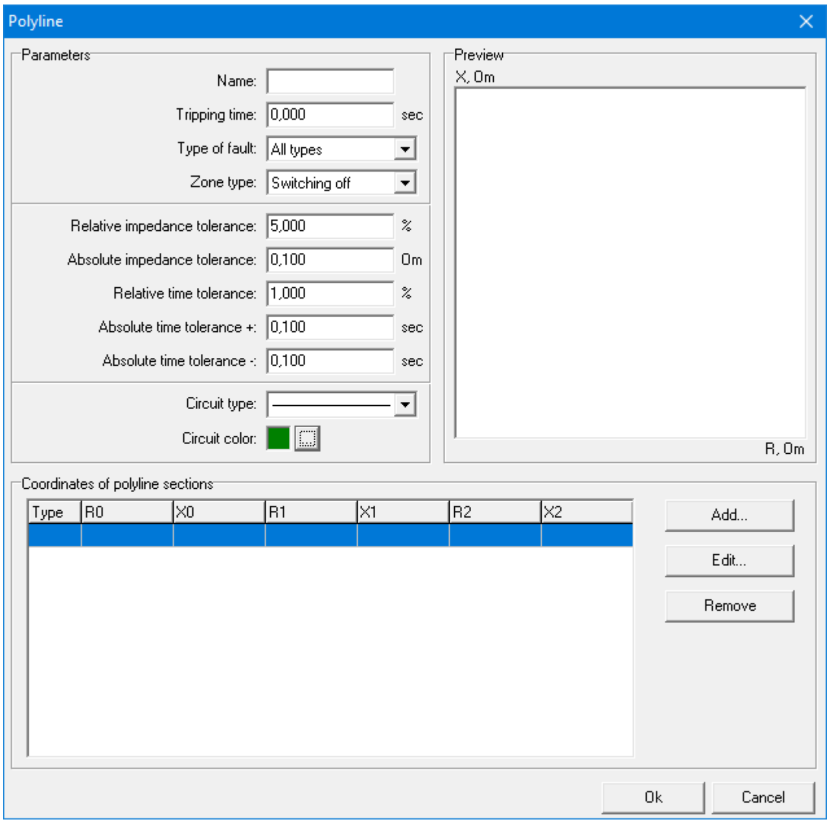


Fig. 4.12. Building polygonal tripping characteristics of distance detector

In the "*Parameters*" field sets name, tripping time, line type, color, type of fault etc. These characteristics are defined similarly as in the building of characteristics of distance detectors in form of an ellipse. The characteristic itself consists of individual fragments - line segments and arcs.

To build the fragment of the characteristic - click on the "**Ok**" button – a following window will appear (Figure 4.13).

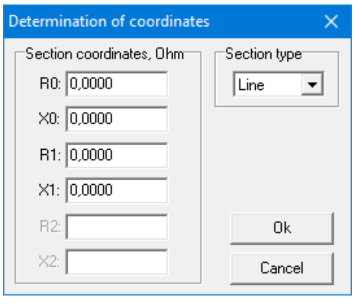


Fig. 4.13. Defining of coordinates for building the characteristic in the form of polyline

In the "*Section type*" field select the type: the line or arc. In the "*Section coordinates* " field you must set coordinates for a start and an end of the line (if this is the first fragment during building) or the coordinates of the end of the following section. For arcs the coordinates of three points through which the arc is drawing must be specified (for the first section), or two points - for the next section. To save this information - click "**Ok**" button.

Remember that you don't need to set coordinates of end point for the last section of polyline because the program automatically connects end point coordinates of the last section to the start point of the first section.

In the process of building, the image of characteristic displays in the "*Preview*" box. The selected fragment of characteristic is highlighted by thicker line.

In the process of building the characteristic, it is possible to make correction by pressing "**Add**", "**Edit**", "**Remove**" buttons (Fig. 4.12).

Example of built characteristic as polyline is shown in Fig. 4.14.

All built characteristics are stored in the library, which is accessed from the appropriate window (see Fig. 4.9).

In the "*Tripping zones of protection stages*" (see Fig. 4.9), in addition to the function of forming new characteristic (button "**Add**"), you can edit the characteristic properties by using the "**Edit**", "**Remove**", "**Copy**" buttons.

It is possible to set and display the characteristics with the defined tolerances. To do this, in the window (see Fig. 4.9) go to "*Tolerances*" page (Fig. 4.15).

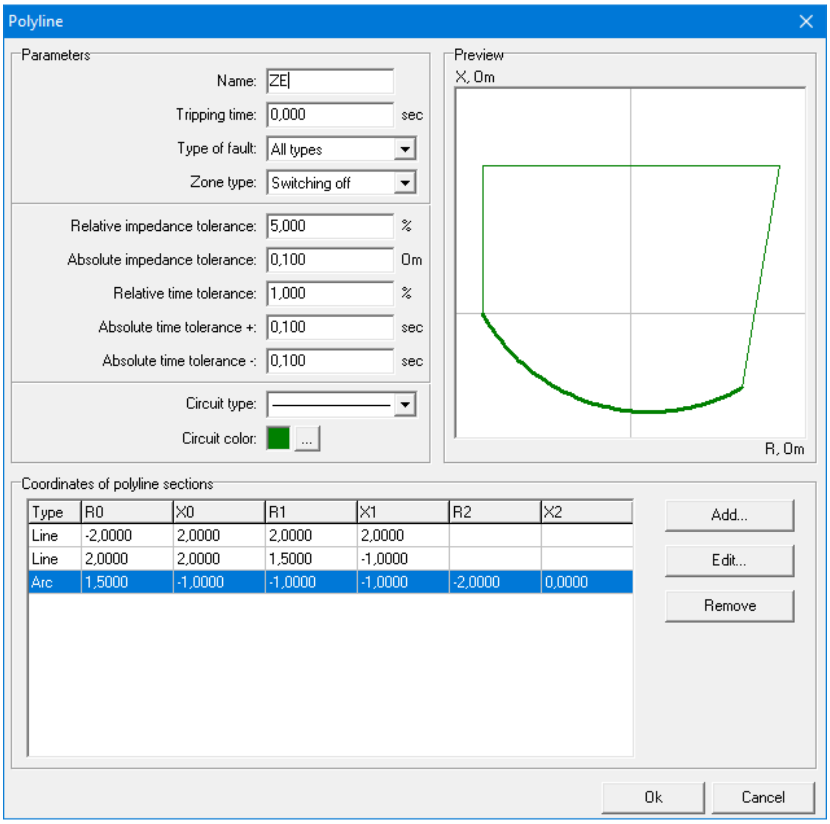


Fig. 4.14. Example of building the characteristic of distance detector in form of a polygon

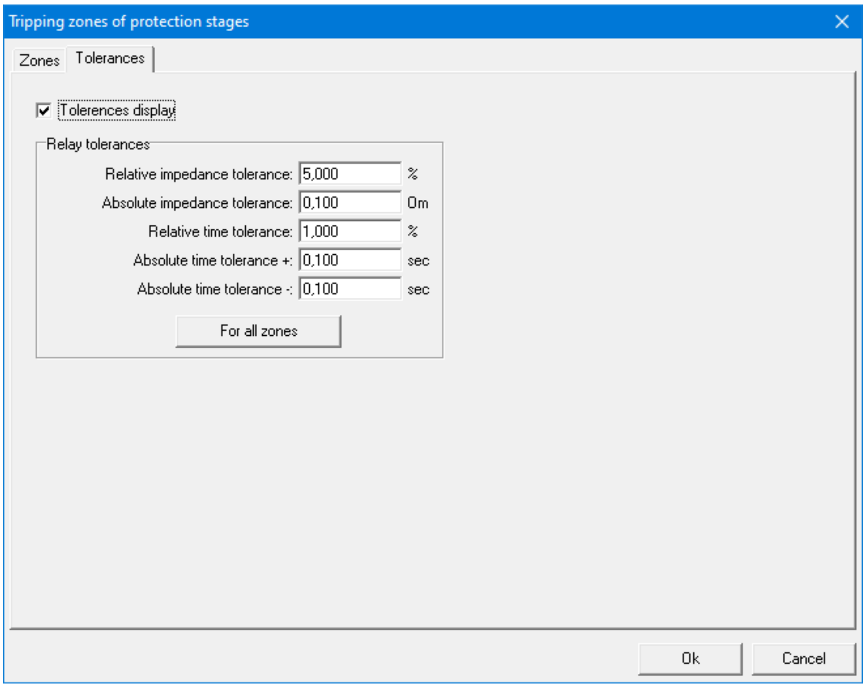


Fig. 4.15. Tolerances of tripping zones of distance protection

To display tolerances and their account in the test, it is necessary to activate the option "*Tolerances display*".

The values of tolerances are set in the "*Relay tolerances*" field.

These tolerances will be taken into account only during the formation of the new characteristic.

There is an opportunity to set the same tolerances for all existing characteristics that are stored in the library. You must fill in the appropriate field (see Fig. 4.15) and click "**For all zones**" button - a warning will appear (Figure 4.16).

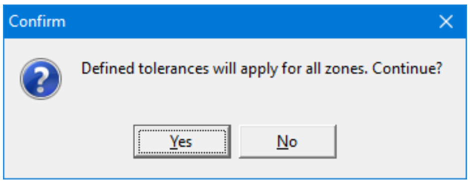


Fig. 4.16. Warning window for setting tolerances of tripping zones

After you click "**Yes**" button, the tolerances will be the same for all zones of distance protection that are present in this object. For those zones that had different tolerances, their tolerances will be lost.

4.5.9. Testing tripping zones in the mode of set of points

To accelerate the process of testing, mode "*Point set* " was developed, which is set in the "*Checking*" field (see Fig.4.6). In this mode, the preparation of information takes place for the complex testing of a previously defined set of points (Figure 4.17).

After activating this mode, opens the field "*Test points set* ", where in the table displays the coordinates of test points and their characteristics: the coordinates in algebraic and exponential forms, the name and time of operation of expected tripping zone, the name and time of operation of real tripping zone (this information is formed after testing) and fixed parameter of test. You can specify the coordinates of test points, using one of the following ways:

- by double "click" on point on the impedance plane;
- using the "**Add**" button that previously sets by "mouse" in the "*Impedance plane*" field;
- using the "**Add**" button that previously sets with the keyboard in the "*Test Point*" field.

On the impedance plane, formed points displays with color that were specified in the configuration. Access to configuration of graphics is made by using the "*Graphics*" command in the main menu item "*Configuration*" (Figure 4.18).

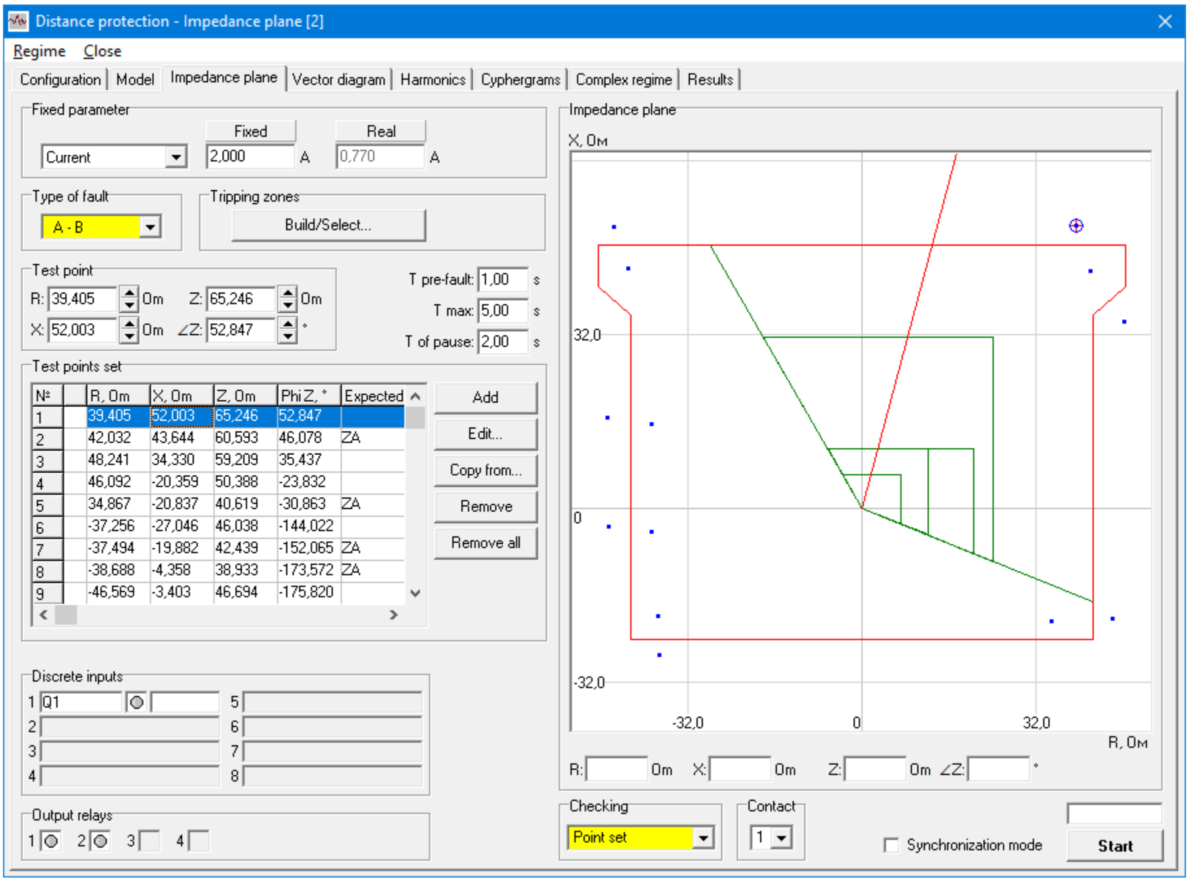


Fig. 4.17. Mode "Set of points"

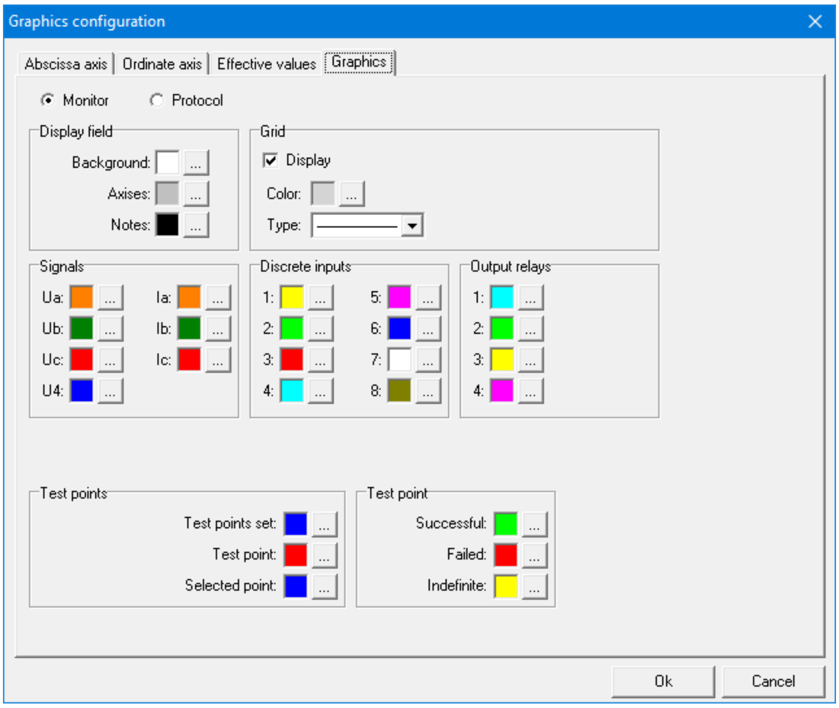


Fig. 4.18. Window of graphics configuration of the module "Distance Protection"

In the "*Test points*" field you can set the color for representing the formed set of test points, the test point and the selected point.

The set of points – are the points formed in the table "*Test points set* " (see Fig. 4.17). Test point - a point, the coordinates of which are set in the "*Test Point*" field (see Fig. 4.17), the shape of this point is the intersection. The selected point - a point selected from the table "*Test points set* " and has a shape in form of a circle.

After the formation of the table, it is possible to perform certain commands with the defined set of points by pressing the corresponding buttons in the "*Test points set*" field (Fig. 4.17):

- "**Edit**" button allows you to change the coordinates of a selected point from the set of points;
- "**Copy from**" button allows you to copy test points, previously created in other modes. The mode from which the copying is performed selects from the dialog box (Figure 4.19) that appears on your PC screen after you press this button;
- "**Remove**" button allows you to delete the selected point from the set;
- "**Remove All**" button. After executing this command, the whole set of test points will be deleted.

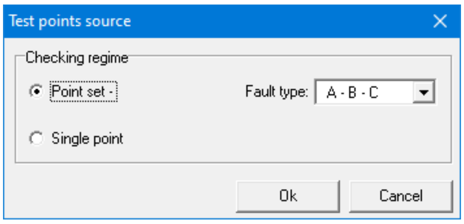


Fig. 4.19. Window of selection of source of test points

The result of executed commands is shown in the table and in the "*Impedance plane*" field.

It is possible to change the display of the table columns. To hide or show a column of the table, you can use the local menu (Figure 4.20).

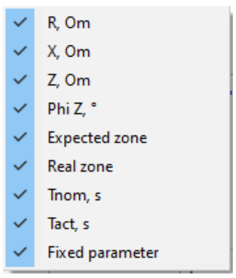


Fig. 4.20. Information of the table "Test points set"

4.5.10. Data format RIO and analog of XRIO

It is possible to read information about the distance protections from files in the international format data RIO or analog of XRIO. This significantly improves the user work, because almost all foreign digital protections operate with this data format.

XRIO – it is format using the XML technology.

Data in the RIO or analog of XRIO format loads by using the "*Load*" command form the main menu item "*Object*". After activating the menu "*Object*", a submenu will appear that shows the possible actions with files (Figure 4.21).

Fig. 4.21. Operation with files menu

After activating the "*Load*" command, on the PC screen you will receive the standard WINDOWS box (Fig. 4.22)

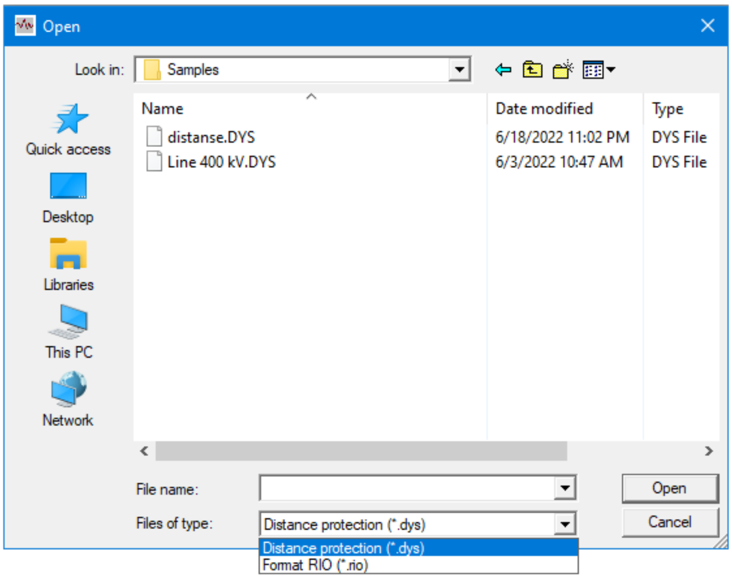


Fig. 4.22. The window of a file selection

In the "File type" you must specify the type of the file with *.RIO or *.XRIO extension (files with *.DYS extension refer to format GRAN). After that, only files with the extension *.RIO and *.XRIO will be present in the main field of the window (see Fig. 4.22). After selecting the desired file, the object of distance protection will be loaded.

4.5.11. Launching cyphergrams

For starting cyphergrams in the "*Impedance plane*" click button **"Start".**

After clicking on the "**Start**" button, the "DEVICE" will generate harmonic signals of phase currents and voltages, which automatically will be formed by the following information:

- coordinates of the locked point on the impedance plane;
- value of the determined parameter (model of the defined impedance, current or voltage);
- type of fault (three-phase, two-phase or single-phase);
- model parameters of system and transmission line;
- defined frequency (sets in the *"Vector diagram"* page).

The values of the phase currents and voltages can be viewed on the page "*Vector diagram*" or on the impedance plane, if the proper view mode of the coordinates were set (see Section 4.5.1 and Section 4.6).

The generation depends on the test mode. In the test mode for one point the generation is performed once, in the test for set of points, the generation will be performed alternatively for each point of the table, beginning from the selected.

In the test mode for one point, you can change the coordinates of this point in the process of generation. Coordinates can be changed by "mouse" on impedance plane, with the keypad in the "*Test Point*" field or by using the arrow buttons next to the corresponding coordinate field with the defined on the page "*Model*" step. This mode can be used to determine the tripping zone of the distance detector when this zone previously is unknown. Remember, in this mode the time of operation is not controlled.

In the test mode for one point, the generation can be stopped by one of the following ways:

- pressing the "**Stop**" button (after clicking on "**Start**" button and beginning of generation, the button will change its name to "**Stop**" and will flash);
- by operation of discrete input that is configured for "*Device halt*" mode.

After the generation stops, the test results are forming. In case of operation, the real zone and real time of operation are displayed in the "*Tripping zone*" field. If no operation occurs over the time of generation then the corresponding fields remain blank.

On the impedance plane the test results are shown as follows: the color that shows the test result is defined in the configuration "*Graphics*" (see Fig. 4.18) - successful, unsuccessful or uncertain; by default - green – successful, red – unsuccessful, yellow – undefined; and the form determines the operation of discrete input (dot - operated, crossed lines - did not operated).

In the test for set of points, the generation is done automatically for each point, starting from the point selected from the table. In this mode, the change of the coordinates of points during generation is impossible. For each point the generation is performed within the time specified in the field "*T max*", or until operation of discrete input. In generation between two points, you can specify a pause in the "*T of pause*."

Test results for each point – the real tripping zone, the real time of operation are displayed in the appropriate fields of the table. In addition, in the first column of the table the total test result is shown: "+" - successful, "-" - unsuccessful "+ / -" undefined.

On the impedance plane the test result displays similarly to the test for one point.

4.6. The "Vector diagram" page

View of the "*Vector diagram*" page is shown in Fig. 4.23.

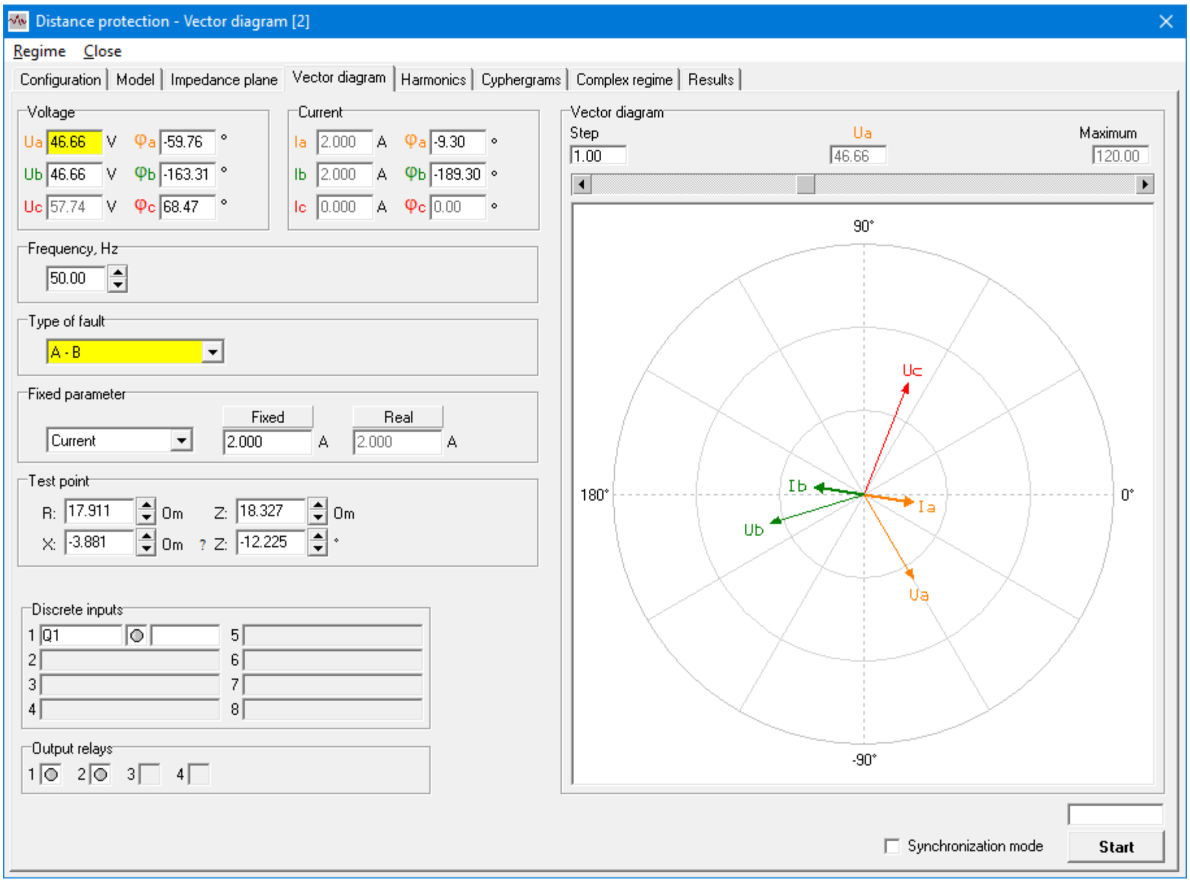


Fig. 4.23. Vector diagram of the module "Distance Protection"

The work on the page "*Vector diagram*" was described in detail in Section 3.3. But there are some distinctions.

The initial vector values of phase currents and voltages correspond to the test point on the page "*Impedance plane*". If the user will change the values of phase voltages and currents on this page, both in module and in phase, the coordinates of the test point on the impedance plane will change automatically.

Similarly as in the page "*Impedance plane*" it is possible to set the fault type. After this, one of the models of the electrical network will be implemented (4.3) - (4.18). Unlike the "*Impedance plane*" page, on the "*Vector diagram*" page you can be specify the "*Independent*" mode of alternating of currents and voltages, in addition to various types of faults modes. For this mode the coordinates of test point on the impedance plane will not be recalculated and, after moving to the "*Impedance plane*" page, the information about independent values of phase voltages and currents will be lost. This mode can be used, for example, to form dead time (for current) for the advanced mode.

On the "*Vector diagram*" page in the fields "*Determined parameter*" and "*Test point*" displays the values of the determined parameter and coordinate of the test point on the impedance plane respectively. These fields are not available to the user.

For starting cyphergrams in the "*Vector diagram*" click button **"Start".**

Launching of the cyphergrams is performed similarly as from the page "*Vector diagram*" of the module "*Independent source*" and was described in detail in Section 3.3.3.

4.7. The "Harmonics" page

This page is similar to the same page of the module "*Independent source*" (see Section 3.4).

4.8. The "Cyphergrams" page

This page is similar to the same page of the module "*Independent source*" (see Section 3.5).

4.9. The "Complex regime" page

This page provides the opportunity to form the complex regime, based on the mode coordinates created on the pages: "*Impedance plane*", "*Vector diagram*", "*Harmonics*", "*Cyphergrams*".

Working on this page is similar to working with the page "*Complex regime*" of module "*Independent source*" (see Section 3.7 of this manual).

4.10. The "Results" page

This page is similar to the same page of the "*Independent source*" module (see Section 3.8 of this manual).

5. MODULE "CURRENT PROTECTION"

Module "Current protection" is designed for automatic testing and adjusting of complex overcurrent protections, performed on electromechanical and digital bases. Allows you to test the multi-stage current protections, directional current protections with random operating characteristics.

5.1. The "Configuration" page

After activating the module "*Current protection*", on the PC screen the window will appear (Figure 5.1).

On the "*Configuration*" page in the group field "*Device*" the general characteristics are specified, in the group field "*Alternating current*" - nominal and maximum allowable settings of the protection are specified, similar to the module "*Independent source*" (see Section 3.2).

In combined field "*Contact number*" defines the number of binary input of the "DEVICE" to which the terminal of tested protection relay connects.

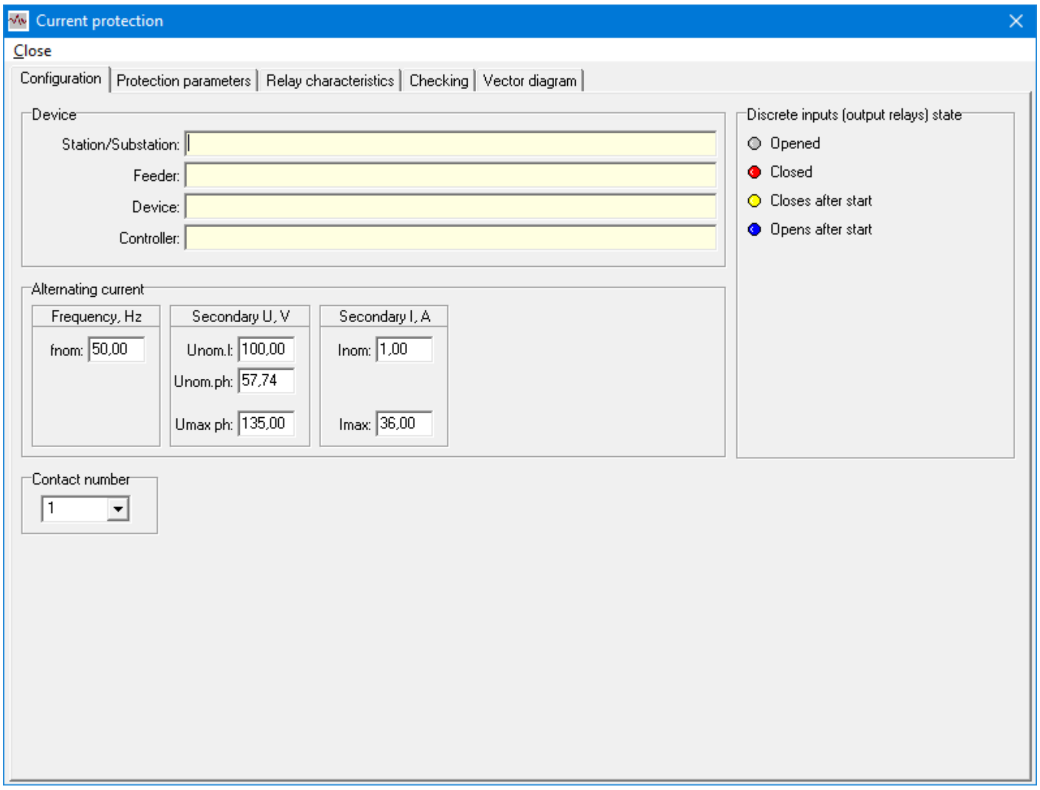


Fig. 5.1. Protection configuration page

5.2. The "Protection parameters" page

General view of the page is shown in Fig. 5.2.

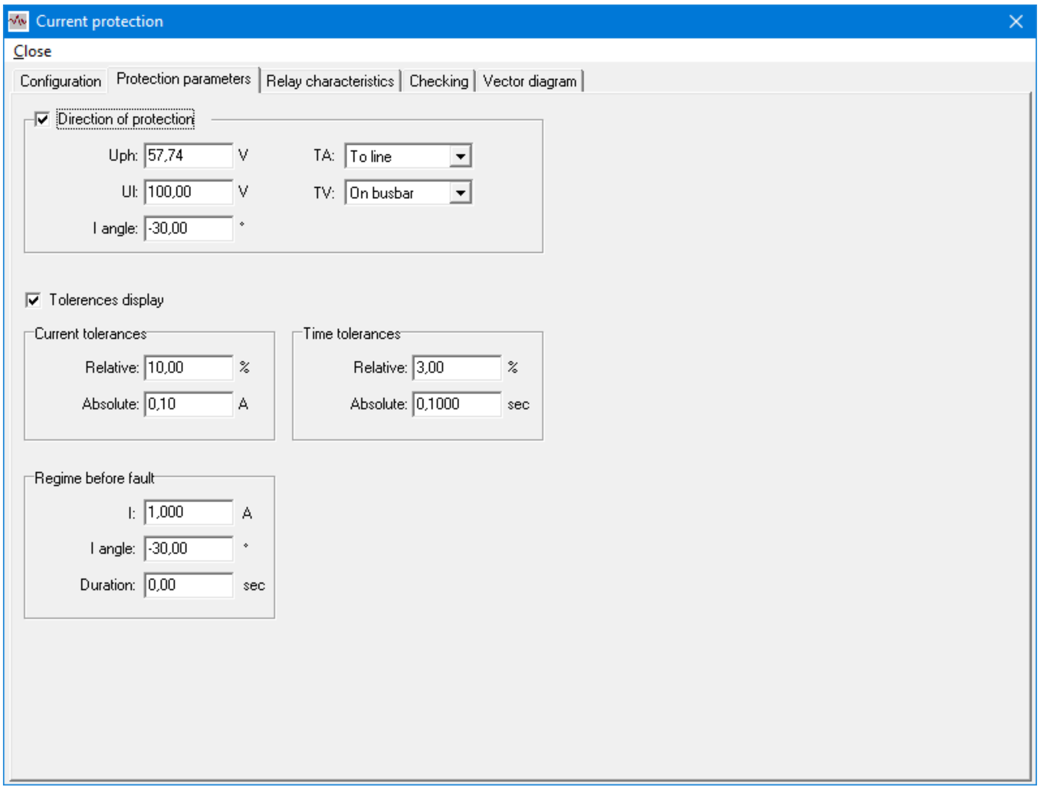


Fig.5.2. The "Protection parameters" page

In a group field "*Direction of protection*" the character of protection defines - directed or not. If you need to test the directional current protection, then it is necessary to initialize the option "*Direction of protection*". For current transformers the direction sets: "*In line*" or "*To the busbar*", for voltage transformers sets the connection of voltage transformers -"*To line*" or "*On busbar*". Also in the appropriate fields voltage value defines (phase or linear) and the initial value of the phase of current. In the case of directional current protection it is the angle between voltage and current (depending on the type of short-circuit). When checking the usual current protection, this angle corresponds to the initial phase of the current, which is generated by the "DEVICE". When activating the option "*Direction of protection*", the "DEVICE" would generate currents, depending on the type of short-circuit and also - symmetrical voltage system. If this option is unchecked - the "DEVICE" will only generate currents.

In group fields - "*Time tolerances*" and "*Current tolerances*" defines relative and absolute tolerances of protection for current and for time. The account of defined tolerances will be made in case of initializing the option "*Tolerances display*".

In a group field "*Regime before fault*" the characteristics of pre-fault mode are specified. If you don't need the pre-fault mode, set the value "0" in the "*Duration*" field.

5.3. The "Relay characteristics" page

The "*Relay characteristics*" page is shown in Fig. 5.3.

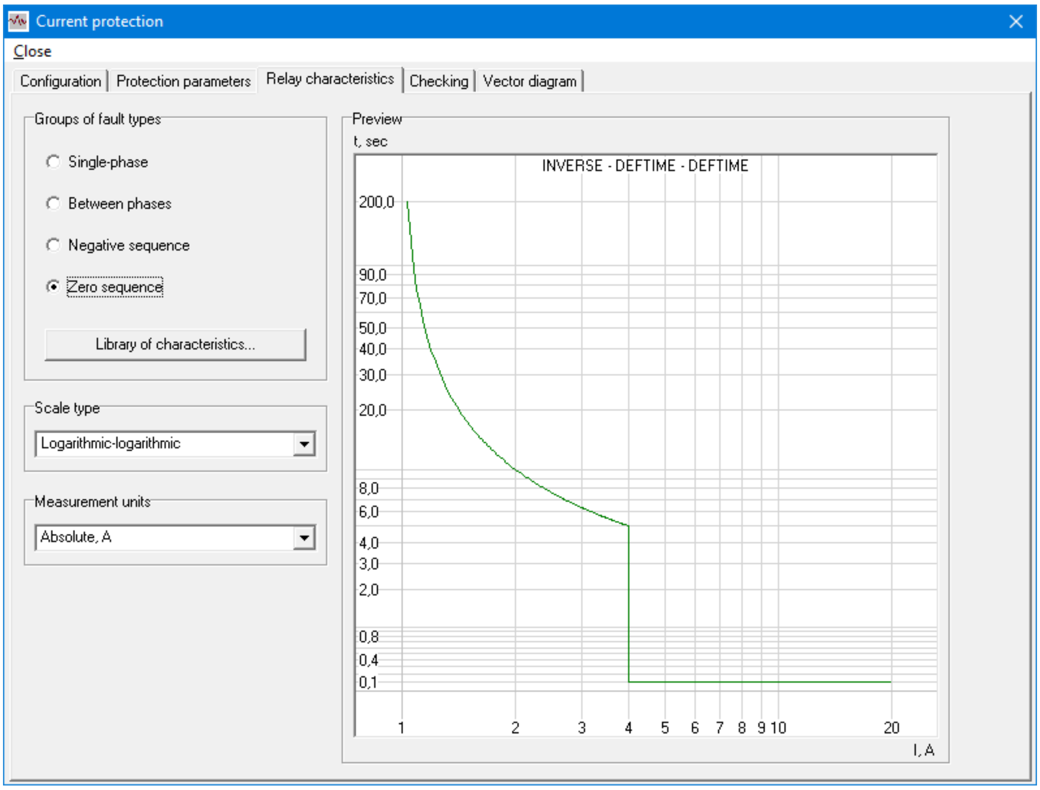


Fig. 5.3. Relay characteristics page

On this page you can create a library of characteristics from which to choose the desired characteristic for a defined type of current protection.

In the "*Groups of fault types*" sets the fault types, for each of which creates a library of characteristics. There are following groups of characteristics:

- characteristics of protection for single-phase fault;
- characteristics of protection for the between-phases fault;
- characteristics of protection that respond to current of negative sequence;
- characteristics of protection that respond to current of zero sequence.

It is possible to generate and store in the library current characteristics of any complexity.

The desired characteristic can be selected from a library of characteristics, or in the case of its absence in the library, it can be formed.

To do this, click on the "**Library of characteristics**" button, which is placed in the "*Groups of fault types*" field – the following window will appear (Figure 5.4).

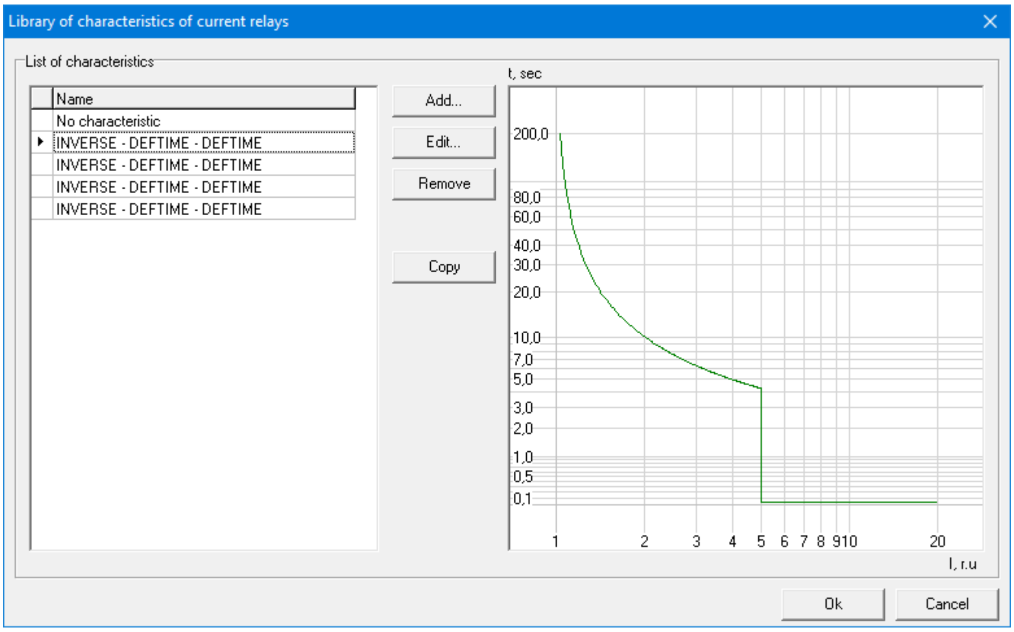


Fig. 5.4. The library of characteristics

The "*List of characteristics*" field displays the names of all characteristics that are available in the library. The desired characteristic selects from the list. Selected characteristic will be displayed in the box on the right. After selecting the desired characteristics, you must click on the "**Ok**" button. When you select the paragraph "*No characteristic*" - characteristic will be missing for a defined type of fault.

In this window, using the appropriate buttons, you can perform the following operations:

- add new characteristic;
- edit existing ones;
- remove characteristic from the library;
- copy characteristic.

To form a new protection characteristic you need to click on the "**Add**" button - the following window will appear (Figure 5.5).

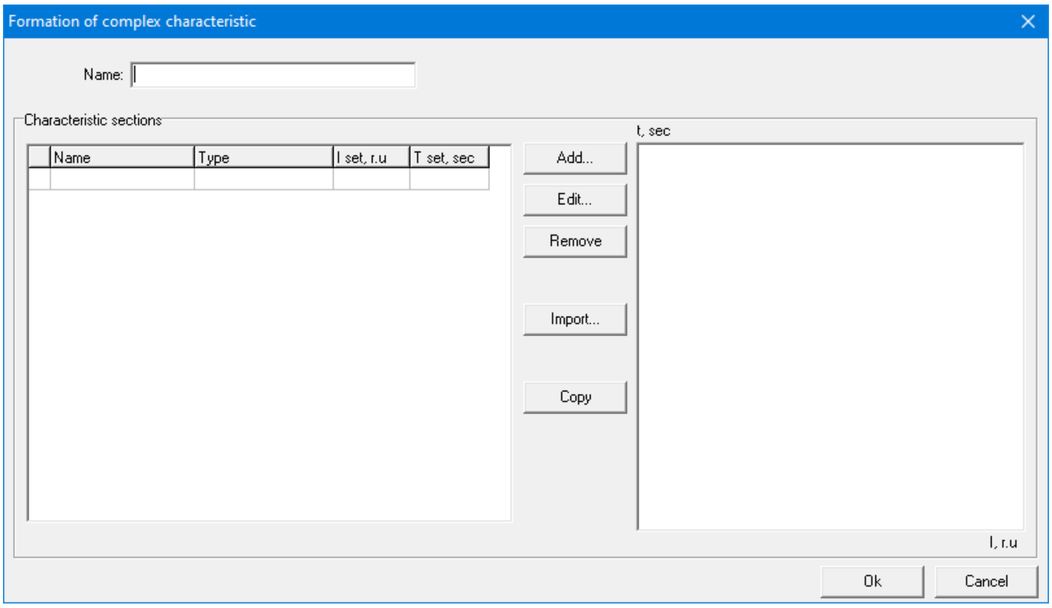


Fig. 5.5. Formation of complex characteristic

Characteristic builds from individual sections. To add a new section, click on "**Add**" button – a window will appear (Figure 5.6).

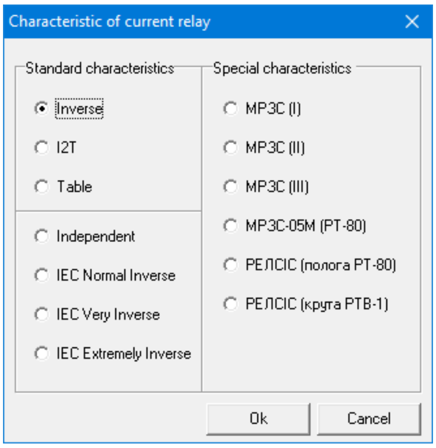


Fig. 5.6. Typical characteristics of current relay

In this box are all possible typical characteristics of current protection. To select the desired characteristics it is necessary to check it in the list and click "**Ok**" button. All characteristics arbitrarily divided into groups. The first group of typical characteristics ("*Inverse*", "*I2T*", "*Table*") and some special characteristic requires specifying additional information. The characteristics "*Independent*", "*IEC Normal Inverse*", "*IEC Very Inverse*", "*IEC Extremely Inverse*" and some special characteristic - do not require specifying additional information, they are rigidly defined.

If you select the type of characteristics "*Inverse*" then a window appears (Figure 5.7)

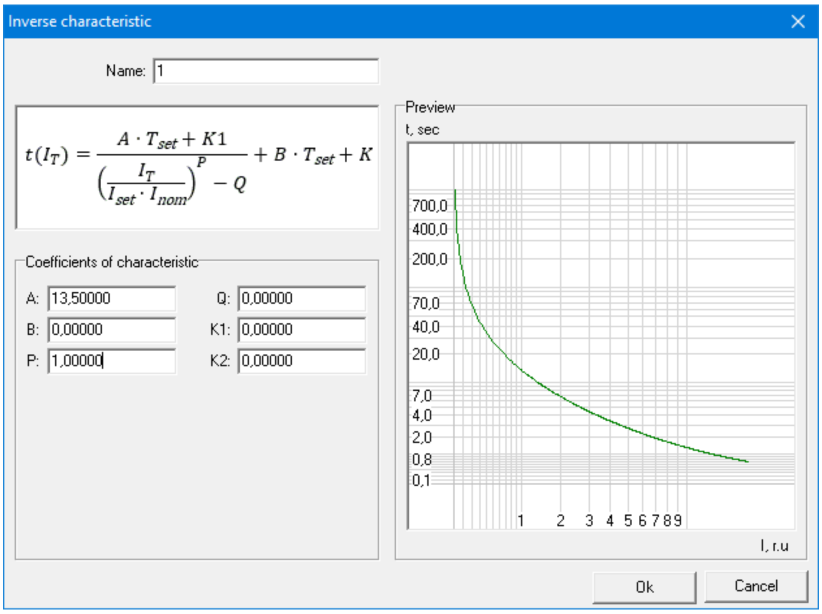


Fig. 5.7. The inverse characteristic

This window shows general equation, by which the inverse characteristic is formed, and the fields in which user inputs the corresponding values of the characteristic coefficients. The "*Preview*" field shows the specified characteristics.

After entering the appropriate values of the coefficients, in the edit field "*Name*" enter the name of the characteristic and press the "**Ok**" button.

If you select the type of characteristics "*I2T*", a window will appear (Figure 5.8)

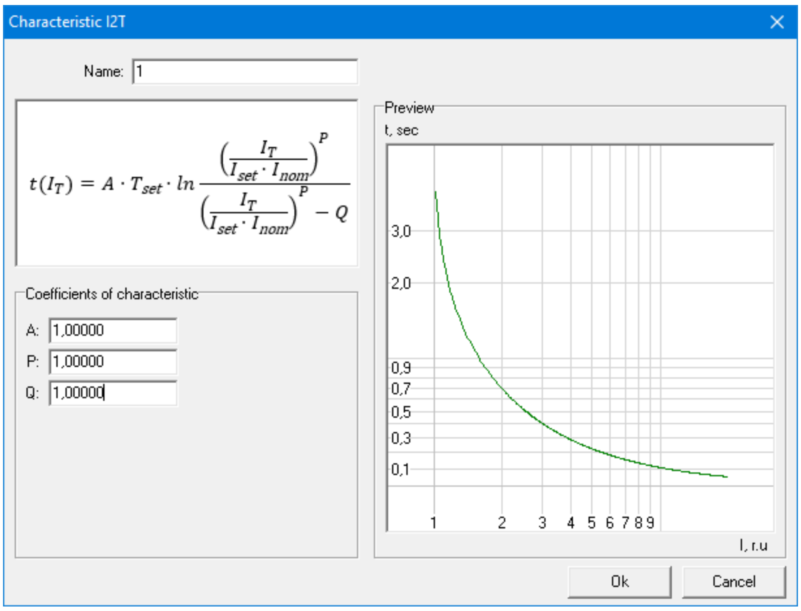


Fig. 5.8. Characteristic I2T

The coefficients of the characteristic are defined in the edit fields of "*Coefficients of characteristic*".

If the user needs to specify a custom characteristic, he must select the type "*Table*". In this case, the window will appear (Figure 5.9). In tabular form, enters the points coordinates of the characteristic. As you input the coordinates of points, the "*Preview*" window shows the building characteristic. To insert a new point you must use the button "**Ok**". It is possible to edit the coordinates of the selected point (the button "**Edit**") and delete the selected point or all points (the "**Remove**" and "**Remove All**" buttons).

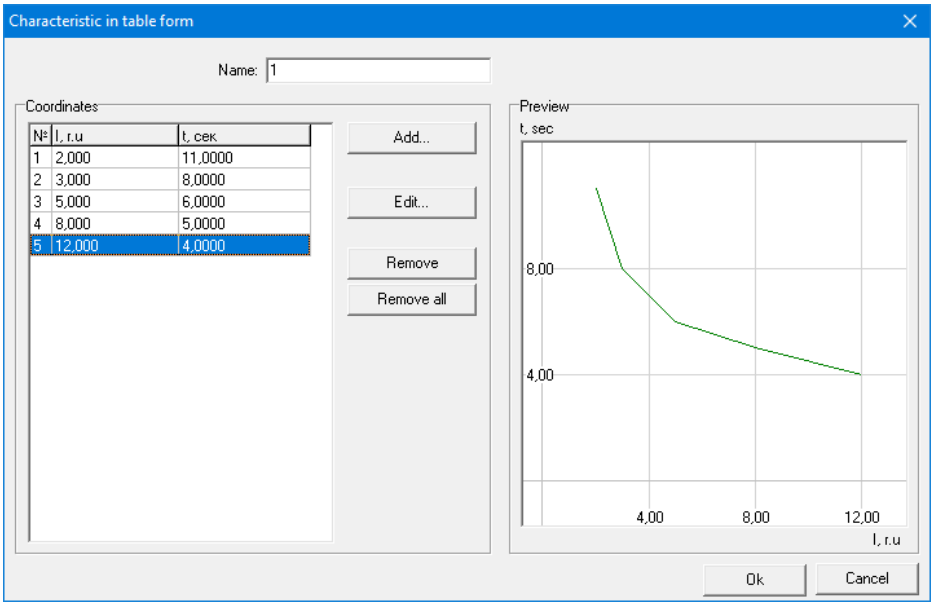


Fig. 5.9. Tabular form that represents the characteristic

The user can specify the characteristics with the fixed values of the coefficients, which are based on the equation of the inverse characteristic (Fig. 5.7). These characteristics are: "*IEC Normal Inverse*" (A = 0.14; B = 0; P = 0.02; Q = 1; K1 = 0; K2 = 0), "*IEC Very Inverse*" (A = 13.5; B = 0; P = 1 ; Q = 1; K1 = 0; K2 = 0), "*IEC Extremely Inverse*" (A = 80; B = 0; P = 2; Q = 1; K1 = 0; K2 = 0).

It is possible to set the independent characteristic. To do this, when forming the characteristic, select the type of characteristic "*Independent*" (see Fig. 5.6). When you select this characteristic - a window appears (Figure 5.10).

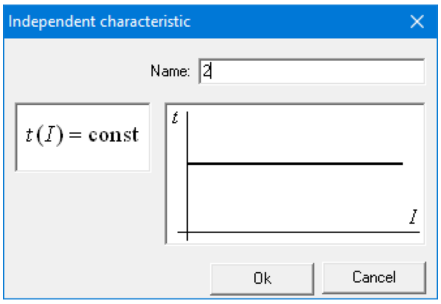


Fig. 5.10. Independent characteristic

There are also some special characteristics.

After the formation of individual sections of the characteristic, in the window (see Fig. 5.6) will be shown a list of all the specified sections. Then it is necessary to set in the corresponding fields for each section the setting values for current and time, respectively, "*I set*" and "*T set*". The "*Preview*" field displays the complex characteristic. Also in the edit field "*Name*" you must specify the name of the complex characteristic.

This window provides the ability to edit some sections of characteristic (the "**Edit**" button), delete sections of characteristic ("**Remove**" button), copy sections ("**Copy**" button), as well as to import sections of characteristic, recorded in DCC format ("**Import**" button).

After you click "**Ok**" button, build characteristic would be written to the library.

In the "*Scale type*" field (see Fig. 5.3 the scale sets to display characteristic. The following display scales are provided:

- current – linear, time - linear;
- current – logarithmic, time - logarithmic;
- current – linear, time - logarithmic;
- current – logarithmic, time - linear.

In the "*Measurement units*" field, for the current scale, the following measurement units are specified:

- relative;
- absolute, A.

The "*Preview*" field displays a general view of the specified characteristic of current protection.

5.4. The "Checking" page

General views of the page is shown in Fig. 5.11.

After activation of this page, in the "*Time characteristic*" field displays the characteristic of current protection, which is formed on the page "*Relay characteristics*". In this field, a user can use the local menu specific operations related to image scaling and selecting the test points.

On this page you specify type of fault (in the "*Type of fault*" field) - three-phase fault, all kinds of two-phase faults, single-phase fault, and also set currents for inverse and zero sequences. Depending on the type of fault, in the "*Time characteristic*" field the corresponding characteristic of the current protection will be shown, and also the corresponding vector diagrams of currents and voltages will be formed. The page "*Vector diagram*" displays voltages and currents that correspond to the selected type of fault, and racing point which value is displayed in the "*Test point*".

It is possible to test the protection by individual set points or run complex test for predetermined set of points.

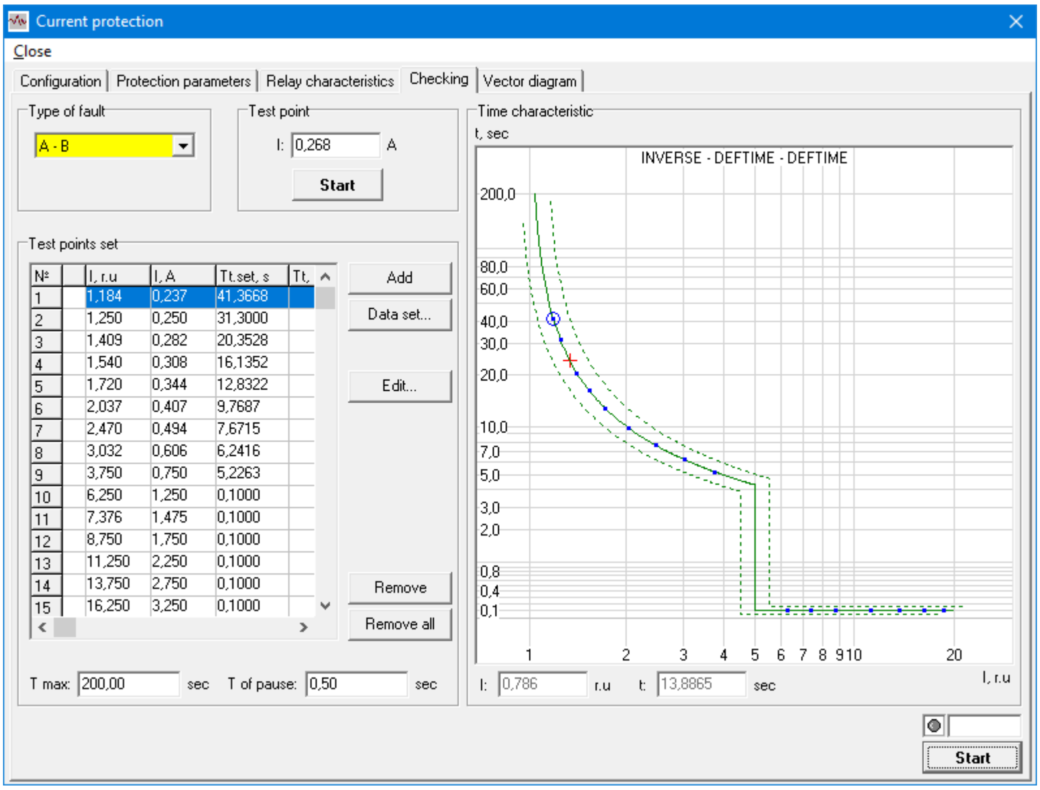


Fig. 5.11. The "Checking" page of the module "Current protection"

In the first case, in the "*Test Point*" field sets the value of current, by which a test performs. The current value can be set directly in the field "*I*" or, using the "mouse", on the time characteristic of protection in the "*Time characteristic*". Then "**Start**" button presses – the "DEVICE" begins to generate a defined current until the operation of protection. After the operation of protection, in the "*Time characteristic*" field, fixes the point that corresponds to a defined current and real time of operation. In case when the protection did not operate, the current generation will continue over some time. This time is specified by the user in the field "*T max*". The value of this time must be set larger than the maximum time of operation of the current protection. The test point and test results are then listed in the table "*Test points set*".

For complex test of current protection characteristics it is necessary to form a set of test points. These points are formed in the "*Test points set*" field.

This field displays in tabular form the test points and their characteristics:

- test values of current in absolute units;
- relative value of current *I, r.u*, which is defined by the expression: $I_{\text{r.u}} = I / I_{set} \cdot I_{nom}$, where I - test value of current in absolute units; I_{set} - the value of the current setting of the first section of characteristic of current protection in relative units (relative to the nominal current); I_{nom} - the value of the nominal current of protection;
- expected time of operation $T_{t.set}$;

- maximum and minimum value of time of operation (respectively $T_{t.max}$, $T_{t.min}$), calculated on the basis of allowable errors for the current and for the time of operation.

It is possible to change the display of the columns of the table. You can hide or show a column in the table from local menu, which appears after pressing the right "mouse" button.

You can add the value of current to the array using the "**Add**" button in the "*Test points set*" field; thus the point specified in the "*I*" field would be added to the array.

It is possible to specify the set of points using the "**Data set**" button in the field "*Test points set*". In this case, a dialog box opens in which you need to specify the initial and final value of the current and the step of current between points.

To edit the test points use the "**Edit**" and "**Remove**" buttons. The editing functions will apply to the selected point of the table. To remove all points of the array use the button "**Remove All**".

To return current protection to its original state you must set pause after testing of each test point. The duration of this pause is specified in the "*T of pause*" field.

The colors that represent the characteristics of protection, test points and test results are specified in a dialog box "*Graphics configuration*" (Fig. 5.12), which appears after executing the command "*Graphic*" from the main menu "*Configuration*".

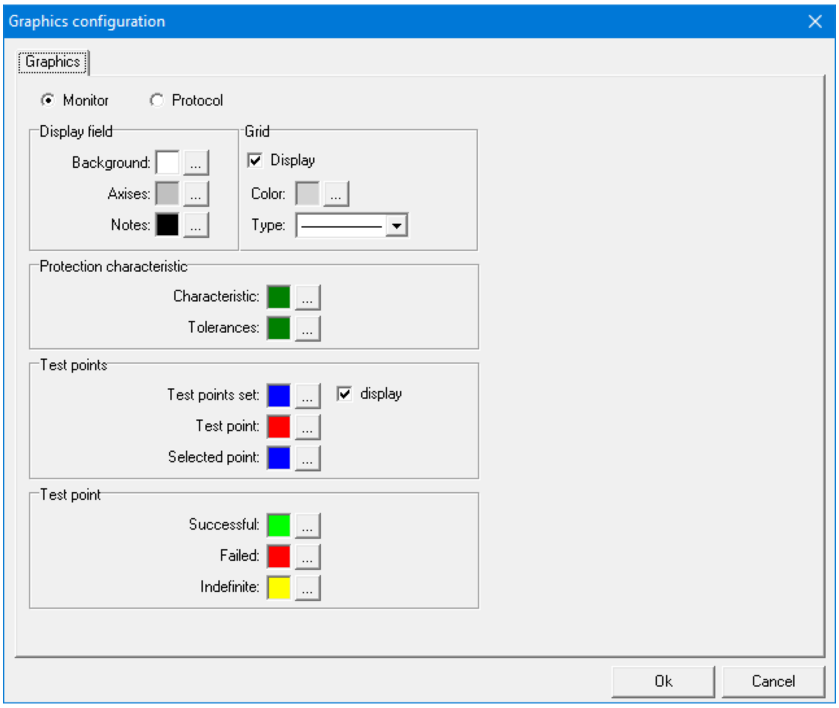


Fig. 5.12. Window of graphic configuration of the module "Current protection"

For complex testing of current protection click "**Start**" button - the "DEVICE" will alternatively generate the defined value of current taken from the table "*Test points set*". In case of operation of protection, in the "*Time characteristic*" field will appear points that match the coordinates of operation of protection. In the first column of the table "*Test points set*" the information about the test results for each point would be displayed: "+" - successful; "-" - unsuccessful; "+ / -" -

undefined. The result "undefined" enters for the following reasons: the user sets *Tmax* that limits the upper part of real characteristic of current protection, it means that higher than the value of *Tmax* the characteristic became not available for analysis. Analysis of the result is based on comparison of the expected time value of operation with the real time value, taking into account the set errors.

To explain the analysis of the test results, in the Fig. 5.13 is shown the example of current protection characteristic. Depending on the value of testing current and operation result, the characteristic plane can be divided into 5 zones. The display plane is limited to the abscissa axis *I*, ordinates axis *t*, the maximum value of the expected operation time *Tmax*, and the maximum value of the testing current *Imax*.

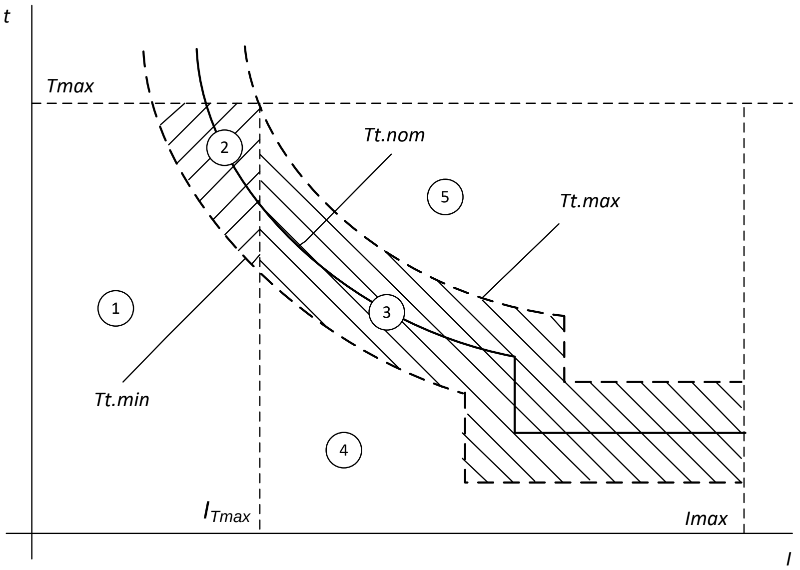


Fig. 5.13. Analysis of the test results of current protection

1st zone is limited by the axes of abscissas and ordinates, the maximum value of the expected time of operation, the curve that corresponds to the minimum time of operation of protection *Tt.min*, and the line passing through the point of intersection of the line *Tmax* and curve *Tt.max* (I_{Tmax}). If the current protection did operate in this zone, the result will be - "unsuccessful"; if did not operate - "undefined".

2nd zone is limited by curve *Tt.min*, lines *Tmax* and I_{Tmax}. If the current protection did operate in this zone, the result will be - "successful"; if did not operate - "undefined".

3d zone is limited by curves *Tt.min*, *Tt.max*, lines *Imax* and I_{Tmax}. If the current protection did operate in this zone, the result will be - "successful"; if did not operate - "unsuccessful".

4th zone is limited by abscissa axis, line I_{Tmax} and curve *Tt.min*. . If the current protection did operate in this zone, the result will be - "unsuccessful"; if did not operate - "successful".

5th zone is limited by lines *Tmax*, *Imax* and curve *Tt.max*. . If the current protection did operate in this zone, the result will be - "unsuccessful"; if did not operate - "successful".

5.5. The "Vector diagram" page

On this page (Figure 5.14) is shown a vector diagram of currents and voltages which would be generated by the "DEVICE". The values of currents, voltages and their phases depends on the settings of "*Checking*" page: fault type, testing current and the type of protection – directed or non-directed. The vector diagram is passive, that means that on that page, you cannot specify and correct the values of currents and voltages.

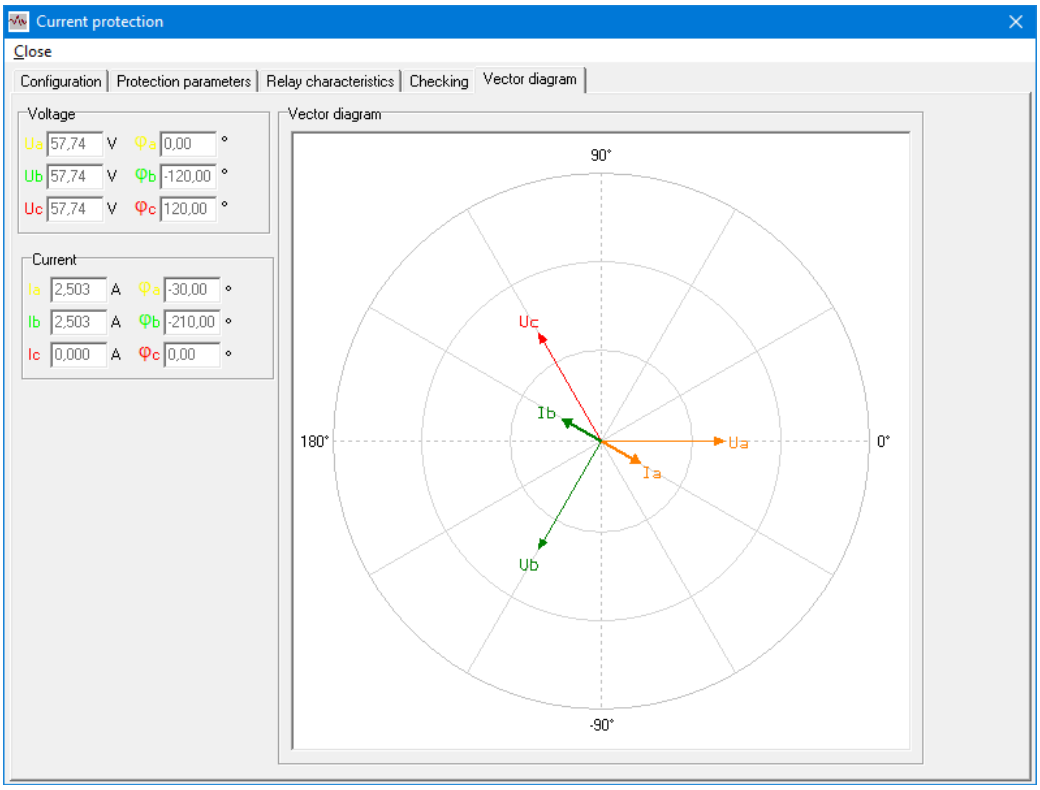


Fig. 5.14. The "Vector diagram" page

6. MODULES OF GROUP "SIMPLE RELAYS"

6.1. General

Modules of group "Simple relays" are designed to automatically test and adjust simple relay devices performed on electromechanical and digital basis. These modules allow you to test the electrical characteristics of the DC and AC voltage and current relays, power direction relays, current direction relays and frequency relays.

6.2. Module "Current relays"

Designed to test simple current relays with independent characteristic.

After activating this module the following window will appear (Figure 6.1).

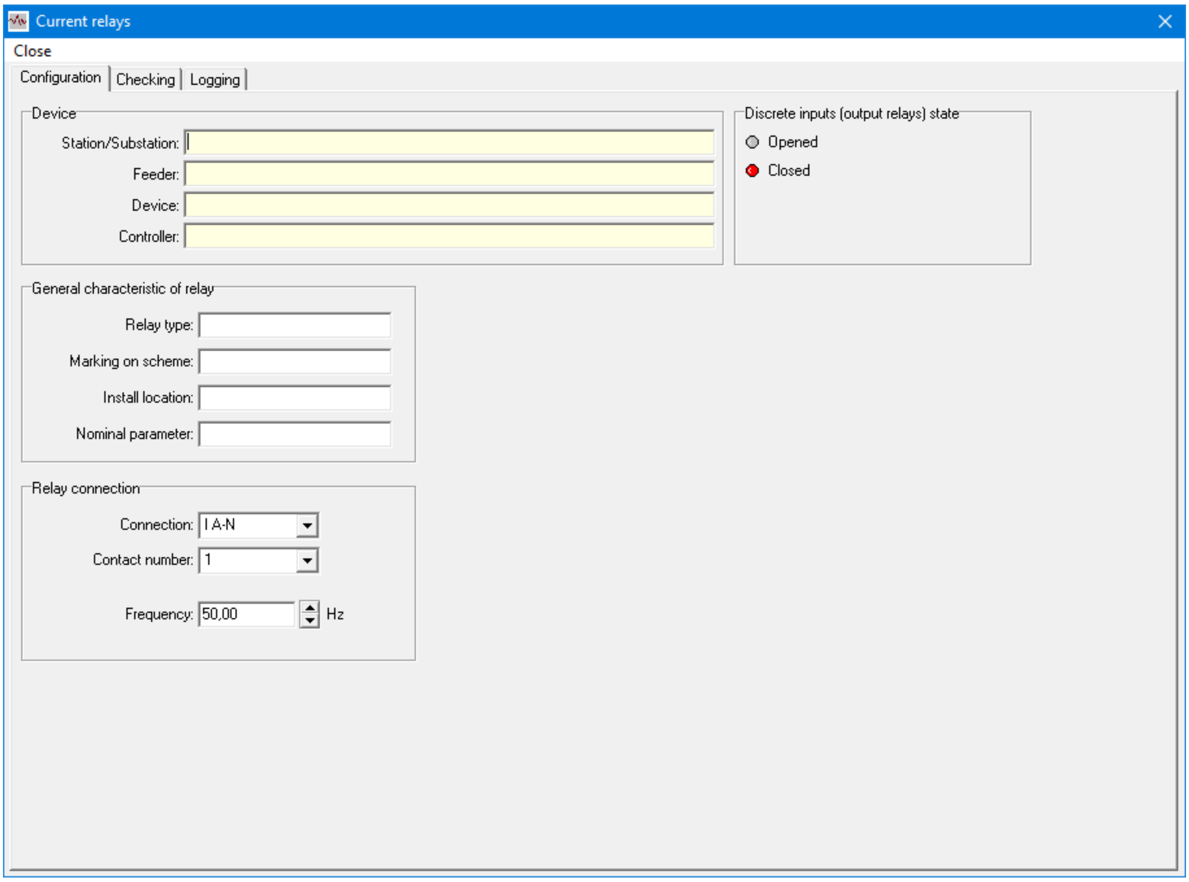


Fig. 6.1. Current relays test module (configuration page)

Current relay test module contains three pages.

6.2.1. The "Configuration" page

Here the user specifies the general characteristics of the relay.

In the "DEVICE" field the following information inputs:

- name of the station (substation);
- feeder;
- device;
- controller.

In the "*General characteristic of relay*" field the following information inputs:

- type of relay;
- its marking on the scheme;
- installation location;
- nominal setting.

In the "*Relay connection*" field:

- sets the scheme of connection of the relay coil to the "DEVICE". Possible connections of the relay coil to the current sources are: *"I A-N"*, *"I B-N"*, *"I C-N"*, or to the sum of currents of all sources "*I ABC-N*";
- sets the number of discrete input of the "DEVICE", to which the contact of current relay connects. Number of connection contact is selected from the list;
- sets the value of frequency of alternating current.

The relay must be connected to the "DEVICE" according to the given configuration.

6.2.2. The "Checking" page

In this page inputs the information, which is used directly to test the relay (Figure 6.2).

In "*Character of value changing*" field sets the mode of alternation of current, which is generated from the "DEVICE" to the current relay. There are two modes of current alteration - for the non-linear dependence, as shown in Fig. 6.2. or by linear character. The alternation of the current value selects from the list in the "*Characteristic*" field. The use of non-linear characteristic of the current alternation can significantly reduce the testing time of the relay – first the current increases rapidly, then when approaching the relay operation zone, the rate of change of current is reduced to provide the necessary accuracy of test.

Below, in the corresponding fields, sets the parameters of change of current characteristic:

- "*I Begin*" - the initial value of current;
- "*I End*" - the end value of current;
- "*T*" – time of changing the current from minimum to maximum value (determines the rate of increasing);
- "*T of pause*" – duration of pause between individual tests.

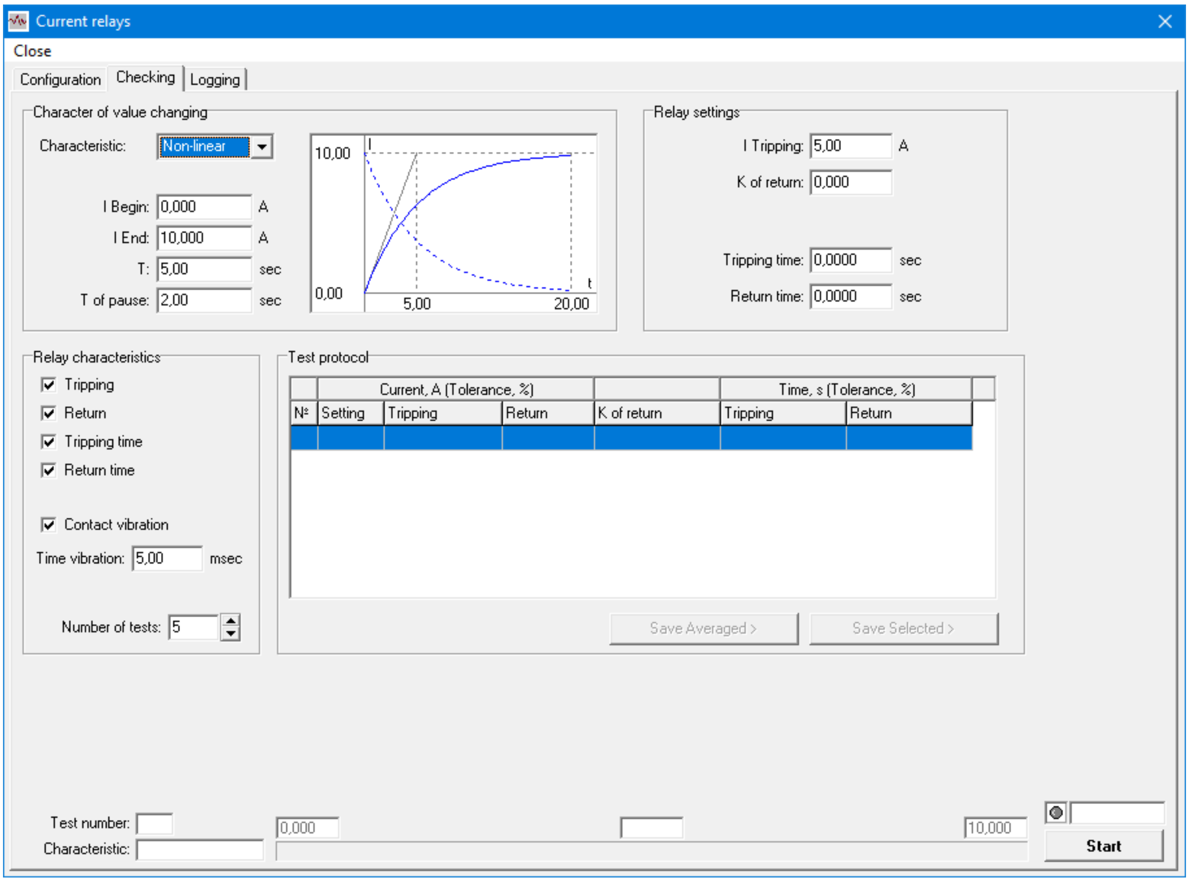


Fig. 6.2. Page for testing the current relay

In the "*Relay settings*" field, the nominal values of current relay defines:

- "*I Tripping*" – setting value of current of the relay;
- "*K of return*" - the expected return coefficient of relay;
- "*Tripping time*" - expected time of relay operation;
- "*Return time*" - the expected time of relay return.

In the "*Relay characteristics*" field the characteristics of the relay are set, that needed to be tested, along with test conditions.

The next parameters of relay can be tested:

- "*Tripping*" - determines the real current of operation of the relay;
- "*Return*" - determines the current of return of relay and calculates the real return coefficient of relay;
- "*Tripping time*" - determines time of operation of relay;
- "*Return time*" - determines time of relay return.

To specify which characteristics of relay need to be tested it is necessary to carry out their initialization.

Characteristics of the relay can be taken with account of contact vibration or without account of vibration. Without the account of contact vibration, all the characteristics of the relay will be taken with the account of the first closing (opening) of relay contacts.

To take into account the vibration you must initialize option "*Contact vibration*" and specify the time of vibration of contacts in milliseconds. After completing the test, the contact will be considered closed (opened), when, after the operation, time of closed (opened) state of contact is greater than the specified time in the "*Time vibration*" field.

In the "*Number of tests*" field sets the number of tests to be performed for testing the current relay with a specified setting value.

Upon completion of all preparatory operations you need to click "**Start**" button - the device will automatically test the relay. The name button then changes to "**Stop**". Operation of the device will be finished after completing all planned tests, or at any time by clicking the "**Stop**" button.

During the test, the page displays information about the test name and its number.

After testing each characteristic, the intermediate information will be shown in the "*Test protocol*". The information will be displayed in absolute units and in %, that shows the deviation of real relay settings from the settings specified in the "*Relay setting*". If the setting values of relay did not specified, the relay errors do not calculate.

6.2.3. The "Logging" page

After completing all tests, click "**Save**" button in the "*Test protocol*" field to save the results of tests - the average test results will be written to the table on page "*Logging*" (Fig. 6.3).

This page displays the averaged data (data averages by the number of tests performed during the test of current relay).

You can connect another current relay and test it the same way. On the "*Logging*" page the information about the characteristics of another relay would be written in the next line.

If the user wants to remove some line in the protocol, he must select this line and press "**Remove**" button.

To save the test protocol you must add the obtained results to the archive (see Section 2.4).

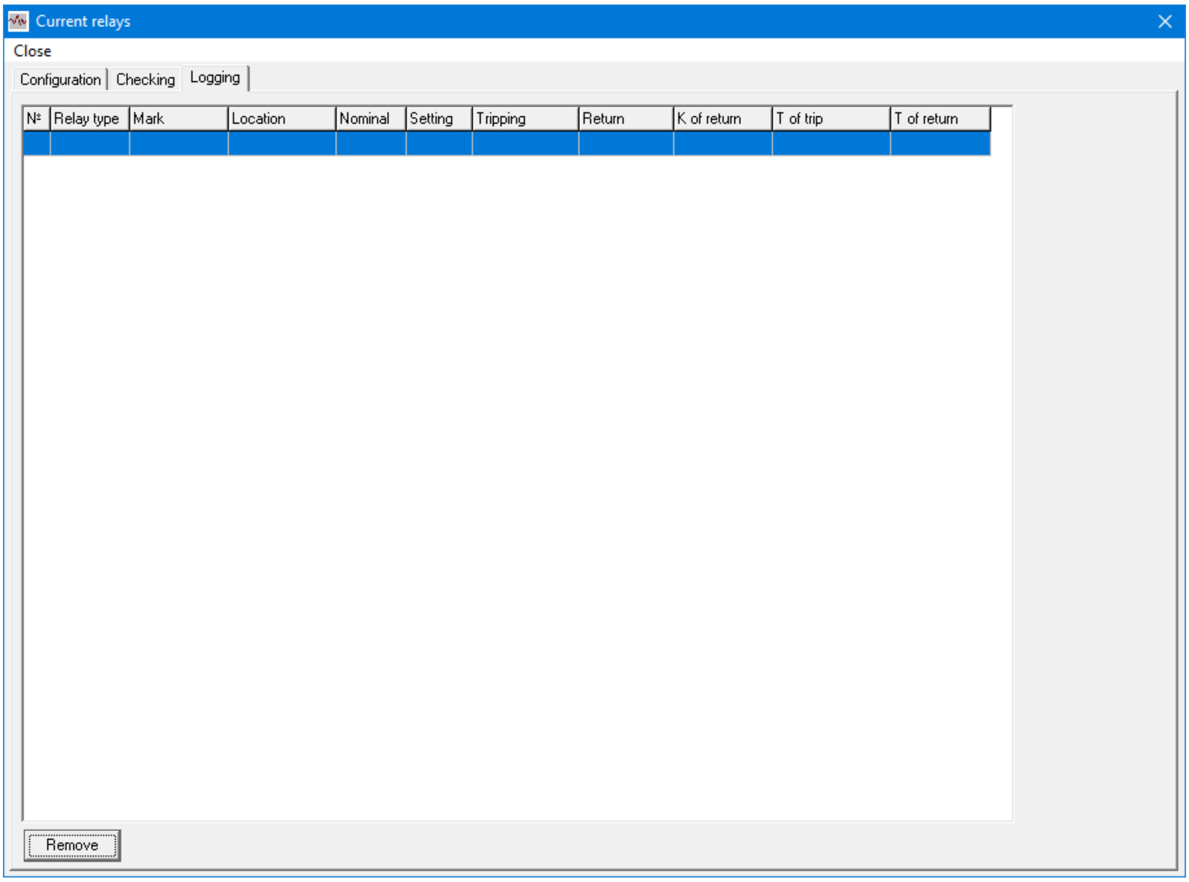


Fig. 6.3. Page of logging the test results of current relay

6.3. Module "Voltage relays"

After activation of module "*Voltage relays*" the following window will appear (Figure 6.4).

Test information for voltage relay inputs similarly as for the current relay, except for the field "*Relay connection*". In this field, you must select from the list the connection scheme of the relay *"U A-N"*, *"U B-N"*, *"U C-N"*, *"U A-B"*, *"U B-C"* or *"U C-A"*, and connect the relay coil to the selected voltage source of the "DEVICE". Remember that when you connect the relay to the voltages *"U A-N"*, *"U B-N"*, *"U C-N"* the user can change the voltage in the range 0 - 125 V, and when connected to a voltage *"U A-B"*, *"U A-C"*, *"U B-C"* - in the range 0 -250 V.

All other test operations with voltage relay perform similarly as for the current relay. Unlike current relay, the test parameter of voltage relay is voltage.

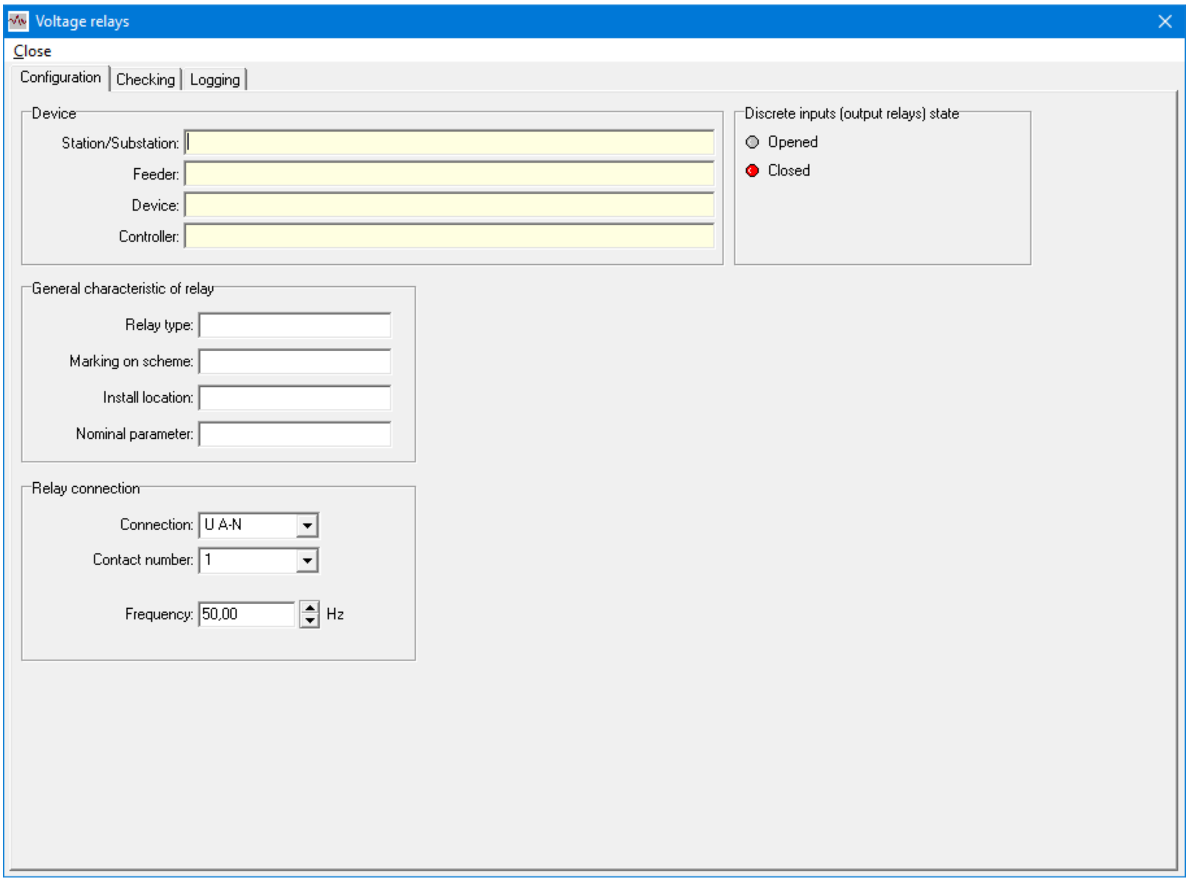


Fig. 6.4. Test module of voltage relays (page "Configuration")

6.4. Module "Intermediate relays"

This module is used to test the intermediate and signal relays (with one coil) for both AC and DC.

After activating the module, on the PC screen a window will appear (Figure 6.5).

As for the current or voltage relays, in the fields "*Device*" and "*General characteristics of relay*" information about the relay inputs.

In the "*Relay connection*" field sets:

- type of current of relay: "*direct*" or "*alternating*";
- relay type - voltage or current;
- connection of relay – for current relay the possible connection schemes to current source are: *"I A-N"*, *"I B-N"*, *"I C-N"*, or the sum of all current sources *"I ABC-N"*; for voltage relays – connection to the voltage source: *"U A-N"*, *"U B-N"*, *"U C-N"*, *"U A-B"*, *"U B-C" or "U C-A"*;
- defines contact number, by which the testing of the characteristics of the relay be accomplished;
- sets frequency for AC relays.

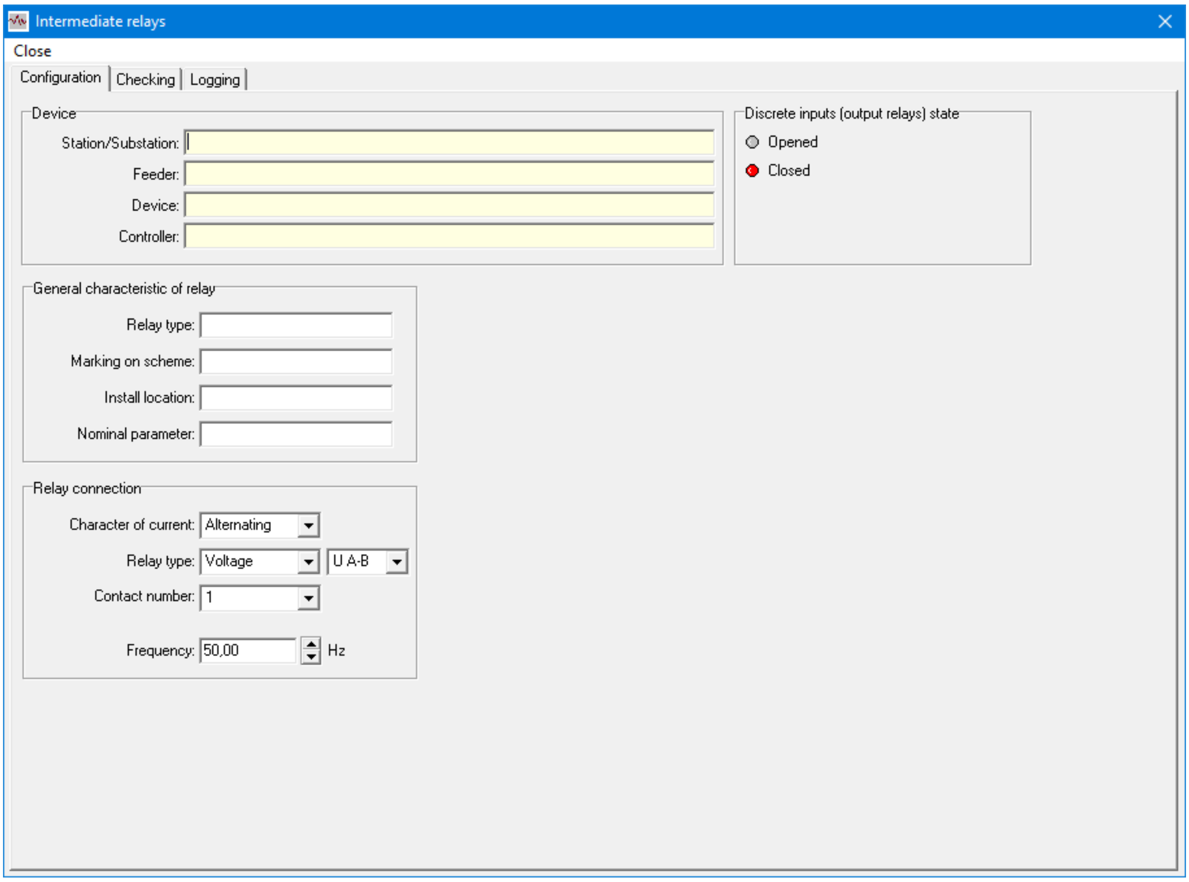


Fig. 6.5. Page of module configuration "Intermediate relays"

To test the relay user must go to "*Checking*" page. This page looks like a similar page for testing current relay (see Fig. 6.2) or voltage relay. Further testing of auxiliary relays is carried out similarly as the current or voltage relays.

6.5. Module "Frequency Relays"

Designed to test the relay frequency with independent characteristic.

After activating module "*Frequency Relays*" on the PC screen the following window will appear (Figure 6.6).

The "*Configuration*" page

As for the current, voltage or auxiliary relays, in the "*Device*" and "*General characteristics of relay*" fields the information about the relay inputs.

On the same page displays relay connection scheme:

- sets the connection scheme of voltage relay coil to the "DEVICE". The possible schemes of connections of the relay coil to the voltage sources are: *"U A-N"*, *"U B-N"*, *"U C-N"*, *"U A-B"*, *"U A-C"*, *"U B-C"*;
- sets number of discrete input of the "DEVICE" to which the frequency relay contact connects.

The relay connects to the "DEVICE" according to this manual.

To test the relay user must go to "*Checking*" page. This page looks like a similar page for testing current relay (see Fig. 6.2). Further testing of frequency relays is carried out similarly as the current, voltage or intermediate relays. Except, that parameter of change is the frequency of the signal generated by the device. Additionally, the field of "*U*" provides the ability to specify effective value of voltage.

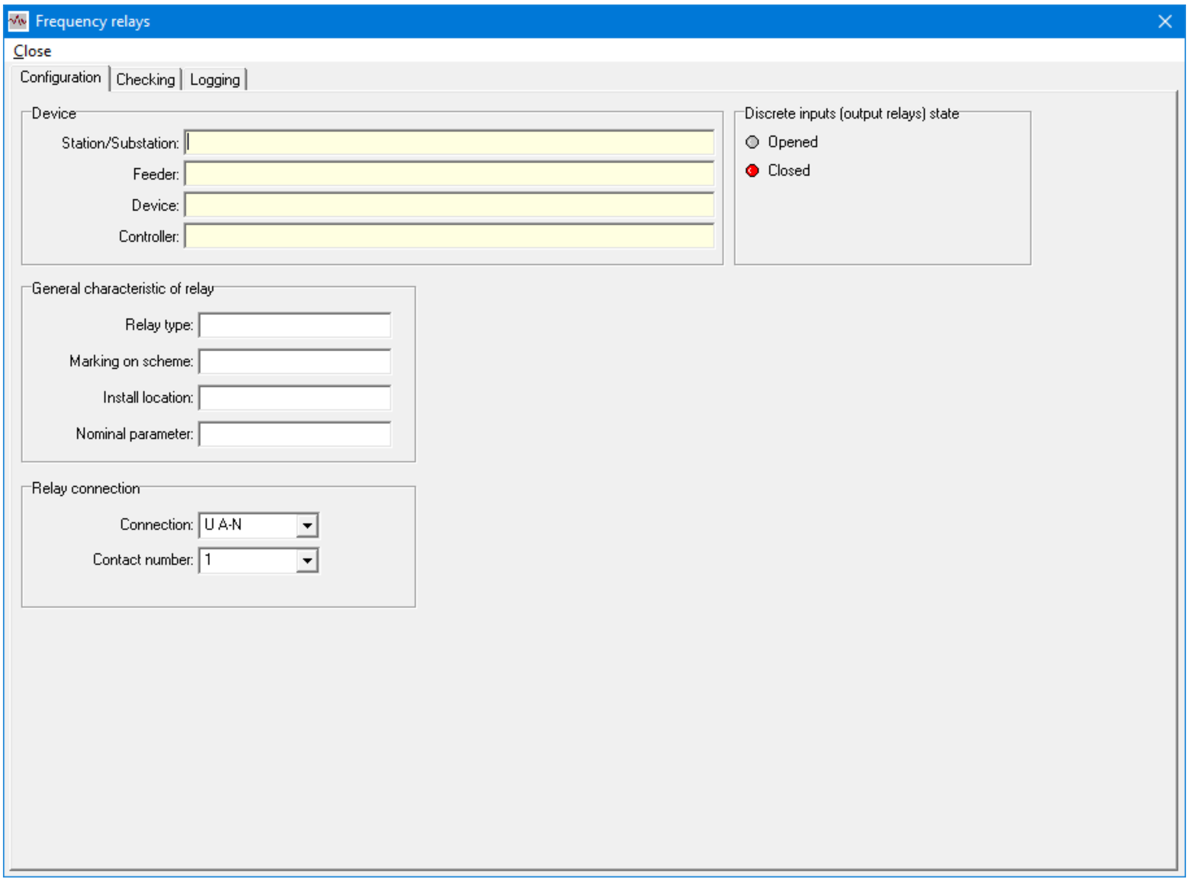


Fig. 6.6. Module "Frequency Relays" (configuration page)

6.7. Module "Differential Relays"

Designed to test the differential relays with restrained characteristics.

6.7.1. The "Configuration" page

After activating the module "*Differential relays*" the following window will appear on the PC screen (Figure 6.10).

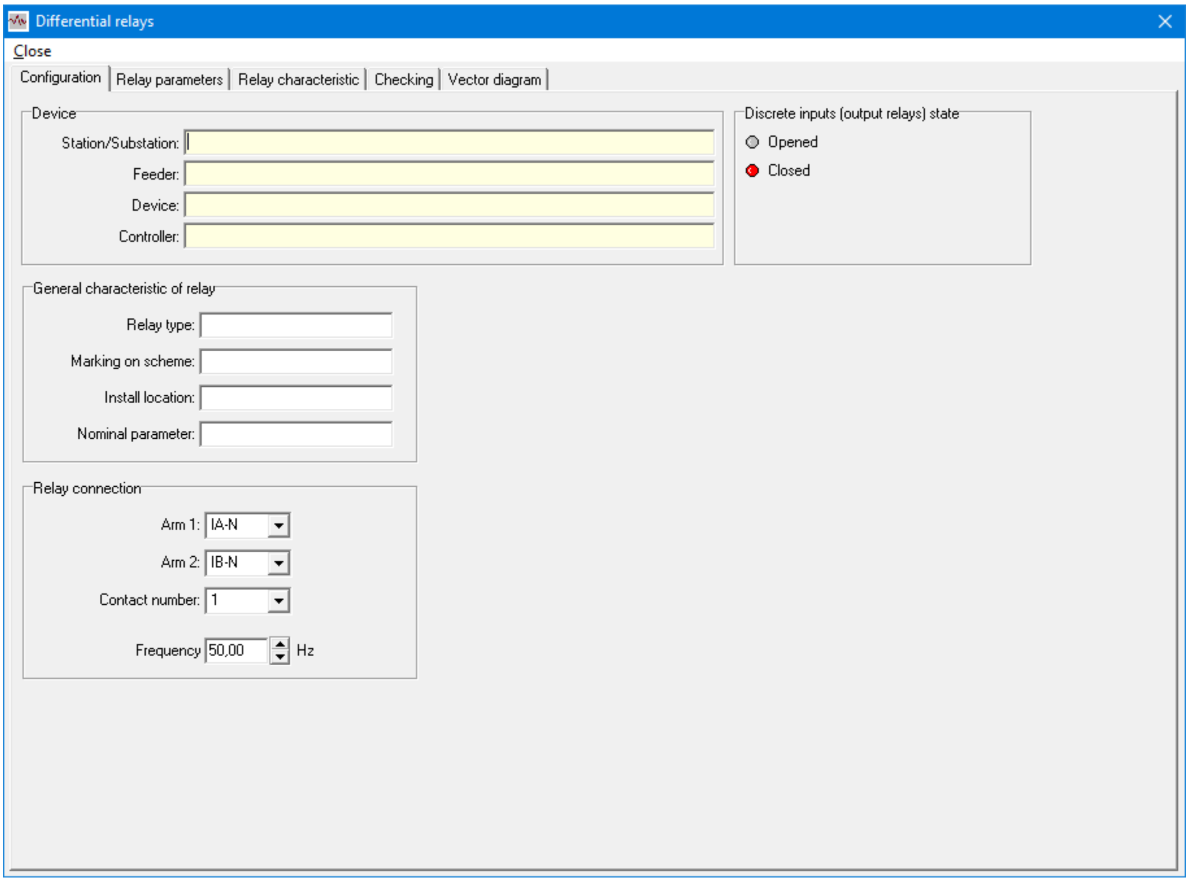


Fig. 6.10. The "Configuration" page for differential relays

As for the current or voltage relays in the "*Device*" and "*General characteristics of relay*" fields inputs the general information about differential relay.

In the "*Relay connection*" field sets the current channels, to which the differential relay coil should be connected, and also specifies the number of discrete input to which the output contact of the differential relay should be connected.

6.7.2. The "Relay parameters" page

On this page the parameters of differential relay defines that will be tested. View of this page is shown in Fig. 6.11.

In the "*Differential current*" field, the value of cutoff current of differential relay *Idiff* >> in relative units defines, and also defines the minimum value of differential relay operation *Idiff* >. These values correspond to the restrained characteristic of the differential relay, which is shown in Fig. 6.12.

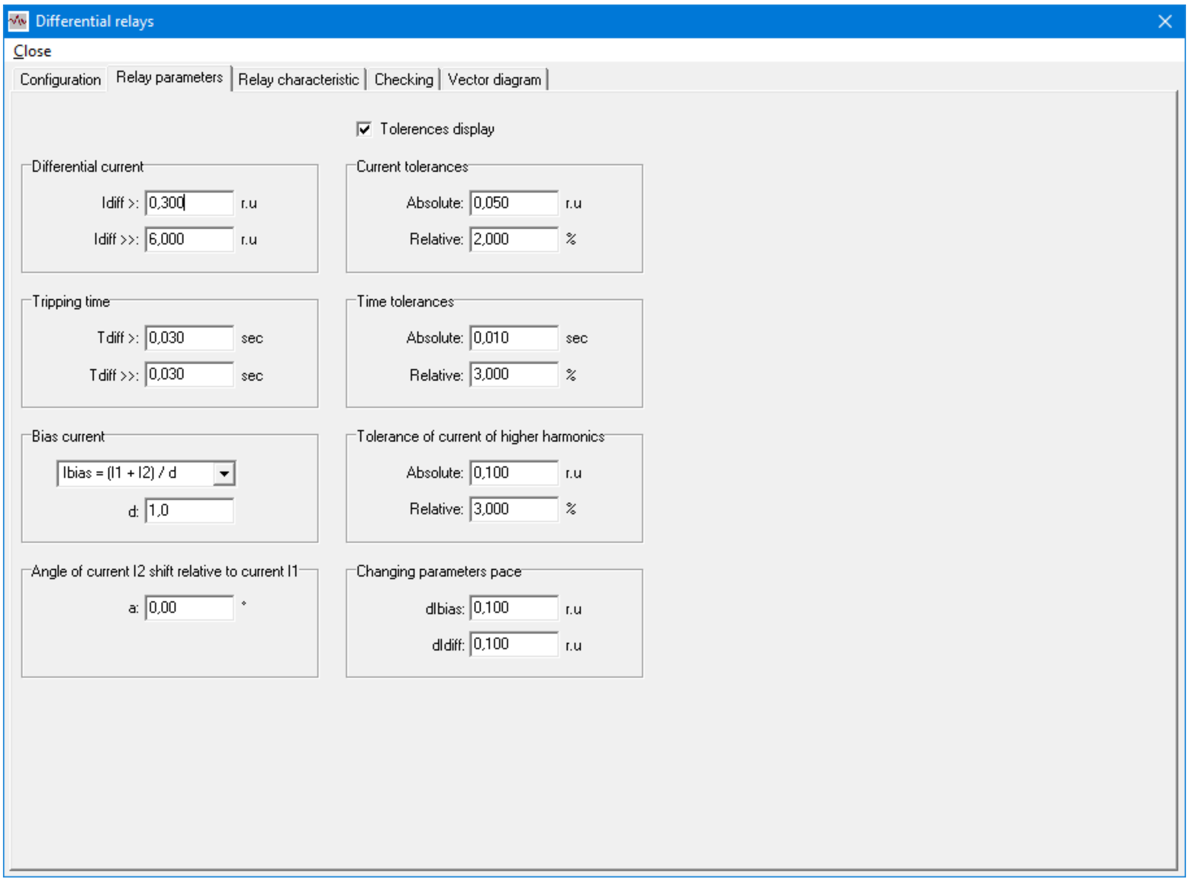


Fig. 6.11. The "Relay parameters" page

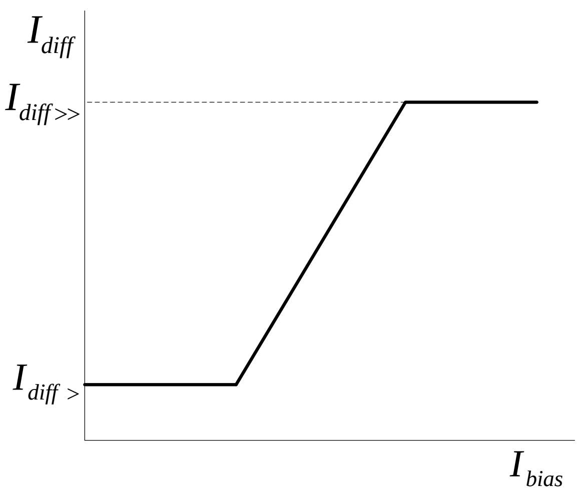


Fig. 6.12. The "Relay parameters" page

In the "*Tripping time*" field sets the time of operation of cutoff current and the time of operation of relay at minimum value of differential current, respectively *Tdiff* >> and *Tdiff* >.

In the "*Current tolerances*" field defines the value of current tolerance. The tolerance can be specified in absolute units (relative) or relative (in per cents). If the user set the value of the tolerance in relative and in absolute units, the calculation will be made by greater of these two values.

In the "*Bias current*" field defines the type of restraining characteristic and restraining coefficient (divider) value, by which the restraining current will be calculated. The most common differential relays are relays in which the restraining current is determined by the expression:

$$I_{bias} = (I_1 + I_2)/d, \tag{6.2}$$

where I_1, I_2 - the currents in the shoulders of protection; I_{bias} - current in the restraining coil; d – restraining coefficient (divider).

In the "*Time tolerances*" field defines the values of relay tolerances by time. The tolerance can be specified in absolute units (seconds) or relative units (in per cents). If the user set the value of the tolerance in relative and in absolute units, the calculation will be made by greater of these two values.

In the "*Tolerance of current of higher harmonics*" field sets the tolerance value by the current of higher harmonics. The tolerance can be specified in absolute units (relative) or relative units (in per cents). If the user set the value of the tolerance in relative and in absolute units, the calculation will be made by greater of these two values.

Restraining characteristic of the differential relay with account of the tolerances by current is shown in Fig. 6.13. The figure shows the forming of restraining characteristics of the relay, with account of defined tolerances.

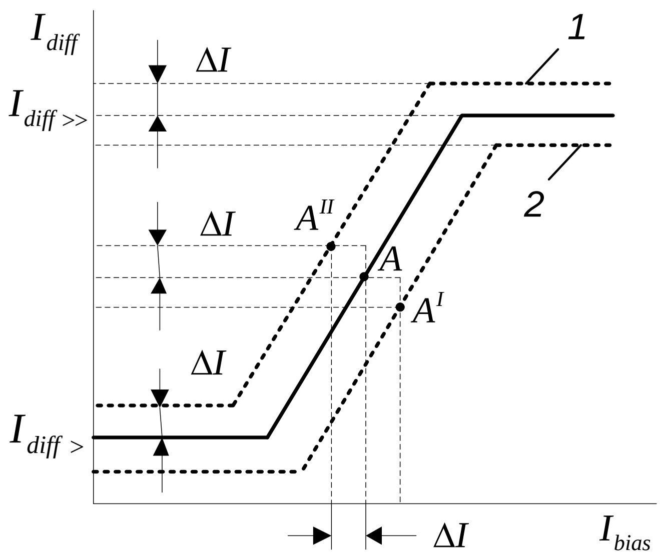


Fig. 6.13. Restrained characteristic of relay with account of tolerances

6.7.3. The "Relay characteristics" page

This page is designed to build the restraining characteristics of relay, to record and read such characteristics from libraries. Overall view of "*Relay characteristics*" page is shown in Fig. 6.14. The possibility is provided to form the libraries with restraining characteristics at basic frequency.

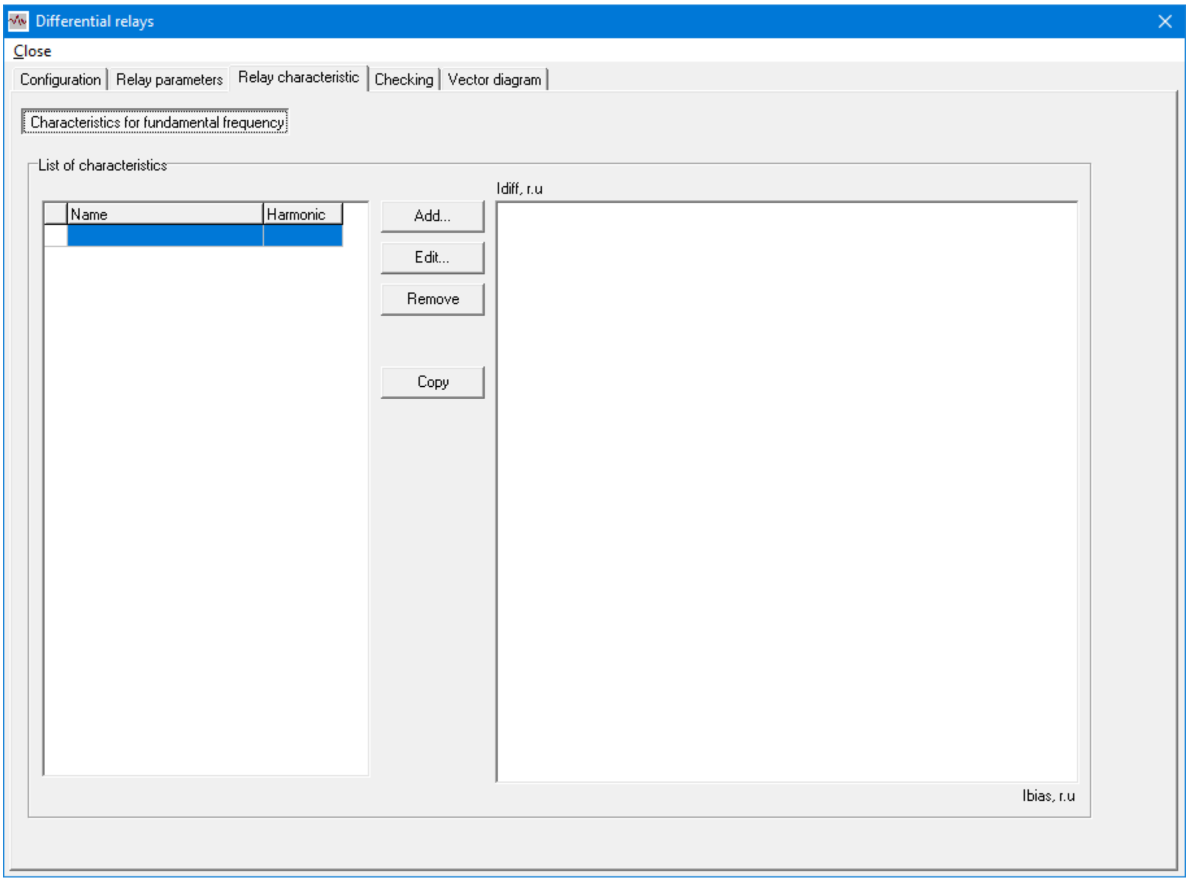


Fig. 6.14. The "Relay characteristics" page

On the left side of the "*List of characteristics*" field, a list of the formed characteristics is displayed. The table contains the characteristic names and the harmonic numbers. For the characteristic at basic frequency, in the "*Harmonic*" field, the number "1" will always display, and it cannot be corrected.

Characteristic that was selected from the list will appear in the display. Restraining characteristic at the basic frequency will be displayed in the coordinates: *Idiff (r.u)* - the ordinate axis and *Ibias (r.u)* - the abscissa axis.

We will consider the formation of restraining characteristic at basic frequency.

For the construction of new characteristic you must click on the "**Add**" button – the window will appear (Figure 6.15).

In the field "*Name*" you must specify the name of the characteristic which will be displayed in the list of characteristics (see Fig. 6.14).

You can build the restraining characteristic in two methods: "by points" and "by direction". The method selects using the dependent switches in the "*Coordinates of characteristic points*" field. The first method involves direct specifying of the coordinates of each point of the characteristic. Second method involves setting beam, which begins on the abscissa axis (*Ibias*) at a given angle.

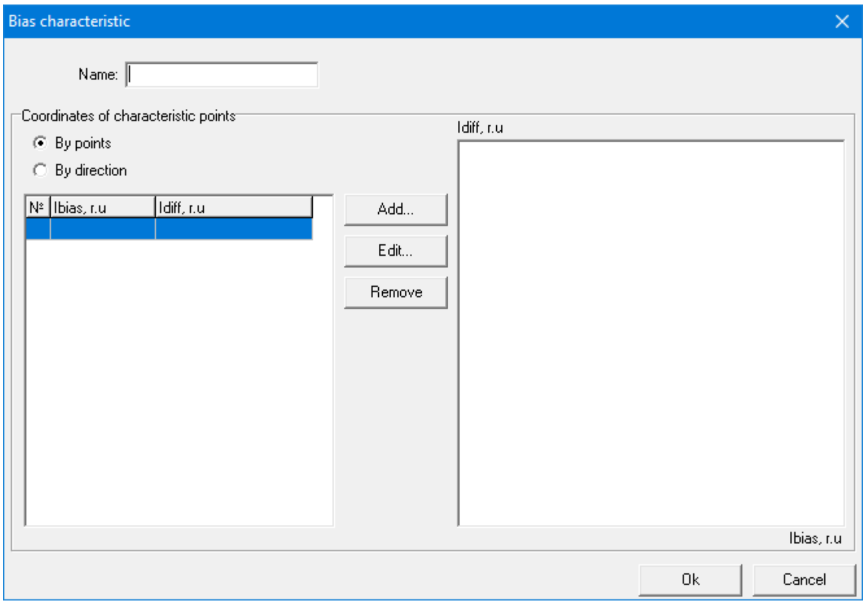


Fig. 6.15. Construction of restraining characteristic at basic frequency

To build the characteristic - click on the "**Add**" button – a window will appear (Figure 6.16 or Fig. 6.17) (depending on the chosen method of construction). In this window you must set the point coordinates of the restraining characteristic and click "**Ok**" button – the specified point will appear in the field "*Coordinates of characteristic points*" (see Fig. 6.15). In the display field of this window you will see the section of characteristic that matches the specified coordinates. Similarly, all points of coordinates of the restraining characteristic are set.

During the construction of characteristic by the method "by points", in the appropriate window fields (Fig. 6.16) sets the coordinates of each point of the characteristic. Restraining characteristic is formed by connecting these points.

During the construction method "by direction", sets the coordinates of beams, which start at the abscissa axis (point is specified in the "*Ib*" field (Fig. 6.17)) at a given angle (the angle can be specified by the incline coefficient (the "*Kbias*" field) or in degrees (field "*Phi bias*")). Points of characteristic will be positioning at the crossing of corresponding beams.

Added points of characteristic can be edited or deleted. To do this, use the appropriate buttons.

After the completion of construction of restraining characteristic you must click "**Ok**" button (see Fig. 6.15) - formed characteristic will be stored in the library, its name will appear in the "*List of characteristics*" field (see Fig. 6.14), and its view will be shown in the display field.

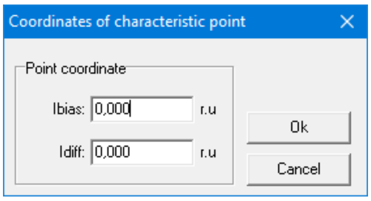


Fig. 6.16. Construction of the characteristic "by points"

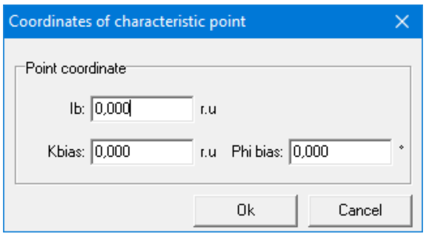


Fig. 6.17. Construction of characteristic "by direction"

Built characteristic can be corrected. To do this, you need to select it from the list of characteristics (see Fig. 6.14) and click "**Edit**" button – a window will appear (see Fig. 6.15) with the parameters of restraining characteristic. In the appropriate fields of this window you need to make the necessary changes.

It is possible to remove built characteristics and copy them. To do this, use the buttons "**Remove**" or "**Copy**" (see Fig. 6.14).

6.7.4. The "Checking" page

From this page, the direct test of the differential relay is performed – the parameters of restraining that were formed on the page "*Relay characteristic*" would be tested. The "*Checking*" page is shown in Fig. 6.18.

Remember that the restraining characteristic is formed on the base of constructed characteristic with regard to the restrictions specified on the page "Relay parameters".

Consider how the test of restraining characteristic by the basic frequency performs.

Before you begin to test the relay, you must perform a number of preparatory operations:

- in the edit field "*Basic currents of arms*" sets the rated values of currents of differential protection arms, to which the differential relay coils are connected;
- in the edit field "*T max*" sets the maximum value of time during which the test for one point is performed. Thus you set the limit to the time of generation of current by the "DEVICE" in case when the differential relay do not operate;
- in the field "*T of pause*" sets the value of time to create break time between adjacent points of test.

At this, the points for relay test are forming - each point corresponds to a certain value of restraining current and differential current. To accelerate the testing process, the opportunity is provided to perform the complex relay test, which means – to test the determined set of points. To do this, in the field "*Test points set*" the user defines the coordinates of the set of points. These points are shown in the "*Bias characteristic*" field. You can specify the coordinates of test points, using one of the following methods:

- by double "clicking" the point in the field "*Bias characteristic*";

- using the "**Add**" button (the coordinate previously sets using the "mouse" in the field "*Bias characteristic*");
- in combined field "*Test point*" using keyboard and then clicking "**Add**" button in the combined field "*Test points set*".

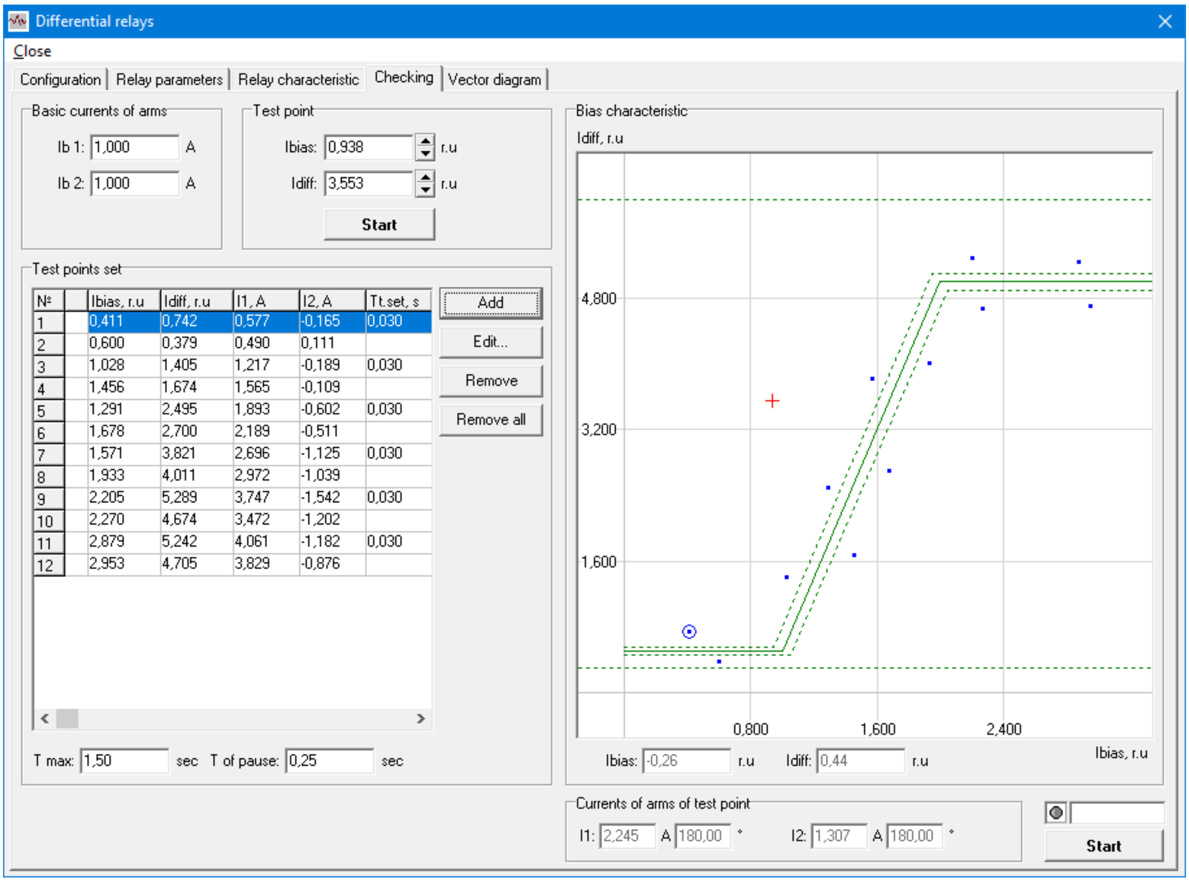


Fig. 6.18. The "Checking" page

Points that were formed in the field "*Bias characteristic*" are shown in color that was specified in the configuration. You can pass to graphic configuration, using the "*Graphics*" command in the main menu item "*Configuration*".

After the formation of the table there is the ability to perform the following commands with the defined set of points:

- "*Edit*" – allows to change the coordinates of the point, selected from the set of points;
- "*Remove*" allows you to remove the selected point from the set of points;
- "*Remove All*" - The whole set of points will be removed after executing this command.

After performing all the preparatory operations you can proceed to testing the differential relay.

To do this, click "**Start**" button - the "DEVICE" will continuously generate currents of a certain value, depending on the coordinates of the test points that are specified in the table in the "*Test points set*" field.

The values of the currents, generated by the "DEVICE" on the two current channels, with addresses set on the page "*Configuration*", are determined by the expressions:

$$I_1 = 0{,}5 \cdot (I_{bias} \cdot d + I_{diff}) \cdot I_{b1};$$
$$I_2 = 0{,}5 \cdot (I_{bias} \cdot d - I_{diff}) \cdot I_{b2}, \quad (6.3)$$

where I_{bias}, I_{diff} - the coordinates of the point (values of restraining and differential currents, respectively) set in the table "*Test points set*", *d* – restraining coefficient (divider), which is set in the "*Configuration*" page (see Fig. 6.11); I_{b1}, I_{b2} - nominal currents in the arms of protection (in format RIO and analog of XRIO these values are called scale factors).

The currents I_1, I_2 will be generated by the "DEVICE" in opposite phases.

The test will start with the selected from the table point. The pause between tests for each point will exist, the value of which corresponds to the time specified in the field "*T of pause*".

During the test, in the first column of the table the test result will be displayed: if the test is successful for this point, the symbol will be "+" - if not, the symbol will be "-".

A positive result is considered in the following cases:

- the relay operated at points located above the restraining characteristic of relay, with regard to tolerances, at the time that did not exceed the time specified in "*Relay parameters*" page;
- the relay did not operated at points located below the restraining characteristic of relay with regard to tolerances.

If the point is located in the zone, bounded by characteristics *1*, *2*, that corresponds to the defined tolerances (see Fig. 6.13), the result is considered positive if both operating and not operating of differential relay cases.

In all other cases, the result is considered negative.

The fourth and fifth columns displays the values of currents that are generated by the "DEVICE" in the arms of the differential relay. Their values are calculated according to (6.3).

The sixth and seventh columns displays the setting value of operating time and real value of operation of relay.

It is possible to change the view of columns of the table. You can hide or show a column of the table, using the local menu (Figure 6.19).

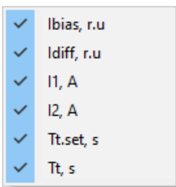


Fig. 6.19. Information from the table "Test points set"

The test process will be completed after testing all the points that were specified in the field "*Test points set*". The user can stop the test at any time by pressing the "**Stop**" button (after the "DEVICE" begins to work, the button "**Start**" changes its name to "**Stop**" and starts flashing).

To test the single test point, you can use the button "**Start**" in the group field "*Test Point*". After completing the test, the test point and the test result will be added to the table "*Test points set*".

6.7.5. The "Vector diagram" page

This page shows the vectors of currents, which are fed to the arms of relays. For the restraining characteristic at basic frequency, in addition to current values, the vector diagram of currents displays.

7. MODULE "SYNCHRONIZER"

Module "Synchronizer" is designed for adjusting and testing the synchronizing devices of both foreign and domestic firms. These devices can be constructed by electromechanical, semiconductor or digital technology.

You can activate the module "*Synchronizer*" from the main menu "*Module*" using the command "*Synchronizer*" (see Fig. 1.2).

The module consists of the following interconnected functional blocks, placed on separate pages:

- "Configuration;
- "Synchronizer parameters";
- "Checking";
- "Results".

7.1. The "Configuration" page

The overall view of the page "*Configuration*" is shown in Fig. 7.1.

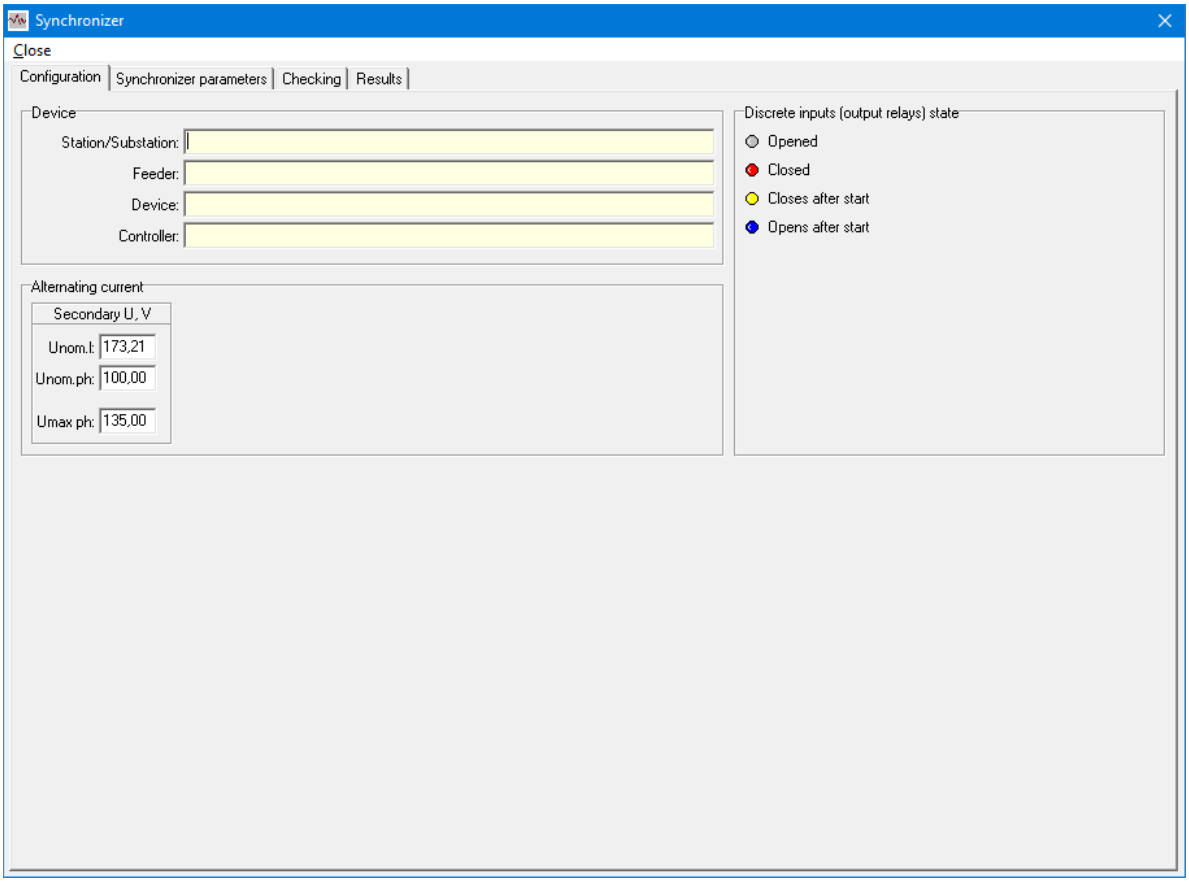


Fig.7.1. The "Configuration" page

The "*Configuration*" page specifies the information about the device, which is tested (the "*Device*" field), and the limit voltage (in the "*Alternating current*" field).

7.2. The "Synchronizer parameters" page

The overall view of page "*Synchronizer parameters*" is shown in Fig. 7.2.

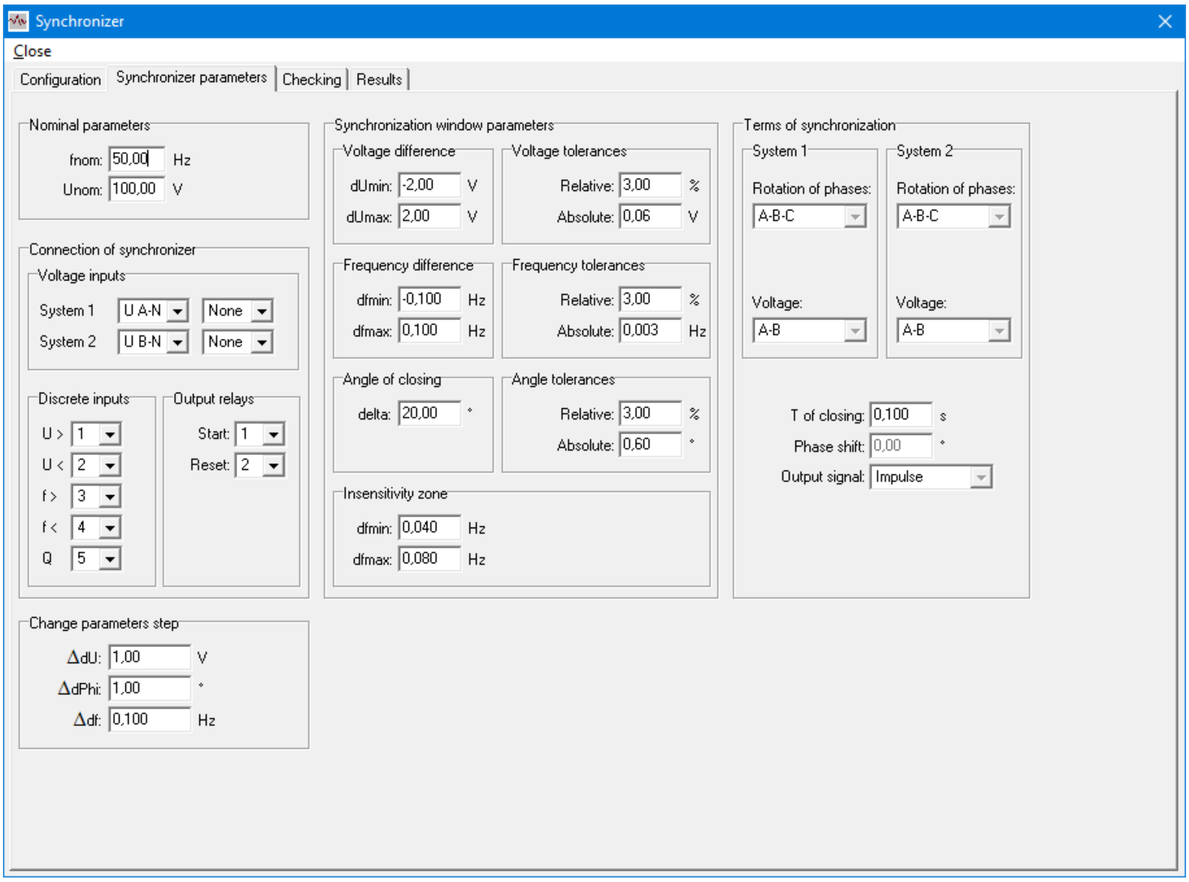


Fig. 7.2. The "Synchronizer parameters" page

In the field "*Nominal parameters*" sets nominal voltage and frequency of synchronizer.

In the field "*Connection of synchronizer*" sets the physical inputs of the "DEVICE", to which the synchronizer is connected. The field "*Connection of synchronizer*" in turn, consists of separate fields:

- "Voltage inputs";
- "Discrete inputs";
- "Output relays".

"*Voltage inputs*" - voltage circuits of the synchronizing and synchronized systems. Possible connections to voltage circuits of the "DEVICE" are: *U A-N*, *U B-N*, *U C-N*. The system monitors the connection, for example, if system 1 has the connection *U A-N*, then the system 2 may only have connections *U B-N* or *U C-N*. In addition, it is possible to connect the synchronizer to additional voltage circuits. By default, these circuits are not used.

"*Discrete inputs*". To test the synchronizer, the channels are defined, through which the commands transmit from the synchronizer to the "DEVICE" to increase or decrease the value of voltage and frequency (respectively U>, U <, f>, f <), as well as commands to close the circuit breaker (Q). Depending on the type of synchronizer, not all channels are used. The system provides automatic control of the selection of discrete inputs numbers. Using the same discrete input for the implementation of various commands is not allowed.

"*Output relays*". For modern digital synchronizers there are discrete inputs for starting the synchronizer and the command RESET is present. For this purpose, you have the ability to use the output relays of the "DEVICE" ("*Start*", "*Reset*"). As in the previous case, the system provides automatic control of the process of selecting the output relays numbers – it is not allowed to use the same output relay for the implementation of different commands.

In the field "*Synchronization window parameters*" the following parameters are set:

- "*Voltage difference*" - minimum *dUmin* and maximum *dUmax* allowable values of system voltage difference at which the synchronization is allowed;
- "*Voltage tolerances*" - relative and absolute tolerances;
- "*Frequency difference*" - minimum *dfmin* and maximum *dfmax* allowable values of system frequency difference at which the synchronization is allowed;
- "*Frequency tolerances*" - the relative and absolute tolerances;
- "*Angle of closing*" - the maximum *delta* angle between the vectors of voltages at which synchronization is allowed;
- "*Angle tolerances*" - the relative and absolute tolerances;
- "*Insensitivity zone*" - a zone of synchronizer insensitivity by frequency *dfmin*, *dfmax*. If the difference between frequencies of the systems lies in the defined zone, the synchronizer does not issue commands to increase or decrease the frequency.

In the "*Terms of synchronization*" the following information defines:

- "*Rotation of Phases*" - for synchronizing and synchronized systems sets either direct or inverse phase sequence;
- "*Voltage*" - for both systems sets the voltage that is used to connect the synchronizer. There are following voltages: *A-N, B-N, C-N, A-B, B-C, C-A, B-A, C-B, A-C, A-B-C, A-C-B, AB-BC-CA, AC-CB-BA*;
- "*T of closing*" - sets the real time of operation of the circuit breaker. Uses to simulate the synchronization with account of time of operation of the circuit breaker on which the command for closing is issued by the synchronizer;
- "*Phase shift*" – sets the phase shift between systems that are synchronized due to connection groups of the transformers;

- "*Output signal*" – sets the signal form that is generated by the synchronizer on the output after all conditions of synchronization are carried out. There are following waveforms: "*Impulse*", "*Continuous*", "*Missing*".

In the field "*Change parameters step*" sets steps for discrete change of voltage difference, the difference of the angles between voltages and frequency difference for system 2 and 1 respectively. These values are used for discrete change of the corresponding parameters on the "*Checking*" page (see Section 7.3).

7.3. The "Checking" page

General view of the page is shown in Fig. 7.3.

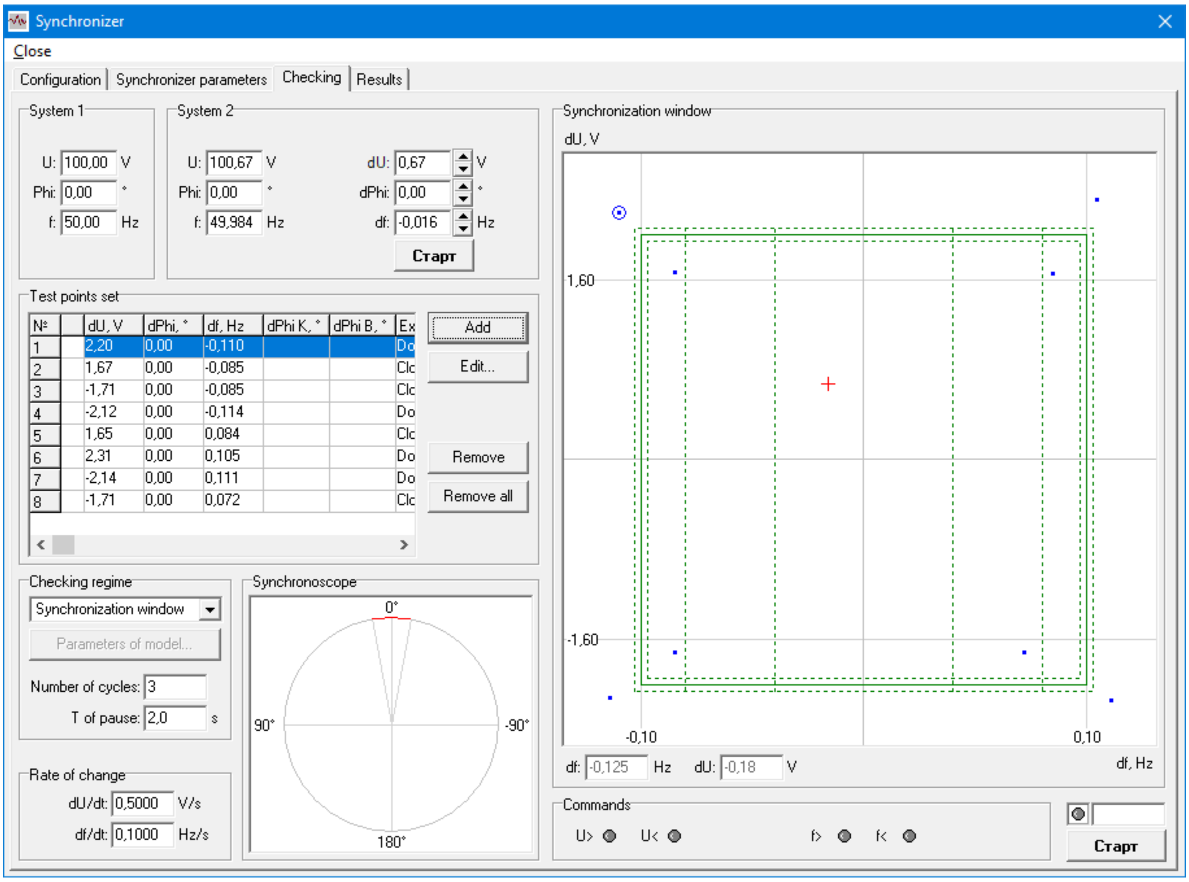


Fig. 7.3. The "Checking" page

The page contains the following fields:

- "System 1";
- "System 2";
- "Test points set";
- "Checking regime";
- "Rate of change";

- "Synchroscope";
- "Synchronization window";
- "Commands".

The "*System 1*" field.

In this field, sets the parameters of the system according which the synchronization will be implemented. These parameters remain constant during the synchronization process. In the corresponding fields sets the values of voltage *U* (its effective value), initial phase *Phi* and frequency *f*. After starting the synchronization mode, the "DEVICE" will generate voltage to system 1 voltage input of the synchronizer by the following expression:

$$u = \sqrt{2} \cdot U \cdot sin(2 \cdot \pi \cdot f + Phi).$$

In the field "*Synchronization window*" the parameters of the system 1 are presented in two mutually perpendicular lines that intersect at the origin. According to this point the synchronizer parameters *dUmin, dUmax, dfmin, dfmax* are calculated. These values are defined on the page "*Synchronizer parameters*". Based on these values, the rectangle will be displayed - synchronization window.

The "*System 2*" field.

In this field sets the initial parameters of the system, which is synchronized. In the corresponding fields sets the values of voltage *U* (its effective value), the initial phase *Phi* and frequency *f*. In the fields *dU*, *dPhi*, *df* - the difference of the corresponding parameters of the systems 2 and 1 will be displayed. User can also set the differences between parameters of system 2 and 1 - *dU, dPhi*, *df* in the corresponding fields. In this case, according to these values and the values of the system 1 parameters, automatically will be calculated and displayed in the corresponding fields the parameters of the system 2. Test point with defined coordinates *dU* and *df* will be displayed with symbol "x" in the "Synchronization window". You can also perform a discrete change of these parameters by pressing the arrow keys located to the right of the corresponding fields. Step of change sets on the page "*Synchronizer parameters*" (see Section 7.2).

Parameters of the system 2 can be set using the "mouse". You must put the pointer to the corresponding point in the "*Synchronization window*" (coordinates of the floating point are displayed at the bottom of the "*Synchronization window*" field) and click the left "mouse" button - the selected point locks in the field, and the calculated values (that corresponds to the selected point) of parameters of system 2 will be displayed in the corresponding fields "*System 2*", corresponding to the selected point.

The "*Synchronization window*"

This field displays in the coordinates *dU* and *df*:

- the synchronizer parameters that displays as a rectangle;
- allowable error of the synchronizer parameters;
- synchronizer dead zone by the frequency;

- test point, which corresponds to a relative coordinates of the system 2. These coordinates defines as the difference between the corresponding parameters of the system 2 and 1;
- set of test points represented in tabular form in the "*Test points set*" field;
- limit lines by voltage and frequency. Beyond these lines it is impossible to form a test point;
- hodograph of change of system 2 parameters during synchronization, which is formed during testing.

Using the local menu in the "*Synchronization window*", you can perform certain operations on the selecting of test point and image scaling.

If the user wants to change the color palette of the "*Synchronization window*", he must execute command "*Graphics*" from the menu "*Configuration*". After that the window will appear on PC screen (Figure 7.4)

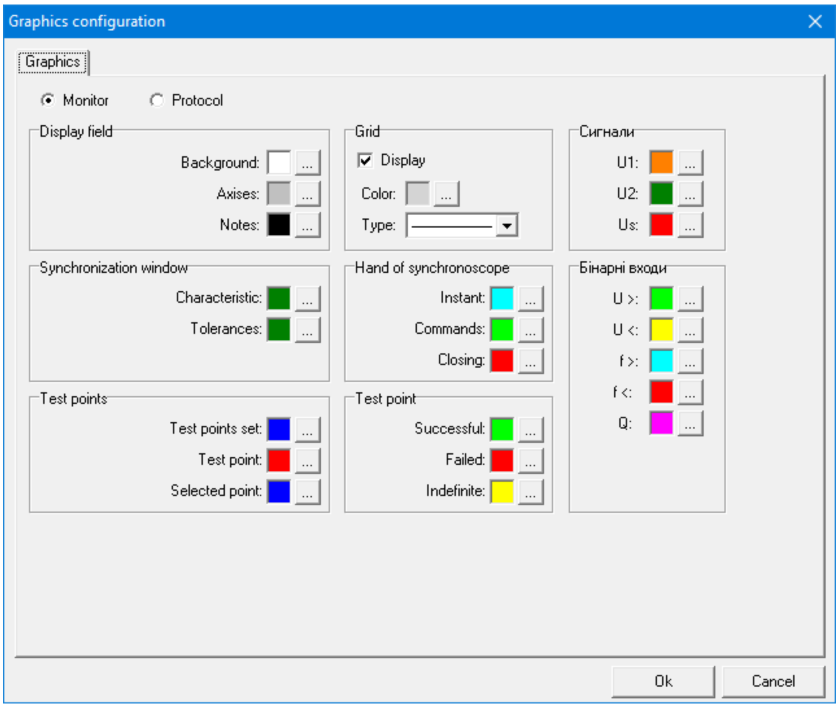


Fig. 7.4. Graphics configuration

With the help of this window, the user can change the display field, the grid, and set the desired colors in the synchronization window and in the window of synchroscope.

The "*Test points set*" field

In this field, the table is forming with relative coordinates of system 2, which is synchronized with the system 1: *dU, dPhi, df*. These coordinates can be set by one of three ways:

- set the test point (*dU, df*) in the field "*Synchronization window*" with the "mouse" and make a double "click" (except for the mode "*Defined trajectory*");
- select the test point (*dU, df*) in the field "*Synchronization window*" with the "mouse" and click "**Add**" button in the "*Test points set*" field;

- set the coordinates of the test point (*dU, dPhi, df*) directly in the field "*System 2*" and click "**Add**" button in the field "*Test points set*".

In the field "*Test points set*" there is the ability to delete individual test points, delete all points and edit selected points. To do this, use the buttons "**Edit**", "**Remove**", "**Remove All**".

Representation of the columns of the table "*Test points set*" can be changed using the local menu.

The "*Checking regime*" field.

In this field sets the test mode of the synchronizer. There are following test modes:

- "Synchronization window";
- "Linear model";
- "Nonlinear model";
- "Defined trajectory".

Mode "*Synchronization window*".

In this mode, the synchronization window is tested – will the synchronizer send a signal to close the circuit breaker when the test points that characterize the initial state of the system 2 are within the rectangle outlined by the parameters of synchronizer *dUmin, dUmax, dfmin, dfmax*, or will not the synchronizer send a signal to close the circuit breaker when the points that characterize the system 2 are outside the rectangle.

Remember, that during the test of the synchronizer in this mode, the change of voltage and frequency of the system 2 does not occur - it means that the commands from the synchronizer for the increase (decrease) of the frequency and voltage are ignored.

In the case when the synchronizer does not send a signal to close the circuit breaker, the test will be performed during the time that corresponds to the number of cycles *N* (full arrow turns of the synchroscope). That time defines by the following expression:

$$T = N/\Delta f,$$

where Δf - the frequency difference between the systems.

Number of cycles *N* is specified in the "*Number of cycles*" field.

Mode "*Linear model*".

After starting the test mode, depending on the commands received from the synchronoscope, the voltage and frequency of the system 2 will change to the acceptable values (*dU*, *df*). Then at the time when *dPhi* is within the acceptable limits (visually displayed by the position of the arrow of synchroscope), the synchronizer will form a signal to close the circuit breaker.

The voltage and frequency of the system 2 will change by the linear law:

$$f_2 := f_2 \pm df/dt \cdot t,$$

$$U_2 := U_2 \pm dU/dt \cdot t,$$

where df/dt, dU/dt - the rate of change of frequency and voltage values respectively. Its values are set in the corresponding fields "*Rate of change*".

In this mode, the "*Number of cycles*" field is replaced by "*Tmax*", in which sets the maximum time for which the synchronization is expected.

Mode "*Nonlinear model*".

This mode is designed to test the operation of synchronoscope in conditions that are maximum close to real, which means with regard to models of generator and turbine with relevant systems of frequency and voltage regulation.

The model of turbogenerator motion in the idling mode at the change of rotation frequency within the 2700 - 3300 turns/min can be represented by a linear differential equation of the first order:

$$T_j \frac{d\omega_g}{dt} - M_T + k_{res} \cdot \omega_g = 0, \tag{7.1}$$

where T_j - time constant of motion of rotating masses of turbine; - ω_g- angular frequency of rotation of the turbine; - M_T - torque of the turbine; - k_{res} - resistance coefficient that determines the losses of turbine because of the friction with the air and in the turbine bearings.

The turbine model is represented by the inertial element of the first order. Its equation has the form:

$$T_T \frac{dM_T}{dt} + M_T - \mu = 0, \tag{7.2}$$

where T_T - the equivalent time constant of the turbine; M_T - torque of the turbine; μ - The position of the turbine control valves, through which the steam inlets into the turbine.

We assume that in the idling mode the synchronizer acts on the speed controller that in turn acts on the turbine control valves. Equation for the speed regulator with the account of restrictions has the following form:

$$\begin{gathered} \mu = k_{sc} \cdot (\omega_g - \omega_{set}), \\ \mu_{min} \le \mu \le \mu_{max}, \end{gathered} \tag{7.3}$$

where k_{sc} - amplifier coefficient of speed controller, a value that is inversely proportional to the statism of the regulatory characteristic of the regulation system; ω_{set} - setpoint of the speed controller on which the synchronizer acts during synchronization; μ_{min}, μ_{max} - restrictions on the shift of the turbine control valves.

When the generator operates in the idling mode there is no current in the stator winding, thus no reaction of the rotor - the electromagnetic generator state is described by a differential equation of first order:

$$T_{d0} \frac{dE_q^{"}}{dt} + E_q^{"} - U_r = 0, \tag{7.4}$$

where T_{d0} - the time constant of the electromagnetic state of the generator; $E_q^{"}$ - quadrature-axis supertransient EMF of the generator, which is proportional to the flux of the stator winding of the generator; U_r - voltage on the rings of the rotor of excitation winding of the generator, which in relative units is equal to the magnitude of the signal of the system of excitation current regulation of the generator.

When the generator operates in the idling mode, the voltage on the stator winding of the generator is equal to the supertransient EMF: $U_g = E_q^{"}$. With the account of this, the equation (7.4) can be written as:

$$T_{d0}\frac{dU_g}{dt} + U_g - U_r = 0. \tag{7.5}$$

Practically all modern power generators on the power plants are operating with a thyristor or brushless excitation systems governed by excitation controls of strong action. Taken into account that these excitation systems along with regulation systems are almost uninertious, the equation of excitation controller of strong action (voltage on the rings of the rotor in relative units is equal to the signal on the output of the regulation system) has a view:

$$U_r = k_{0U} \cdot (U_g - U_{set}) + k_{1U} \cdot \frac{dU_g}{dt},$$
$$U_{r.min} \le U_r \le U_{r.max}, \tag{7.6}$$

where k_{0U}, k_{1U} - the amplifier coefficients on the channels of voltage deviation and the derivative of voltage; U_{set} - controller setpoint for the voltage deviation on the change of which the synchronizer acts; $U_{r.min}$, $U_{r.max}$ - restrictions on the signal of the thyristor excitation system.

As can be seen from the equations that describe the action of a powerful controller, they have no channels of derivatives from the excitation current, rotor run-out angle, and the frequency deviation. This assumption is valid because these channels operate practically during disturbances in the system when the generator is operating in parallel with the system.

Thus, the equations (7.1) - (7.6) with sufficient accuracy describe the behavior of the turbine and the generator when operating the unit in idle mode. They also adequately reflect the processes during the synchronization between the generator and the system.

The model is implemented in relative units. During its implementation the voltage and frequency are recalculated into the absolute units, taking into account the nominal voltage and frequency that were specified on the page "*Synchronizer parameters*" in the fields "*Nominal parameters*".

Time constants and coefficients used in the model (7.1) - (7.6) are specified with the average values for powerful turbogenerators. Their values are following:

$$T_j = 5\ s;\ T_T = 0{,}5\ s;\ k_{sc} = -15;\ \mu_{min} = 0;\ \mu_{max} = 1;\ k_{res} = 0{,}01;$$

$$T_{d0} = 5\ s;\ k_{0U} = -50;\ k_{1U} = -10;\ U_{r.min} = 0;\ U_{r.max} = 1.$$

The user can change the defined parameters. To do this, open the dialog box (Figure 7.5) by clicking on the "**Parameters of model**" button.

For digital implementation of the model (7.1) - (7.6), the strict first-order implicit method is applied - implicit Euler method.

When using a non-linear model of test mode, the model (7.1) - (7.6) are used as a synchronized system 2. When working with this model, the setting values of controllers of the speed of rotation and excitation controller of great force are changing by the command from the synchronizer at a rate which is specified in the "*Rate of change*" field.

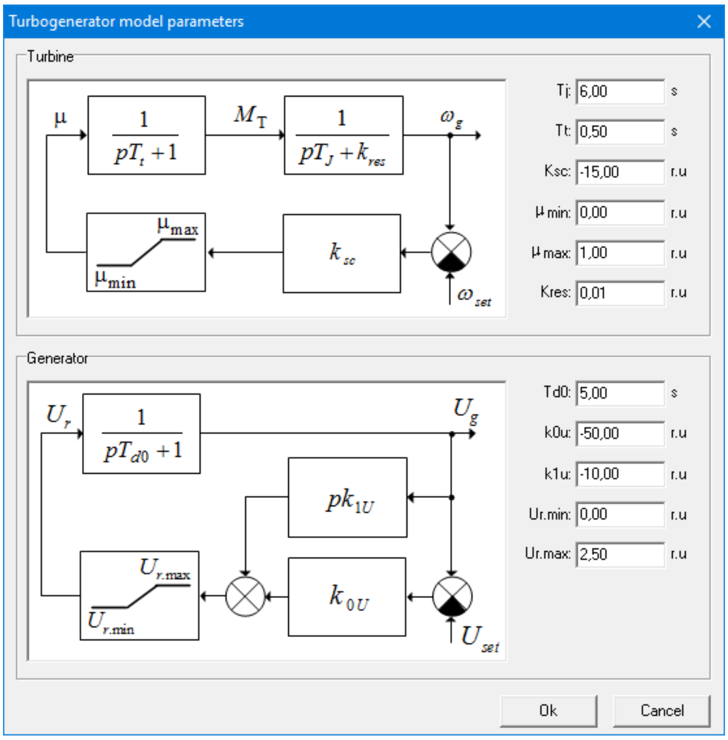


Fig. 7.5. The window of change of parameters of turbine model

Mode "*Defined trajectory*".

This mode involves changing the voltage and frequency of the system 2 at a given linear trajectory.

The trajectory of change can be specified in one of two ways. In the first way, the initial and end values of the voltage module, angle and frequency are set directly in the corresponding fields of the group field "*System 2*" (Fig. 7.6).

The defined linear trajectory is displayed in the field "*Synchronization window*".

The second way is to set the start and end points of the trajectory directly in the field "*Synchronization window*" using the "mouse". The numerical values of the graphically defined points of the trajectory are displayed in the appropriate fields of the group field "*System 2*".

The rate of change of voltage and frequency is based on the trajectory and on the base of the rate of change of voltage or rate of change of frequency, which are specified in the group field "*Rate of change*".

After starting the test in this mode, the change in voltage and frequency will be carried out by the defined trajectory and with defined rate until the command from the synchronizer for closing of the circuit breaker or until reaching the endpoint.

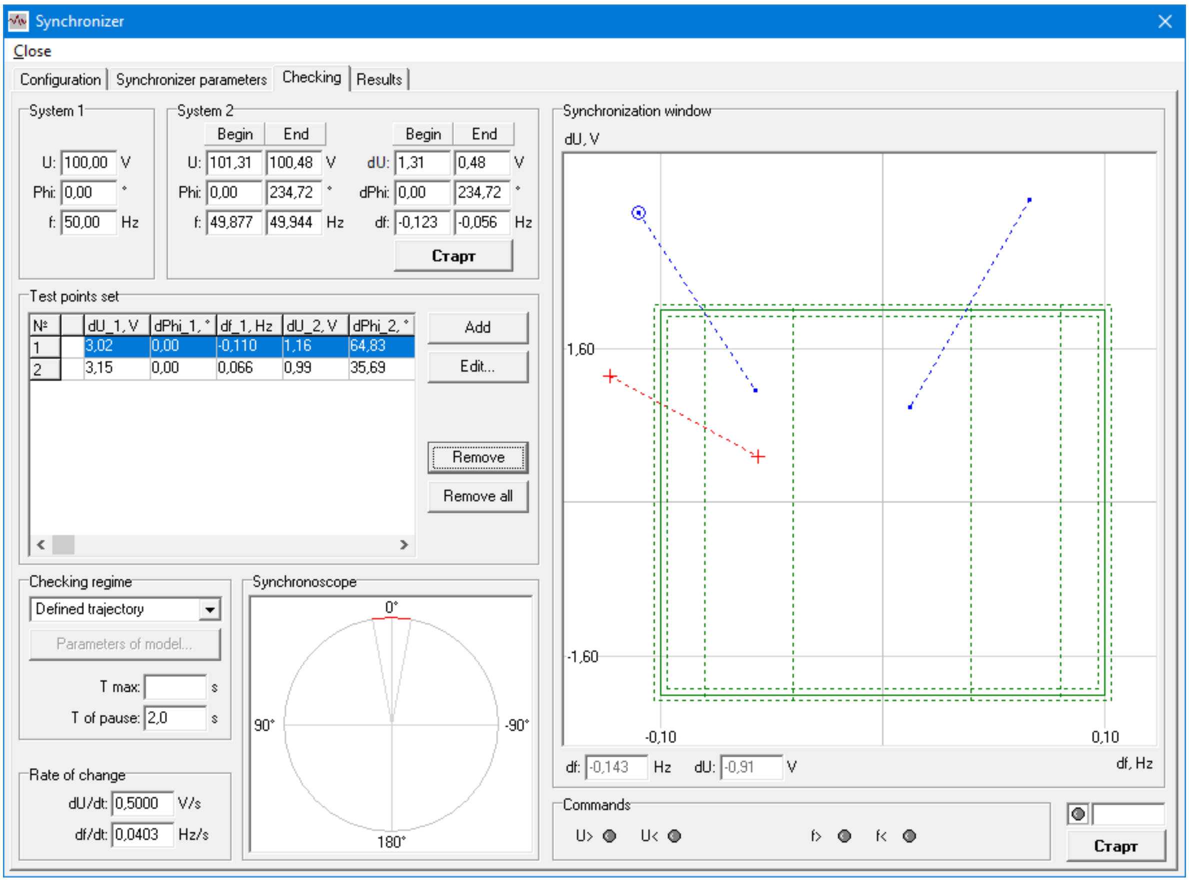


Fig. 7.6. Test mode of the defined trajectory

The "*Synchronoscope*" field.

In this field, a synchronoscope is displayed, the needle of which rotates with the sliding frequency, which in turn is determined as the difference in the frequencies of system 1 and system 2.

The *"Commands"* field.

This field visualize the commands to increase (decrease) the frequency (f>, f <) and to increase (decrease) the voltage (U>, U <). Information about commands is received from the synchronizer through the discrete inputs of the "DEVICE" which were defined on the page *"Synchronizer parameters"*. If the command is present then the corresponding lamp is shown in red, if the command is missing - in gray.

7.4. Checking the synchronizer

After filling in all the fields on the page "*Checking*" you can directly proceed to the test of the synchronizer.

Click the "**Start**" button. According to the specified parameters the "DEVICE" will generate the voltages of the certain values, depending on the testing mode.

The dynamic sequential test will be implemented for the points recorded in the "*Test points set*" field. The test will start with the selected point from the table. There will be pause between tests for each point, which is set in the field "*T of pause*".

The test result will be displayed in the first column of the table. If the test for specific point is successful, the symbol "+" will appear - if not, the symbol will be "-".

After starting the "DEVICE", the button "**Start**" changes to "**Stop**" and starts flashing. The user can at any time stop the test by pressing the button "**Stop**".

After the test is complete, the user can view the detailed results of the test. To do this, select the desired point from the table "*Test points set*" and use horizontal scrolling to see the results of the test.

Formation of the results in the test mode "*Synchronization window*"

In this mode, for test points that are located in sync window (with account of accuracy), the result will be successful in the case of formation of the signal to close, with the acceptable difference in the angles of synchronized voltages of the system 1 and system 2. Closing shall be, when the synchroscope arrow is in the sector which determines the accuracy of the closing angle. Remember that the signal to close is sent in advance, which takes into account the inertia of the circuit breaker (Closing time, which is specified in the field *"T of closing*" on the *"Synchronization parameters"*). After the signal to close is sent, two arrows will be present in the *"Synchroscope"* field: - sending command to close and closing of the circuit breaker. Their values *dPhi K* (the difference between angles when sending commands to close) and *dPhi B* (the difference between angles while closing the circuit breaker) will be displayed in the table of values.

For test points that are placed outside the synchronization window, the result will be successful when there would be no signal from the synchronizer to close the circuit breaker.

For test points that are within the specified errors (bordered by dashed lines area in the synchronization window) the result will be successful in case when there is no signal to close and also when there is signal to close with allowable differences between angles of synchronized voltages of system 1 and system 2.

Formation of the results in the test modes *"Linear model"*, *"Non-linear model"* and *"Defined trajectory"*.

In these modes, the test result will be successful, when over defined (specified) time of synchronization, the command to close under the following conditions were not formed:

- final position of the test point is within the synchronization window with regard to specified accuracy;
- at the time of closing of the circuit breaker, the synchroscope arrow is positioned in the sector which determines the error in closing angle.

In these modes the *"Synchronization window"* field shows the path of the test point during the synchronization process. The *"Test points set"* table will show the values of differences between voltages, angles and frequencies of System 1 and System 2 for the moment of sending the command to close (respectively *dU K, dPhi K, df K*), and also for the moment of closing the circuit breaker (*dU B , dPhi B, df B*).

You can also perform the test for a single moving test point, the value of which is displayed in the *"System 2"* field. To do this, click **"Start"** button, which is located in the same field. After the test is complete, this point and it's test result will be added to the table *"Test points set"* (see Fig. 7.3).

7.5. The "Results" page

On the "*Results*" page in graphical form displays information about the process of generating voltages as well as the state of selected discrete inputs and output relays over the generation time.