Institute of Power Engineering

Automation and Protection Laboratory

DIFFERENTIAL PROTECTION RELAY RRTC-3/2 and RRTC-3/3

for two and three windings transformers

MANUAL

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Table of contents

1. Basic characteristics of the RRTC-3 protection relay

- it eliminates the need for using compensating current transformers,
- if used with bay control unit unequipped with differentia protection function, it ensures backed up protection of the transformer,
- the relay configuration approach eliminates the need of any current transformers ratios or the transformer voltage ratio calculations,
- the „vectorscope" and „osciloscope" functions enables easy detection of the current circuits connection errors,
- the protection criteria signals recorder gives the feedback needed for assuring proper security and sensitivity factors during all of operation events,
- stabilized differential characteristic in relation with current second and fifth harmonic stabilization ensures correct operation of the protection during every conditions,
- service settings in relation with the protection criteria signals recordings enables correct operation of the relay during saturation of the current transformers.

2. Relay purpose

RRTC-3 relay realizes the differential protection function. It is designed as the transformers, generators, generator-transformer power units and motors internal short-circuits protection. It can be used as a substitute of the RRTT-7 protection relay. It can also be used as a supplementary of the bay control units unequipped with differential protection function. In all mentioned above cases, thus the differential protection relay is independent to the bay control unit, very high protection reservation is achieved. It is very important, because typically transformers are not covered by the zones of the remote backup protection relays. For the two windings transformers, RRTC-3/2 relay should be used and for three windings transformers RRTC-3/3 relay should be used.

3. Principle of operation

RRTC-3 relay is fully digital, thus there is no need for using the **compensating current transformers**. The relay allow setting of six types of transformer connection groups: Yy0; Yy6; Yd1; Yd5; Yd7; Yd11. Three windings transformer protection relay HV side is star connected and for MV1 and MV2 sides the same types of winding connection may be set as for the two winding transformer. Other types of the transformer connection groups may be prepared on request.

Stabilized differential characteristic ensures correct operation of the relay during transformer voltage regulation and will not allow the unwanted tripping caused by current transformers errors. Differential protection stabilization with use of the current second and fifth harmonics prevents relay unwanted tripping during transformer magnetizing inrush, excessive transformer voltage increases, during frequency lowering and in case of current transformers saturation.

Service settings allows taking into account the system and equipment conditions in which the protected transformer is operating, which means especially: transformer short circuit voltage and dynamic errors of the current transformers.

Feedback on the mentioned aspects is delivered by the protection criteria signals recorder, which stores amplitudes of the stabilizing and differential currents and of the 100 Hz and 250 Hz current components. The recorder is triggered during transformer magnetizing

current inrush and in case of internal or external short-circuits if the measured differential current excides the minimal differential current I_{r0} setting. The recorder has the capacity for storing 30 events. Next events are overwriting previously stored recordings. The protection criteria signals recorder is supplemented by the fault recorder, which records phase currents signals in each side of the protected transformer. Stored recordings are the basis of the protection settings verification. Thanks to that, the proper protection operation security factor may be achieved in the whole range of the differential protection characteristic, including the 100 Hz and 250 Hz current components stabilization impact areas.

For the very high currents, what means higher than the currents related with the short-circuit voltage of the transformer, differential protection operates as the overcurrent function, what guarantees the protection tripping even during current transformers deep saturation.

Differential current I_r and stabilizing current I_h values, set and recorded in the RRTC-3 relay, are converted into the transformer high voltage side current transformers level.

Differential current I_r and stabilizing current I_h are calculated in accordance to the equations showed bellow:

$I_r=|\underline{I}_1+\underline{I}_2+\underline{I}_3|$

$I_h = I_{max} - 0{,}5I_r$

Where:

$\underline{I}_1$, $\underline{I}_2$, $\underline{I}_3$ - currents flowing to the transformer (for the two winding transformer, two currents are taken into account and for three winding transformer, three currents are taken into account),

I_{max} – maximal current flowing to the transformer,

I_r – differential current,

I_h – stabilizing current.

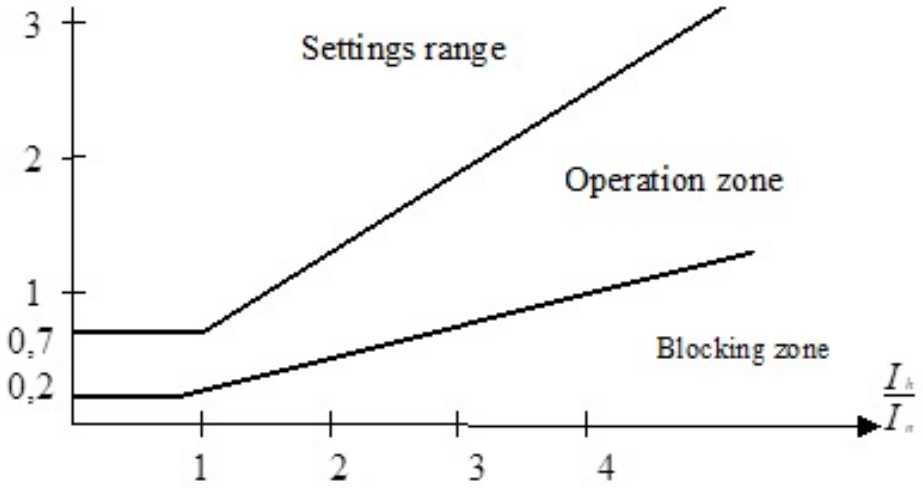

Fig. 1. RRTC-3 differential protection relay operation characteristic

Conditions for protection tripping occurs if differential current I_r is higher than the stabilizing sum. Stabilizing sum is made as stabilizing current multiplied by stabilizing factor setting and enlarged by 100 Hz and 250 Hz stabilization components.

Minimal value of the stabilizing sum is equal to the minimal differential current setting I_{r0}. Settings of the 100 Hz and 250 Hz stabilizing factors are located in the service settings group.

Additional current circuits monitoring function is available in the RRTC-3 protection relay. The function is monitoring currents asymmetry in each side of the protection. If the asymmetry occurs in only one of the protected transformer sides, than after settable delay (minimum 10 s) the relay is forming the internal malfunction signal (Bs). Simultaneously the minimal differential current setting I_{r0} will be raised to the nominal current value of the current transformer in the high voltage side of the protected transformer (independently from the I_{r0} setting). That function may be blocked trought the settings.

4. Connections

Fig. 2 and Fig. 3 are presenting (respectively) the connection diagrams of the RRTC-3 protection relay to the two and three windings transformers circuits. Basic aspects of the RRTC-3 connection schem are:

- the need for useing of the compensating current transformer is eliminated,
- each threephase current transformer should be connected into star connection,
- each star point of the threephase current transformers may be grounded directly on the current transformer terminals.

The RRTC-3 current inputs windings bigining points are connected to the odd terminals of the relay terminal stripe. If, for example, Yy0 transformer connection group is assumed, than during normal operation when currents are flowing into the bigining points of the transformer high voltage winding and are flowing out from the bigining points of the transformer medium voltage winding. If currents transformers are connected in a different scheme than showed on Fig. 2 and Fig. 3, it is necessary to take into account the specificity of the protection relay mentioned above. If the biginning and the end points of the one of the threephase current transformer set are swapped, then the transformer connection group seen by the protection relay will be 6 hours shifted (for example: Yd11 connection group will be changed into Yd5 connection group)

Attention: ***sometimes transformer is "shifted" in relation to the grid. It means that its L1 phases are connected to its "c" column, L2 phases are connected to the "b" column ang L3 phases are connected to its "a" column. Such connection scheme causes that star/delta transformer connection group will be changed. For example: transformer with Yd11 connection group (written on the nominal plate) will have Yd1 real connection group in such case. In described conditions, transformer real connection group should be set in the protection relay.***

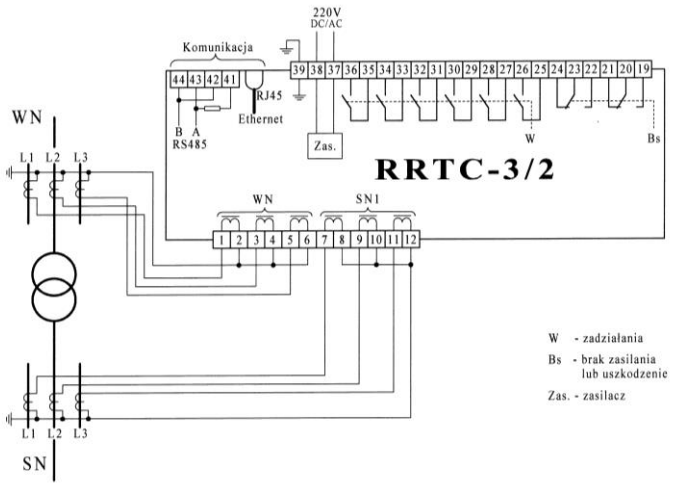

Fig. 2. RRTC-3/2 protection relay connection scheme for the two windings transformer

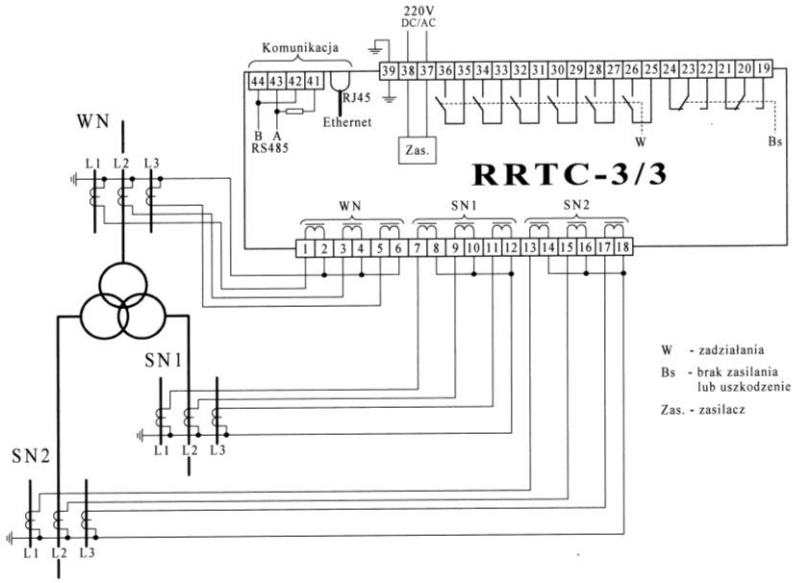

Fig. 3. RRTC-3/2 protection relay connection scheme for the three windings transformer

5. Protections settings

Setting up the protections is possibile with use of the protection relay keyboard and display or with use of PC. It is necessary to set up the following parameters:

- differential protection minimal differential current setting I_{r0} (default setting for 0,5 I_{nt}). For the RRTC-3 relay, the protected transformer HV side current transformers secondary current during nominal load should be considered as the relays I_{nt} current.
- stabilization factor (default setting for the transformer is equal 0,5),
- protected transformer connection group,
- transformer windings nomial voltage,
- current transformers nominal primary currents for each side of the transformer,
- which side of the protected transformer (HV, MV1, MV2) current transformers primary current should be displayed on the relays screen during normal conditions,
- current data and time (if they have to corrected),
- enable or disable the current circuits monitoring function. If the current circuits monitoring function is enabled, it is neccessery to set the current asymmetry detection level (in %), operation time delay and drop off time.

If the relay setup is carried out with use of PC, service settings is also available. Service settings are implicitly set by the Institute of Power Engineering in the way showd bellow:

Ceof 100Hz	100Hz limit
5,0	4,0 (20,0)
Ceof 250Hz	250Hz limit
4,0	1,0 (5,0)
Ceof MOD	RTT limit
3,0	5,0 (25,0)

Limits values depends on the HV side current transformer nominal secondary current I_n. Without brackets are given values for I_n = 1 A and in brackets are given values for I_n = 5 A.

Withdrawal from the default settings is acceptable only in agreement with the Institute of Power Engineering to better match the protection relay configuration to a unusual operation conditions. Institute of Power Engineering is analyzing (where possible) the data stored in the relays recorders and does not preclude future adjustment of the default settings.

6. Operation via relay's keyboard and display

Communication with the user is realized with use of relay's 5-keys keyboeard and the 4-line / 20 characters LCD display. Setting up may also be done with use of PC connected to the relay's RS-232 port. The maitenence works are then much faster and easier, also all protection functions settings and features such as oscilloscope, vectorscope and criteria recorder are available thorough such connection. The nRRTC-vC03 or newer software must be installed on the PC used for relay maitenence works.

On the relay front panel two LED diodes are located. The green diode lightning means correct operation of the relay (stand by state). The red diode lightning means tripping of the differential protection.

Relay front panel keyboard keys functions are described bellow. The maitenence of the relay with use of the keyboard is organized on the basis of movement in the loop in one direction. The entrance to the new loop (lower level of the configuration) is made by pressing ENTER key while pressing the MENU key scrolls the loop in one direction. To exit the current loop the user must continue scrolling to the beginning of the loop.

MENU - moves to the next settings window (loop) or to the next digit, scrolls event log,

"+", "-" - increases or decreases the value of the selected setting or selected numbers, changes displayed transformer connection group, active only during settings change or during entering the password,

ENTER - opens selected function, confirms setting value,

KASOWANIE - resets the red LED diode after protection tripping, closes the test procedure, provides a return to the menu after giving the wrong password.

6.1 Settings

After opening the "Settings" window, the user has to chose one of the oprions: "Browsing", "Change" or "Exit".

The „browsing" option does not requires password ente ring. With use of „MENU" key, the user may change the windows with relay current settings.

Chosing the "change" option brings the password screen. The password should be entered with use of the "+" and "-" keys. After entering the correct password, settings screens

will be brought. To chose the parameter to change (signed with the star "*"), the user should use the "MENU" key. Change of the selected parameter is done with use of the "+" and "-" keys. Confirmation of the setting change is done with use of the "ENTER" key, which will automatically bring the next settings window. In the last settings window, the user must chose to "Save the settings changes" or to "Abandon the settings changes". Choosing the first option with use of the "ENTER" key will cause activation of the new relay settings. Choosing the second option will leave the previous relay settings. Choosing the "EXIT" option will cause return to the menu main window.

Attention: After entering the correct password, it is stored for about 10 minutes. During that time, there is no need for re-entering the password when chosing options to save the settings changes or to start the "test" procedure.

6.2 Measurements

Chosing the „Measurments" window will display (for each phase) current values of:

- differential current (I_r),
- stabilizing current (I_h),
- primary currents of the transformer HV side (I_{HV}),(WN)
- primary currents of the transformer MV (I_{MV}) or MV1 (I_{MV1}) and MV2 (I_{MV2}) side,(SN)
- currents asymmetry in each side of the transformer,
- current data and time.

Relay I_r and I_h currents are presented in reference to the HV side current transformers secondary side (current transformer ratio, transformer connection group and voltage ratio is taken into account). For I_r and I_h currents calculation, phase currents decreased by zero sequence current are taken into account. Zero sequence current is calculated as $I_0=(\underline{I}_1+\underline{I}_2+\underline{I}_3)/3$, where $(\underline{I}_1 + \underline{I}_2 + \underline{I}_3)$ is the phase currents vector sum of transformer HV or MV side.

6.3 Event recorder

Event recorder is storing (with a resolution of 10 ms) the following events: differential protection tripping and droping off, current circuits monitoring function alarm (if the function is not blocked), settings change, relay power supplying, data change, tests performing, internal malfunction.

In case of settings change, basic setting parameters will be stored. In case of differential protection tripping, in addition phase currents values of each side of the transformer and maximum values of differential (I_r) and stabilizing (I_h) currents (recorded 20 ms after pickup) will be stored.

After filling up the internal memory, subsequent events will overwrite the oldest ones. The capacity of the event recorder allows to save up to 80 events.

Choosing the „Recorder" option will bring up the last event screen. With use of "MENU" key, the user may scroll the recorded events from the last to the oldest. Pressing the "ENTER" key will cause returning to the main menu.

6.4 Test

The :test" function allows protection tripping state emulation (closing of the relay trip contacts W and opening of the internal malfunction contacts Bs). The condition of performing the test is to enter a password. After opening the window and chosing the "test" function, pressing the ENTER key will cause change of the binary outputs state. After that, the contacts

will be closed for one second or as long as the key is pressed. To exit the “Test” function, the user must press the “RESET” key. Re-closing of the output contacts may be achieved by double-pressing the “ENTER” key.

Attention: ***After entering the correct password, it is stored for about 10 minutes. During that time, “settings” and “test” functions do not need to re-enter the password.***

7. Operation via PC

To operate the RRTC-3 relay through the RS-232 link, the PC with WINDOWS operating system, RS-232 cable and nRRTC-vXXX software is needed.

Key benefits of operating the protection relay with use of PC are:

- clarity and ease of making any adjustments,
- simultaneous access to a greater number of measurements and recorded events,
- ability to use an oscilloscope and vectorscope,
- access to the criteria recorder and fault recorder,
- the ability to print recordings from oscilloscope function and criteria recorder
- the possibility of reading out and changing user password ant to clean recorders.

The nRRTC-vXXX is versatile software for operating the RRTC-2 and RRTC-3 protection relays. Bellow, software functions available for RRTC-3 will be described.

After starting the nRRTC-vXXX software, its main window will be showed on the PC scrren (as presented on Fig. 4).

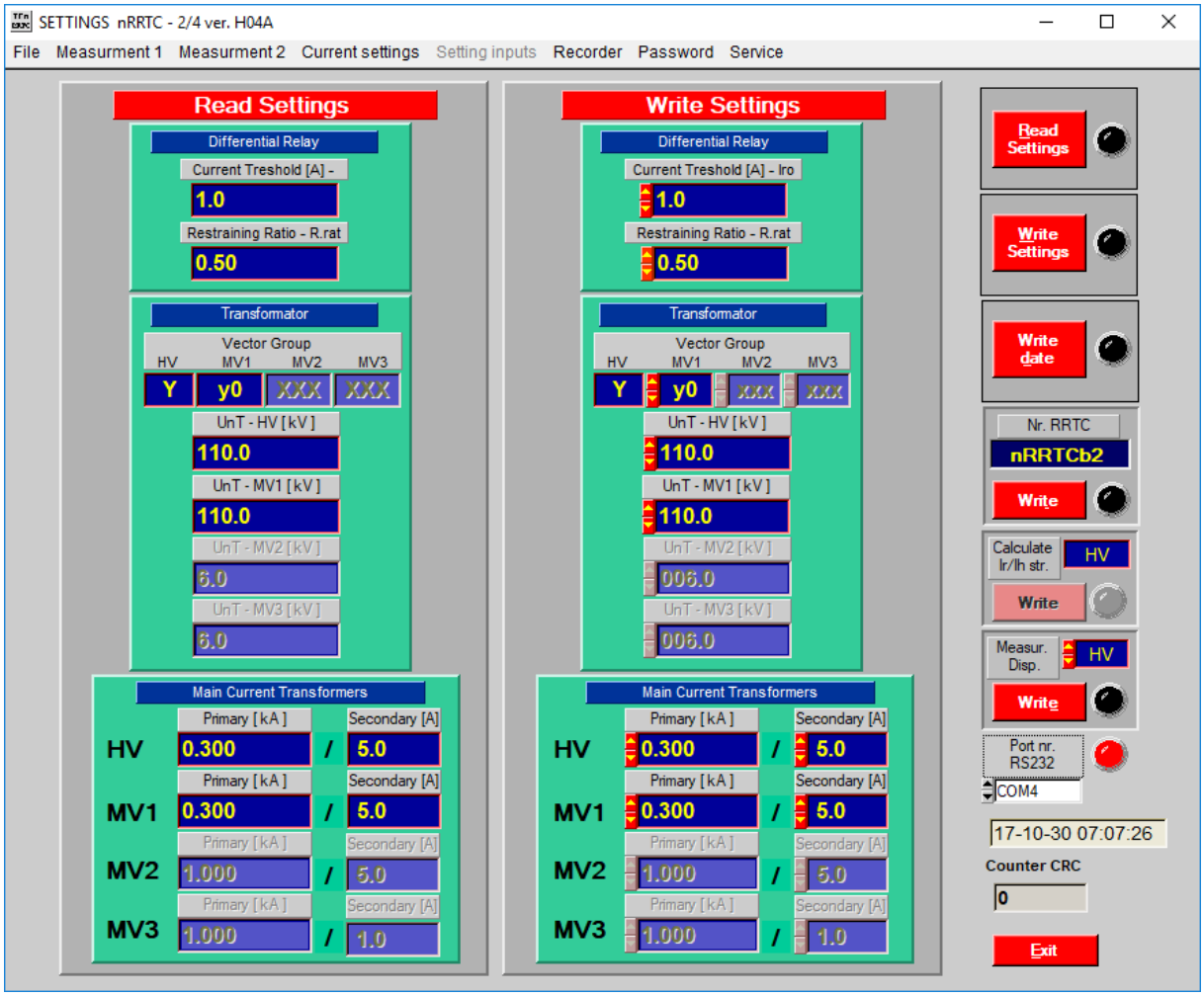

Fig. 4. The nRRTC-vXXX software main window

On the left hand side of the software main window, the „Loaded settings" column is placed. It contains the Settings values read from the protection relay connected to the PC. In the middle of the main window, the „Settings to send" column is placed, which contains the settings values prepared to be send to the protection relay connected to the PC. Parameters values in the „Settings to send" column may be adjusted by user with use of PC mouse and keybord.

On the right hand side of the nRRTC-vXXX software main window additional buttons and sub-windows are placed for the following puropose:

„Load settings"	the button allows to refresh (load from the relay) the „Loaded settings" column and to check the current settings of the relay connected to the PC. It is especially important ro refresh the „Loaded settings" column values after connecting to the new relay after working with previus one.
"Send settings"	pressing the button causes saving the settings values from the „Settings to send" column in the relay connected to the PC. If the seving was done correctly, the „Loaded settings" column will be refreshed automatically.
"Save date"	pressing the button cause rewiting the PC system date and time into the protection relay.
"RRTC NAME"	the subwindow shows the individual signature of the relay connected to the PC. The signature may be modified by user (it may consist of 8 signs). After making the change, it has to be saved to the relay by pushing the "Save" button. After each pressing of „Load settings" button the "RRTC NAME" subwindow is refreshed.
"Refresh I_r/I_h of the side"	subwindow is inactive.
"Disp. measurements"	the subwindow shows the side of the transformer from which phase currents measurements are presented on the relay display during normal operation. The transformer side from which the measurements are presented may be selected through the subwindow. After selection, it has to be saved to relay with use of the "Save" button. After each pressing of „Load settings" button the "Disp. measurements" subwindow is refreshed.
"RS323 port number"	in this subwindow, the relay RS232 port number should be set after starting the nRRTC-vXXX software. Througt that port number the RRTC-3 relay will be connected to the PC.
"Exit"	pushing that button will cause closing of the nRRTC-vXXX software.

Under the "RS323 port number" subwindow, current date and time (constantly refreshed from the relay) is showd.

On the top of the nRRTC-vXXX software main window the MENU toolbar is located. That toolbar contains the File, Measurements 1, Measurements 2, Overcurrent protection settings, Recorder, Password and Maintenance buttons.

7.1 "File" button

The "File" button allows aploading data from the archive stored on the PC ("Open" command), saving data to the PC archive ("Save" command), printing the data ("Print" command) and closing the nRRTC-vXXX software ("Exit" command). After chosing the "Open", "Save" or "Print" command, subwindow will be opened that will allow to chose data types which user want to use (RRTC settings, event recordings, criteria recordings). Fragment of the screen presenting the "File" menu opening after pushing the "File" button is showd on the Fig. 5.

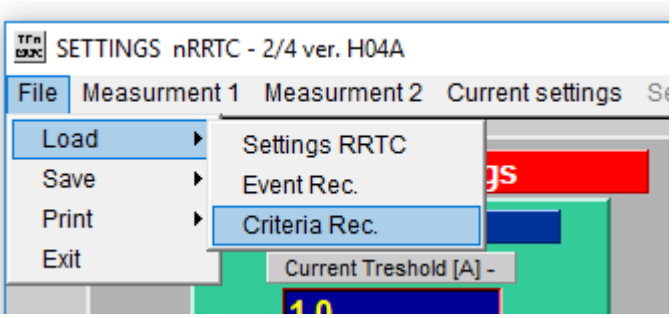

Fig. 5. Commends available in the "File" menu

"File"-"Save"-"Save RRTC settings" – that operations will cause opening of the dialog box allowing to chose the saving localization and the file name in which current settings of the protection relay connected to the PC will be stored. Default file name is made of relay signature and current date. Settings files have the *.nst* extension.

"File"-"Save"-"Save events log" – that operation will cause opening of the dialog box allowing to chose the saving localization and the file name in which comlete events log of the protection relay connected to the PC will be stored. Default file name is made of relay signature and current date. Event log files have the *.zdn* extension.

"File"-"Save"-"Save criteria rec." – that operation reqires prior downloading of the criteria recordings from the relay to the PC (see the "Recorder" command). If mentioned downloading is not perform, the "No data" messedge will be displayed. If the criteria recordings was downloaded from the relay to the PC, described operation will cause opening of the dialog box allowing to chose the saving localization and the file name in which criteria recordings of the protection relay connected to the PC will be stored. Default file name is made of relay signature and current date. Criteria recorder files have the *.rkt* extension.With use of the **"File"-"Save"-"Save criteria rec."** operation, only the downloaded criteria recordings will be stored. If more criteria recordings are available in the relay (maximum 30 recordings may be stored in the relay), each recording should be downloaded from the relay and than stored on PC with use of the **"File"-"Save"-"Save criteria rec."** operation. Many criteria recordings may be appended to the criteria recorder file stored on PC. In one file up to 100 criteria recordings may be stored.

Using the **"File"-"Open"** commands do not require to be connected with the relay.

“File”-“Open”-“Open RRTC settings” – that operations will cause opening of the dialog box allowing to chose the localization and the file name of the settings file previously stored on the PC to be opened. In the dox, only the *.nst* extension files will be showed. After opening the RRTC settings file, values stored in it will be uploaded into the „Settings to send” column on the main window of the nRRTC-vXXX software and also to the “Reset recorders/Service settings” window (see the “Maitenance” command) and the “Settings change – Currents asymmetry” window (see the “Overcurrent protection settings”). If the user want to upload the settings to the relay (in such case, connection with the relay has to be established before), he should push the “Send settings” button in each of the windows mentioned above. After that „Load settings” button in the main window should be pressed and new relay settings should be verified.

“File”-“Open”-“Open events log” – that operations will cause opening of the dialog box allowing to chose the localization and the file name of the events log file previously stored on the PC to be opened. In the dox, only the *.zdn* extension files will be showed. The events log file will be automatically opened in the Notepad software.

“File”-“Open”-“Open criteria rec.” – that operations will cause opening of the dialog box allowing to chose the localization and the file name of the criteria recorder file previously stored on the PC to be opened. In the dox, only the *.rkt* extension files will be showed. The criteria recorder file will be automatically opened in the criteria recorder window (further description in the “Recorder” section).

“File”-“Print”-“RRTC settings/limiters/It>” – that operations allows printing of the current settings of the connected relay or the settings file stored on PC (in such case connection with the relay is unnecessary).

“File”-“Print”-“Events log” – that operations allows printing of the events log stored on the relay connected to the PC.

“File”-“Print”-“Criteria rec.” – that operations allows printing of the criteria recorgings currently uploaded form the connected relay criteria recorder or from the file stored before (in such case connection with the relay is unnecessary).

7.2 “Measurements 1” button

Pressing the “Measurements 1” button allows constant readout of the transformer HV side secondary currents values from the connected relay. The following values are read:

- Maximal currents:
  - maximal differential current,
  - maximal stabilizing sum, which is obtained by multiplying together the stabilizing current and stabilizing factor and is enlarged by the 100 Hz and 250 Hz currents stabilizing factors. Stabilizing sum may also be decreased after external fault detection,
  - maximal stabilizing current,
  - maximal 100 Hz current;
  - maximal 250 Hz current.
- Differential currents for each phase.
- Stabilizing currents for each phase.
- 100 Hz currents for each phase.

7.3 “Measurements 2” button

Pressing the “Measurements 2” button allows constant readout of the primary phase currents (from each side of the transformer) from the connected relay. The following function contains also the osciloscop and vectoroscop feature. After pushing the button, the following subwindows will be opened:

- Transformer HV side currents,
- Transformer MV1 side currents,
- Transformer MV2 side currents,
- Oscyloscope – the left hand side subwindows present L1, L2 and L3 currents from the HV side (subwindow on the top), L1, L2 and L3 currents from the MV1 side (subwindow in the middle) and L1, L2 and L3 currents from the MV2 side (subwindow on the bottom). The right hand side subwindows present the HV, MV1 and MV2 sides currents in each phase. Example of the oscyloscope screen is showed on the Fig. 6. For each window signals amplification factor may be set in the range from 0,5 to 20. In the bottom right part of the oscyloscope screen, three buttons are located: “Currents read out START/STOP”, “Print”, “Exit”. Pushing the “Currents read out START/STOP” button starts or stop the current signals readout from the relay (stoping of the read out occurs after reading out complet periode of the signals). The “Print” button allows printing of the currently presented signals.
- Vectoroscope – it’s window presents vector diagram of the transformer each side currents. For the proper operation of the vectoroscope function, current flow in the L1 HV side circuit is neccessery. Vectors amplification factor may be set separately for each side of the transformer in the range from 0 to 10.
- Transformer currents – subwindow presents all current signals measured by the RRTC-3 relay.

The “Oscyloscope” and “Vectoroscope” functions allow the relay connection verification for example during commissioning.

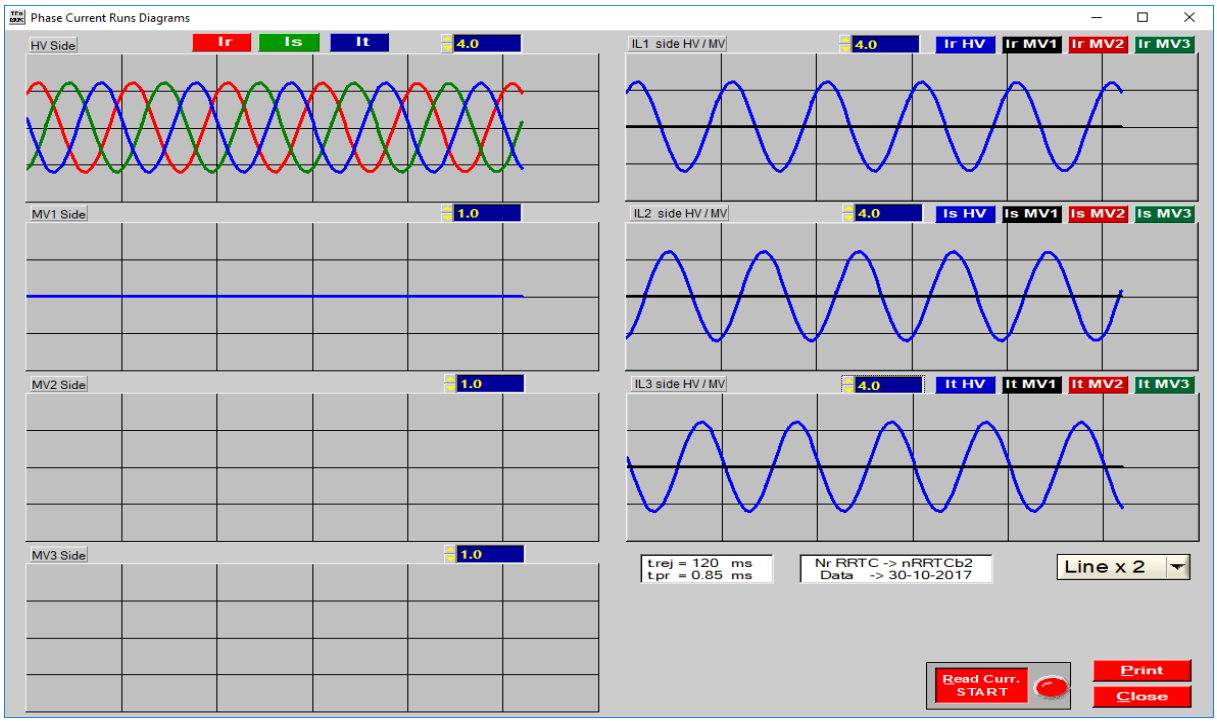

Fig. 6. Measurements 2 osciloscope subwindow

7.4 “Overcurrent protection settings” button

The RRTC-3 “Overcurrent protection settings” command allows enabling, disabling and setting up of the current circuits monitoring function. After chosing the **“Overcurrent protection settings”-“Current asymmetry monitoring”** commands the following subwindow will appear – see **Błąd! Nie można odnaleźć źródła odwołania.**.

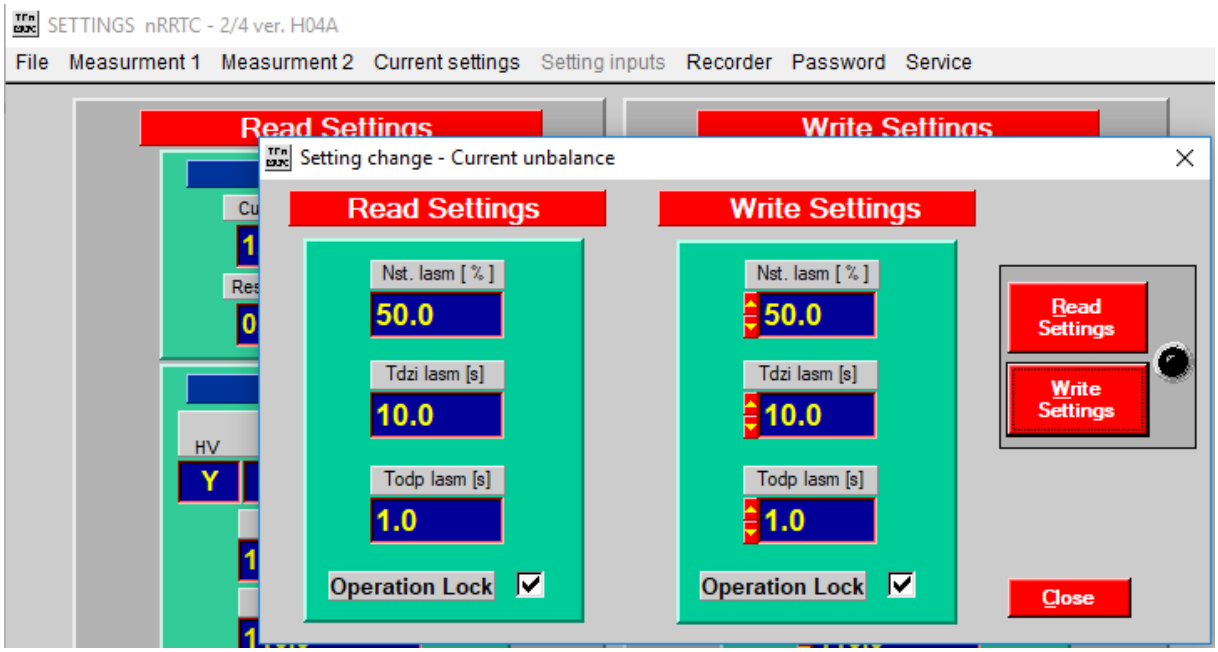

Fig. 7. “Curent asymmetry monitoring” function settings subwindow – function blocked state

On the left hand side of the “Curent asymmetry(unbalance) monitoring” subwindow the “Loaded settings” column is located in which current function settings downloaded from the relay are presented. In the middle of the subwindow the “Settings to save” column is placed. That column contains the settinds values rady to be send to the connected relay. The Settings to save” column parameters values may be modified by user with use of PC mouse and keyboard. On the right hand side of the “Curent asymmetry monitoring” subwindow the following two buttons are located:

- “RS323 settings download” – pressing the button refreshes (reading out from the connected relay) the “Loaded settings” column values, what allows to check the current settings of the “Curent asymmetry monitoring” function (it is especially important after swiching connection from one relay to another).
- “RS323 settings upload” – pressing the button sends the “Settings to save” column values to the connected relay. If the uploading was succesfull, the Loaded settings” column values will be automatically refreshed.

To block the “Curent asymmetry monitoring” function, the user should select the “Disable function” square located in the bottom of the “Settings to save” column and than he should press the “RS323 settings upload” button to save the settings to the relay (see 7).

Attention:

Tdzi – Trip Time, Todp – Time drop off

7.5 “Recorders” button

The “Recorders” command gives the acces to the protection relay recorders functions. After chosing that command, the sub menu will appear, through which user may chose which recorder does he want to open: “Open the events recorder”, “Open the criteria recorder”.

Selecting the **“Recorders”-“Open the events recorder”** commands will open the events recorder subwindow and will download the events log from the connected relay - see Fig. 7.

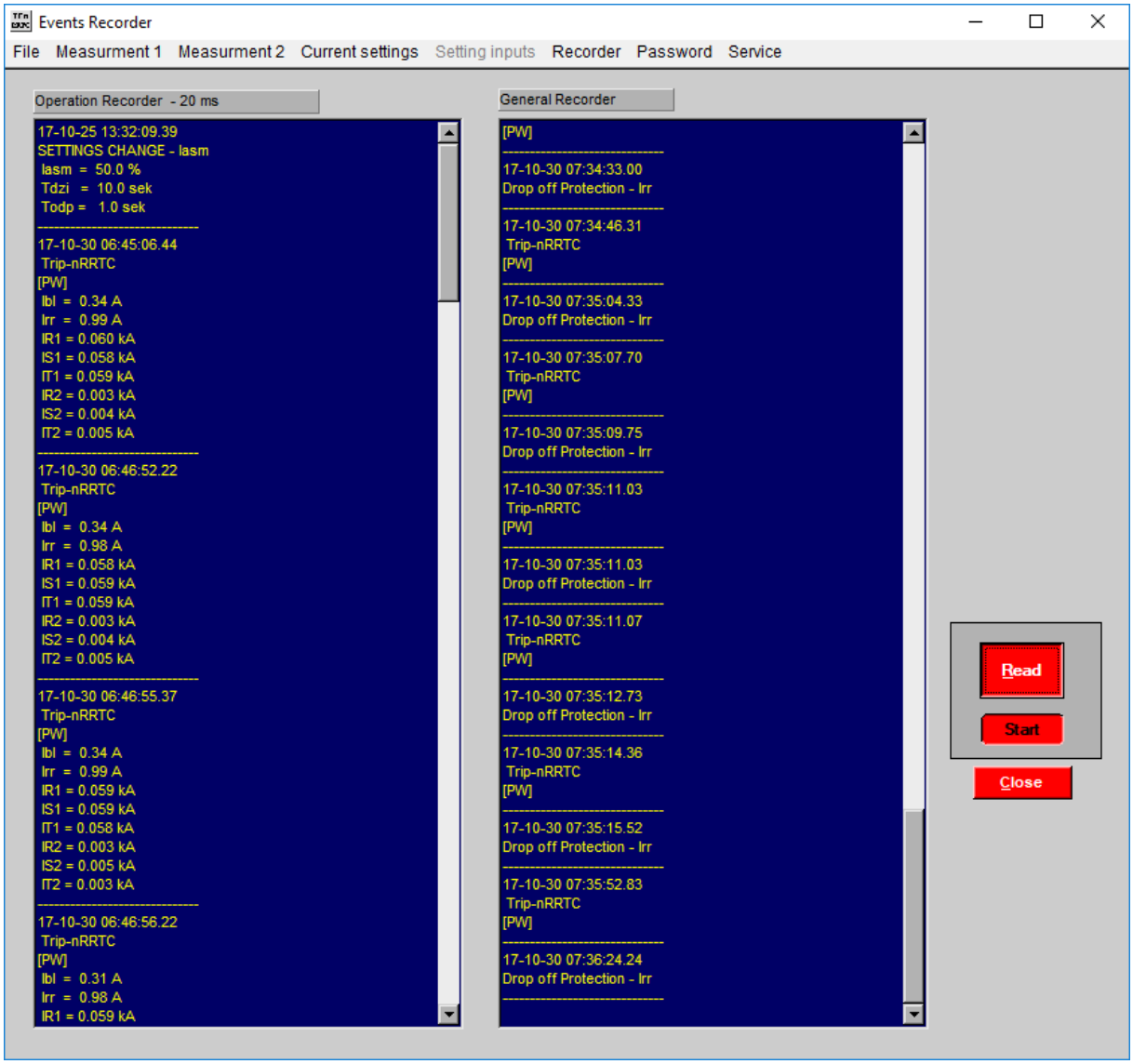

Fig. 7. Events recorder subwindow

In the “General recorder” column (located in the middle of the subwindow) list of the recorded events is stored. The events recorder saves with the 10 ms time resolution the following types of events:

- differential protection tripping and dropping off,
- current circuits monitoring function operation (event: “Current circuit fault - … side”) if the function is not blocked,

- relay settings change,
- switching off the power supply,
- date change,
- performing the “test” procedure,
- internal malfunction.

In the “Operation recorder – 20 ms” additional information for each event is included:

- for the relay settings change event – settings values send to the relay are included,
- for the differential protection tripping event – transfoermer each side phase currents, maximal differential current (I_r) and maximal stabilizing current (I_b) values retrievd after 20 ms from the differential protection function pick up.

Selecting the **“Recorders”-“Open the criteria recorder”** commands will open the criteria recorder subwindow and will download the criteria recordings list from the connected relay - see Fig. 8 (list of recordings is located in the bottom on the left hand side of the subwindow).

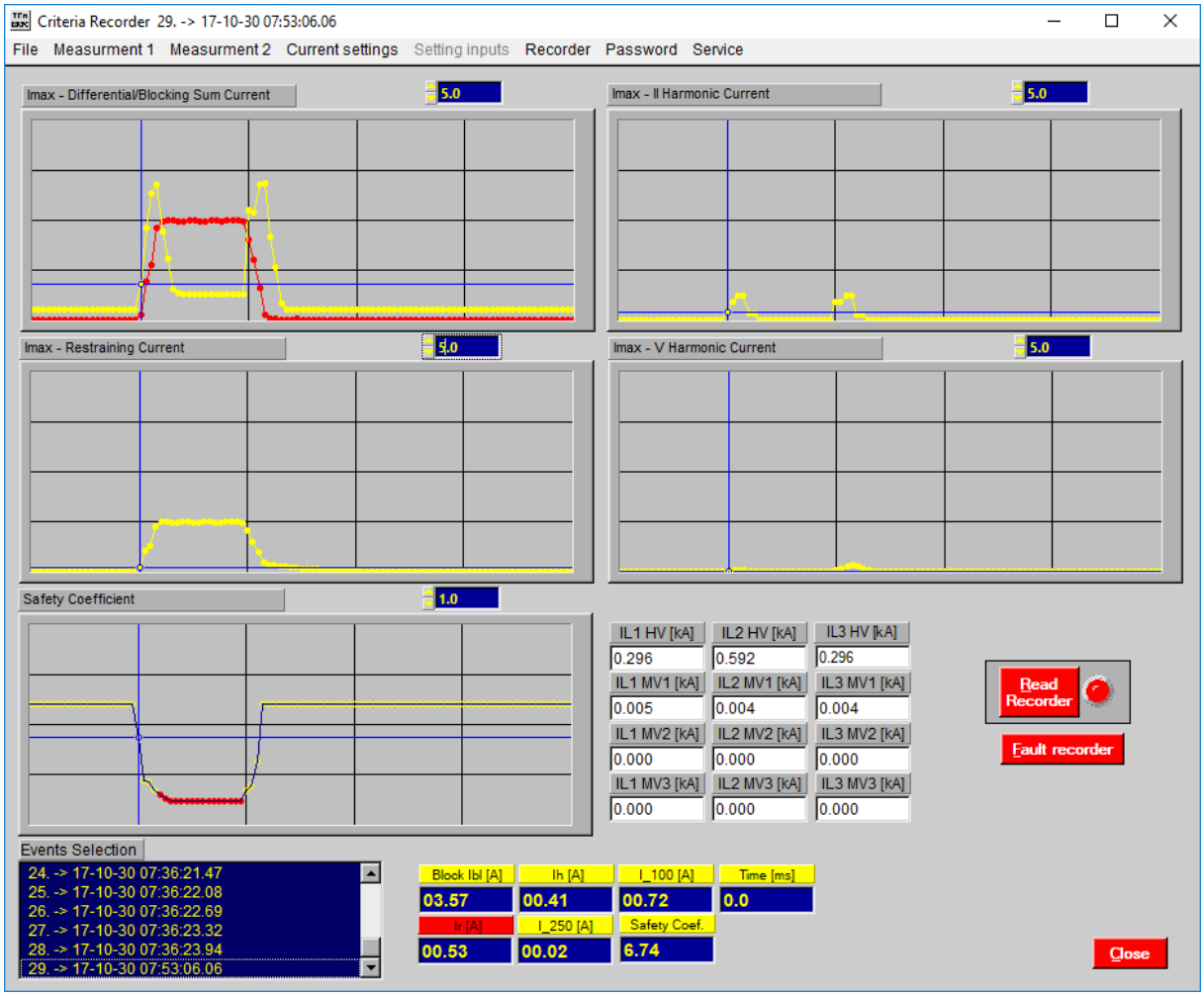

Fig. 8. Criteria recorder subwindow

To download the recording to the PC, the user should select the recording date from the recordings list (it will be marked with yellow color) and then he should push the right mouse button (the mouse cursor should be placed inside the recordings list subwindow) or the “Enter” key on the keyboard. Then, selected recording will be downloaded to PC (it may take

up to tens seconds). Each time, only one recording may be downloaded. If the user want to download another recording, the download process mast be repeated.

Each recording stored by the criteria recorder consist of two parts: **criteria recording** and **fault recording**. The recording starts 100 ms before the recorder triggering and ends after 400 ms from the pick up. The ctriteria recorder is triggered always when the differential current exceeds the minimal differential current setting I_{r0}, also during the transformer energizing (if transformer inrush current is high enough) and during external faults (if the differential current caused by current transformers errors exceeds the the minimal differential current setting I_{r0}).

Up to 30 recordings may be stored in the criteria recorder. After filling up the recorder, each new recording will overwrite the oldest one in the relay's memory.

7.5.1 Criteria recorder

After selecting and downloading the recording from the relay, criteria recording will be opened in the recorder subwindow (see fig. 10). Criteria recording consist of five waveforms (each waveform amplification factor may be separately specified in range from 1 to 20):

- "Maximal differential current / sum" (top left hand side waveform) – waveform presents the following signals: the maximal differential current (selected from the three phases) marked with red line and the maximal stabilizing sum marked with yellow line. If the maximal differential current line exceeds the maximal stabilizing sum line, it will mean that differential protection is tripping. The maximal stabilizing sum consists of: stabilizing current multiplied by the stabilizing factor, 100 Hz current component multiplied by the 100 Hz stabilizing factor (not more than 100 Hz current limiter setting) and 250 Hz current component multiplied by the 250 Hz stabilizing factor (not more than 250 Hz current limiter setting). The maximal stabilizing sum may not be higher than the RTT limit setting.
- "Imax current – stabilizing branch" (middle left hand side waveform) - waveform presents the maximal stabilizing current signal.
- "Security factor" (bottom left hand side waveform) - waveform presents the differential protection security factor signal. Security factor is calculated as a stabilizing sum devided by the maximal differential current. Security factor signal is marked with the yellow line and if it's value drops bellow 1,3 it is marked with red line. Security factor value lower than 1 means that differential protection is tripping. If during transformer energizing and during external faults security factor is marked with red line (security factor value is in the 1,0 – 1,3 range), it means that differential protection settings are to sensitive and should be adjusted.
- "Imax current – second harmonic" (top right hand side waveform) - waveform presents the maximal second harmonic component signal (out of three phases) in the differential current.
- "Imax current – fifth harmonic" (middle right hand side waveform) - waveform presents the maximal fift harmonic component signal (out of three phases) in the differential current.

Under the "Imax current – fifth harmonic" waveform there is subwindow presenting the each transformer side primary phase currents values recorded 20 ms after recorder triggering.

On the middle bottom part of the recorder window seven subwindows are located, presenting recorded signals values for the time moment selected by the cursor. Cursors may

be moved with use of the PC mouse (simultaneously for every waveform), by clicking in the desired point of one of the waveform or with use of keyboard cursor keys.

In the bottom right part of the the recorder window three buttons are located:

- "Load rec." – pressing the button will refresh the list of recordings available in the connected relay.
- "Fault rec." – pressing the button will open the fault recorder subwindow.
- "Exit" – pressing the button will cause closing of the recorder subwindow and returning to the main window of the nRRTC-vXXX software.

7.5.2 Fault recorder

After pressing the "Fault rec." button located in the bottom right part of the the criteria recorder window, fault recorder subwindow will be opened and recording currently opened in the criteria recorder will be presented. Example of the fault recorder subwindow is showed on the Fig. 9.

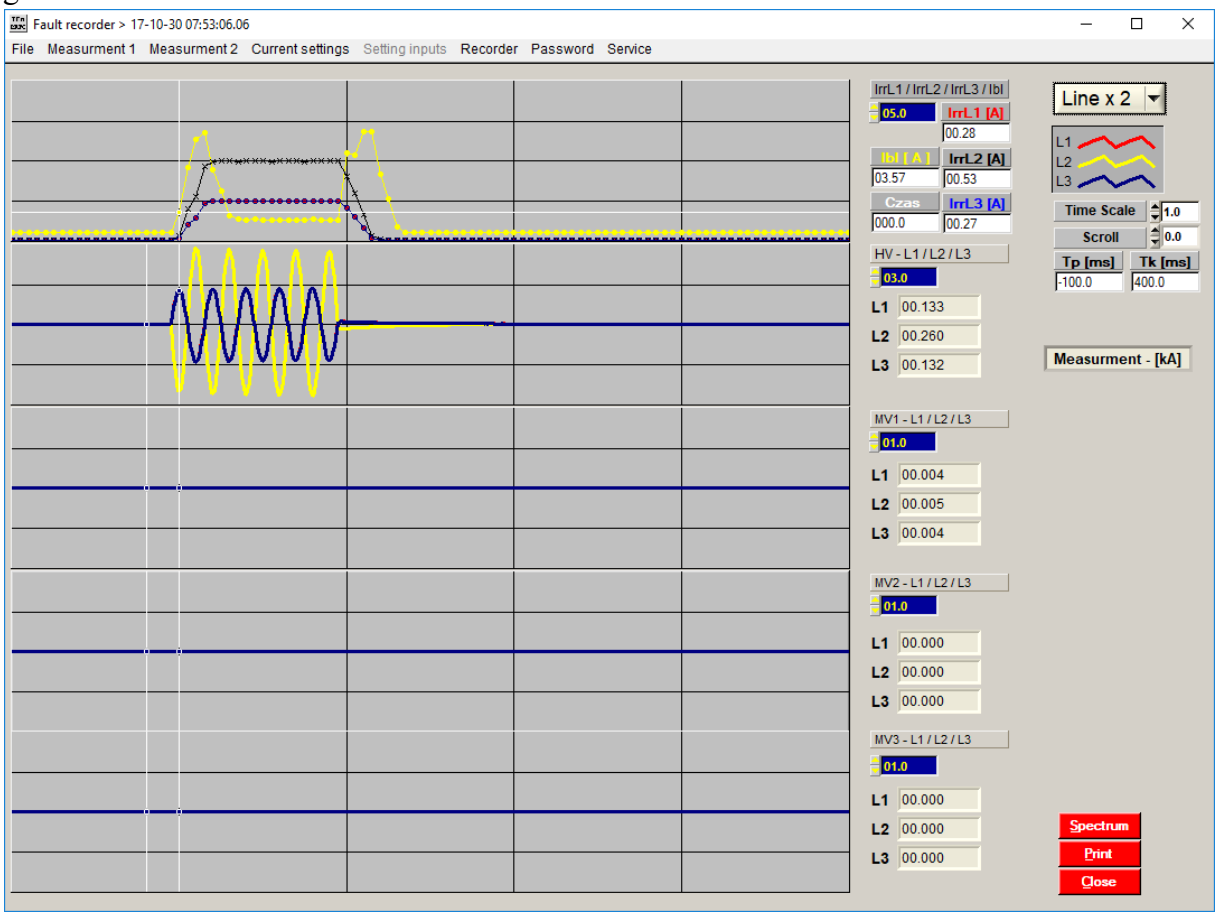

Fig. 9. Fault recorder subwindow

On the left hand side of the fault recorder window waveforms are presented with the same time range as currently opened criteria recording. On the top waveform, maximal stabilizing sum signal and differential currents for each phase are presented (values calculated by the relay). Rest of the waveforms present the phase currents signals from the transformer HV, MV1 and MV2 (if available) side respectively.

On the right hand side of each waveform, amplification subwindow (signals may be amplified in the range from 0,1 to 20) and signal value subwindow (for current cursor position) are placed. Cursors may be moved (simultaneously for all waveforms) with use of

PC mouse (by clicking in the desired point of the top waveform) or keyboard cursor keys. Stabilizing sum and differential currents values are calculated in the relay for the time moment corresponding to the current cursor position (values are relative to the transformer HV side levels). Phase currents of each side of the transformer are presented as RMS values calculated in 20 ms window ending in the current cursor position (values are referring to the current transformers primary sides).

On the right hand side of the fault recorder window the following elements are placed:

- "Line x 2" / "Line x 1" / "Points" selection box – selecting one of the option allows waveforms signals presentation change (fat lines, thin lines, points respectively),
- "Time scale" box – it allows time scaling of the waveforms signals (scaling facor range from 0,1 to 10),
- "Scrolling" box – it allows waveforms scrolling after waveforms time scale extension (scrolling ranfe from 0 to 100),
- "Tp [ms]" and "Tk [ms]" boxes – they are showing current waveforms time range presented in the fault recorder window (full time range of the fault recording is starting from -100 ms and ends at 400 ms).

On the right bottom side of the fault recorder window three buttons are placed:

- "Spectrum" – pressing that button cause opening the spectrum analysis window. In that window transformer each side phase currents harmonic decomposition is presented (only during stady state).
- "Print" – pressing that button opens the dialog box allowing currently presented screen printing.
- "Exit" – pressing that button cause closing of the fault recorder window and returning to the criteria recorder window.

7.6 "Password" button

"Password" button allows reading of the current password from the connected relay and sending the new password to it. General rule is formed that the person with PC (with nRRTC - vXXX software installed) allowed to connect it to the relay is also allowed to read out and change the relay's password. Default password in each RRTC-3 relay is „++++++++". New password may contains any combination of exactly 8 "+" or "-" signs.

7.7 "Service" button

"Maintenance" command allows cleaning of the relay's recorders and counters. It also gives acces to the service settings and RS485 port configuration.

Chosing the **"Service"-„Rec. clearing / RS485 conf."** command openes the "Recorders clearing / Service settings" window showed on

Fig. 10.

On the lest side of the "Recorders clearing / Service settings" window four buttons are placed (see 1. on the

Fig. 10). Pressing the following buttons causes: events log clearing ("Clear events log" button), criteria and fault recorder clearing ("Clear criteria rec." button), reseting the relay power up counter ("Reset power up counter" button) and reseting the relay tripp counter ("Reset tripp counter" button).

In the middle of the “Recorders clearing / Service settings” window service settings are placed (see 2. on the

Fig. 10). “Loaded settings” column presents the service settings values downloaded from the connected relay. “Settings to send” column presents service settings values prepared to be send to the connected relay. “Settings to send” column parameters values may be adjusted with use of PC mouse or keyboard. On the left side of the “Settings to send” column two buttons are placed:

„Load settings” the button allows to refresh (load from the relay) the „Loaded settings” column and to check the current service settings of the relay connected to the PC. It is especially important to refresh the „Loaded settings” column values after connecting to the new relay after working with previus one.

“Send settings” pressing the button causes saving the service settings values from the „Settings to send” column in the relay connected to the PC. If the seving was done correctly, the „Loaded settings” column will be refreshed automatically.

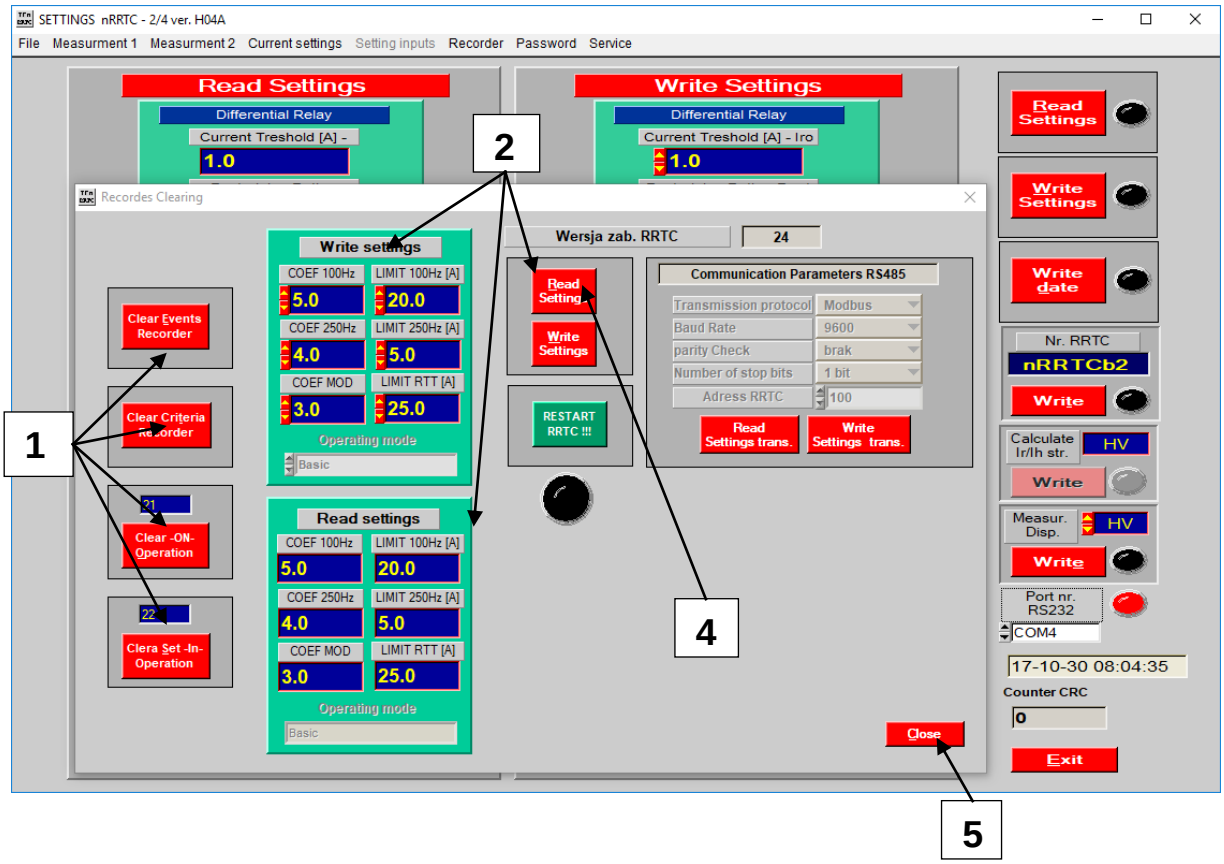

Fig. 10. “Service”-„Rec. clearing / RS485 conf.” window

In the top right part of the „Rec. clearing / RS485 conf.” window RS485 connection settings are located (see 3. on the

Fig. 10). Pressing the “Load connection parameters” button causes downloading of the RS485 connection settings from the relay. After that, user may (if needed) adjust that settings.

To send changed connection parameters, the “Send connection parameters” button should be pressed.

In the middle of the „Rec. clearing / RS485 conf.” window the “RRTC reset” button is placed (see 4. on the

Fig. 10). Pressing that button will reset the connected relay.

In the bottom right side of the „Rec. clearing / RS485 conf.” window “Exit” button is placed (see 5. on the

Fig. 10). Pressing that button will close the „Rec. clearing / RS485 conf.” window and the software main window will be showed.

8. Laboratory and operational measurements

8.1 Basic operational tests

- Protection relay tripp circuits check may be performed for example with use of the relay "Test" function available through its front panel display and keys. The check should be done during each installation inspections.
- Loss of DC power supply or realy internal malfunction sygnalisation check may be done by swiching off the DC voltage which is supllying the relay.
- Current circuits continuity check may be performed during normal operation of the protected transformer by each side phase currents comparison. The currents should be symerical on each transformer side, also the differential currents should be much smaller than the stabilizing currents.
- If any works were done on the current circuits, those circuits should be checked with use of current injecting protection tester.
- During periodic protection relay tests it is advisable to check the stored criteria recordings. Correct shapes of the stored waveforms (recorded mostly during external faults) proves the efficiency of the relay (during external faults stabilizing sum signals should be much higher than the differential currents signals).
- Periodically (for example: every five years) it is advisable to perform primary ans secondary current injection tests of the relay.

8.2 RRTC-3 starting differential current I_r measurement from the primary side of the current transformers

Attention: During protection relay tests with use of asymmetrical currents it is necessary to block the current circuit monitoring function, which will affect the value of the relay starting differential current

To measure the RRTC-3 starting differential current I_r from the primary side of the current transformers, the user should inject the primary current to the current circuit to be tested, till the relay tripping.

In the relay, phase primary currents measurements are available for each side.phase of the transformer. Differential and stabilizing currents are presented in relation to the secondary side of the current transformers installed in the HV side of the transformer. If the one phase current is injected, occurrence of the differential and stabilizing currents in other phases is an effect of zero sequence currents elimination function of the relay.

Performing the primary cuttents injection tests are very important, especially after carried out repairs and modernizations, because during such tests protection relay oeration and its current circuits are verified.

The expected value of the starting primary current for a different testing connections is presented in the Table 1. For primary tests with injected currents up to 2400 A, lightweight primary currents injection tester "DOK" is adapted (manufactured by Institute of Power Engineering).

Table 1. The multiplication factor value, by which the relay differential current seting I_r should be multiplied to obtain the primary value of the relay differential starting current depending on the connection configuration during tests

Transformer connection group	Three phase test current injection in the transformer:		Two phase test current injection in the transformer:		One phase test current injection in the transformer:	
	HV side	MV side	HV side	MV side	HV side	MV side
Y – D	ϑ_{WN}	$\vartheta_{WN}\vartheta_T$	ϑ_{WN}	$\frac{\sqrt{3}}{2}\vartheta_{WN}\vartheta_T$	$\frac{3}{2}\vartheta_{WN}$	$\sqrt{3}\vartheta_{WN}\vartheta_T$
Y – Y	ϑ_{WN}	$\vartheta_{WN}\vartheta_T$	ϑ_{WN}	$\vartheta_{WN}\vartheta_T$	$\frac{3}{2}\vartheta_{WN}$	$\frac{3}{2}\vartheta_{WN}\vartheta_T$

Where: I_r – differentia current setting,

ϑ_{WN} – transformer HV side current transformers ratio,

ϑ_T – transformer ratio,

8.3 Differential protection stabilizing characteristic measurements

Short-circuits in the transformers are mostly asymmetrical, because of that tests with use of two current sources without phase shift are recommended. Tests performed that way simulate one phase or two phase short-circuits inside or outside the protected transformer.

Instructions on how to connect the two current sources to the tested RRTC-3 protection relay and formulas for calculating currents injected on both sides of the transformer are shown below (Table 2).

Correctness of the test system connection should be always checked by injecting the cross-currents (which will simulate the current flowing through transformer during external short-circuit) into the relay. During that test, differential current measured by the relay should be close to zero. To simulate the cross-current it is important to keep the injected one phase currents on bought sides of the transformer in the same phase (independently from the transformer connection grupe). In the RRTC-3 protection relay, transformers MV sides currents are converted into the HV side. Differential and stabilizing currents values are related to the transformer HV side currents transformers secondary side level.

To measure the stabilizing characteristic $I_r=f(I_h)$ of the RRTC-3 relay, user should inject test currents I_1 and I_2' into two sides of the protection relay. Connection metod of the test currents I_1 and I_2' in dependence to the transformer connection group is presented in the Table 2. The currents I_1 and I_2' should be in phase. For differential and stabilizing current calculation the I_2' (which is injected into the protection relay as a secondary current of the MV side of the transformer) should be recalculated to the transformer HV side current transformers primary level (I_2) as $I_2=I_2'/k$, where k factor depends on transformer and current transformers ratios.

Table 2. RRTC-3 stabilization characteristic measuremen I_1 and I_2' test currents connection scheme in dependence to the transformer connection group

Transformer connection group	HV side (I_1 current)		MV side (I_2' current)		Relation between I_2 and I_2' currents
	Flowing in	Flowing out	Flowing in	Flowing out	
Yd11	L1	L2	L1	0	$I_2=I_2'\frac{\sqrt{3}\vartheta_{WN}\vartheta_T}{\vartheta_{SN}}$ $k=\frac{\sqrt{3}\vartheta_{WN}\vartheta_T}{\vartheta_{SN}}$
	L2	L3	L2	0	
	L3	L1	L3	0	
Yd1	L1	L3	L1	0	
	L2	L1	L2	0	
	L3	L2	L3	0	
Yd7	L3	L1	L1	0	
	L1	L2	L2	0	
	L2	L3	L3	0	
Yd5	L2	L1	L1	0	
	L3	L2	L2	0	

	L1	L3	L3	0	
Yy0	L1 L2 L3	L2 L3 L1	L1 L2 L3	L2 L3 L1	$\dot{I}_2 = \dot{I}_2 \frac{\vartheta_{WN}\vartheta_T}{\vartheta_{SN}}$ $k = \frac{\vartheta_{WN}\vartheta_T}{\vartheta_{SN}}$

Differential I_r and stabilizing I_h currents are described by the following equations:

- differential current: $I_r=|\underline{I}_1-\underline{I}_2|$ ($\underline{I}_2$ current is flowing out from the relay and so it is taken into the equation with the "-" sign),
- stabilizing current: $I_h=\max(|\underline{I}_1|, |\underline{I}_2|) - 0{,}5\ I_r$

If only cross-current is flowing through the transformer, the measured by the relay differential current I_r value should be close to zero.

During described test, phase angle error of the current sources should be as small as possible (for example: below 1°). In such situation, for calculating the injected differential and stabilizing currents, RMS values of $|\underline{I}_1|$ and $|\underline{I}_2|$ test currents may be used.

The UCT-GT protection relays tester (manufactured by Institute of Power Engineering) is adapted for RRTC-3 relay stabilizing characteristics measurements. It is equipped in differential protection test mode, in which differential (I_r) and stabilizing (I_h) currents values to be injected into relay ander test are settable. In the described mode transformer *k* factor, described as:

- for transformers with Y-D connection group: $k = \frac{\sqrt{3}\vartheta_{WN}\vartheta_T}{\vartheta_{SN}}$
- for transformers with Y-Y connection group: $k = \frac{\vartheta_{WN}\vartheta_T}{\vartheta_{SN}}$

is also settable as one of the tester parameters.

The chanell A of the tester is intended for connection with the relay as the transformer HV side secondary current. The chanell B is intended for connection with the relay as the transformer MV side secondary current. Chanell B current is also multiplied by *k* factor setting value. The UCT-GT tester (like the protection relay) reverses the direction of current in the channel B. Because of that, for example during Yy0 transformer differential protection tests, red connectors of the A and B chanels should be connected to the L1 phases starting points/contacts of the relay current inputs related with HV and MV side of the transformer.

Current second and fifth harmonic stabilization should be verified in the same connection schem with only differential current injected into the relay. The best solution for that verification is to inject specific value of the current second or fifth harmonic component and then increase the basic component of that current till the differential protection tripping. In such test the starting value of the differential current will be measured and not its drop off value (which is different then starting value). Current second and fifth harmonic stabilization may also be verified with use of only one current source injecting the current into only one side of the protection relay. In such case also stabilizing currents will be calculated and so, measured starting differential currents will be different from the previous test schem, because both types of stabilization (from the stabilizing current and from the harmonic component stabilization) will add up.

9. Procedure in case of internal malfunction

9.1 Normal operation state

The RRTC-3 relay is monitoring its power suplly voltage, settings correctness and internal software integrity. If the results of that self-testing procedure are correct, the green "stand by" diode located on the front panel is glowing and Bs contacts 23-22 and 20-19 are closed.

9.2 Internal malfunction

If for example as a result of very strong electromagnetic interference relay internal software operation is interrupted, automatic restart system will try to reset the relay to normal state. If such operations are ineffective, then:

- if the green "stand by" diode and red "tripping" diode located on the front panel are not glowing or the Bs contacts are opened, user should try to re-enter the correct relay settings and if it will not help, he should contact the service;
- if the green "stand by" diode located on the front panel is not glowing and the red "tripping" diode is blinking, user should switch off the relay power supply and after a few seconds, turn it back on. If these actions are ineffective, user should contact service (tel.+48 22 836 89 24).

10.Technical data

Table 3. RRTC-3 relay technical data

GENERAL INFORMATION	
Nominal current I_n	5 A or 1 A
Nominal auxiliary voltage	88 ÷ 250 V AC/DC
Power consumption in the auxiliary voltage circuit	10 VA/W
Nominal frequency	50 Hz
Burden per current input at nominal current load	< 0,2 VA
Current constant overload capability per current input	2 I_n
Current thermal overload capability per current input	80 I_n per 1 s
Current dynamic overload capability per current input	200 I_n
Accuracy	5%
Operate time	15 ms ÷ 35 ms
Reset time	<150 ms
BINARY OUTPUTS CIRCUITS	
Constant overload capability	8 A
Brake (open) capability at 220 V DC and L/R = 40 ms	0,12 A
INSULATION HIGH VOLTAGE CAPABILITY	
AC voltage	2kV/50Hz/1min
ENVIRONMENTAL CONDITIONS	
Nominal operation ambient temperature range	-5º C ÷ +40º C
Nominal storage ambient temperature range	-25º C ÷ +70º C
Encloser protection level (according to IEC 60529)	IP40 (IP20 for contacts)
DIFFERENTIAL PROTECTION FUNCTION SETTINGS	
Minimal (starting) differential current I_{r0}	(0,1 ÷ 0,7) I_n
Stabilization factor k_h	0,2 ÷ 0,7
PROTECTED TRANSFORMER PARAMETERS SETTINGS	
Transformer HV winding connection configuration	Y
Transformer MV1 winding connection configuration	y0; y6; d1; d5; d7; d11
Transformer MV2 winding connection configuration*	y0; y6; d1; d5; d7; d11
Transformer HV winding nominal voltage	3,0 kV ÷ 440 kV
Transformer MV1 winding nominal voltage	3,0 kV ÷ 440 kV
Transformer MV2 winding nominal voltage*	3,0 kV ÷ 440 kV
CURRENT TRANSFORMERS PARAMETERS SETTINGS	
HV side current transformer nominal primary current	40 A ÷ 5000 A

MV1 side current transformer nominal primary current	40 A ÷ 5000 A
MV2 side current transformer nominal primary current*	40 A ÷ 5000 A
CURRENT CIRCUITS MONITORING FUNCTION SETTINGS	
Current asymmetry starting level (for HV, MV1 and MV2 side)	20% ÷ 50%
Operation time delay	(10 ÷ 60) s
Drop off time delay	(1,0 ÷10) s
Minimal current necessary for function operation	>0,1 I_n
SERVICE SETTINGS**	
100 Hz current component stabilizing factor	10% ÷ 40%
100 Hz current component stabilization limit	(0 ÷ 8) I_n
250 Hz current component stabilizing factor	10% ÷ 40%
250 Hz current component stabilization limit	(0 ÷ 8) I_n
Unconditional tripping threshold (current cutoff)	(2 ÷ 10) I_n

Where:

* - rewers to the RRTC-3/3 relay dedicated for three windings transformer protection,

** - change of the standard values of the service settings is allowed only in cooperation with Institute of Power Engineering,

*** - exceeding the unconditional tripping threshold level by differential current causes protection relay tripping independently from the stabilization conditions.

11.Relay dimentions

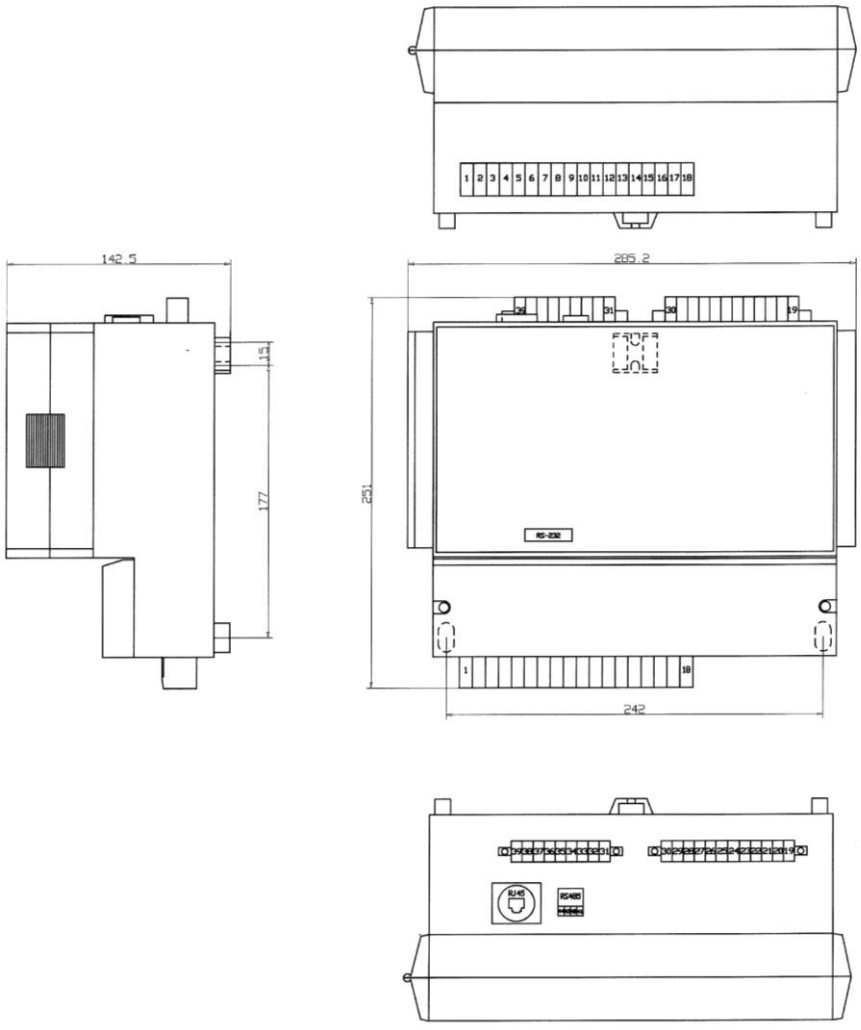

Fig. 11. RRTC-3 relay surface mounting enclosure dimentions

12.Communication

The RRTC-3 differential protection relay is equipped with three types of communication ports:

- RS232 port located on the relay's front panel - it is used for local maintenance with use of the laptop (see point 7),
- RS485 port (41 – 44 contacts on the relay terminal stripe) – it is used for connecting the relay with the decentralized control system (DCS) with use of MODBUS RTU protocol. RS485 port may be also used for remote maintenance with use of the nRRTC-vxxx software or it's newer version (correct RRTC-2/3 transmission protocol should be set in the relay's RS485 port connection settings – see point 7.7),
    - Ethernet port (with RJ45 socet) – it is dedicated for the relay's remote maintenance with use of the nRRTC-vH04Atcp - or later (***English version in preparation - downloadable from: https://ien.com.pl/pliki-do-pobrania***) software with use of the Ethernet network .

13.Guidelines for RRTC-3 relays remote maintenance with use of the Ethernet network communication

The MOXA NE-4100T (www.moxa.com) Ethernet communication module is used in the RRTC-3 relays for Ethernet remote communication. The NE-4100T module have to be configurated by user with use of the „Network Enabler Administrator" software which is provided with the RRTC-3 relay. It is also available on the manufacturer website: www.moxa.com. After installation of the mentioned software, relay maintenance through the virtual serial port is also available. Hovever, for relay maintanance it is recommended to use IP communication, then the virtual serial port communication.

Below, it will be explained how to configure and use communication via Ethernet network using the TCP protocol IP address and port number.

13.1 NE-4100T module configuration

After „Network Enabler Administrator" software installation and opening, user should start with searching of the NE-4100T modules connected to the network. To do that, he should select the "Configuration" command from the top menu and then „Broadcast Search" commang. Described commands should open the „Broadcast Search" window as shown on the Fig. 12.

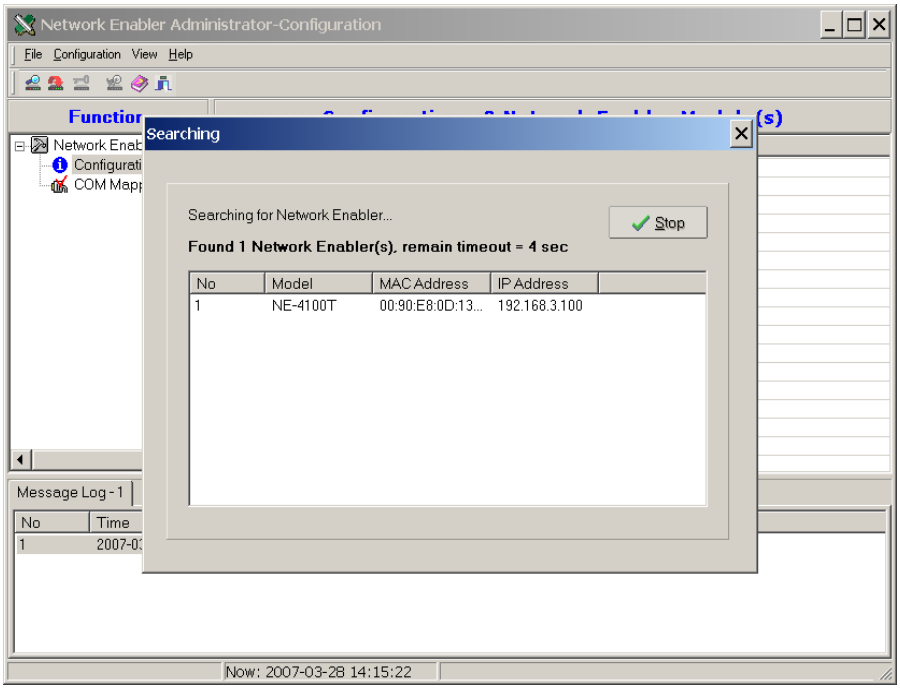

Fig. 12. "Network Enabler Administrator" software „Broadcast Search" window

In the „Broadcast Search" window, connected NE-4100T modul IP number is shown. Many NE-4100T modules may be connected to the network. To cooperate with many modules, each of them should have the unique IP number. To do that, user should double-click on the selected module to edit its connection parameters. It will open the "Configuration" subwindow, as shown on the Fig. 13.

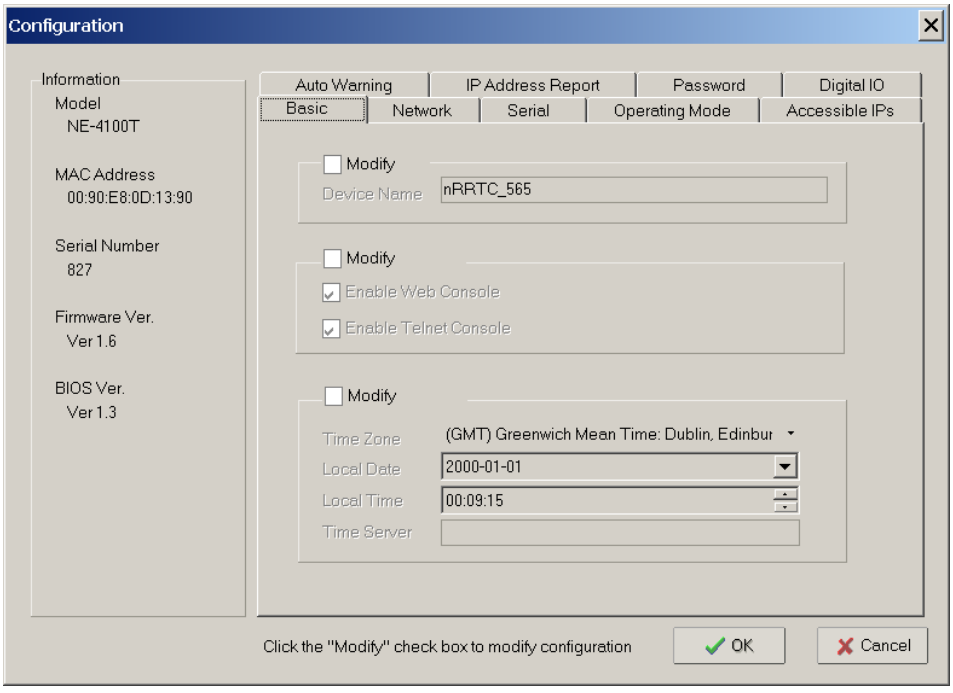

Fig. 13. "Network Enabler Administrator" software NE-4100T module "Configuration" subwindow

In the "Configuration" subwindow, user should select the "Network" tab and then select the "Modify" box in the "IP Address" area. That will enable the selected module IP address modification as shown of Fig. 14.

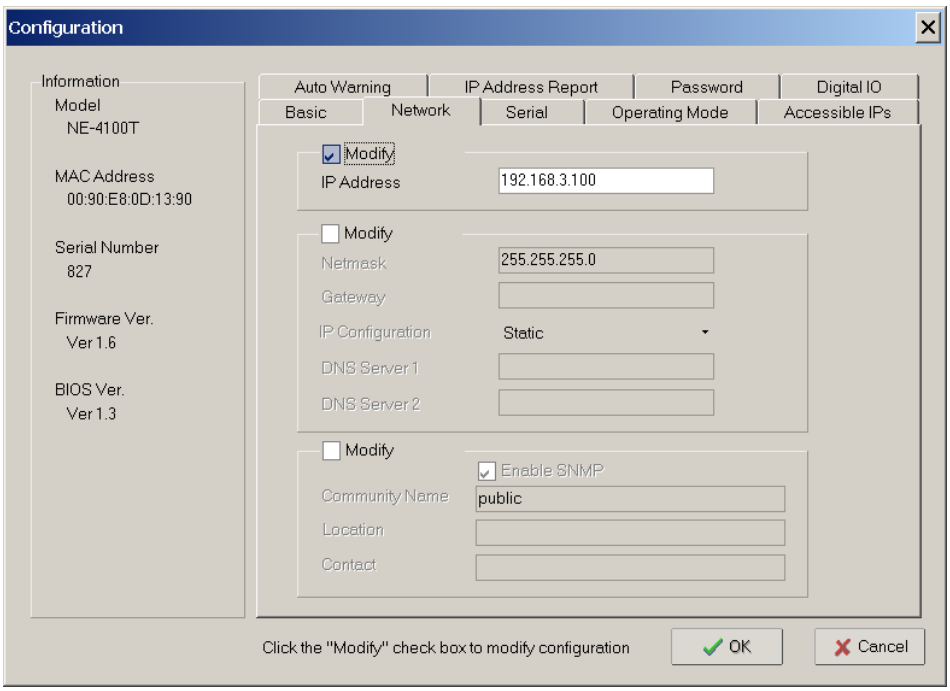

Fig. 14. "Network Enabler Administrator" software NE-4100T module "Configuration" subwindow "Network" tab

After entering the unique IP number for the selected module, user may select the „Accessible IPs" tab which allows entering the IP numbers of the PCs that are permitted to connect with selected NE-4100T module and so with the RRTC-3 relay. It will open the subwindow as shown on Fig. 15.

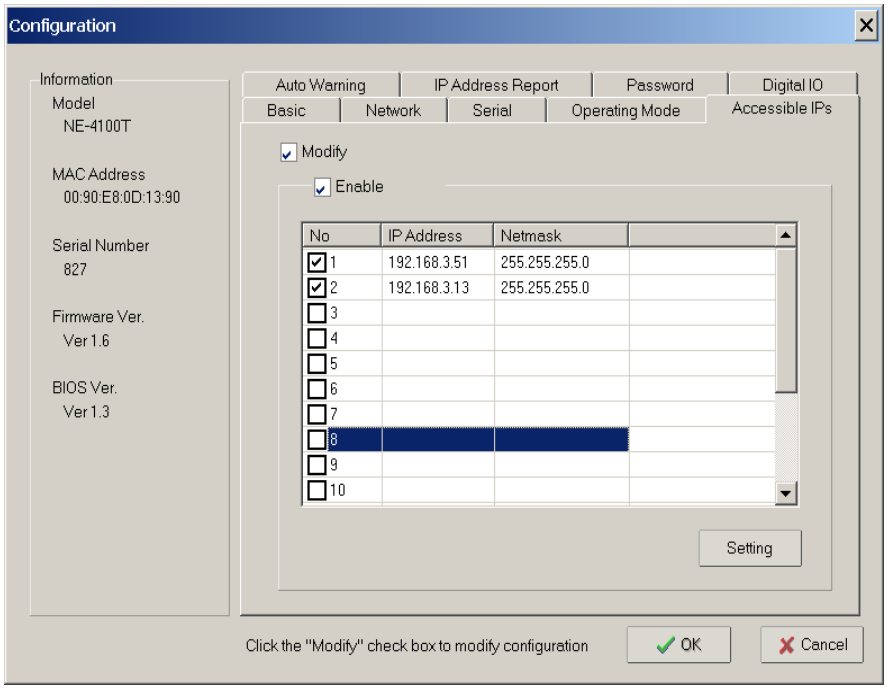

Fig. 15. "Network Enabler Administrator" software NE-4100T module "Configuration" subwindow „Accessible IPs" tab

In the „Accessible IPs" tab, should also select the „Modify" box what will allow making changes. Next, user should select the "Enable" boxes in the "No" column of the „Accessible IPs" table (see Fig. 15) to enable the IP address control for NE-4100T module communication. After entering and enabling changes described above, with use of the "OK"

button, NE-4100T module will be allowed to communicate only with the PCs with the specific IP addresses, selected in the „Accessible IPs" tab. IP addresses of the PCs allowed to communicate with the NE-4100T module may be entered in the „Accessible IPs" tab after double-clicking on one of sixteen rows of the „Accessible IPs" table. After entering the IP number, user should select the row number box referring to the entered IP address in the "No" column of the „Accessible IPs" table - as it is done for 1 and 2 row numbers on the Fig. 15.

The next step of the NE-4100T module configuration is to check the „Operating Mode" tab settings (Fig. 16).

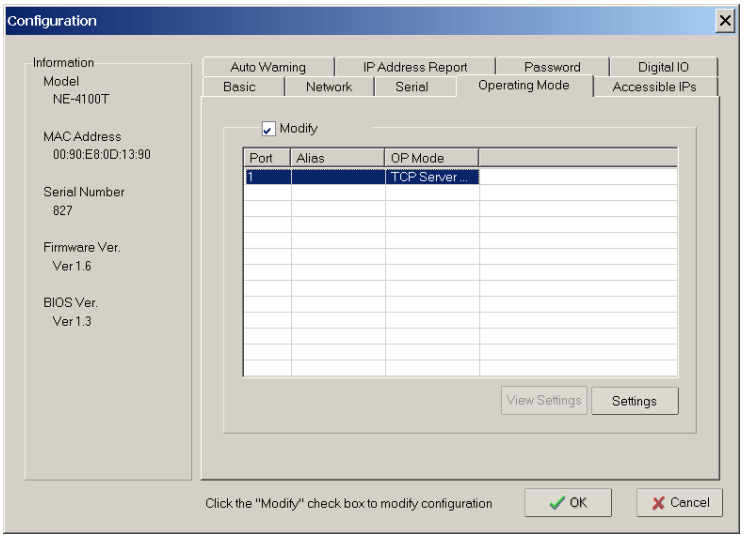

Fig. 16. "Network Enabler Administrator" software NE-4100T module "Configuration" subwindow „Operating Mode" tab

In that tab „TCP Server Mode" operation mode should be selected. Parameters of the „TCP Server Mode" operation mode such like: the number of supported clients and TCP port number may be customized by opening the "Settings" window, but after that users of other systems connecting with the RRTC-3 relay should be informed about the changes. Fig. 17 shows the „TCP Server Mode" operation mode "Settings" window.

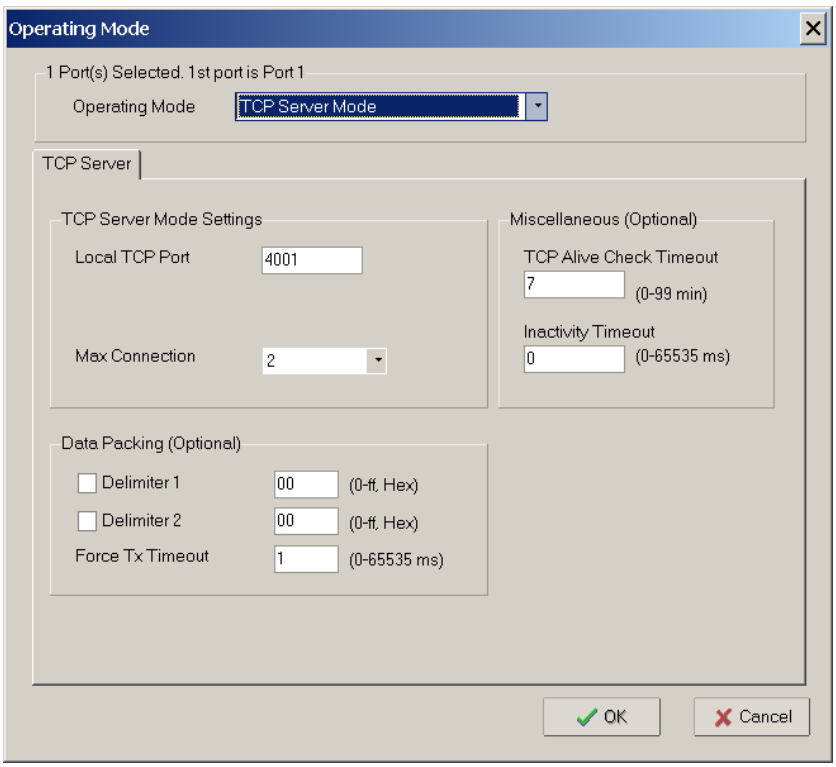

Fig. 17. "Network Enabler Administrator" software NE-4100T module "Configuration" subwindow „Operating Mode" tab „TCP Server Mode" operation mode "Settings" window

13.2 RRTC protection relay nRRTC-vxxxtcp software configuration for remote maintenance communication

For remote Ethernet communication with the RRTC-3 relays the nRRTC-vxxxtcp software or its newer version is provided. The nRRTC-vxxxtcp software has the additional "IP list" button located in the bottom right corner of the software main window. Beside of that, "Edit IP addresses" additional command is located in the top menu "Maintenance" tab.

To configurate relay Ethernet communication, user should select the **"Maintenance"-"Edit IP addresses"** command from the softwer top menu bar. It will oopen the "Communication configuration" window – Fig. 18. In that window the „nRRTC Server IP address" setting should be selected. In that setting, the previously selected NE-4100T module IP address should be entered (numbers should be devided with dots) and confirmed with "Enter" key (see Fig. 18). After that, user should enter the 4001 port number in the "nRRTC server port number" setting – see Fig. 19. After editing the mentioned settings, chnges may be saved by pushing the "Save configuration" button or rejected by closing the "Communication configuration" window.

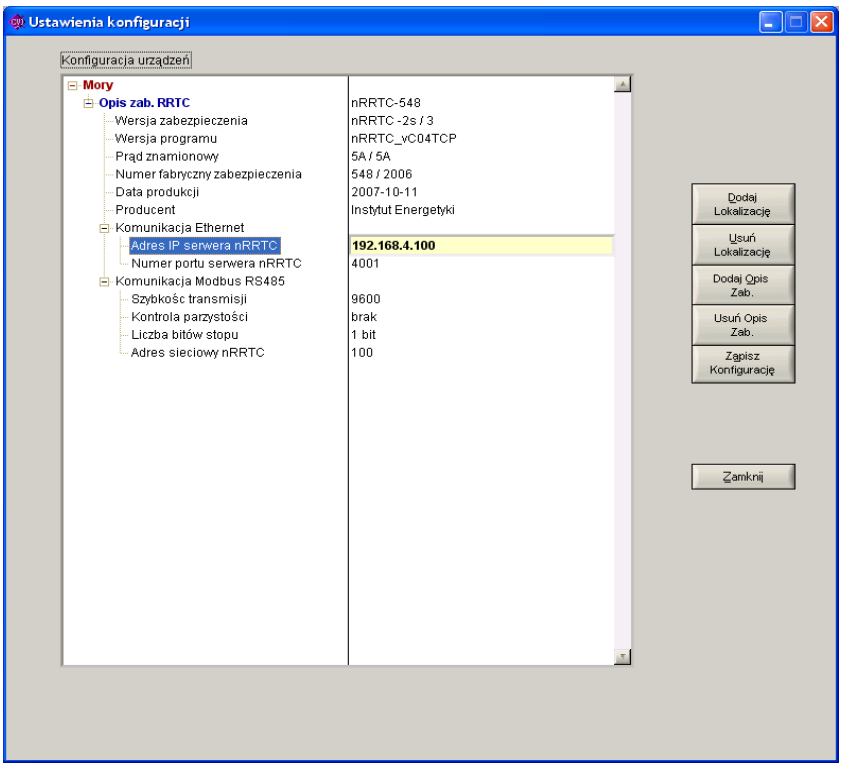

Fig. 18. The nRRTC-vxxxtcp software "Communication configuration" window – editing the „nRRTC Server IP address" setting

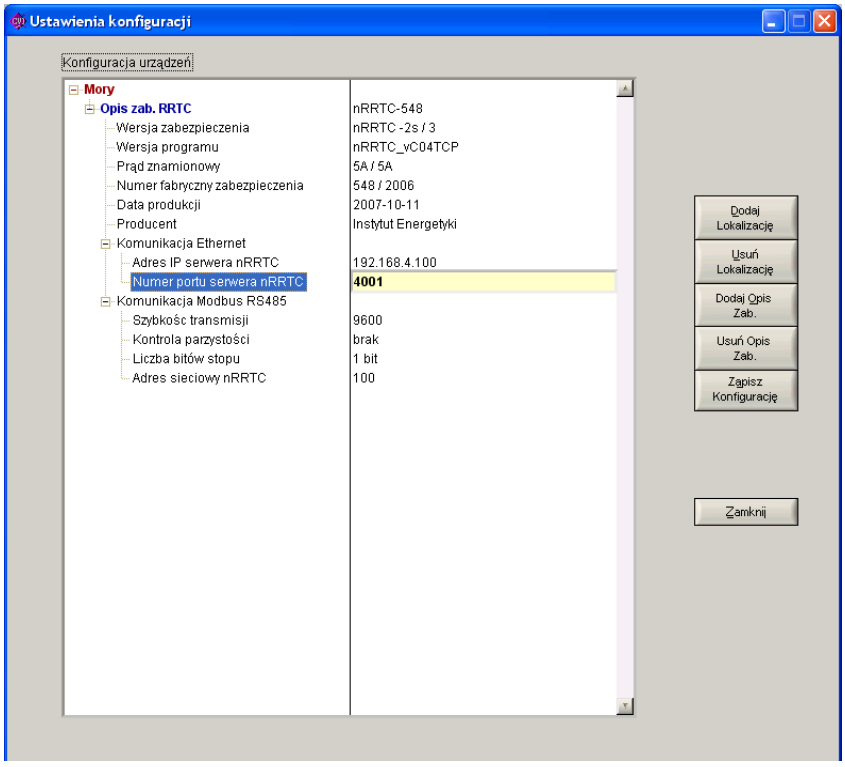

Fig. 19. The nRRTC-vxxxtcp software "Communication configuration" window – editing the "nRRTC server port number" setting

13.3 Establishing the connection

To establish the connection with the relay, user should press the "IP list" button in the nRRTC-vxxxtcp software main window. It will open the "Communication configuration" window with disabled editing capabilities (Fig. 20).

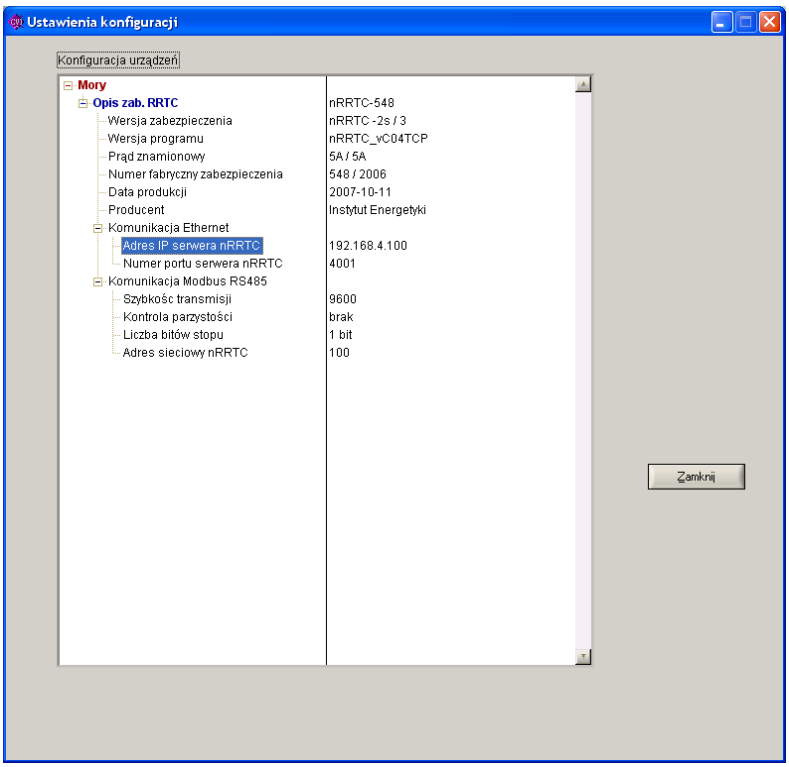

Fig. 20. The nRRTC-vxxxtcp software "Communication configuration" window opened without editing capabilities after pressing the "IP list" button

By clicking on the „nRRTC Server IP address" setting, software will try to establish the connection with the relay. If the connection is established the "Communication configuration" window will be automatically closed.

From that moment, the principles of RRTC-3 relay operating via PC are the same as for the maintenance via the RS232 serial port (see point 7).

14. Guidelines for RRTC-3 relay status readout through MODBUS RTU protcol

14.1 RS485 communication parameters for MODBUS RTU protocol

Communication speed and other RS485 communication parameters may be adjusted with use of the nRRTC-vXXX software by **"Maintenance" - „Rec. clearing / RS485 conf."** command (see point 7.7). User may select one out of five communication speeds: 4800 bps, 9600 bps, 19200 bps, 28800 bps, 38400 bps. Stop bits may be configured as 1 bit or 2 bits. Parity bit may be selected as: even, odd or none.

14.2 MODBUS protocol supported functions

MODBUS protocol function no. 3 (Read Holding Registers – see Table 4) and no. 4 (Read Input Registers – see Table 5) are supported by RRTC-3 relays. In accordance to the applied registries numbering sequence, the first register will be assigned as registry no. 0. Parameters which occupy two MODBUS register addresses are a floating-point numbers with a length of 4 bytes.

Table 4. RRTC-3 relays register map for the MODBUS function 3 (Read Holding Registers)

Address	Parameter	Units/comments
0 1	Differential starting current	[A]
2 3	Stabilizing factor	Value in 0,2 ÷ 0,7 range
4	Transformer HV winding connection configuration	Only younger 8 bits used
5	Transformer MV1 winding connection configuration*	Only younger 8 bits used
6	Transformer MV2 winding connection configuration*	Only younger 8 bits used
7 8	Transformer HV winding nominal voltage	[kV]
9 10	Transformer MV1 winding nominal voltage	[kV]
11 12	Transformer MV2 winding nominal voltage	[kV]
13 14	Transformer HV winding current transformer nominal primary current	[kA]
15 16	Transformer HV winding current transformer nominal primary current	[A]
17 18	Transformer MV1 winding current transformer nominal primary current	[kA]
19 20	Transformer MV1 winding current transformer nominal primary current	[A]
21 22	Transformer MV2 winding current transformer nominal primary current	[kA]
23 24	Transformer MV2 winding current transformer nominal primary current	[A]
25	„$I_r/I_{h\ side}$” ratio settings**	Only younger 8 bits are used
26	“Display measurements” settings***	Only younger 8 bits are used
27	Firmware version	Only younger 8 bits are used
28 29 30 31	RRTC relay assigned name	8-bit ASCII string
32	Number of relay switchings on	Only younger 8 bits are used
33	Number of relay trippings	Only younger 8 bits are used
34 35	Current second harmonic stabilization factor	----
36 37	Current fifth harmonic stabilization factor	----
38 39	Current second and fifth harmonic sum stabilization factor	----
40 41	Current second and fifth harmonic sum stabilization limit	[A]
42 43	Current second harmonic stabilization limit	[A]
44 45	Current fifth harmonic stabilization limit	[A]

Where:

* - Transformer HV, MV1 and MV2 winding connection configuration byte values: y0=0, y6=1, d1=2, d5=3, d7=4, d11=5, xxx=6.

** - $I_r/I_{h\ side}$ ratio settings byte values: HV=0, MV1=1, MV2=2, MV3=3.

*** - Display measurements settings byte values: HV=0, MV1=1, MV2=2, MV3=3.

Table 5. RRTC-3 relays register map for the MODBUS function 4 (Read Input Registers)

Address	Parameter	Units/comments
0	Stabilizing current first harmonic	[A]
1		
2	Differential current	[A]
3		
4	Current second harmonic	[A]
5		
6	Current fifth harmonic	[A]
7		
8	Stabilizing current (stabilizing sum)	[A]
9		
10	Phase L1 differential current	[A]
11		
12	Phase L2 differential current	[A]
13		
14	Phase L3 differential current	[A]
15		
16	Phase L1 stabilizing current	[A]
17		
18	Phase L2 stabilizing current	[A]
19		
20	Phase L3 stabilizing current	[A]
21		
22	Transformer HV side phase L1 current	[kA]
23		
24	Transformer HV side phase L2 current	[kA]
25		
26	Transformer HV side phase L3 current	[kA]
27		
28	Transformer MV1 side phase L1 current	[kA]
29		
30	Transformer MV1 side phase L2 current	[kA]
31		
32	Transformer MV1 side phase L3 current	[kA]
33		
34	Transformer MV2 side phase L1 current	[kA]
35		
36	Transformer MV2 side phase L2 current	[kA]
37		
38	Transformer MV2 side phase L3 current	[kA]
39		
40	RRTC relay tripping and internal malfunction status*	Only younger 8 bits are used
41	RRTC relay tripping (byte value=3)	Only younger 8 bits are used
42	RRTC relay dropping off (byte value=37)	Only younger 8 bits are used
43	Current circuits monitoring function operations for transformer HV side (byte value=33)	Only younger 8 bits are used
44	Current circuits monitoring function operations for transformer MV1 side (byte value=34)	Only younger 8 bits are used
45	Current circuits monitoring function operations for transformer MV2 side (byte value=35)	Only younger 8 bits are used
46	System error (byte value=4)	Only younger 8 bits are used
47	RRTC test procedure execution (byte value=2)	Only younger 8 bits are used

Where:

* - RRTC relay tripping and internal malfunction status byte values:
1 - Data range error.
2 - RRTC test procedure execution.
3 - RRTC relay tripping.
4 - System error.

5 - RRTC firmware damage.
6 - loss of analog digital converter voltage (U_{adc})
7 – EEPROM memory damage.
8 - RAM memory damage.
7 - RTC clock damage.
15 - nRRTC software data range error.
20 - Transformer connection group data damage.
23 - Service settings data range error.
31 - Ethernet communication module malfunction.
33 - Current circuits monitoring function operations for transformer HV side.
34 - Current circuits monitoring function operations for transformer MV1 side.
35 - Current circuits monitoring function operations for transformer MV2 side.
36 - Current circuits monitoring function I_{asm} data range error.
37 - RRTC relay dropping off

Attention: stored data is automatically erased after readout

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