Application manual
REL 551-C1*2.3
Line differential protection terminal

About this manual

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Chapter 1 Introduction

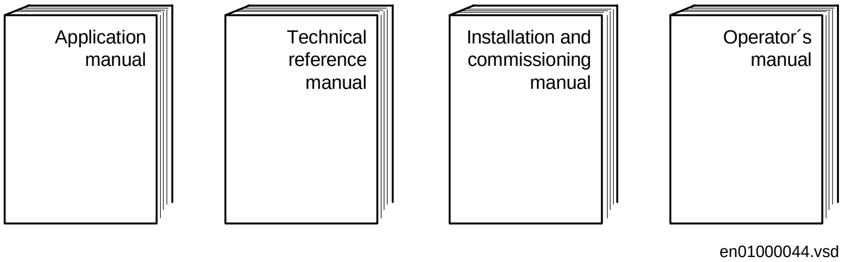
About this chapter

This chapter introduces you to the manual as such.

1 Introduction to the application manual

1.1 About the complete set of manuals to a terminal

The complete package of manuals to a terminal is named users manual (UM). The *Users manual* consists of four different manuals:



The Application Manual (AM) contains descriptions, such as application and functionality descriptions as well as setting calculation examples sorted per function. The application manual should be used when designing and engineering the protection terminal to find out when and for what a typical protection function could be used. The manual should also be used when calculating settings and creating configurations.

The Technical Reference Manual (TRM) contains technical descriptions, such as function blocks, logic diagrams, input and output signals, setting parameter tables and technical data sorted per function. The technical reference manual should be used as a technical reference during the engineering phase, installation and commissioning phase and during the normal service phase.

The Operator´s Manual (OM) contains instructions on how to operate the protection terminal during normal service (after commissioning and before periodic maintenance tests). The operator´s manual could be used to find out how to handle disturbances or how to view calculated and measured network data in order to determine the reason of a fault.

The Installation and Commissioning Manual (ICM) contains instructions on how to install and commission the protection terminal. The manual can also be used as a reference if a periodic test is performed. The manual covers procedures for mechanical and electrical installation, energising and checking of external circuitry, setting and configuration as well as verifying settings and performing a directionality test. The chapters and sections are organised in the chronological order (indicated by chapter/section numbers) the protection terminal should be installed and commissioned.

1.2 Intended audience

1.2.1 General

The application manual is addressing the system engineer/technical responsible who is responsible for specifying the application of the terminal.

1.2.2 Requirements

The system engineer/technical responsible must have a good knowledge about protection systems, protection equipment, protection functions and the configured functional logics in the protection.

1.3 Related documents

Documents related to REL 551-C1*2.3	**Identity number**
Operator’s manual	1MRK 506 104-UEN
Installation and commissioning manual	1MRK 506 106-UEN
Technical reference manual	1MRK 506 105-UEN
Application manual	1MRK 506 118-UEN
Technical overview brochure	1MRK 506 103-BEN

1.4 Revision notes

Revision	Description
2.3-00	First revision

Chapter 2 General

About this chapter

This chapter describes the terminal in general.

1 Features

- Versatile local human-machine interface (HMI)
- Simultaneous dual protocol serial communication facilities
- Extensive self-supervision with internal event recorder
- Time synchronization with 1 ms resolution
- Four independent groups of complete setting parameters
- Powerful software ‘tool-box’ for monitoring, evaluation and user configuration
- Pre-configured protection terminal for cost-effective engineering and commissioning
- Compact half 19" case size
- Phase-segregated line differential protection with current circuit supervision
- Non-directional phase and residual overcurrent protection
- Thermal overload protection
- Three-pole tripping
- Disturbance and event recording functions

2 Application

The main purpose of the REL 551-C1 terminal is the protection, control and monitoring of overhead lines and cables. It provides for three-pole tripping. The true current differential protection provides excellent sensitivity and phase selection in complex network configurations. The terminal is also specially suitable for short line applications withgalvanic pilots for distances up to 4 km that require an insulation level up to 15 kV.

3 Design

Type tested software and hardware that comply with international standards and ABB´s internal design rules together with extensive self monitoring functionality, ensure high reliability of the complete terminal.

The terminal’s closed and partly welded steel case makes it possible to fulfill the stringent EMC requirements.

All serial data communcation is via optical connections to ensure immunity against disturbances.

A fully functional terminal comprising a compact hardware, pre-selected protection, control and monitoring functions that were carefully chosen, configured and tested to meet a broad range of application requirements. This ready to connect and commission feature makes this product a cost effective solution for both new installations and the refurbishment of existing installations.

4 Requirements

4.0.1 General

The operation of a protection measuring function is influenced by distortion, and measures need to be taken in the protection to handle this phenomenon. One source of distortion is current transformer saturation. In this protection terminal, measures are taken to allow for a certain amount of CT saturation with maintained correct operation. This protection terminal can allow relatively heavy current transformer saturation.

4.0.2 Current transformers

Classification

he performance of the REL 551 terminal depends on the conditions and the quality of the current signals fed to it. The protection terminal REL 551 has been designed to permit relatively heavy current transformer saturation with maintained correct operation. To guarantee correct operation, the CTs must be able to correctly reproduce the current for a minimum time before the CT will begin to saturate. To fulfil the requirement on a specified time to saturation the CTs must fulfil the requirements of a minimum secondary e.m.f. that is specified below.

There are several different ways to specify CTs. Conventional magnetic core CTs are usually specified and manufactured according to some international or national standards, which specify different protection classes as well. However, generally there are three different types of current transformers:

- high remanence type CT
- low remanence type CT
- non remanence type CT

The high remanence type has no limit for the remanence flux. This CT has a magnetic core without any airgap and a remanence flux might remain for almost infinite time. In this type of transformers the remanence flux can be up to 70-80% of the saturation flux. Typical examples of high remanence type CT are class P, TPS, TPX according to IEC, class P, X according to BS (British Standard) and nongapped class C, K according to ANSI/IEEE.

The low remanence type has a specified limit for the remanence flux. This CT is made with a small airgap to reduce the remanence flux to a level that does not exceed 10% of the saturation flux. The small airgap has only very limited influence on the other properties of the CT. Class TPY according to IEC is a low remanence type CT.

The non remanence type CT has practically negligible level of remanence flux. This type of CT has relatively big airgaps in order to reduce the remanence flux to practically zero level. At the same time, these airgaps minimize the influence of the DC-component from the primary fault current. The airgaps will also reduce the measuring accuracy in the non-saturated region of operation. Class TPZ according to IEC is a non remanence type CT.

The rated equivalent limiting secondary e.m.f. E_{al} according to the IEC 60044-6 standard is used to specify the CT requirements for REL 551. The requirements are also specified according to other standards.

Conditions

The requirements are a result of investigations performed in our network simulator. The tests have been carried out with an analogue current transformer model with a settable core area, core length, air gap and number of primary and secondary turns. The setting of the current transformer model was representative for current transformers of high remanence and low remanence type. The results are not valid for non remanence type CTs (TPZ).

The performance of the protection was checked at both symmetrical and fully asymmetrical fault currents. A source with a time constant of about 120 ms was used at the tests. The current requirements below are thus applicable both for symmetrical and asymmetrical fault currents.

Both phase-to-earth, phase-to-phase and three-phase faults were tested for internal and external fault locations. The protection was checked with regard to stability and dependable tripping.

All testing was made without any remanence flux in the current transformer core. The requirements below are therefore fully valid for a core with no remanence flux. It is difficult to give general recommendations for additional margins for remanence flux. They depend on the reliability and economy requirements.

When current transformers of low remanence type (TPY) are used, practically no additional margin is needed.

For current transformers of high remanence type (e.g. TPX), the small probability of a fully asymmetrical fault, together with maximum remanence flux in the same direction as the flux generated by the fault, has to be kept in mind at the decision of an additional margin. Fully asymmetrical fault current will be achieved when the fault occurs at zero voltage (0°). Investigations have proved that 95% of the faults in the network will occur when the voltage is between 40° and 90°.

Fault current

The current transformer requirements are based on the maximum fault current for faults in different positions. Maximum fault current will occur for three-phase faults or single-phase-to-earth faults. The current for a single phase-to-earth fault will exceed the current for a three-phase fault when the zero sequence impedance in the total fault loop is less than the positive sequence impedance.

When calculating the current transformer requirements, maximum fault current should be used and therefore both fault types have to be considered.

Cable resistance and additional load

The current transformer saturation is directly affected by the voltage at the current transformer secondary terminals. This voltage, for an earth fault, is developed in a loop containing the phase and neutral conductor, and relay load. For three-phase faults, the neutral current is zero, and only the phase conductor and relay phase load have to be considered.

In the calculation, the loop resistance should be used for phase-to-earth faults and the phase resistance for three-phase faults.

General current transformer requirements

The current transformer ratio should be selected so that the current to the protection is higher than the minimum operating value for all faults that are to be detected.

The minimum operating current for the differential protection function in REL 551 is 20% of the nominal current multiplied with the CTFactor setting. The CTFactor is settable between 0.40-1.00.

The current transformer resulting ratio must be equal in both terminals. The resulting current transformer ratio is the primary current transformer ratio multiplied with the CTFactor. The CTFactor is used to equalise different primary current transformer ratio in the two terminals or to reduce the resulting current transformer ratio to which the minimum operating current is related.

Different rated secondary current for the current transformers in the two terminals is equalised by using REL 551 with the corresponding rated current.

All current transformers of high remanence and low remanence type that fulfil the requirements on the rated equivalent secondary e.m.f. E_{al} below can be used. The current transformers should have an accuracy class comparable to 5P or better. The characteristic of the non remancence type CT (TPZ) is not well defined as far as the phase angle error is concerned, and we therefore recommend contacting ABB Automation Products AB to confirm that the type in question can be used.

Current transformer requirements for the differential protection function for CTs according to the IEC 60044-6 standard

The current transformers must have a rated equivalent secondary e.m.f. E_{al} that is larger than the maximum of the required secondary e.m.f. E_{alreq} below. The requirements according to the formulas below are valid for fault currents with a primary time constant less than 120 ms.

Requirement 1

$$E_{al} > E_{alreq} = \frac{I_{kmax} \cdot I_{sn}}{I_{pn}} \cdot 0.5 \cdot \left(R_{CT} + R_L + \frac{0.25}{I^2_R}\right)$$

(Equation 1)

Requirement 2

$$E_{al} > E_{alreq} = \frac{I_{tmax} \cdot I_{sn}}{I_{pn}} \cdot 2 \cdot \left(R_{CT} + R_L + \frac{0.25}{I^2_R}\right)$$

(Equation 2)

where

I_{kmax}	Maximum primary fundamental frequency fault current for internal close-in faults (A)
I_{tmax}	Maximum primary fundamental frequency fault current for through fault current for external faults (A)
I_{pn}	The rated primary CT current (A)
I_{sn}	The rated secondary CT current (A)
I_R	The protection terminal rated current (A)
R_{CT}	The secondary resistance of the CT (Ω)
R_L	The loop resistance of the secondary cable and additional load (Ω).

The factor 0.5 in Equation 1 is replaced with 0.53 and 0.54 for primary time constants of 200 ms and 300 ms respectively.

The factor 2 in Equation 2 is replaced with 2.32 and 2.5 for primary time constants of 200 ms and 300 ms respectively.

Requirement 3

$$E_{al} > E_{alreq} = 0.12 \cdot f \cdot I_{sn} \cdot \left(R_{CT} + R_L + \frac{0.25}{I_R^2}\right)$$

(Equation 3)

Requirement 4

$$E_{al} > E_{alreq} = \frac{IminSat}{100} \cdot CTFactor \cdot I_R \cdot \left(R_{CT} + R_L + \frac{0.25}{I_R^2}\right)$$

(Equation 4)

where

f	Nominal frequencey (Hz)
I_{sn}	The rated secondary CT current (A)
I_R	The protection terminal rated current (A)
R_{CT}	The secondary resistance of the CT (Ω)
R_L	The loop resistance of the secondary cable and additional load (Ω)
IminSat	Set saturation detector min current (100-1000% of I_R)
CTFactor	Set current scaling factor (0.4-1.0)

Requirement 3 and 4 are independent of the primary time constant.

Current transformer requirements for CTs according to other standards

All kinds of conventional magnetic core CTs are possible to be used with REL 551 terminals if they fulfil the requirements that correspond to the above specified according to the IEC 60044-6 standard. From the different standards and available data for relaying applications it is possible to approximately calculate a secondary e.m.f. of the CT. It is then possible to compare this to the required secondary e.m.f. E_{alreq} and judge if the CT fulfils the requirements. The requirements according to some other standards are specified below.

Current transformer according to IEC 60044-1

A CT according to IEC 60044-1 is specified by the secondary limiting e.m.f. E_{2max}. The value of the E_{2max} is approximately equal to E_{al} according to IEC 60044-6.

$$E_{al} \approx E_{2max}$$

(Equation 5)

The current transformers must have a secondary limiting e.m.f. E_{2max} that fulfills the following:

$$E_{2max} > \text{maximum of } E_{alreq}$$

(Equation 6)

Current transformer according to British Standard (BS)

A CT according to BS is often specified by the rated knee-point e.m.f. E_{kneeBS}. The value of the E_{kneeBS} is lower than E_{al} according to IEC 60044-6. It is not possible to give a general relation between the E_{kneeBS} and the E_{al} but normally the E_{kneeBS} is 80 to 85% of the E_{al} value. Therefore, the rated equivalent limiting secondary e.m.f. E_{alBS} for a CT specified according to BS can be estimated to:

$$E_{alBS} \approx 1.2 \cdot E_{kneeBS}$$

(Equation 7)

The current transformers must have a rated knee-point e.m.f. E_{kneeBS} that fulfills the following:

$$1.2 \cdot E_{kneeBS} > \text{maximum of } E_{alreq}$$

(Equation 8)

Current transformer according to ANSI/IEEE

A CT according to ANSI/IEEE is specified in a little different way. For example a CT of class C has a specified secondary terminal voltage U_{ANSI}. There is a few standardized value of U_{ANSI} (e.g. for a C400 the U_{ANSI} is 400 V). The rated equivalent limiting secondary e.m.f. E_{alANSI} for a CT specified according to ANSI/IEEE can be estimated as follows:

$$E_{alANSI} = \left|20 \cdot I_{sn} \cdot R_{CT} + U_{ANSI}\right| = \left|20 \cdot I_{sn} \cdot R_{CT} + 20 \cdot I_{sn} \cdot Z_{bANSI}\right|$$

(Equation 9)

Z_{bANSI}	The impedance (i.e. complex quantity) of the standard ANSI burden for the specific C class (Ω)
U_{ANSI}	The secondary terminal voltage for the specific C class (V)

The CT requirements are fulfilled if:

$$E_{alANSI} > \text{maximum of } E_{alreq}$$

(Equation 10)

Often an ANSI/IEEE CT also has a specified knee-point voltage $U_{kneeANSI}$. This is graphically defined from the excitation curve. The knee-point according to ANSI/IEEE has normally a lower value than the knee-point according to BS. The rated equivalent limiting secondary e.m.f. E_{alANSI} for a CT specified according to ANSI/IEEE can be estimated to:

$$E_{alANSI} \approx 1.3 \cdot U_{kneeANSI}$$

(Equation 11)

The current transformers must have a knee-point voltage $U_{kneeANSI}$ that fulfills the following:

$$1.3 \cdot U_{kneeANSI} > \text{maximum of } E_{alreq}$$

5 Terminal identification

5.1 Application

Serial number, software version and the identification names and numbers for the station, the object and the terminal (unit) itself can be stored in the REx 5xx terminal. Also the serial numbers of included modules are stored in the terminal. This information can be read on the local HMI or when communicating with the terminal through a PC or with SMS/SCS.

The base currents, voltages and rated frequency must be set since the values affect many functions. The input transformers ratio must be set as well. The ratio for the current and the voltage transformer automatically affects the measuring functions in the terminal.

The internal clock is used for time tagging of:

- Internal events
- Disturbance reports
- Events in a disturbance report
- Events transmitted to the SCS substation control system

This implies that the internal clock is very important. The clock can be synchronized (see Time synchronization) to achieve higher accuracy of the time tagging. Without synchronization, the internal clock is useful for comparisons among events within the REx 5xx terminal.

5.2 Calculations

Uxr and Ixr (x = 1-5) are the rated voltage and current values for the analog input transformers within the REx 5xx terminal. UxScale and IxScale are the actual ratio for the main protection transformer at the protected object. These values will be used to calculate the present voltage and current in the protected object. Uxb and Ixb defines base voltage and current values, used to define the per-unit system used in the terminal for calculation of setting values.

The current transformer secondary current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 12)

where:

I_{SEC} = secondary rated current of the main CT

I_{PRIM} = primary rated current of the main CT

Is = primary setting value of the current

The relay setting value IP>> is given in percentage of the secondary base current value, Ixb, associated to the current transformer input Ix:

$$IP>> = \frac{Is_{SEC}}{Ixb} \cdot 100$$

(Equation 13)

The value of Ixb can be calculated as:

$$Ixb = \frac{\text{Rated primary current}}{\text{CT ratio}}$$

(Equation 14)

Chapter 3 Common functions

About this chapter

This chapter presents the common functions in the terminal.

1 Time synchronisation (TIME)

1.1 Application

Use time synchronisation to achieve a common time base for the terminals in a protection and control system. This makes comparision of events and disturbance data between all terminals in the system possible.

Time-tagging of internal events and disturbances is an excellent help when evaluating faults. Without time synchronisation, only the events within the terminal can be compared to one another. With time synchronisation, events and disturbances within the entire station, and even between line ends, can be compared during an evaluation.

1.2 Functionality

Two main alternatives of external time synchronisation is available. Either the synchronisation message is applied via any of the communication ports of the terminal as a telegram message including date and time, or as a minute pulse, connected to a binary input. The minute pulse is used to fine tune already existing time in the terminals.

The REx 5xx terminal has its own internal clock with date, hour, minute, second and millisecond. It has a resolution of 1 ms.

The clock has a built-in calendar for 30 years that handles leap years. Any change between summer and winter time must be handled manually or through external time synchronisation. The clock is powered by a capacitor, to bridge interruptions in power supply without malfunction.

The internal clock is used for time-tagging disturbances, events in Substation monitoring system (SMS) and Substation control system (SCS), and internal events.

1.3 Calculations

The internal time can be set on the local human-machine interface (HMI) at:

Settings
  Time

The time is set with year, month, day and time.

The source of the time synchronisation is set on the local HMI at:

Configuration

Time

When the setting is performed on the local HMI, the parameter is called TimeSync-Source. The time synchronisation source can also be set from the CAP 531 tool. The setting parameter is then called SYNCSCR. The setting alternatives are:

- None (no synchronisation)
- LON
- SPA
- IEC
- Minute pulse positive flank
- Minute pulse negative flank

The function input to be used for minute-pulse synchronisation is called TIME-MIN-SYNC.

The internal time can be set manually down to the minute level, either via the local HMI or via any of the communication ports. The time synchronisation fine tunes the clock (seconds and milliseconds). If no clock synchronisation is active, the time can be set down to milliseconds.

2 Setting group selector (GRP)

2.1 Application

Different conditions in networks of different voltage levels require high adaptability of the used protection and control units to best provide for dependability, security and selectivity requirements. Protection units operate with higher degree of availability, especially, if the setting values of their parameters are continuously optimised regarding the conditions in power system.

The operational departments can plan different operating conditions for the primary equipment. The protection engineer can prepare in advance for the necessary optimised and pre-tested settings for different protection functions. Four different groups of setting parameters are available in the REx 5xx terminals. Any of them can be activated automatically through up to four different programmable binary inputs by means of external control signals.

2.2 Functionality

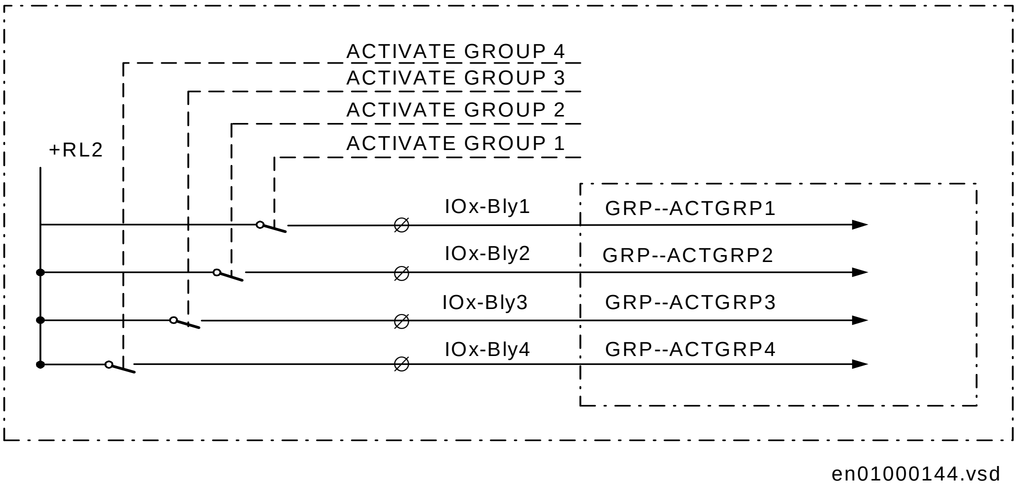
Select a setting group by using the local HMI, from a front connected personal computer, remotely from the station control or station monitoring system or by activating the corresponding input to the GRP function block.

Each input of the function block is configurable to any of the binary inputs in the terminal. Configuration must be performed under the menu:

Configuration
  Functions
    Active Group
      FuncInputs

Use external control signals to activate a suitable setting group when adaptive functionality is necessary. Input signals that should activate setting groups must be either permanent or a pulse longer than 200 ms.

More than one input may be activated simultaneously. In such cases the lower order setting group has priority. This means that if for example both group four and group two are set to activate, group two will be the one activated.



2.3 Design

The GRP function block has four functional inputs, each corresponding to one of the setting groups stored within the terminal. Activation of any of these inputs changes the active setting group. Four functional output signals are available for configuration purposes, so that continuous information on active setting group is available.

3 Setting lockout (HMI)

3.1 Application

Unpermitted or uncoordinated changes by unauthorized personnel may cause severe damage to primary and secondary power circuits. Use the setting lockout function to prevent unauthorized setting changes and to control when setting changes are allowed.

By adding a key switch connected to a binary input a simple setting change control circuit can be built simply allowing only authorized keyholders to make setting changes. Security can be increased by adding SA/SMS overrides that prevents changes even by keyholders.

3.2 Functionality

Activating the setting restriction prevents unauthorized personell to purposely or by mistake change terminal settings.

The HMI--BLOCKSET functional input is configurable only to one of the available binary inputs of a REx 5xx terminal. For this reason, the terminal is delivered with the default configuration, where the HMI--BLOCKSET signal is connected to NONE-NOSIGNAL.

The function permits remote changes of settings and reconfiguration through the serial communication ports. The setting restrictions can be activated only from the local HMI.

All other functions of the local human-machine communication remain intact. This means that an operator can read all disturbance reports and other information and setting values for different protection parameters and the configuration of different logic circuits.

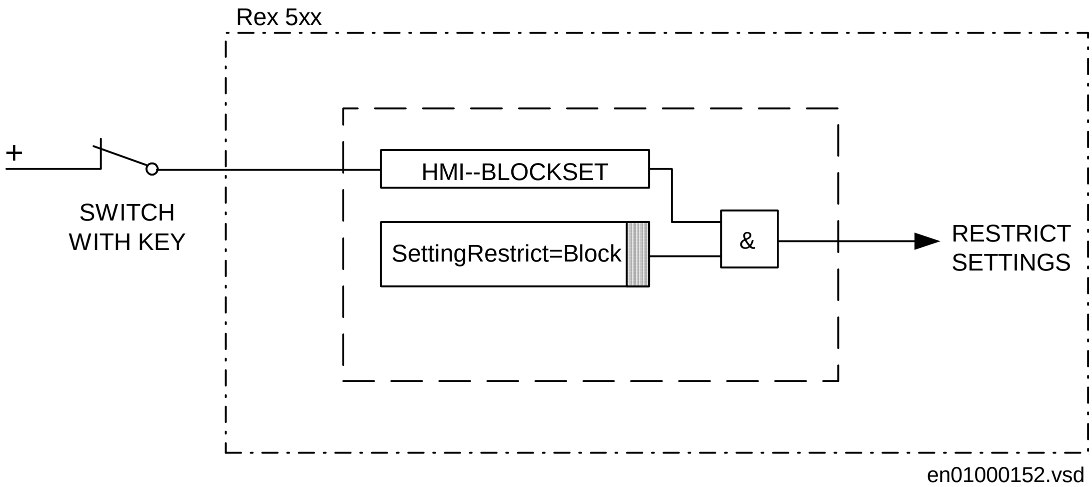


Figure 1: Connection and logic diagram for the BLOCKSET function

4 I/O system configurator (IOP)

4.1 Application

The I/O system configurator must be used in order to recognize added modules and to create internal adress mappings between modules and protections and other functions.

4.2 Functionality

The I/O system configurator is used to add, remove or move I/O modules in the REx 5xx terminals. To configure means to connect the function blocks that represent each I/O module (BIM, BOM, IOM, IOPSM, DCM and MIM) to a function block for the I/O positions (IOP1) that represent the physical slot in the rack.

Available I/O modules are:

- BIM, *B*inary *I*nput *M*odule with 16 binary input channels.
- BOM, *B*inary *O*utput *M*odule with 24 binary output channels.
- IOM, *I*nput/*O*utput *M*odule with 8 binary input and 12 binary output channels.
- MIM, *m*A *I*nput *M*odule with six analog input channels.
- IOPSM, *I*nput *O*utput *Power S*upply *M*odule with four inputs and four outputs.
- DCM, *D*ata *C*ommunication *M*odule. The only software configuration for this module is the I/O Position input.

An REx 5xx terminal houses different numbers of modules depending of the casing size and which kind of modules chosen.

- The 1/1 of 19-inch size casing houses a maximum of 13 modules. But when Input/Output- or Output modules are included, the maximum of these modules are six. The maximum number of mA Input modules are also limited to six.
- The 3/4-size casing houses a maximum of eight modules. The limitation is four modules for Input/Output- or Output modules. The maximum number of mA Input modules are three.
- The 1/2-size casing houses a maximum of three binary modules or one analogue mA Input module.

It is possible to fit modules of different types in any combination in a terminal, but the total maximum numbers of modules must be considered.

Each I/O-module can be placed in any CAN-I/O slot in the casing with one exception. The DCM-module has a fixed slot position which depends on the size of the casing.

To add, remove or move modules in the terminal, the reconfiguration of the terminal must be done from the graphical configuration tool CAP 531.

Users refer to the CAN-I/O slots by the physical slot numbers of the CAN-I/O slots, which also appear in the terminal drawings.

If the user-entered configuration does not match the actual configuration in the terminal, an error output is activated on the function block, which can be treated as an event or alarm.

The BIM, BOM, IOM, IOPSM and DCM share the same communication addresses for parameters and configuration. So they must share I/O module 1-13 (IOxx), which are the same function block. A user-configurable function selector per I/O module function block determines which type of module it is.

All names for inputs and outputs are inputs on the function blocks and must be set from the graphical tool CAP 531.

I/O position

The IOP1 (I/O position) function block is the same for the different casings, independent of the number of slots available. Anyway, it looks different depending of actual configuration. All necessary configuration is done in the CAP 531 configuration tool.

The Sxx outputs are connected to the POSITION inputs of the I/O Modules and MIMs.

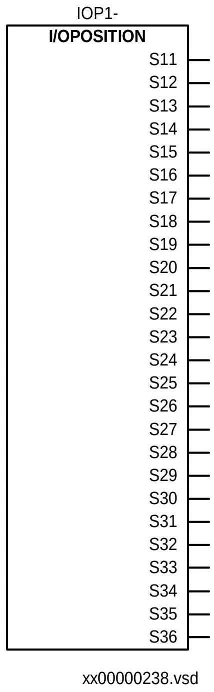


Figure 2: Function block of the I/O position block (IOP1-).

Configuration

The I/O-configuration can only be performed from CAP 531, the graphical configuration tool.

To configure from the graphical tool:

- First, set the function selector for the logical I/O module to the type of I/O module that is used, BIM, BOM, IOM, IOPSM or DCM.
- Secondly, connect the POSITION input of the logical I/O module to a slot output of the IOP function block.

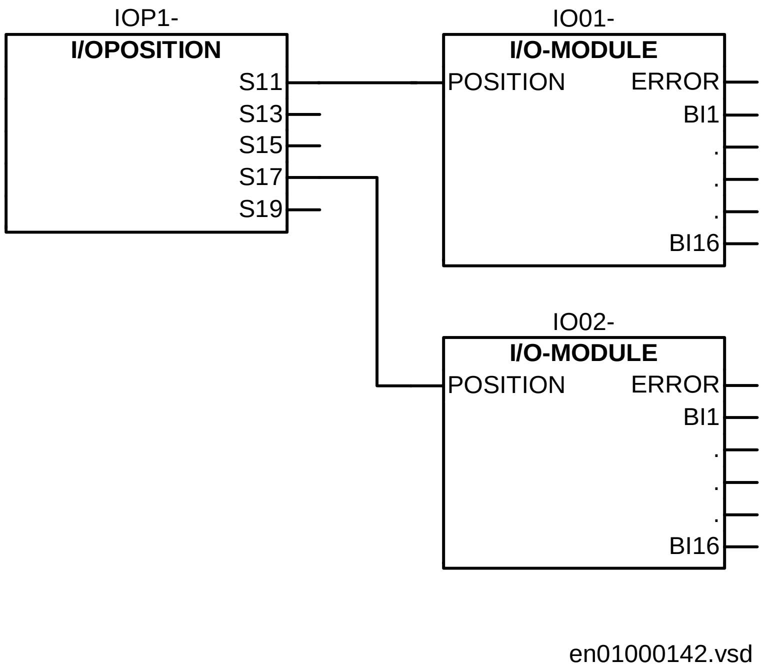


Figure 3: Example of an I/O-configuration in the graphical tool CAP 531 for a REx 5xx with two BIMs.

5 Logic function blocks

5.1 Application

5.1.1 Application

Different protection, control, and monitoring functions within the REx 5xx terminals are quite independent as far as their configuration in the terminal is concerned. The user cannot enter and change the basic algorithms for different functions, because they are located in the digital signal processors and extensively type tested. The user can configure different functions in the terminals to suit special requirements for different applications.

For this purpose, additional logic circuits are needed to configure the terminals to meet user needs and also to build in some special logic circuits, which use different logic gates and timers.

5.2 Functionality

Inverter (INV)

The INV function block is used to invert the input boolean variable. The function block (figure 4) has one input designated IVnn-INPUT where nn presents the serial number of the block. Each INV circuit has one output IVnn-OUT.

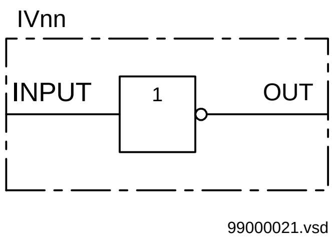


Figure 4: Function block diagram of the inverter (INV) function

Table 1: Truth table for the INV function block

INPUT	OUT
1	0
0	1

Controllable gate (GT)

The GT function block is used for controlling if a signal should be able to pass or not depending on a setting. The function block (figure 5) has one input, designated GTnn-INPUT, where nn presents the serial number of the block. Each GT circuit has one output, GTnn-OUT. Each gate further has a Operation On/Off which controls if the INPUT is passed to the OUT or not.

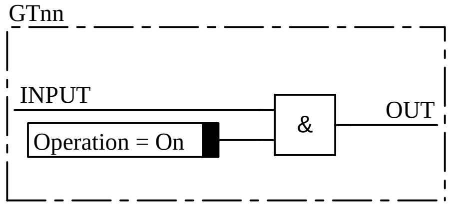


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Figure 5: Function block diagram of the controllable gate (GT) function

The output signal from the GT function block is set to 1 if the input signal is 1 and Operation = On elsewhere it is set to 0. See truth table below.

Table 2: Truth table for the GT function block

INPUT	Operation	OUT
0	Off	0
1	Off	0
0	On	0
1	On	1

OR

OR function blocks are used to form general combinatory expressions with boolean variables. The function block (figure 6) has six inputs, designated Onnn-INPUTm, where nnn presents the serial number of the block, and m presents the serial number of the inputs in the block. Each OR circuit has two outputs, Onnn-OUT and Onnn-NOUT (inverted).

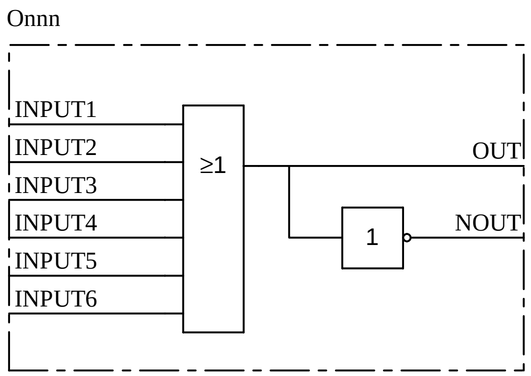

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Figure 6: Function block diagram of the OR function

The output signal (OUT) is set to 1 if any of the inputs (INPUT1-6) is 1. See truth table below.

Table 3: Truth table for the OR function block

INPUT1	INPUT2	INPUT3	INPUT4	INPUT5	INPUT6	OUT	NOUT
0	0	0	0	0	0	0	1
0	0	0	0	0	1	1	0
0	0	0	0	1	0	1	0
...	...	...	...	...	...	1	0
1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	0

AND

AND function blocks are used to form general combinatory expressions with boolean variables. The function block (figure 7) has four inputs (one of them inverted), designated Annn-INPUTm (Annn-INPUT4N is inverted), where nnn presents the serial number of the block, and m presents the serial number of the inputs in the block. Each AND circuit has two outputs, Annn-OUT and Annn-NOUT (inverted).

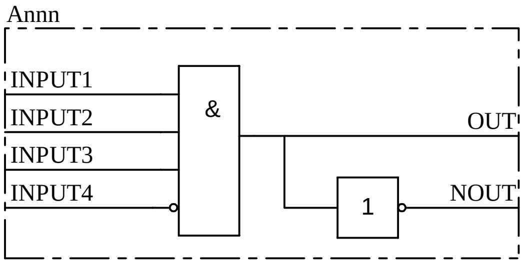

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Figure 7: Function block diagram of the AND function

The output signal (OUT) is set to 1 if the inputs INPUT1-3 are 1 and INPUT4N is 0. See truth table below.

Table 4: Truth table for the OR function block

INPUT1	INPUT2	INPUT3	INPUT4N	OUT	NOUT
0	0	0	1	0	1
0	0	1	1	0	1
0	1	0	1	0	1
0	1	1	1	0	1
1	0	0	1	0	1
1	0	1	1	0	1
1	1	0	1	0	1
1	1	1	1	0	1
0	0	0	0	0	1
0	0	1	0	0	1
0	1	0	0	0	1
0	1	1	0	0	1
1	0	0	0	0	1
1	0	1	0	0	1
1	1	0	0	0	1
1	1	1	0	1	0

Timer

The function block TM timer has outputs for delayed input signal at drop-out and at pick-up. The timer (figure 8) has a settable time delay TMnn-T between 0.00 and 60.00 s in steps of 0.01 s. The input signal for each time delay block has the designation TMnn-INPUT, where nn presents the serial number of the logic block. The output signals of each time delay block are TMnn-ON and TMnn-OFF. The first one belongs to the timer delayed on pick-up and the second one to the timer delayed on drop-out. Both timers within one block always have the same setting.

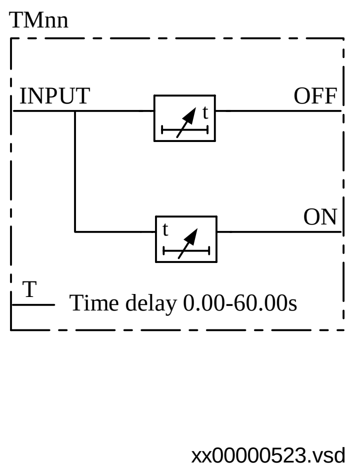

Figure 8: Function block diagram of the Timer function

The function block TL timer (figure 9) with extended maximum time delay at pick-up and at drop-out, is identical with the TM timer. The difference is the longer time delay TLnn-T, settable between 0.0 and 90000.0 s in steps of 0.1 s.

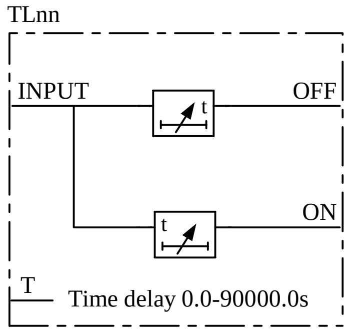

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Figure 9: Function block diagram of the TimerLong function

The input variable to INPUT is obtained delayed a settable time T at output OFF when the input variable changes from 1 to 0 in accordance with the time pulse diagram, figure 10. The output OFF signal is set to 1 immediately when the input variable changes from 0 to 1.

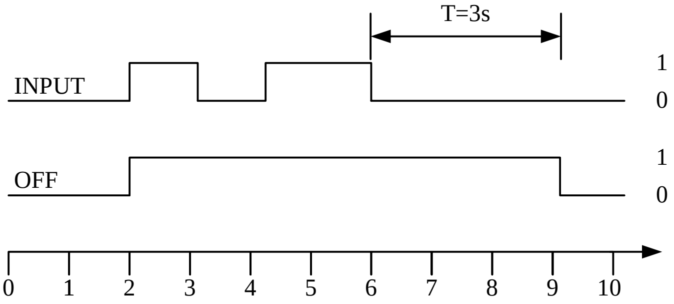

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Figure 10: Example of time diagram for a timer delayed on drop-out with preset time T = 3 s

The input variable to INPUT is obtained delayed a settable time T at output ON when the input variable changes from 0 to 1 in accordance with the time pulse diagram, figure 11. The output ON signal returns immediately when the input variable changes from 1 to 0.

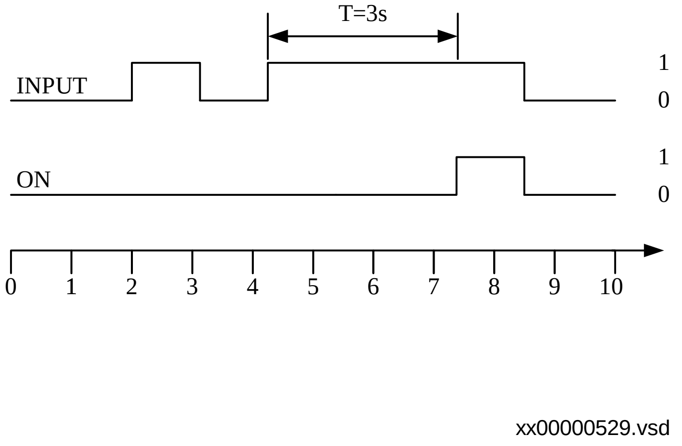

Figure 11: Example of time diagram for a timer delayed on pick-up with preset time T = 3 s

If more timers than available in the terminal are needed, it is possible to use pulse timers with AND or OR logics. Figure 12 shows an application example of how to realize a timer delayed on pick-up. Figure 13 shows the realization of a timer delayed on drop-out. Note that the resolution of the set time must be 0.2 s, if the connected logic has a cycle time of 200 ms.

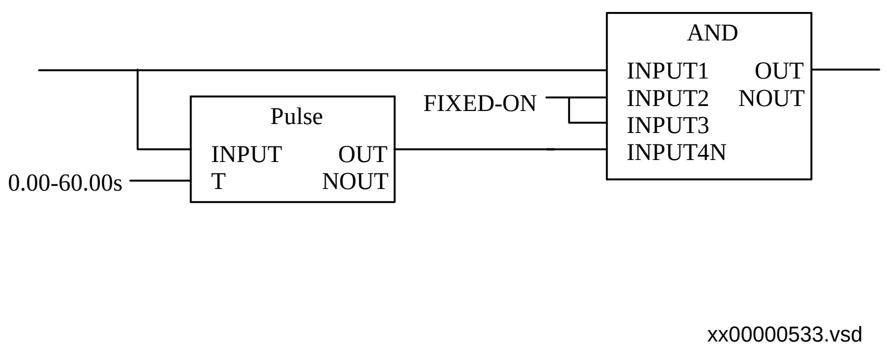

Figure 12: Realization example of a timer delayed on pick-up

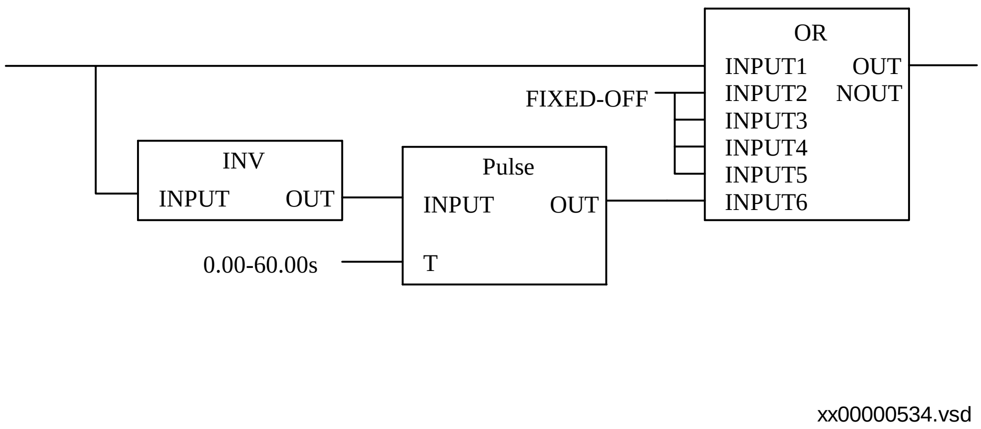

Figure 13: Realization example of a timer delayed on drop-out

Timer settable through HMI/SMS/PST

The function block TS timer has outputs for delayed input signal at drop-out and at pick-up. The timer (figure 14) has a settable time delay TSnn-T between 0.00 and 60.00 s in steps of 0.01 s. It also has an Operation setting On, Off which controls the operation of the timer.The input signal for each time delay block has the designation TSnn-INPUT, where nn presents the serial number of the logic block. The output signals of each time delay block are TSnn-ON and TSnn-OFF. The first one belongs to the timer delayed on pick-up and the second one to the timer delayed on drop-out. Both timers within one block always have the same setting.

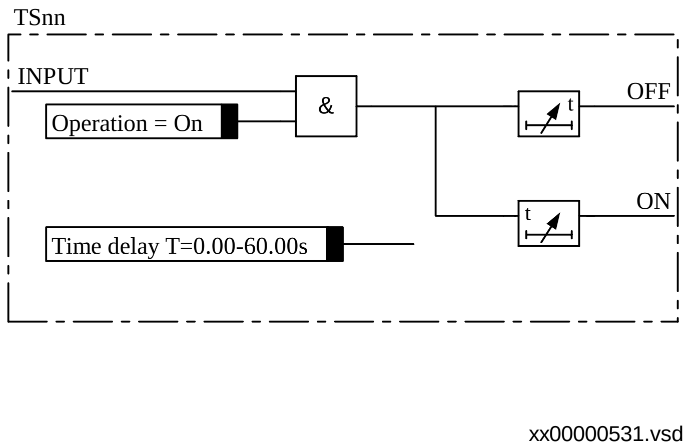

Figure 14: Function block diagram of the Settable timer function

For details about the function see the description of TM Timer.

Pulse

The pulse function can be used, for example, for pulse extensions or limiting of operation of outputs. The pulse timer TP (figure 15) has a settable length of a pulse between 0.00 s and 60.00 s in steps of 0.01 s. The input signal for each pulse timer has the designation TPnn-INPUT, where nn presents the serial number of the logic block. Each pulse timer has one output, designated by TPnn-OUT. The pulse timer is not retriggable, that is, it can be restarted first after that the time T has elapsed.

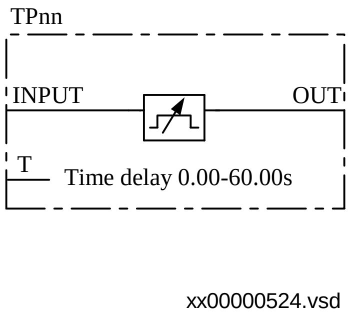

Figure 15: Function block diagram of the Pulse function

The function block TQ pulse timer (figure 16) with extended maximum pulse length, is identical with the TP pulse timer. The difference is the longer pulse length TQnn-T, settable between 0.0 and 90000.0 s in steps of 0.1 s.

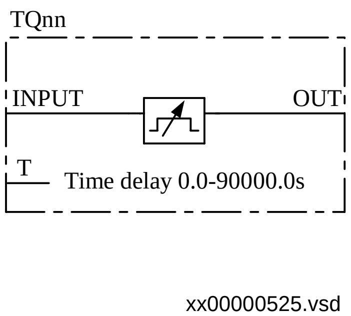

Figure 16: Function block diagram of the PulseLong function, TQ

A memory is set when the input INPUT is set to 1. The output OUT then goes to 1. When the time set T has elapsed, the memory is cleared and the output OUT goes to 0. If a new pulse is obtained at the input INPUT before the time set T has elapsed, it does not affect the timer. Only when the time set has elapsed and the output OUT is set to 0, the pulse function can be restarted by the input INPUT going from 0 to 1. See time pulse diagram, figure 17.

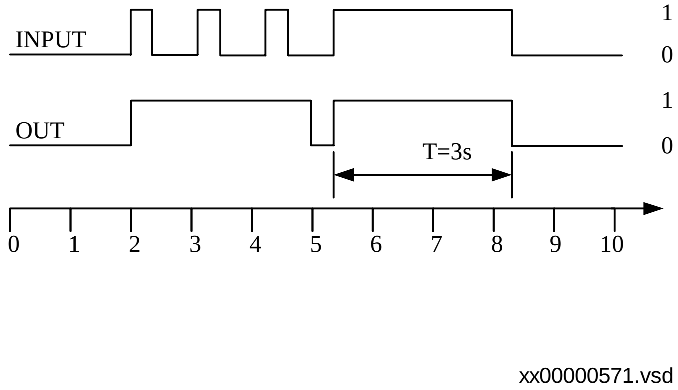

Figure 17: Example of time diagram for the pulse function with preset pulse length T = 3 s

Exclusive OR (XOR)

The function block exclusive OR (XOR) is used to generate combinatory expressions with boolean variables. XOR (figure 18) has two inputs, designated XOnn-INPUTm, where nn presents the serial number of the block, and m presents the serial number of the inputs in the block. Each XOR circuit has two outputs, XOnn-OUT and XOnn-NOUT (inverted). The output signal (OUT) is 1 if the input signals are different and 0 if they are equal.

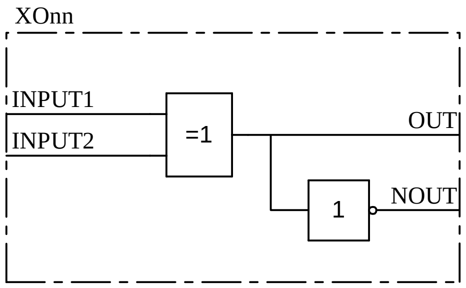

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Figure 18: Function block diagram of the XOR function

The output signal (OUT) is set to 1 if the input signals are different and to 0 if they are equal. See truth table below.

Table 5: Truth table for the XOR function block

INPUT1	INPUT2	OUT	NOUT
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	1

Set-Reset (SR)

The function block Set-Reset (SR) (figure 19) has two inputs, designated SRnn-SET and SRnn-RESET, where nn presents the serial number of the block. Each SR circuit has two outputs, SRnn-OUT and SRnn-NOUT (inverted). The output (OUT) is set to 1 if the input (SET) is set to 1 and if the input (RESET) is 0. If the reset input is set to 1, the output is unconditionally reset to 0.

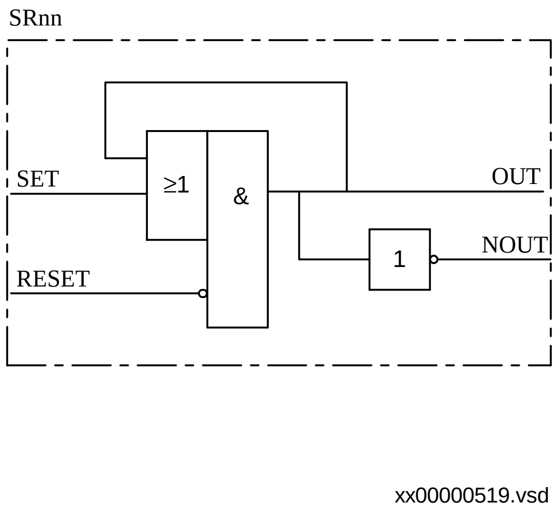

Figure 19: Function block diagram of the Set-Reset function

Set-Reset with/without memory (SM)

The function block Set-Reset (SM) (figure 20) with/without memory has two inputs, designated SMnn-SET and SMnn-RESET, where nn presents the serial number of the block. Each SM circuit has two outputs, SMnn-OUT and SMnn-NOUT (inverted). The output (OUT) is set to 1 if the input (SET) is set to 1 and if the input (RESET) is 0. If the reset input is set to 1, the output is unconditionally reset to 0. The memory setting controls if the flip-flop after a power interruption will return to the state it had before or if it will be reset.

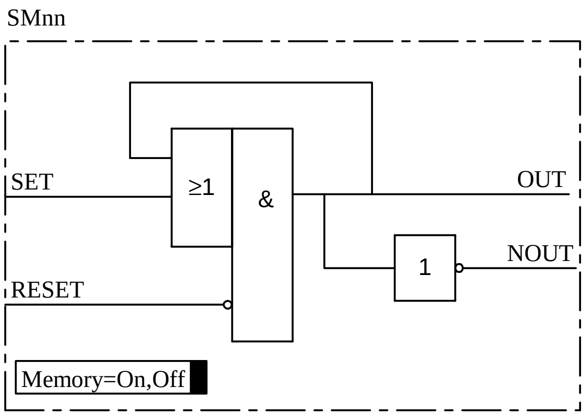

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Figure 20: Function block diagram of the Set-Reset with/without memory function

5.3 Calculations

For the AND gates, OR gates, inverters, normal SR (Set-Reset) flip-flops, XOR gates and MOVE elements no settings exist.

For the normal On/Off delay timers and pulse timers the time delays and pulse lengths are set from the CAP 531 configuration tool.

Both timers in the same logic block (the one delayed on pick-up and the one delayed on drop-out) always have a common setting value. Setting values of the pulse length are independent of one another for all pulse circuits.

For the controllable gates, settable timers, SR flip-flops with/without memory the setting parameters are accessible through the HMI and SMS.

Configuration

The configuration of the logics is performed from the CAP 531 configuration tool.

Execution of functions as defined by the configurable logic blocks runs in a fixed sequence in two different cycle times, typical 6 ms and 200 ms.

For each cycle time, the function block is given an execution serial number. This is shown when using the CAP 531 configuration tool with the designation of the function block and the cycle time, for example, TMnn-(1044, 6). TMnn is the designation of the function block, 1044 is the execution serial number and 6 is the cycle time.

Execution of different function blocks within the same cycle time should follow the same order as their execution serial numbers to get an optimal solution. Always remember this when connecting in series two or more logical function blocks. When connecting function blocks with different cycle times, the MOVE function blocks can be used. These function blocks synchronize boolean signals sent between logics with slow execution time and logics with fast execution time. The MOVE functions are available as additional configurable logic circuits.

Note!

Be always careful when connecting function blocks with a fast cycle time to function blocks with a slow cycle time.

So design the logic circuits carefully and check always the execution sequence for different functions. In other cases, additional time delays must be introduced into the logic schemes to prevent errors, for example, race between functions.

6 Self supervision (INT)

6.1 Application

The REx 5xx protection and control terminals have a complex design with many included functions. The included self-supervision function and the INTernal signals function block provide good supervision of the terminal. The different safety measures and fault signals makes it easier to analyze and locate a fault.

Both hardware and software supervision is included and it is also possible to indicate possible faults through a hardware contact and/or through the software communication.

Internal events are generated by the built-in supervisory functions. The supervisory functions supervise the status of the various modules in the terminal and, in case of failure, a corresponding event is generated. Similarly, when the failure is corrected, a corresponding event is generated.

Apart from the built-in supervision of the various modules, events are also generated when the status changes for the:

- built-in real time clock (in operation/out of order).
- external time synchronization (in operation/out of order).

Events are also generated:

- whenever any setting in the terminal is changed.
- when the content of the Disturbance report is erased.

The internal events are time tagged with a resolution of 1 ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, that is, when it is full, the oldest event is overwritten. The list cannot be cleared and its content cannot be modified.

The list of internal events provides valuable information, which can be used during commissioning and fault tracing.

The information can only be retrieved with the aid of the SMS. The PC can be connected either to the port at the front or at the rear of the terminal.

6.2 Functionality

The self-supervision status can be monitored from the local HMI or via the PST Parameter Setting Tool or a SMS/SCS system.

Under the Terminal Report menu in the local HMI the present information from the self-supervision function can be viewed. A detailed list of supervision signals that can be generated and displayed in the local HMI is found in the Installation and Commissioning Manual.

In the PST under Terminal Report these summary signals are available:

- InternalStatus
- CPU-Status

When an internal fault has occurred, extensive information about the fault from the list of internal events can be retrieved from the PST under the menu Terminal Report - Internal Events.

A self-supervision summary can be obtained by means of the potential free alarm contact located on the power supply module. The function of this output relay is an OR-function between the INT--FAIL signal (figure 23) and a couple of more severe faults that can happen in the terminal (figure 22).

Some signals are available from the function block InternSignals (INT), see figure 21. The signals from this function block can be connected to an Event function block, which generates and sends these signals as events to the station level of the control system. The signals from the INT-function block can also be connected to binary outputs for signalization via output relays or they can be used as conditions for other functions if required/desired.

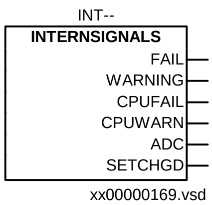


Figure 21: Function block INTernal signals.

Individual error signals from I/O modules and time synchronization can be obtained from respective function block of IOM-, BIM-, BOM-, MIM-, IOPSM-modules and from the time synchronization block TIME.

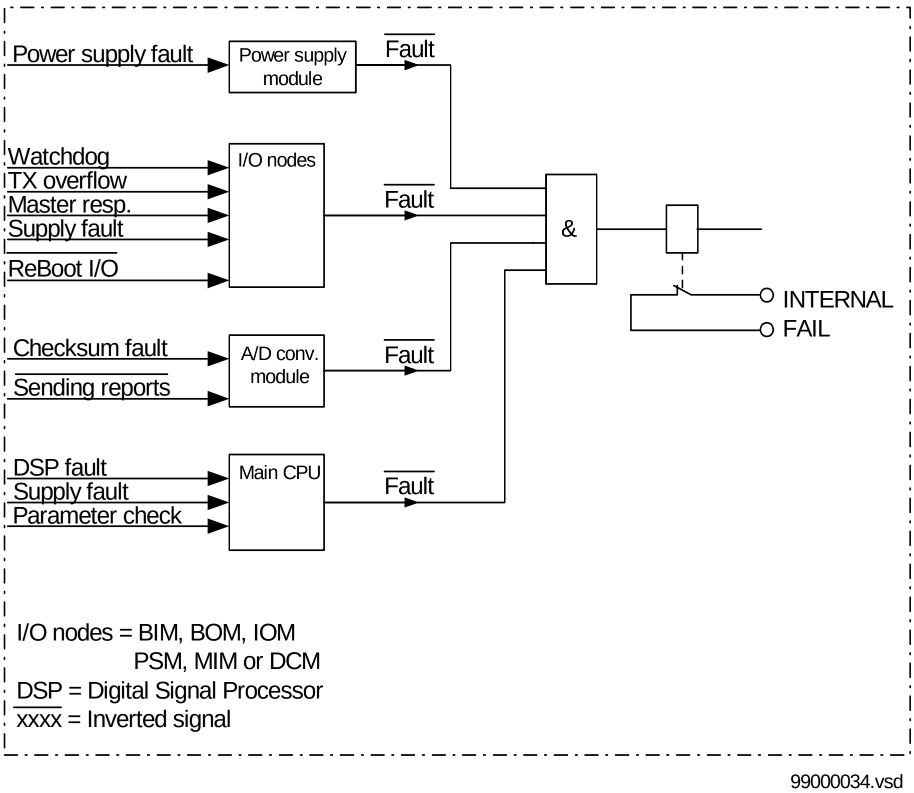


Figure 22: Hardware self-supervision, potential-free alarm contact.

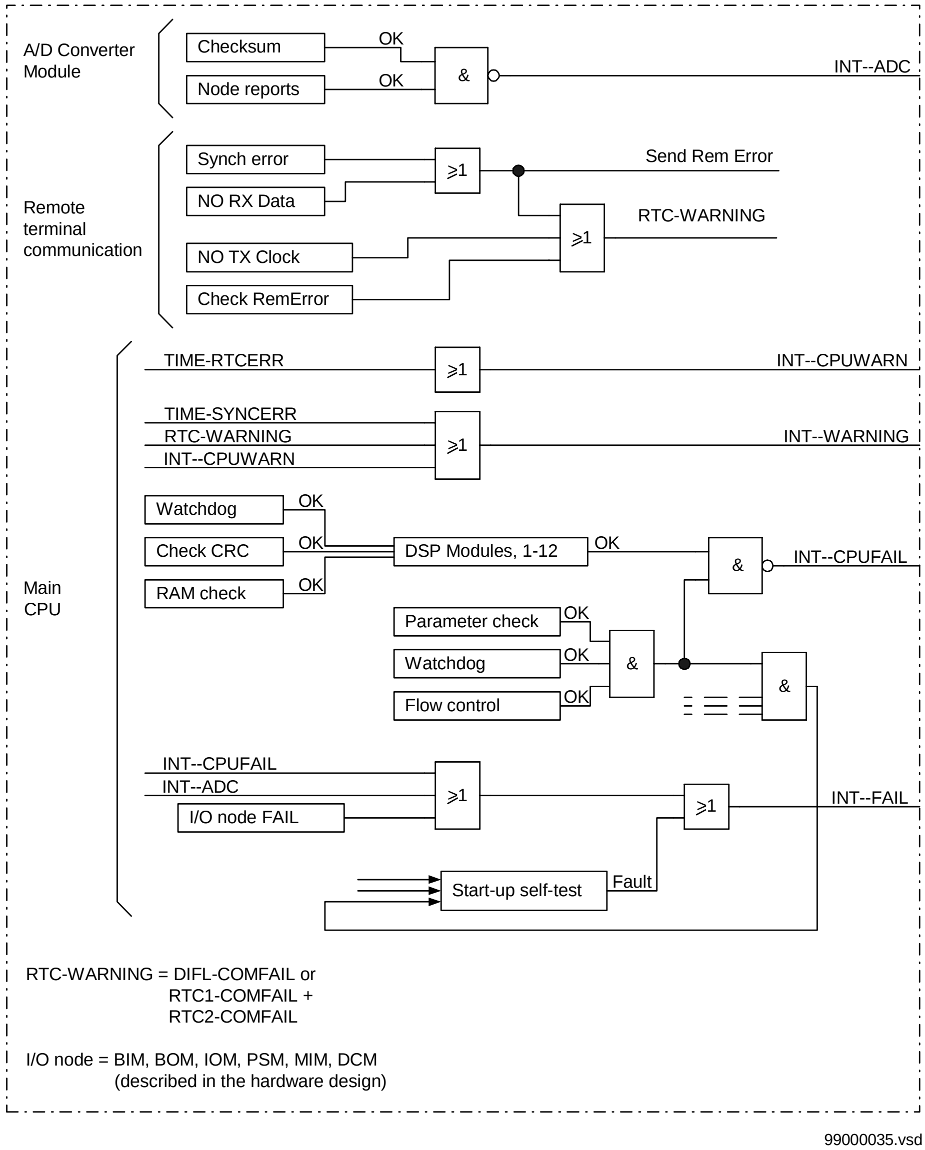


Figure 23: Software self-supervision, function block INTernal signals.

7 Blocking of signals during test

7.1 Functionality

This blocking function is only active during operation in the test mode, see example in Figure 24. When exiting the test mode, entering normal mode, this blocking is disabled and everything is set to normal operation. All testing will be done with actually set and configured values within the terminal. No settings etc. will be changed. Thus no mistakes are possible.

The blocked functions will still be blocked next time entering the test mode, if the blockings were not reset.

The blocking of a function concerns all output signals from the actual function, so no outputs will be activated.

Each of the terminal related functions is described in detail in the documentation for the actual unit. The description of each function follows the same structure (where applicable).

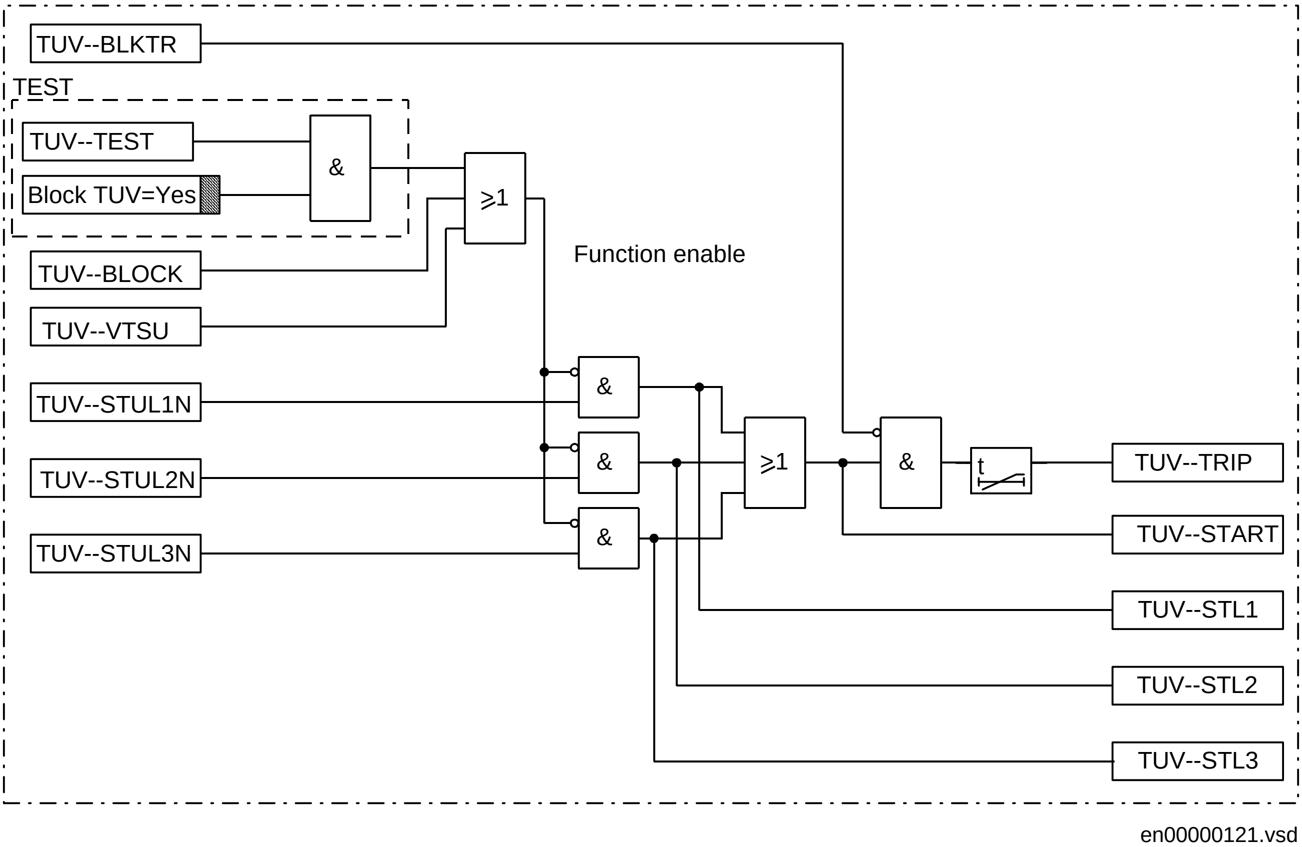


Figure 24: Example of blocking the Time delayed Under-Voltage function.

Chapter 4 Line differential

About this chapter

This chapter describes the line differential functions in the terminal.

1 Line differential protection (DIFL)

1.1 Application

The line differential protection function can be used on two-terminal-lines. It can be applied on MV, HV as well as on EHV overhead lines and cables. The measurement is phase segregated, which gives correct phase selection for all types of faults, including simultaneous faults on double circuit lines and faults between lines at different voltage levels.

The differential protection is neither affected by voltage and current reversal at series compensated systems, nor by harmonics produced by HVDC or SVC installations. Unequal CT ratio in the two line ends can be compensated for.

Note!

Transformers or tapped loads in the protected zone are normally not allowed.

Two binary signals can be exchanged between the terminals. The signals can be persistent, when used for other than tripping purposes.

The differential protection requires a 56/64 kbit/s digital communication link, which can be achieved either by dedicated optical fibres or by multiplexed channels. Communication is required in both directions.

The line differential function in the protection of version 2.3 is compatible with earlier versions 1.1, 1.2 and 2.0.

The maximum transmission time for which the differential function will operate is 12 ms. For longer transmission times, the differential function will be blocked and an alarm “Communication Failure” will be given. The tripping function will not be blocked at route switching, as long as the communication time is in the range of 12 ms, neither will a false operation be caused by any changes in the communication time.

The exchanged message is controlled by added check-sum information and corrupted telegrams are not evaluated.

1.2 Functionality

The Line differential function offers phase-segregated true current differential protection for transmission, subtransmission and distribution networks. The function compares the currents entering and leaving the protected overhead line or cable. This is done by exchanging the value of the three phase currents in both directions every 5 ms, integrated in a common digital message. The currents are evaluated in both terminals on a per phase basis that prevents the problem of the current summation approach and provides phase selection information for single-pole tripping. The operating characteristic is shown in figure 26.

A dependable communication link is needed to allow exchange of the current information between the terminals at the line ends. Direct optical fiber or galvanic commnication link are supported, as well as more complex digital communication systems like multiplexed and route switched networks.The transmission time is continuously measured to provide correct synchronization of local clocks.

Two independent binary signals can be transmitted from one line side to the other through the differential communication link for direct intertrip logics or information purposes.

The Line differential function uses the same communication functionality and hardware for communication with remote end as used for the function “Binary signal transfter to remote end (RTC)”. These items are described in the Remote end data communication chapter for the software and in the Digital communication module chapter for the hardware. The settings that has to be made for these items are also desribed in each chapter respectively.

In figure 25 a simplified block diagram of the line differential protection function is shown.

Patented saturation detectors evaluate each phase current locally, utilising the unfiltered samples issued every ms. The detection is based on the secondary current behaviour. At current transformer saturation, the stabilisation is increased at both terminals in the saturated phase. Therefore, phase segregated “saturation” signals are included in the transmitted message.

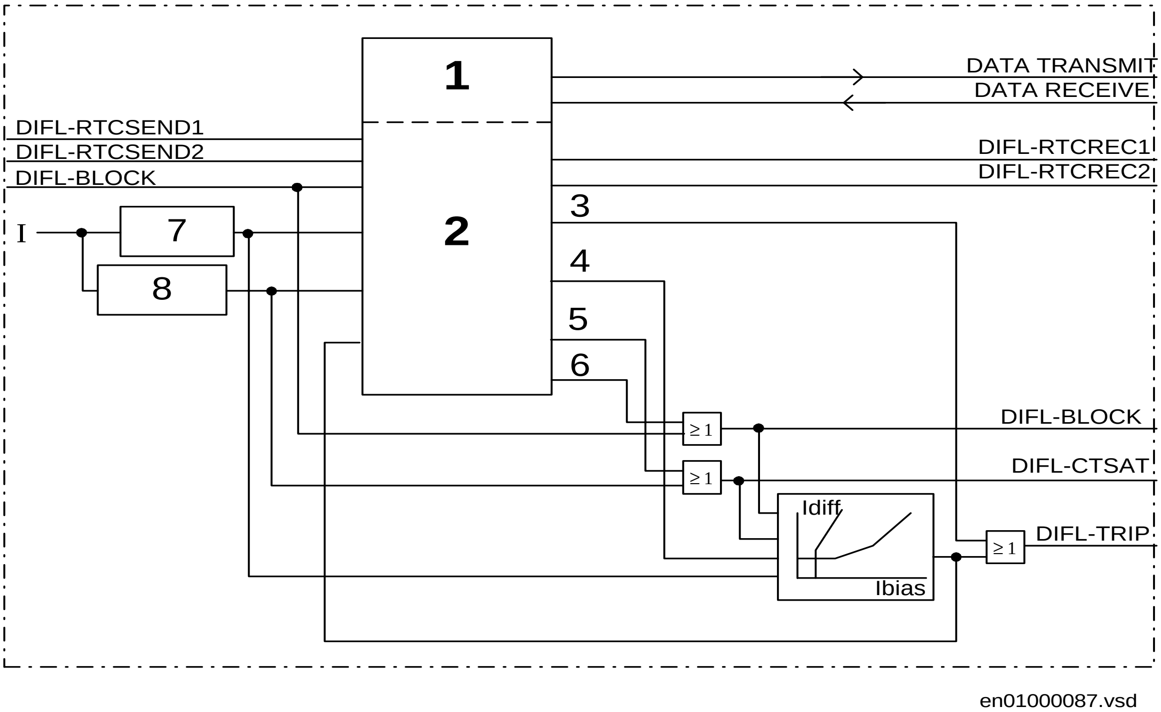
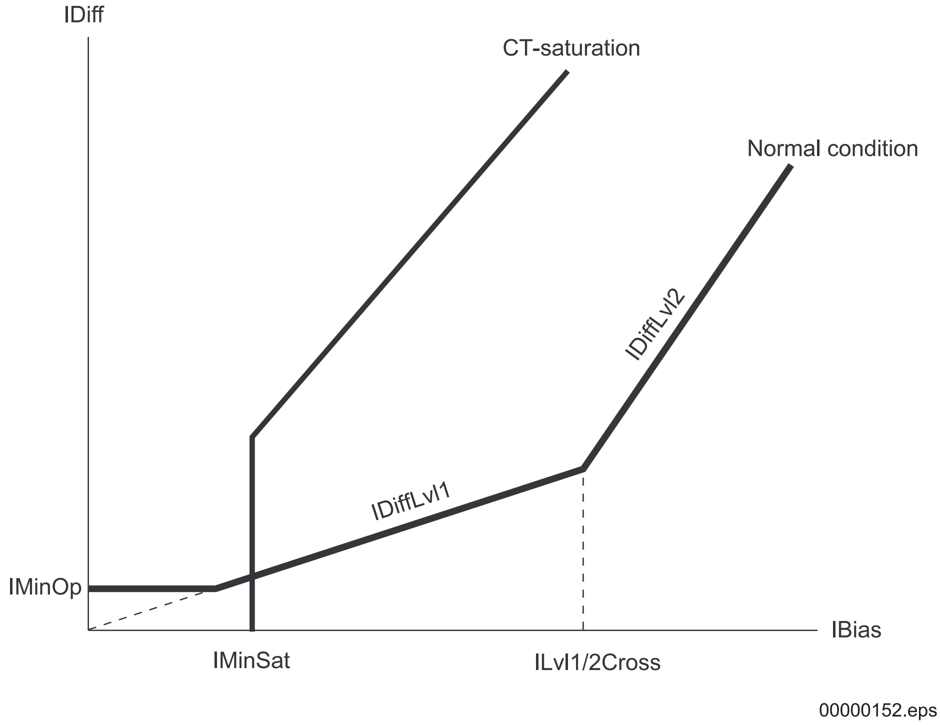


Figure 25: Simplified block diagram, line differential protection function

Where:

1	Communication interface
2	Communication logic
3	Remote trip
4	Remote current value
5	Remote saturation detection
6	Remote block
7	Fourier filter
8	Saturation detector



Where:

IMinOp	Minimum differential operation current
IMinSat	Minimum phase current for saturation detection operation
IDiffLvl1	Slope 1 stabilisation
IDiffLvl2	Slope 2 stabilisation
ILvl1/2Cross	Slope 2 intersection

Figure 26: Stabilisation characteristic.

1.3 Design

General

The line differential function is designed to work with digital communication systems. To ensure compatibility with a wide range of communication equipment and media, the relay is designed to work within the signalling bandwidth of a standard CCITT PCM channel at 64 kbits/s. To enable the use in North American EIA PCM systems working at 56 kbits/s, some of the interfacing modules can be adapted to this bit rate.

Note!

A safe and reliable operation of the differential function requires the transmission time to be equal in both directions between the two terminals. If the transmission time in the two directions not equal this will produce a false differential current that is load current multiplied by sine of the angle corresponding to half the transmission time difference. A 1 ms difference will create a differential current that is 16% of load current at 50 Hz and 19% at 60 Hz.

For negligible influence the difference in transmission time must be less than 0.2 ms.

For further information see section "Time synchronization", especially section "Effect of unequal transmission time delay".

Note!

The maximum transmission time for which the differential function will operate is 12 ms. For longer transmission times, the differential function will be blocked and an alarm "Communication Failure" will be given.

Current differential function

This section describes the filtering used for the Line differential function and the evaluation of the local and remote current based on these filter values.

Current filtering

The phase currents are sampled with 2000 Hz sampling frequency. Of two consecutive samples, one sample is achieved after an interpolation to achieve a set of samples related to the same instant (skew adjustment). After the interpolation, one set of samples is achieved every ms. The phase currents are Fourier filtered, and the fundamental (50/60 Hz) component in the current, is represented with the Fourier coefficients **a** and **b**, see equation 15 and equation 16. The Fourier filters produces a set of **a** and **b** coefficients every ms. These coefficients represent the *sin* and *cos* components, related to a local fundamental frequency reference.

$$I_{phase} = f(t) = f(\omega_f) + f(\omega \neq \omega_f)$$

(Equation 15)

$$f(\omega_f) = a \cdot \sin\omega_f t + b \cdot \cos\omega_f t$$

(Equation 16)

The transmitted current information to the remote end consists of the **a** and **b** coefficients. These coefficients carry the entire amplitude and phase angle information. For a static current, the coefficients do not change their value during the cycle. During dynamic conditions, the “primary” current changes, and thus also **a** and **b** change with time.

Due to the design of the A/D-converters, the primary sampling is not synchronized in the terminals at the two ends of the line and thus neither is the Fourier filtering. In order to be able to compare current values taken at the same instant at the two ends a special algorithm has been included. This consists of a reference clock in each terminal, not the same as used for the Fourier filtering, together with a time skew adjustment of the Fourier filter outputs. The mechanism for synchronizing the clocks in the terminals at the two line ends are described later on.

The **a** and **b** coefficients for the three phase currents are transmitted every even 5 ms of the reference clock, that is at 0 ms, 5 ms, 10 ms etc. Since the sampling is not synchronized to the reference clock a linear interpolation to an even 5 ms time instance is performed between a set of **a** and **b** coefficients taken immediately before the even 5 ms and a set of **a** and **b** coefficients taken immediately after, see figure 27.

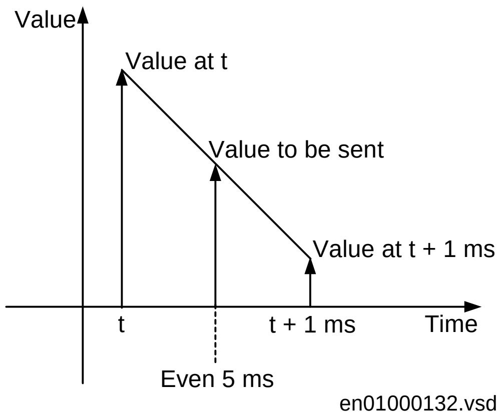
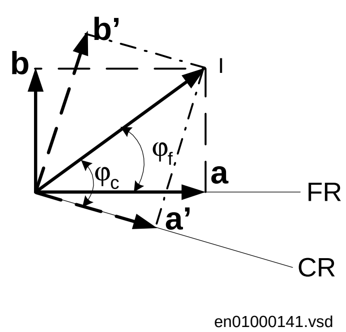


Figure 27: Interpolation of a and b

The reference clock is actually a 0 to 39999 microsecond timer. Samples shall be sent every even 5 ms, that is every n*5 ms there n is an integer 0,1, 2..., 7. This corresponds to a phase angle φc = n*1.8*fn there fn is the set frequency of the terminal. When the sample is to be sent the phase angle of the reference for the Fourier filter φf is checked. These two phasors will create two coordinate systems according to figure 28. The **a** and **b** coefficients from the Fourier filter uses FR as reference. To be able to compare currents from the two ends the **a** and **b** coefficients have to be referenced to the reference clock common for the two terminals, that is CR. In order to do that the output from the Fourier filter is rotated with an angle according to equation 17 creating a new set of coefficients, **a’** and **b**’. The transmitted data consists of the set of these new coefficients **a’** and **b’** together with the n value mentioned above for which they were calculated.

$$a' + jb' = (a + jb)e^{-(\varphi_f - \varphi_c)} \qquad \text{(Equation 17)}$$



Where:

I	Phase current
FR	Fourier filter reference
CR	Master/slave reference clock

Figure 28: Fourier filter coefficient transformation

At the evaluation, the received **a’** and **b’** coefficients are compared with the locally calculated **a’** and **b**’ coefficients that are related to the same n value as the received ones. The data messages that are transmitted every 5 ms also contain check bits to detect the false information. A message that does not pass the check is rejected and will neither be evaluated for tripping nor used for synchronization of the clocks. A new message will be received 5 ms later. When a message is rejected during an internal fault, the operation time is prolonged by 5 ms. The design of the messages is described in chapter Data communication.

By utilizing Fourier filtering, the influence of non-fundamental frequency currents is reduced. The inrush current when energizing and the outfeed current at external faults caused by the capacitive stored energy in the line, are dominated by non-fundamental frequency components. The minimum operating current must be set high enough to achieve stability at these two conditions. The filtering allows a lower set operating value than unfiltered quantities would allow. The use of Fourier quantities makes the scheme independent of the communication link time delay, as long as the reference clocks are synchronized or the time difference is known. Therefore, the communication delay is of interest only for the synchronization of local clocks. Naturally, the transmission time is added to the basic operating time.

Owing to this design, the measurement does not need to be blocked to avoid false tripping when the communication delay is changed. The protection will be blocked if the communication delay cannot be identified within 200 ms, due to disturbances in the communication. The stability of the local clocks allows operation without synchronization for a time period of more than 200 ms. If the protection is blocked due to communication disturbances, the protection is automatically deblocked when the communication is established and the local clocks are synchronized again.

Current evaluation

The differential protection evaluation is carried out in both terminals and performed individually for each phase. By using phase segregated evaluation, correct phase selection is achieved for **any** type of fault.

At the evaluation, a differential and a bias current are calculated for each phase by vectorial and scalar summation of the local and remote currents, represented by the **a'** and **b'** coefficients. The scalar sum is divided by two in order to achieve the bias current. The differential and bias values are calculated for each phase according to equation 18 and equation 19.

$$I_{Diff} = \left|\overline{I_{Local}} + \overline{I_{Remote}}\right|$$

(Equation 18)

$$I_{Bias} = \frac{\left|\overline{I_{Local}}\right| + \left|\overline{I_{Remote}}\right|}{2}$$

(Equation 19)

The value for I_{Diff} is then used directly when evaluating differential and bias values against characteristic while for bias following value, equation 20, is calculated and used for each phase:

$$(I_{Bias})_{Evaluate} = \text{Max}\,\{[(I_{Bias})_{Own\ phase}]\ \text{OR}\ [0.5 \cdot (I_{Bias})_{Other\ phases}]\}$$

(Equation 20)

The differential and bias currents are compared and a trip situation is indicated in the phases where the differential current is above the characteristic according to Figure 29. For tripping, 2 or 3 out of 4 consecutive measurements are required to indicate a trip. The selection between the required 2 or 3 evaluations is user selecctable.

The minimum operate current (*IMinOp*), the two slopes (*IDiffLvl1* and *IDiffLvl2*) and the intersection between slope 1 and 2 (*ILvl1/2Cross*) can be set. This characteristic takes care of the measuring errors in the primary current transformer and the protection, when the current transformer is **not** saturated. At current transformer saturation, the stabilization is increased in both terminals in the saturated phase, see Figure 29. Therefore, phase segregated “saturation” signals are included in the transmitted message.

Note!

IMinSat is not set, nor evaluated, as a percentage of I_{Bias} *but as a percentage of I1b and evaluated on a phase current base. It is therefor not mathematically correct to show IMinSat in the* I_{Diff}/I_{Bias} *diagram but this is done due to that the slope has to be shown in the diagram.*

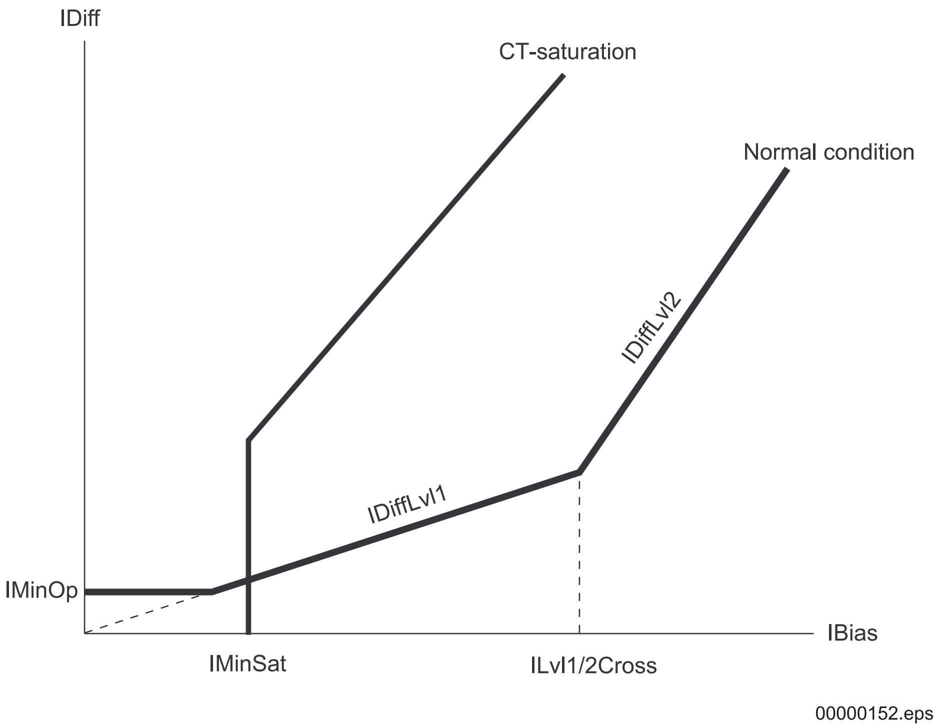


Figure 29: Stabilization characteristic.

Saturation detector

A patented saturation detectors evaluate each phase current locally, utilizing the unfiltered samples issued every ms. The detection is based on the secondary current behaviour. In case of a saturation, the current decreases abruptly, from a high amplitude value to a low one, followed by a low rate of change. This condition is checked by means of three consecutive current samples, at t-2, t-1 and t, according to figure 30.

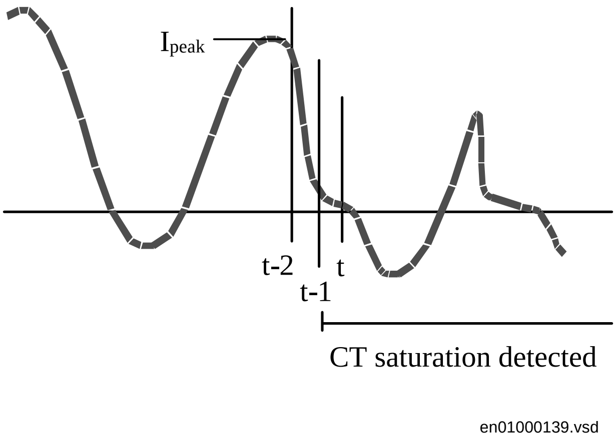


Figure 30: CT-Saturation Detector

A saturation is detected if the conditions in equations 21 to 9 are fulfilled. I_{peak} is the maximum current since last zero crossing. IMinSat is a setting. It should be noted that equation 21 is based on sample value, the value I_{peak} is actually compared with $\sqrt{2}\times$IMinSat.

$$I_{Peak} \geq IMinSat$$

(Equation 21)

$$[I(t-2) - I(t-1)] \geq K_3 \cdot I_{Peak}$$

(Equation 22)

$$[I(t-1) - I(t)] \leq K_2 \cdot I_{Peak}$$

(Equation 23)

$$I(t) \le K_1 \cdot I_{Peak}$$

(Equation 24)

Equation 21 indicates that the current must have been above IMinSat since last zero crossing. Equation 22 means that the slope of the current between t-2 and t-1 must be higher than a certain factor of I_{peak}. Equation 23 means that the slope of the current between t-1 and t must be lower than a certain factor of I_{peak}. Equation 24 means that the current value at t must be lower than a certain factor of I_{peak}.

The use of saturation detectors enables minimum current transformer requirements, together with maximum sensitivity.

Time synchronization

The communication link delay measurement and synchronization of internal clocks in the line differential function is an essential part of the successful operation of the function. In this section is described:

1. transmission time measurement,
2. clock synchronization and
3. compensation for differences in oscillator frequency.

The time synchronization is based on a master-slave concept not to be mixed up with the master-master concept used for current evaluation. At the time synchronization, the slave synchronizes its internal clock in the line differential function (not the real time clock used for time tagging of events etc) to the master.

Transmission time measurement

The transmission time is measured by comparing local send and receive times for messages transmitted between the two terminals, the master and the slave, the so-called ping-pong method. The messages are normally transmitted at a rate of one every 5 ms. The clock used for time tagging these messages is not linked to the absolute time in the terminals, used for example for time tagging of events etc. Instead it is based on a 0 to 39999 microsecond internal clock in the differential function which has a resolution of 1 µs which is controlled by the oscillator for the CPU.

The maximum transmission time for which the differential function will operate is 12 ms. For longer transmission times, the differential function will be blocked and an alarm “Communication Failure” will be given. The tripping function will not be blocked at route switching, as long as the communication time is within 12 ms, neither will a false operation be caused by any changes in the communication time.

In figure 31 it is shown how a message is sent from the slave to the master and another from the master to the slave. The message from the slave is sent at time t1. This time is stored at the slave. The message is received at the master at the time t2. The time a message is sent is taken as the time when the last bit of the message is sent, last bit of stop flag, and the time a message is received is taken as the time the last bit of the stop flag is received.This time is stored in the master and sent to the slave by the following message at time t3. This time is stored in the master and sent to the slave by the following message. The first message is received at the slave at the time t4. This time is stored at the slave. Taking into consideration the difference Δt between the clocks in the two terminals and the time it takes for a message to be transmitted from one terminal to the other, Td, the associations in equations 25 and 26 can be set up.

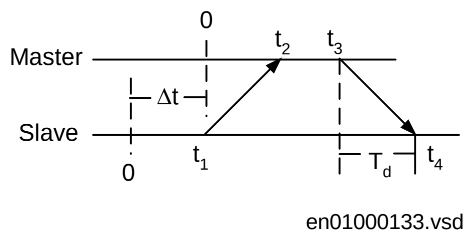


Figure 31: Exchange of messages between slave and master

$$t_2 = t_1 + T_d - \Delta t$$

(Equation 25)

$$t_4 = t_3 + T_d + \Delta t$$

(Equation 26)

To insure that the times t1, t2 and t3, t4 respectively belongs to the same message, each message is given a number which is stored and transmitted together with the message. After the time t3 has been received by the slave, the slave will combine the four times and calculate the transmission time, Td, in the communication link, assuming that the transmission time is equal in both directions. The equation for this is according to equation 27.

$$T_d = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$$

(Equation 27)

The assumption that the transmission time is equal in both directions depends on the fact that with knowledge of only the four times mentioned above it is possible only to determine two unknown variables, in this case the total transmission time and the difference Δt between the two clocks. If the difference would be known it would instead be possible to determine the transmission time in each direction. From equation 27 it can further be seen that any difference between the clocks in the slave and master will not effect the calculation of Td since both times within each bracket is only local times.The value Td calculated for the transmission time is not used directly in the algorithm for synchronizing the clocks in the slave and master or time adjustment of samples but only for controlling the stability of the communication channel and that it is within the maximum allowable transmission time of 12 ms.

Clock synchronization

If the clocks in the slave and master were synchronous t2 should be equal to t1 + Td. Now assume that there are a small difference Δt, according to figure 31, between the two clocks. This can, with the above equation, be calculated according to equation 28.

$$\Delta t = \frac{t_1 + t_4}{2} - \frac{t_2 + t_3}{2}$$

(Equation 28)

The first term in equation 28 is actually the midpoint between t1 and t4 and the second is the midpoint between t2 and t3. Δt will therefor be the difference between these two midpoints which will be independent on the transmission time as long as the transmission time is equal in both directions. If the clock in the slave is leading the clock in the master Δt will be >0 and if the clock in the slave is lagging the clock in the master Δt will be <0. Before any compensation for Δt is performed, it is checked that the transmission time Td has been constant for some time and is shorter than maximum value, that is 12 ms. If this is fulfilled the clock in the slave is adjusted by a certain time ta, positive or negative depending on the sign of Δt. The time ta is function of the mean value of Δt for a number of messages and also on the time the communication has been lost. It can be expressed as in equation 29.

$$t_a = f\left(\left(\sum_{n=1}^{c} \Delta t(n)\right) \big/ (c, t_L)\right)$$

(Equation 29)

Where:

$\Delta t(n)$	is measured time difference for message n,
c	is the number of messages for which the mean value of the time difference is calculated and
tL	is the time the communication has been lost.

The dependence on time of lost communication has the purpose of speeding up the synchronization at terminal start up when the difference between the two clocks can be big. If during this process a shift in Td is recognized the adjustment will be stopped until Td again has been constant for a certain time. During a synchronization after terminal start up or if the communication has been interrupted for a number of minutes the differential protection is blocked until the mean value of Δt is below a certain level which can take up to a minute. Since it is only the slave that measures the difference between the two clocks, a block signal is sent from the slave to the master with every message until the slave is synchronized. If the two clocks are synchronized, the clock of the slave will be continuously adjusted up and down depending on the sign of the mean value of Δt with a very small time ta since it is impossible to keep the two clocks exactly synchronized due to for example differences in the oscillators for the CPU in the slave and the master. If a shift in Td is recognized the adjustment will be stopped as mentioned above until Td again has been constant for a certain time. However since the two clocks were already synchronized they will keep on being synchronized for a long time, actually up to tens of minutes, due to the precision of the oscillators and therefor the protection can keep on working. As mentioned above, change in transmission time has no effect on the synchronization between the two clocks and therefor it is not needed to know the exact transmission time only that it is not changing and not too long. For safety reasons the protection will however be blocked if Td is unstable for more than approximately 200 ms due to uncertain communication. When Td becomes stable again the process described above will take place and, if the time of unstable communication has not been long, the clocks will probably still be rather well synchronized so the synchronization procedure will be much faster, normally less than one second before the protections are released again.

Effect of unequal transmission time delay

If the transmission times in the two directions, slave to master and master to slave, are not equal this will produce an error in the current measurement. Assume a difference in transmission time of ΔTd. This will lead to an additional term in equation 28 of -ΔTd/2.

This will lead to that the compared Fourier values will be taken with a -ΔTd/2 ms difference between the two ends. During steady state conditions this will have the effect that a differential current is created with an amplitude of I_{Load} x sin(ΔTd x 180 x f) there I_{Load} is the load current on the line and f is the network frequency. ΔTd is measured in seconds.During changes in currents, both amplitude and phase, the **a** and **b** values will change with time and this will create a somewhat higher differential current than the steady state condition.

The only way of avoiding malfunction, if unequal transmission times are a fact, is to set *IMinOp*, *IDiffLvl1* and *IDiffLvl2* higher than expected “false” differential current.

Compensation for differences in oscillator frequency

As mentioned above the clocks that are used for the synchronization are controlled by the oscillators for the CPU. As for all components also these have some inaccuracy. If nothing is done to this the two clocks will slowly drift apart if the communication fails. The rate of this drift will depend on the magnitude of the difference between the two oscillators. In order to minimize this drift a method for compensating for the drift has been implemented. The principle is as follows. Let the adjustment at a certain time be $t_a(n)$. Measure t_a for some number N of messages. Create the signal Δt_{osc} according to equation 30.

$$\Delta t_{osc} = \left(\sum_{n=1}^{N} t_a(n) \right) / N$$

(Equation 30)

If the two oscillators have exactly the same frequency, Δt_{osc} will be 0. If there exists a difference between them Δt_{osc} will get a value that is equal to the drift in the clock of the slave compared to the master between two adjustments. The value of Δt_{osc} is stored in the CPU and used for regular additional adjustment of the clock in the slave. With this compensation the drift can be decreased to only some percentage of what it should be without compensation, normally less than 10 ppm compared to 100 ppm. This ensures that the system can operate for quite a long time also without a communication channel stable enough for synchronization.

Data message

A data message is sent every 5 ms. The message is based on the HDLC protocol. For more details, see chapter Data communication.

1.4 Calculations

1.4.1 Setting instructions

General

All configuration is performed with CAP 531, the graphical configuration tool. Settings are done according to the following sections.

Selection of protection parameters

The secondary current that is to be compared in both terminals, must be related to a common current transformer ratio. With a CTFactor default setting of 1.00, this is achieved when the current transformers at both terminals have the same rated primary current. When one of the terminals has a higher primary rated current than the other, this can be numerically equalised by the CTFactor setting. By setting the CTFactor in the terminal with the higher primary rated current to the quote between the lower and the higher rated current, the difference is equalised. The nominal primary current for the whole differential protection function ($I_{nominal}$), to which all function data is related, is the lower rated current.

If the primary rated current is much higher than the maximum load current, the differential nominal current ($I_{nominal}$) can be reduced by the CTFactor at both terminals. In this case, the nominal primary current ($I_{nominal}$), to which all function data is related for the differential protection, is equal to the rated primary current multiplied by the CT-Factor.

Identical settings for *IMinOp, IDiffLvl1, IDiffLvl2, ILvl1/2Cross* and *IMinSat* should be used at both terminals.

The minimum operating current, *IMinOp*, is chosen in relation to the fundamental frequency charging current. The primary minimum operating current must not be lower than 2.5 times the total charging current (practically, the charging current when the line is fed from only one terminal).

When current transformers of the same type are used at both terminals, and they are dimensioned according to, “Requirements and technical data”, the default settings: *IDiffLvl1*=20% of IBias, *IDiffLvl2*=50% of IBias and *ILvl1/2Cross*=500% of IBias are applied.

The *IDiffLvl* is increased to 160% of IBias at detected saturation. With current transformers dimensioned according to “Requirements” the default value *IMinSat*=300% of IBias is used. The meaning of this is that the magnitude of the current must have exceeded 3 times the base current (I_b) within the previous half cycle, for the saturation detector to be released. When the current transformer margin *E2max*>3 times, the minimum requirement, the *IMinSat* can be increased to 500%.

By setting the *Evaluate* 2 of 4 instead of the default setting 3 of 4, the operating time can be reduced by 5 ms. The setting 2 of 4 is recommended only when high quality communication is used. The reason for this is the slightly increased risk of false tripping, due to corrupt messages.

The setting parameters for the differential protection function are available in the menu tree in the local HMI under the menu:

Setting
  Function
    Group n
      Differential

For remote setting and local HMI via personal computer, please refer to the corresponding SMS or SCS documents.

Line differential protection communication

To make sure that the differential protection communicates with the correct protection at the opposite terminal, the terminals are numbered. By giving **all** differential protections transmitting over a common multiplexer **individual** identification numbers, communication with the wrong terminal can be avoided. The terminals are given identification numbers 0-255 by a setting parameter. The identification number of the opposite terminal must also be set. This is always necessary.

TerminalNo is the identification that is sent with the message to the remote end. RemoteTermCom is the identification aganinst which the identification of the received message is checked to see that the message orginates from correct terminal.

For the synchronisation of the local clocks, one terminal has to be master, and the other one slave.

The configuration parameters for the differential protection communication are available in the menu tree in the local HMI under:

Configuration
DiffFunction

and

Configuration
TerminalCom
RemTermCom

Chapter 5 Current

About this chapter

This chapter describes the current protection functions.

1 Instantaneous overcurrent protection (IOC)

1.1 Application

unbalanceLong transmission lines often transfer great quantities of electrical power from production to consumption areas. The unbalance of the produced and consumed electrical power at each end of the transmission line is very large. This means that a fault on the line can easily endanger the stability of a complete system.

The transient stability of a power system depends mostly on three parameters (at constant amount of transmitted electrical power):

- The type of the fault. Three-phase faults are the most dangerous, because no power can be transmitted through the fault point during fault conditions.
- The magnitude of the fault current. A high fault current indicates that the decrease of transmitted power is high.
- The total fault clearing time. The phase angles between the EMFs of the generators on both sides of the transmission line increase over the permitted stability limits if the total fault clearing time, which consists of the protection operating time and the breaker opening time, is too long.

The fault current on long transmission lines depends mostly on the fault position and decreases with the distance from the generation point. For this reason the protection must operate very quickly for faults very close to the generation (and relay) point, for which very high fault currents are characteristic.

For this reason instantaneous, non-directional, phase-segregated, overcurrent protection (IOC), which can operate in 15 ms (50 Hz nominal system frequency) for faults characterized by very high currents, is included in some of the REx 5xx terminals. Refer to the ordering information for more details.

The conventional distance protection can manage the fault clearance of earth-faults in most of the cases. In some applications, especially applications with long lines, the clearance can be improved by use of an instantaneous earth-fault protection. Those are for instance:

- In the case of high infeed of fault current from the opposite end of the line, this might increase the fault resistance seen by the distance relay to such a value that the instantaneous step of the distance protection will not operate.
- In applications with series compensated lines, where the capacitor is located at the end of the line and very strong infeed of fault current from that end, will result in a difficult problem for the distance protection to perform a selective fault clearance. This due to the voltage reversal that might occur.

The use of instantaneous overcurrent earth-fault protection is most suitable for long lines in meshed transmission systems. It can also be used for radial lines with low fault current infeed from the opposite end of the line.

The instantaneous residual overcurrent function is very suitable as back-up protection for phase to earth faults close to the terminal. This enables a short back-up faults clearance time for the phase to earth faults with high fault current.

The instantaneous, non-directional, earth-fault overcurrent protection (IOC), which can operate in 15 ms (50 Hz nominal system frequency) for faults characterized by very high currents, is included in some of the REx 5xx terminals. Refer to the ordering information for more details.

1.2 Functionality

The current-measuring elements within one of the built-in digital signal processors continuously measure the current in all three phases, and compare them with the IP>> set value. The logical value of each phase current signal on the output of the digital signal processor (STIL1, STIL2 and STIL3 respectively) is equal to 1 if the measured phase current exceeds the preset value.

The measuring technic is based on measuring of the incoming residual current to the terminal.

The current-measuring elements within one of the built-in digital signal processors continuously measure the zero sequence current, and compare it with the IN>> set value. A recursive Fourier filter filters the current signals, and a separate trip counter prevents high overreaching of the measuring elements. The logical value of the signal on the output of the digital signal processor (IOC--STIN) is equal to 1 if the measured zero sequence current exceeds the pre-set value.

1.3 Design

The simplified logic diagram of the instantaneous phase overcurrent function is shown in figure 32.

The overcurrent function is disabled if:

- The terminal is in TEST mode (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockIOC=Yes)
- The input signal IOC--BLOCK is high.

The IOC--BLOCK signal is a blocking signal of the instantaneous phase overcurrent function. It can be connected to a binary input of the terminal in order to receive a block command from external devices or can be software connected to other internal functions of the terminal itself in order to receive a block command from internal functions. Through OR gate it can be connected to both binary inputs and internal function outputs. The IOC--BLOCK signal blocks also the instantaneous residual overcurrent function, if this is installed in the terminal.

When the instantaneous phase overcurrent function is enabled, the output tripping signals IOC--TRL1, IOC--TRL2, IOC--TRL3, IOC--TRP and IOC--TRIP can operate. The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just a little above the set operating value.

The single phase trip signals IOC--TRL1, IOC--TRL2, and IOC--TRL3 are related to L1, L2, and L3 phases and therefore also suitable for the single phase tripping with single-phase auto-reclosing.

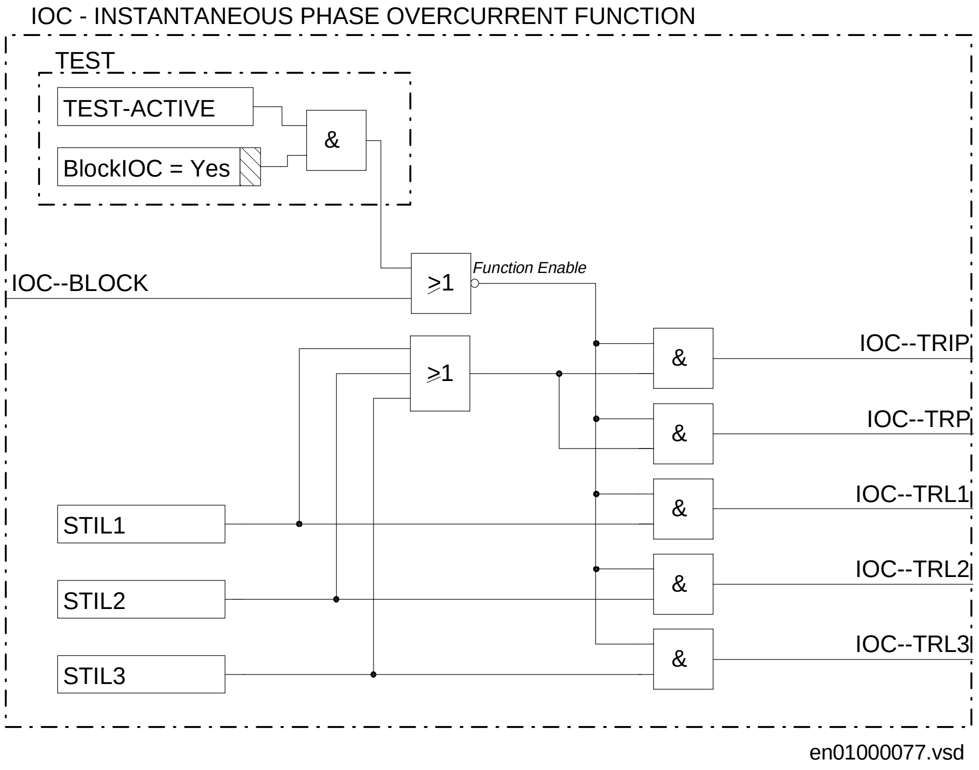


Figure 32: Simplified logic diagram of instantaneous overcurrent protection

The signal IOC--TRP is the logic OR of the three single phase trips. It can be used to trip the circuit breaker if only three phase operation is desired.

The IOC--TRIP output signal behaves as general instantaneous overcurrent trip when in the REx 5xx terminal also the instantaneous residual overcurrent function is implemented; i.e. this signal will be activated in case of any single phase overcurrent or residual overcurrent detection. If only the instantaneous phase overcurrent function is installed in the terminal, then this signal behaves exactly as the signal IOC--TRP and can be used for signalization.

The simplified logic diagram of the instantaneous phase overcurrent function is shown in figure 33.

The overcurrent function is disabled if:

- The terminal is in TEST status (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockIOC=Yes)
- The input signal IOC--BLOCK is high.

The IOC--BLOCK signal is a blocking signal of the overcurrent function. It can be connected to a binary input in order to receive a block command from external devices or it can be configured (software connection) to other internal functions within the terminal itself, in order to receive a block command from internal functions. Through OR gates it can be connected to both binary inputs and internal function outputs.

When the overcurrent function is enabled, the output tripping signals IOC--TRN and IOC--TRIP can operate. The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just beyond the set operating value.

The IOC--TRN signal is related to the residual overcurrent trip.

The IOC--TRIP output signal behaves as general instantaneous overcurrent trip when in the REx 5xx terminal also the instantaneous phase overcurrent function is implemented. I.e. this signal will be activated in case of residual overcurrent detection or in case of any single-phase overcurrent detection (IOC--STIL_: IOC--STIL1 or IOC--STIL2 or IOC--STIL3). If only the residual overcurrent function is implemented in the terminal, then this signal behaves exactly as the signal IOC--TRN and can be used for signalising.

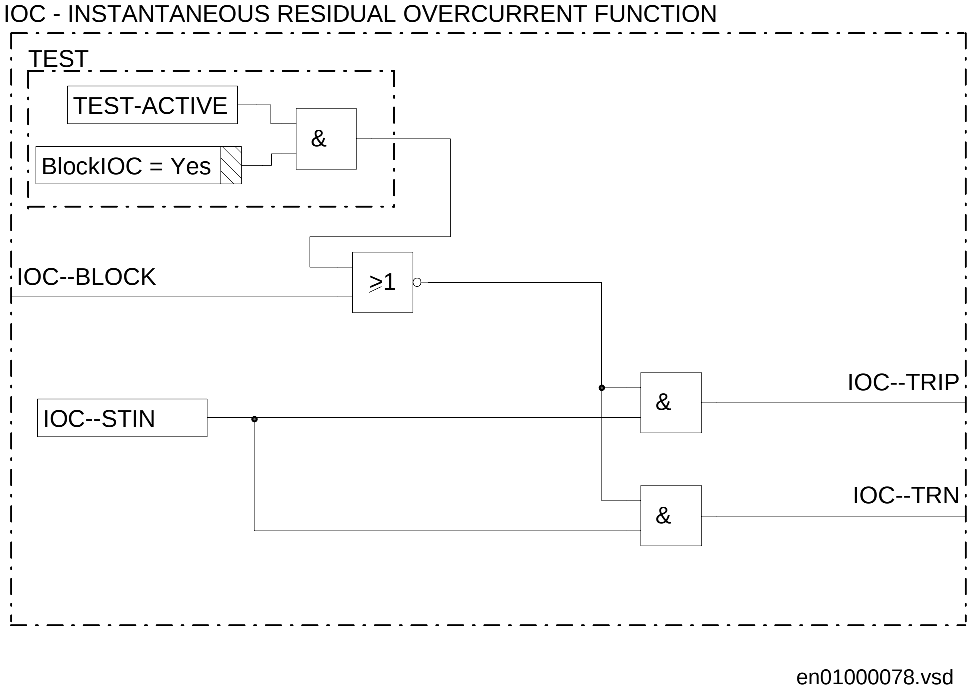


Figure 33: Simplified logic diagram of instantaneous residual overcurrent protection.

1.4 Calculations

1.4.1 Setting instructions

This protection function must operate only in a selective way. So check all system and transient conditions that could cause its unwanted operation.

Only detailed network studies can determine the operating conditions under which the highest possible fault current is expected on the line. In most cases, this current appears during three-phase fault conditions. But also examine single-phase-to-earth and two-phase-to-earth conditions.

Also study transients that could cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when connected to the network and can thus also cause the operation of the built-in, instantaneous, overcurrent protection.

Meshed network without parallel line

The following fault calculations have to be done for three-phase, single-phase-to-earth and two-phase-to-earth faults. With reference to figure 34, apply a fault in B and then calculate the relay through fault phase current I_{fB}. The calculation should be done using the minimum source impedance values for Z_A and the maximum source impedance values for Z_B in order to get the maximum through fault current from A to B.

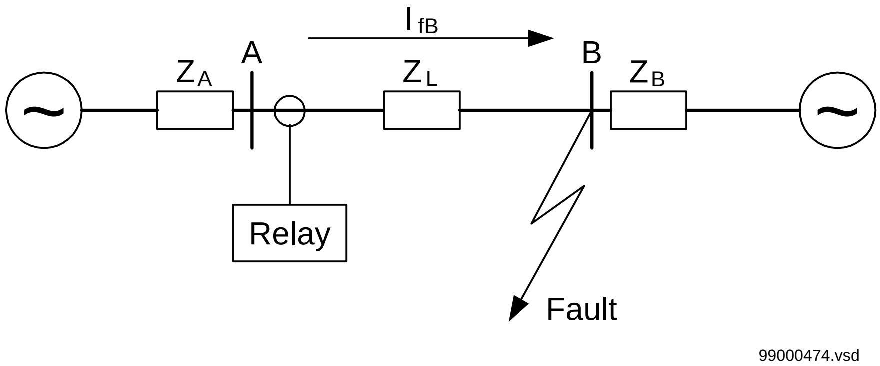


Figure 34: Through fault current from A to B: I_{fB}

Then a fault in A has to be applied and the through fault current I_{fA} has to be calculated (Figure 35). In order to get the maximum through fault current, the minimum value for Z_B and the maximum value for Z_A have to be considered.

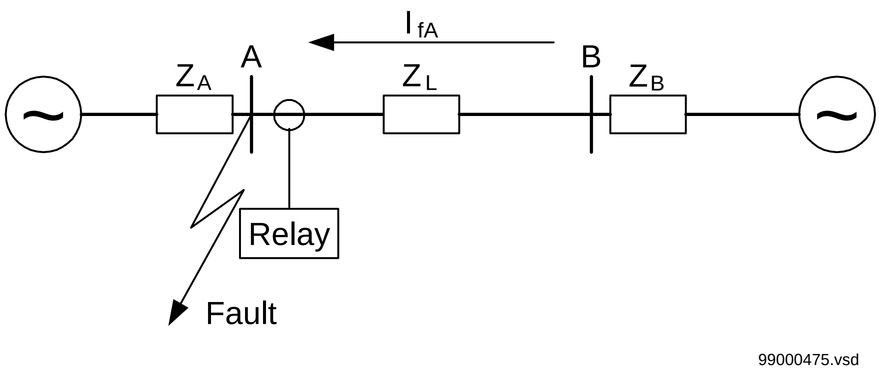


Figure 35: Through fault current from B to A: I_{fA}

The relay must not trip for any of the two trough fault currents. Hence the minimum theoretical current setting (Imin) will be:

$$Imin \geq MAX(I_{fA}, I_{fB})$$

(Equation 31)

A safety margin of 5% for the maximum protection static inaccuracy and a safety margin of 5% for the maximum possible transient overreach have to be introduced. An additional 20% is suggested due to the inaccuracy of the instrument transformers under transient conditions and inaccuracy in the system data.

The minimum primary setting (Is) for the instantaneous phase overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 32)

The protection function can be used for the specific application only if this setting value is equal to or less than the maximum fault current that the relay has to clear (I_F in figure 36).

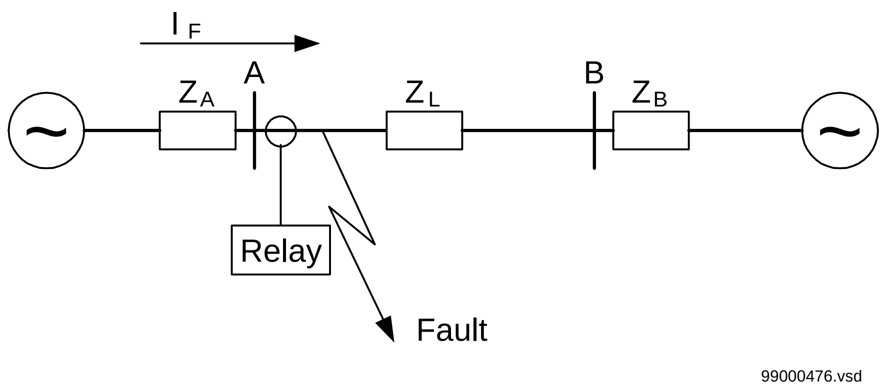


Figure 36: Fault current: I_F

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 33)

Where I_{SEC} is the secondary rated current of the main CT and I_{PRIM} is the primary rated current of the main CT.

The relay setting value IP>> is given in percentage of the secondary base current value, I_{1b}, associated to the current transformer input I1. The value for IP>> is given from this formula:

$$IP>> = \frac{Is_{SEC}}{I_{1b}} \cdot 100$$

(Equation 34)

This is the value that has to be set in the terminal.

Set this value under the setting menu:

Settings
Functions
Group n
InstantOC

Meshed network with parallel line

In case of parallel lines, the influence of the induced current from the parallel line to the protected line has to be considered. One example is given in figure 37 where the two lines are connected to the same busbars. In this case the influence of the induced fault current from the faulty line (line 1) to the healthy line (line 2) is considered together with the two through fault currents I_{fA} and I_{fB} mentioned previously. The maximal influence from the parallel line for the relay in figure 37 will be with a fault at the C point with the C breaker open.

A fault in C has to be applied, and then the maximum current seen from the relay (I_M) on the healthy line (this applies for single-phase-to-earth and two-phase-to-earth faults) is calculated.

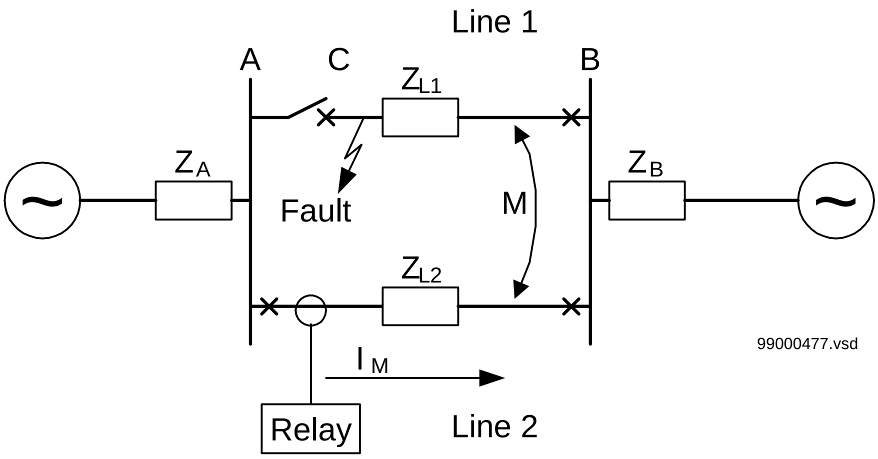


Figure 37: Two parallel lines. Influence from parallel line to the through fault current: I_M

The minimum theoretical current setting for the overcurrent protection function (Imin) will be:

$$Imin \geq MAX(I_{fA}, I_{fB}, I_M)$$

(Equation 35)

Where I_{fA} and I_{fB} have been described in the previous paragraph. Considering the safety margins mentioned previously, the minimum setting (Is) for the instantaneous phase overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 36)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum phase fault current that the relay has to clear.

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 37)

Where I_{SEC} is the secondary rated current of the main CT and I_{PRIM} is the primary secondary rated current of the main CT.

The relay setting value IP>> is given in percentage of the secondary base current value, I_{1b}, associated to the current transformer input I1. The value for IP>> is given from this formula:

$$IP{>>} = \frac{Is_{SEC}}{I_{1b}} \cdot 100$$

(Equation 38)

This is the value that has to be set in the terminal.

Set this value under the setting menu:

Settings
  Functions
    Group n
      InstantOC

1.4.2 Setting instructions

The residual overcurrent protection is very sensitive to the change of zero source impedance. Since it must operate only in a selective way, it is necessary to check all system and transient conditions that can cause unwanted operation.

Only detailed network studies can determine the operating conditions under which the highest possible fault current is expected on the line. In most cases, this current appears during single-phase fault conditions. But also examine two-phase-to-earth conditions, since this type of fault can be higher than single-phase to earth fault in some cases.

Also study transients that can cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when connected to the network and can thus also cause the operation of the built-in, instantaneous, earth-fault protection.

Meshed network without parallel line

The following fault calculations have to be done for single-phase-to-earth and two-phase-to-earth faults. With reference to figure 38, apply a fault in B and then calculate the relay through fault residual current I_{fB}. The calculation should be done using the minimum source impedance values for Z_A and the maximum source impedance values for Z_B in order to get the maximum through fault current from A to B. The zero sequence source impedances are of great importance.

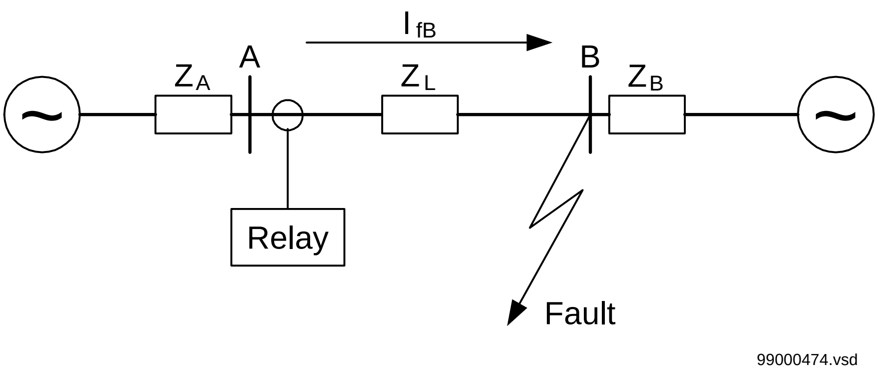


Figure 38: Through fault current from A to B: I_{fB}

Then a fault in A has to be applied and the through fault residual current I_{fA} has to be calculated (Figure 39). In order to get the maximum through fault current, the minimum value for Z_B and the maximum value for Z_A have to be considered.

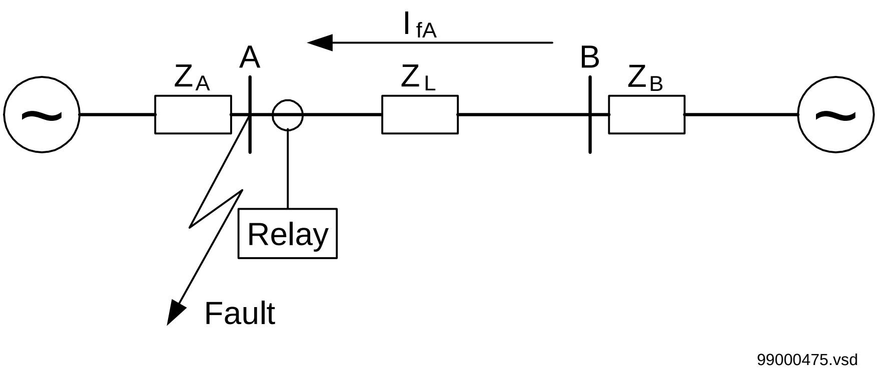


Figure 39: Through fault current from B to A: I_{fA}

The relay must not trip for any of the two trough fault currents. Hence the minimum theoretical current setting (*Imin*) will be:

$$Imin \geq MAX(I_{fA}, I_{fA})$$

(Equation 39)

A safety margin of 5% for the maximum protection static inaccuracy and a safety margin of 5% for the maximum possible transient overreach have to be introduced. An additional 20% is suggested due to the inaccuracy of the instrument transformers under transient conditions and inaccuracy in the system data.

The minimum setting (Is) for the instantaneous residual overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 40)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum fault current that the relay has to clear (I_F in Figure 40).

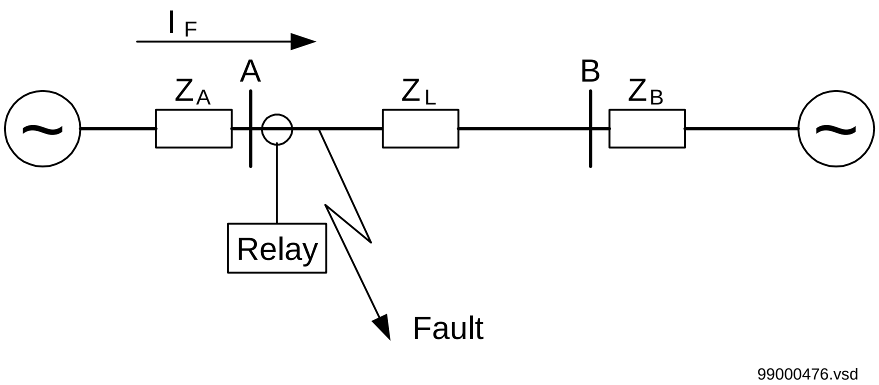


Figure 40: Fault current: I_F

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 41)

Set this value under the setting menu:

Settings
Functions
Group*n*
InstantOC

Note: *n*=1,2,3 or 4, depending on which group to set.

Meshed network with parallel line

In case of parallel lines, the influence of the induced current from the parallel line to the protected line has to be considered. One example is given in figure 41, where the two lines are connected to the same busbar. In this case the influence of the induced residual fault current from the faulty line (line 1) to the healthy line (line 2) is considered together with the two through fault currents I_{fA} and I_{fB} mentioned previously. The maximal influence from the parallel line for the relay in Figure 41 will be with a fault at the C point with the C breaker open.

A fault in C has to be applied, and then the maximum current seen from the relay (I_M) on the healthy line (this applies for single-phase-to-earth and two-phase-to-earth faults) is calculated.

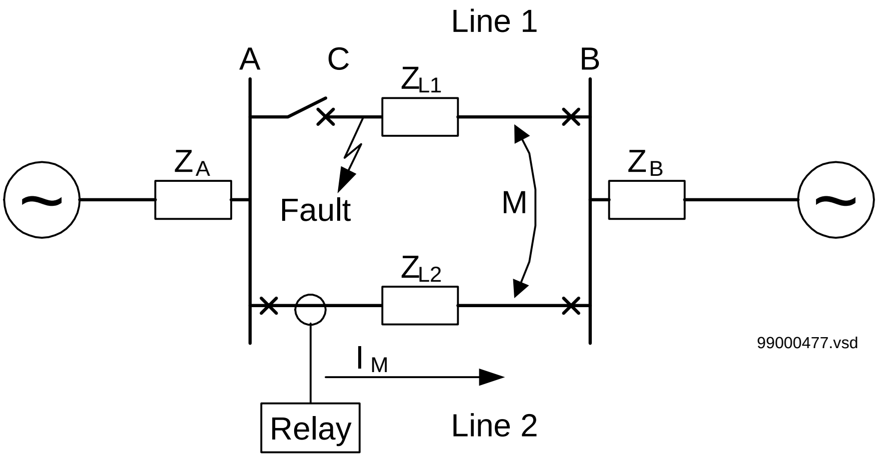


Figure 41: Two parallel lines. Influence from parallel line to the through fault current: I_M.

The minimum theoretical current setting for the residual overcurrent protection function (*Imin*) will be:

$$Imin \geq MAX(I_{fA}, I_{fB}, I_M)$$

(Equation 42)

Where I_{fA} and I_{fB} have been described in the previous paragraph. Considering the safety margins mentioned previously, the minimum setting (Is) for the instantaneous phase overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 43)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum residual fault current that the relay has to clear.

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 44)

Set this value under the setting menu:

Settings
  Functions
    Group*n*
      InstantOC

Note: *n*=1,2,3 or 4, depending on which group to set.

2 Time delayed overcurrent protection (TOC)

2.1 Application

The time delayed phase overcurrent protection can be used as independent overcurrent protection, particularly for radially fed systems, or as back-up protection to the main distance or line differential protection functions. In the first case the protected zone of the time delayed overcurrent protection reaches upto the next overcurrent protection and works in its zone as back-up protection. The programmable time delay (definite time) of the function allows the time selectivity through an appropriate time grading among the overcurrent relays protecting the system.

Where the function acts as back-up for the main line protection, the trip from the overcurrent protection can be activated when the main protection function is blocked (e.g. by the fuse failure protection) or it can be active all the time.

In some cases, where it could be difficult to achieve a selective trip, the function can be used as a helpful overcurrent signallization for the post-fault analysis.

The time delayed residual overcurrent protection (TOC) which is an earth-fault protection, serves as a built-in local back-up function to the main protection function. In most cases, it is used as a back-up for the earth-fault measuring in distance protection.

The function is intended to be used in solidly earthed systems.

The time delay makes it possible to set the relay to detect high resistance faults and still perform selective trip.

The protection, which is non-directional, is included in some of the REx 5xx terminals. Refer to the ordering information for more details.

2.2 Functionality

The current-measuring elements within one of the built-in digital signal processors continuously measure the current in all three phases, and compare them with the IP> set value. A recursive Fourier filter filters the current signals, and a separate trip counter prevents high overreaching of the measuring elements. The logical value of each phase current signal on the output of the digital processor (STIL1, STIL2 and STIL3 respectively) is equal to 1 if the measured phase current exceeds the set value. These signals will instantaneously set their respective output starting signals (TOC--STL1, TOC--STL2, TOC--STL3), if the function is not blocked.

If any of the three phase currents exceeds the set value for a period longer than the set time tP, then a three phase trip is generated from the output signal TOC--TRP.

The current-measuring element within one of the built-in digital signal processors continuously measures the residual current (3I0), and compares it with the IN> set value. A recursive Fourier filter filters the current signal, and a separate trip counter prevents high overreaching of the measuring element. The logical value of the signal on the output of the digital signal processor (TOC--STIN) is equal to 1 if the measured residual current exceeds the pre-set value. This signal will instantaneously set the output start signal (TOC--STN), unless the function is blocked (see “Design”).

The function trip signal (TOC--TRN) can be delayed 0-60 s.

If the residual current exceeds the set value for a period longer than the set value, then a three phase trip is generated from the output signal TOC--TRN.

2.3 Design

The simplified logic diagram of the time delayed phase overcurrent function is shown in figure 42.

The function is disabled (blocked) if:

- The terminal is in TEST mode (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockTOC=Yes).
- The input signal TOC--BLOCK is high.

The TOC--BLOCK signal is a blocking signal of the time delayed phase overcurrent function. It prevents the activation of any trip or starting output signal. It can be connected to a binary input of the terminal in order to receive a block command from external devices or can be software connected to other internal functions of the terminal itself in order to receive a block command from internal functions. Through OR gate it can be connected to both binary inputs and internal function outputs. The TOC--BLOCK signal blocks also the time delayed residual overcurrent protection, if this is installed in the same REx 5xx terminal.

When the function is enabled, there is still the possibility to block the output trips only, without affecting the start signals, that will always be active. This can be obtained with the function input TOC--BLKTR. Similarly to the TOC--BLOCK signal, also the time delayed residual overcurrent protection, if present in the terminal, is blocked from TOC-BLKTR.

The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just a little above the set operating value.

The output trip signal TOC--TRP is a three phase trip. Single phase information is available from the starting signals, that are phase segregated.

The TOC--TRIP output signal behaves as general time delayed overcurrent trip when in the REx 5xx terminal also the time delayed residual overcurrent function is implemented; i.e. this signal will be activated in case of any time delayed overcurrent or time delayed residual overcurrent trip. If only the time delayed phase overcurrent function is installed in the terminal, then this signal behaves exactly as the signal TOC--TRP and can be used for signallization.

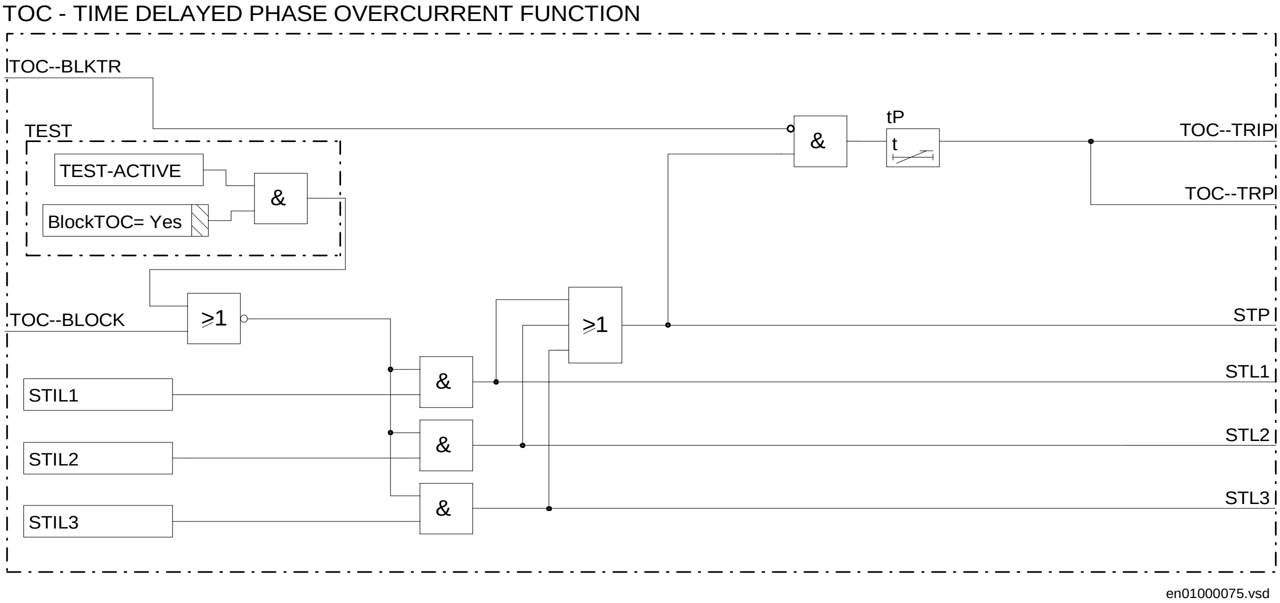


Figure 42: Simplified logic diagram of time delayed phase overcurrent protection

The simplified logic diagram of the time delayed earth-fault protection is shown in figure 43.

The time delayed residual function is disabled if:

- The terminal is in TEST status (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockTOC=Yes).
- The input signal TOC--BLOCK is high.

The TOC--BLOCK signal is a blocking signal of the earth-fault function. It blocks the whole function and prevents the activation of any trip or starting output signals.

It can be connected to a binary input in order to receive a block command from external devices or it can be configured (software connection) to other internal functions within the terminal itself, in order to receive a block command from internal functions. Through OR gates it can be connected to both binary inputs and internal function outputs.

When the residual overcurrent protection is enabled, there is still a possibility to block the trip output only, without affecting the start signals, which always will be active. The input which provides this function is TOC--BLKTR.

The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just a little beyond the set operating value.

The TOC--TRN signal is related to the residual overcurrent trip.

The TOC--TRIP output signal behaves as general time delayed overcurrent trip when in the REx 5xx terminal also the time delayed phase overcurrent function is implemented. I.e. this signal will be activated in case of delayed residual overcurrent trip or in case of time delayed phase overcurrent trip. If only the residual overcurrent function is implemented in the terminal, then this signal behaves exactly as the signal TOC--TRN and can be used for signalization.

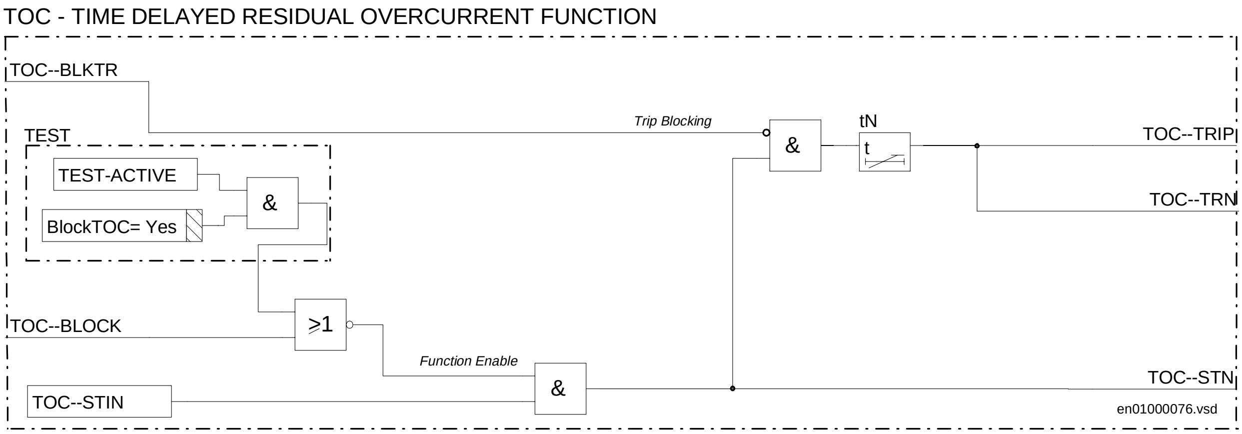


Figure 43: Simplified logic diagram of the TOC-- protection function.

2.4 Calculations

2.4.1 Setting instructions

The current setting value must be selected to permit the detection of the lowest short circuit current without having any unwanted tripping or starting of the function under normal load conditions. The following relation has to be considered for the setting of the primary operating current (Is) of the function:

$$1.2 \cdot \frac{ILmax}{K} < Is < 0.7 \cdot IFmin$$

(Equation 45)

Where:

ILmax	is the maximum permissible load current of the protected unit,
IFmin	is the minimum fault current that the relay has to clear. The values 1.2 and 0.7 are safety factors and
K	is the reset ratio of the overcurrent function: 0.95.

The settable time delay tP allows the time selectivity of the overcurrent function, according to the time grading plan of all the other overcurrent protections in the system. The time setting value should also consider transients that could cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when energized.

Where the time delayed overcurrent function is used as back-up of impedance protection, normally the time delay is set higher than the time delay of distance zone 2 (or 3) in order to avoid interferences with the impedance measuring system.

Setting of operating current IP>

If Is is the primary setting operating value of the function, than the secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 46)

Where:

I_{SEC}	is the secondary rated current of the main CT and
I_{PRIM}	is the primary rated current of the main CT.

The relay setting value IP> is given in percentage of the secondary base current value, I_{1b}, associated to the current transformer input I1. The value for IP> is given from this formula:

$$IP> \ = \ \frac{Is_{SEC}}{I_{1b}} \cdot 100$$

(Equation 47)

This is the value that has to be set in the terminal.

Set this value under the setting menu:

Settings
 Functions
  Group n
   TimeDelayOC

On the value IP>.

Setting of time delay tP

Set the time delay of the function, tP, under the setting menu:

Settings
 Functions
  Group n
   TimeDelayOC

on the value tP.

2.4.2 Setting instructions

The residual overcurrent protection is very sensitive to the change of zero source impedance. Since it must operate only in a selective way, it is necessary to check all system and transient conditions that can cause unwanted operation.

The settings should be chosen in such a way that it can detect high resistance faults on the protected line and still be selective to other residual time delayed protections in both forward and reverse directions. The time setting value should also consider transients that can cause a high increase of the residual line current for short times.

A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when being energised.

In well transposed system, the false earth-fault current is normally lower than 5% of the line current. For non transposed lines a considerably higher false residual current may be found.

In case of extremely short or not fully transposed parallel lines, the false residual current must be measured or calculated when maximum sensitivity is desired. Generally, 80 A is recommended as a minimum primary operation value for the residual overcurrent protection.

General criteria for the primary current setting value of the time delayed residual overcurrent protection is given in the formula below:

$$1.3 \cdot IRmax < Is < 0.7 \cdot IFmin$$

(Equation 48)

Where:

IRmax	is the maximum permissive residual current flowing in the protection unit during normal service conditions and
IFmin	is the minimum residual fault current that the relay has to clear.
1.3	and
0.7	are safety factor values.

Setting of operating current IN>

If Is is the primary setting operating value of the function, then the secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 49)

where I_{SEC} is the secondary rated current of the main CT and I_{PRIM} is the primary rated current of the main CT.

The relay setting value IN> is given in percentage of the secondary base current value, I4b, associated to the current transformer on input I4. The value for IN> is given from the formula:

$$IN> = \frac{Is_{SEC}}{I4b} \cdot 100$$

(Equation 50)

and this is the value that has to be set in the relay.

Set the value under the setting menu:

Settings
  Functions
    Group n (n=1-4)
      TimeDelayOC

For the parameter IN>.

Setting of time delay tN

Set the time delay of the function, tN, under the setting menu:

Settings
  Functions
    Group n (n=1-4)
      TimeDelayOC

3 Definite and inverse time-delayed residual overcurrent protection (TEF)

3.1 Application

This earth-fault overcurrent protection is intended for solidly earthed networks.

Earth-fault overcurrent protection

In case of single-phase earth-faults, the primary fault resistance varies with the network conditions, the type of fault and location of the fault. In many cases, the fault resistance is much higher than the resistance that can be covered by an impedance-measuring distance protections. This can be the case with a phase to earth fault to a tower with large tower footing resistance.

Earth-faults with high fault resistances can be detected by measuring the residual current ($3I_0$).

The inrush current can cause unwanted tripping of the earth-fault overcurrent relay when energizing a directly earthed power transformer. The earth-fault overcurrent protection is therefore provided with second harmonic restraint, which blocks the operation if the residual current ($3I_0$) contains 20% or more of the second harmonic component.

In some cases, it is possible to improve the selectivity by adding a settable minimum operate current (IMin) and a minimum operate time (tMin) to the inverse characteristic. These functions are included in the earth-fault protection modules.

To minimize the operate time, in case of closing the circuit breaker to a fault, the residual overcurrent protection module is provided with a switch-onto-fault logic, which can be activated at breaker closure. The tripping time will temporarily be reduced to 300 ms.

In order to achieve the most sensitive earth fault protection the non-directional function can be used. As the residual current is normally very small during normal operation the setting value can be set very low. In case of small residual currents, due to high resistance phase to earth faults or serial faults, the residual voltage in the system can be very low. A serial fault can be caused by broken phase conductor(s) with no contact to earth, or pole discrepancy in a circuit breaker or a disconnector. The most common type of serial fault is pole discrepancy at breaker maneuvers.

As the residual voltage is often very small at high resistance earth faults and serial faults, any directional element can not be used.

The function can have different types of time-current characteristics; definite time delay or different types of inverse time delay. By using the inverse time delay characteristics some degree of selectivity between non-directional residual protection can be achieved.

3.2 Functionality

3.2.1 Theory of operation

Directional earth-fault overcurrent protection

This protection measures the residual current ($3I_0$) and the residual voltage ($3U_0$). Figure 44 shows the current measuring, time delay and logic circuits (both with and without directional check) of this protection function.

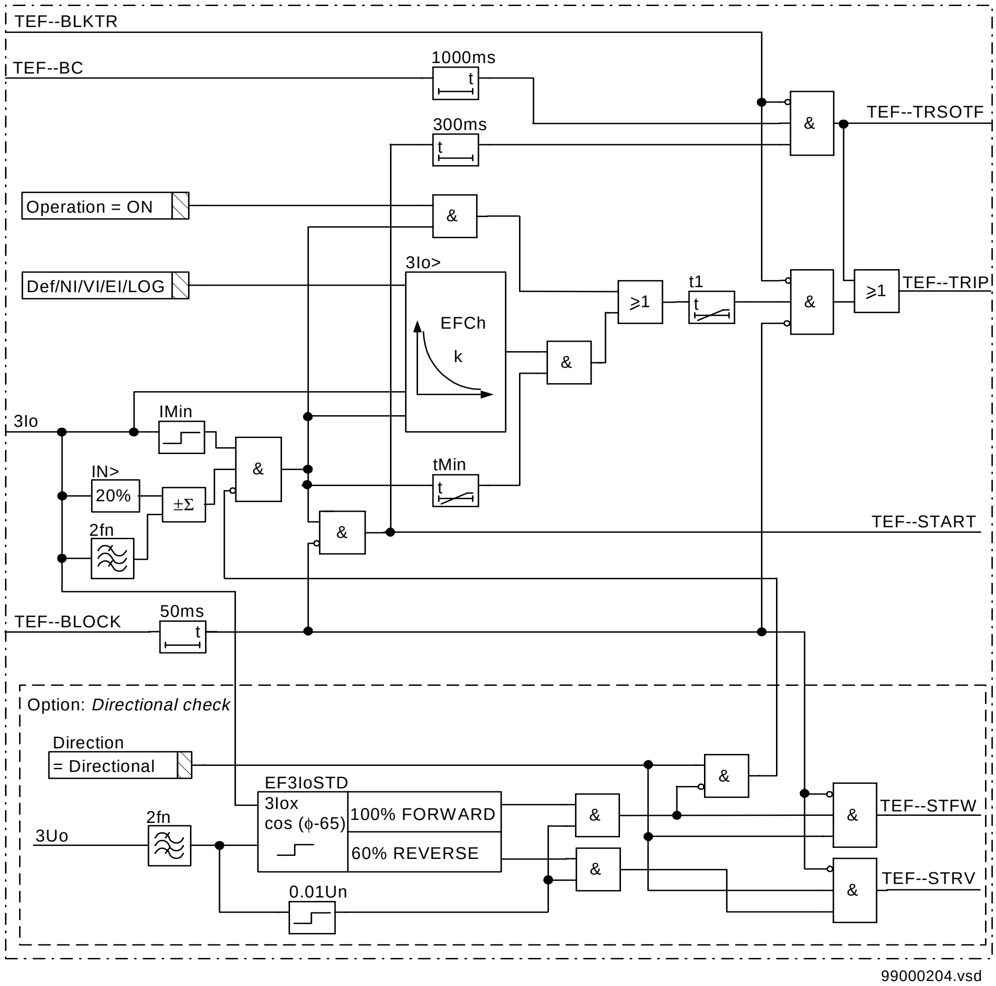


Figure 44: Simplified logic diagram for the residual overcurrent protection

Activate the independent time-delay function by setting *Characteristic*= Def (or inverse time delay according to the setting table). The t1 timer starts when both the definite/inverse time characteristic and the tMin timer operate. The tMin timer starts when the $3I_0$ current to the relay is equal to or higher than the set operate value for IMin and the content of the second harmonic in $3I_0$ is less than 20%.

The inverse time calculation starts when $3I_0$ is equal to or higher than the set operate value for IMin and the content of the second harmonic in $3I_0$ is less than 20%. The inverse time delay is determined by the selection of the characteristic (NI, VI etc.) in the Characteristic setting and the setting of the characteristic IN> current.

The t1 timer is normally set to zero. Use it to add a constant time to the inverse time delay. Figure 45 shows the effect of the IMin and tMin settings on the inverse characteristic.

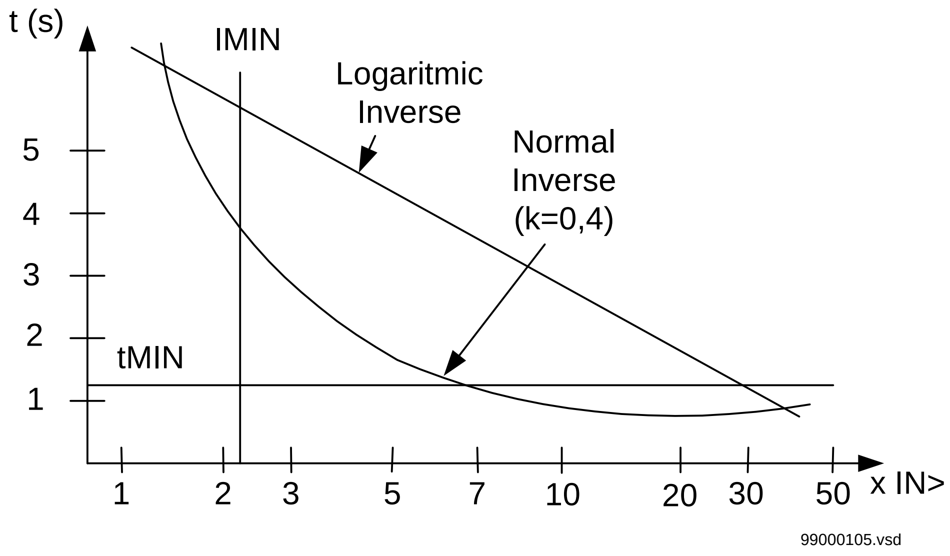


Figure 45: Normal inverse and logarithmic inverse time characteristics.

The switch-onto-fault function is used to minimise the operate time in case of pole discrepancy at breaker closing and in cased of closing on to a fault. The function is released by activating the TEF--BC binary input. The function is activated for 1 second after the reset of the TEF--BC binary input.

The function is blocked by activating the TEF--BLOCK binary input.

Activating the TEF--BLKTR blocks the definite/inverse delay trip outputs TEF--TRIP and the switch-on-to-fault trip TEF-TRSOTF.

3.3 Calculations

3.3.1 Setting instructions

To detect high resistive earth-faults, a low operate current is required. On the other hand, a low setting increases the risk for unwanted operation due to imbalance in the network and the current transformer circuits. Set the minimum operate current (IN> *IMin) of the earth-fault overcurrent protection higher than the maximum false earth-fault current. If the directional function is chosen, set the start level of the directional function (IN> Dir) higher than the maximum false earth-fault current.

The imbalance in the network that causes false earth-fault currents is caused mainly by untransposed or not fully transposed parallel lines with strong zero-sequence mutual coupling. There might also be high imbalance currents for non-transposed single circuit lines if the zero sequence source impedance is low at both line ends. This false earth-fault current is directly proportional to the load current.

In a well-transposed system, the false earth-fault current is normally lower than 5% of the line current.

In case of not fully transposed parallel lines, measure or calculate the false earth-fault current at maximum load.

The choice of time delay characteristics - definite time, normal inverse, very inverse, extremely inverse or logarithmic inverse - depends on the network. To achieve optimum selectivity, use the same type of characteristic for all earth-fault overcurrent protections in the network. This means that in networks already equipped with earth-fault overcurrent relays, the best selectivity is normally achieved by using the same type of characteristic as in the existing relays.

The following formulas for the operate time (in seconds) apply to the characteristic used within the REx 5xx terminal with line protection, see table 6.

Table 6: Operate time formulas

Characteristics	**Operate time (s)**
Normal inverse	$t = \frac{0.14}{I^{0.02} - 1} \cdot k$ (Equation 51)
Very inverse	$t = \frac{13.5}{I - 1} \cdot k$ (Equation 52)
Extremely inverse	$t = \frac{80}{I^2 - 1} \cdot k$ (Equation 53)
Logarithmic inverse	$t = 5.8 - (1.35 \cdot \ln I)$ (Equation 54)

Where:

I	is a multiple of set current $3I_0>$
k	is a time multiplying factor, settable in the range of 0.05 to 1.10

All inverse time characteristic settings are a compromise between short fault clearing time and selective operation in a large current range. The main determining factors are the maximum allowed fault-clearing time at the maximum fault resistance to be covered and the selectivity at maximum fault current.

Set the minimum operate current (IMin) of the earth-fault overcurrent protection to one to four times the set characteristic quantity (IN>) of the inverse time delay. So an inverse characteristic with a low set IN> set to get a short operate time at minimum fault current can be combined with a higher set IMin minimum operate current, to avoid unwanted operation due to false earth-fault currents.

Set the minimum operate time independent of the inverse time characteristic. Normally, set this time longer than the time delay of distance zone 2 in REx 5xx to avoid interference with the impedance measuring system in case of earth-faults with moderate fault resistance within zone 2.

When a solidly earthed, power transformer is energized, an inrush current normally flows in the neutral-to-earth connection of the transformer. This current is divided among other earthed transformers and lines connected to the same bus, inversely proportional to their zero-sequence impedance. The amplitude and time duration of this current can be sufficiently large to cause the unwanted operation of a sensitive earth-fault overcurrent protection.

The earth-fault overcurrent protection has a built-in second harmonic current stabilization, which prevents unwanted operation if the inrush current has a second harmonic content of 20% or more. This is normally the case. On rare occasions, it may be necessary to increase the setting of the operate value for the residual earth-fault overcurrent protection to avoid unwanted operation due to transformer inrush current.

When single-phase auto-reclosing is used, the minimum time of the inverse time delayed residual overcurrent protection (tMin) should be set to be longer than the time from the occurrence of the fault to the reclosing of the breaker at both line terminals. An alternative method is to block the earth fault protection by the autorecloser during the dead time. This avoids unwanted three-phase tripping during a single-phase auto-reclosing cycle controlled by the distance protection.

The polarizing voltage for directional earth-fault overcurrent protection is normally obtained from the broken delta windings of instrument voltage transformers or by internal calculation. The voltage contains a certain amount of harmonics, especially when the protection is connected to CVTs.

Due to the bandpass filtering a polarizing voltage down to 1 percent of the rated voltage will provide correct directional functionality. This is also valid when the protection is connected to CVTs.

The minimum polarizing voltage to the protection (Umin) is calculated from the formula:

$$U_{min} = I_{F\ min} \cdot Z_{0\ min} \cdot \frac{U_{sec}}{U_{prim}}$$

(Equation 55)

Where:

I_{Fmin}	is the minimum primary operate fault current
Z_{0min}	is the minimum zero-sequence impedance seen from the relay
U_{sec}, U_{prim}	are the rated phase voltages of the broken delta connected CVTs (VTs)

Observe that when a blocking scheme or a permissive scheme with current reversal or weak-end-infeed logic is used, IFmin represents the primary operate current of the reverse-looking directional element which is 60% of the forward element.

To even secure operation in unfavorable cases, Umin must be equal to at least 1 volt plus the maximum network frequency false voltage, due to measuring errors in the VT circuits.

If not blocked, the directional comparator operates during the dead time in case of a single-phase auto-reclosure. So the TEF--BLOCK blocking input must be activated during the single-phase auto-reclosing cycle.

4 Thermal overload protection (THOL)

4.1 Application

When the load currents exceed the permitted continuous current there is a risk that the conductor or the insulation will be subject to permanent damage due to overheating. Even moderate overloads under long time give appreciable temperature increase. For example, a current of 1.2 times rated load current gives a temperature rise of 1.2 x 1.2 = 1.44 times rated value.

The temperature rise as a function of time for a fixed load is determined by the so called thermal time constant τ of the element.Moderate overloads are normally not detected by current or impedance measuring relays. A current thermal overload protection can prevent damage caused by excessive temperature increase due to moderate or heavy current overloads.

Electrical cables which can be loaded up to the permissible load current should be provided with thermal protection. For cables surrounded by air, the thermal time constant τ can vary from some few minutes for 10 kV cables with small cross-sectional area to more than one hour for high voltage cables with large cross-sectional area. The shorter time constant valid for cables in air is decisive if some part of the cable is surrounded by air.

For overhead lines and cables placed in the air, the ambient temperature will normally vary considerably. Since the temperature of the element is the sum of the ambient temperature and the temperature rise, the thermal protection for heavily loaded lines should be provided with compensation for the ambient temperature.The heating effect of radiant power from the sun can also be appreciable in some areas.

4.2 Functionality

The function includes a memory that is continuously updated with the heat content of the line based on the RMS value of the line current and the ambient temperature. The current used in the function is the phase current having the highest RMS value out of the three phase currents. The function has two settable operating levels for temperature, one intended for alarm and one intended for tripping. For the tripping function a reset hysteresis is included that can be set between 5 and 30°C while for the alarm function it is fixed at 5°C hysteresis.

For the alarm there is an output denoted ALARM which is active as long as the temperature is above alarm level. For the tripping there are two outputs, one denoted TRIP which gives only a 50 ms pulse at operation and one denoted START which is active as long as the temperature is above tripping level.

The function also includes a possibility for ambient temperature compensation through a mA transducer input. The upper and lower value for the input range can be set between -25 and +25 mA and corresponding temperature between -1000 and + 1000°C. If transducer for ambient temperature is not available the function uses a +20°C reference value instead. This value will also be used if a fault is detected in the transducer circuits or mA input module.

4.3 Calculations

The settings for the THOL function, with exception of the settings for the ambient temperature compensation, can be made on the built-in HMI unit:

Settings
Functions
Group n (n=1...4)
ThermOverLoad

The settings can also be made by aids of the SMS or PST setting tools.

For temperature compensation, input No. 1 on the MIM module No.1 is always used (fixed configuration). Necessary settings for the MIM module are On/Off for activation, time intervals for measuring of current, upper and lower value for the current input and temperatures corresponding to max. respectively min. current. These settings can only be made via the SMS or PST setting tools.

To make the correct settings, the following data are required for the protected object:

- Final temperature rise after continous load with specified load current
- Max. permissible continuous temperature and thermal time constant τ of the object
- Max. ambient temperature
- Max. temperature rise due to radiant power from the sun - if significant

The time constant can be found if a curve is available which shows the temperature rise as a function of time for a given load current. At load current Iload and final temperature rise Tfin the following is valid:

Time:	1 x τ	2 x τ	3 x τ	4 x τ	5 x τ
Temperature rise[1]:	63	86	95	98	99
1) in % of Tfin					

If different values of τ are calculated from the curve, select the lowest value of τ to obtain the best protection.

The time to function is calculated from the formula:

$$t = \tau \cdot \ln \frac{\left(\frac{I}{I_{base}}\right)^2 - p^2}{\left(\frac{I}{I_{base}}\right)^2 - \frac{T_{trip} - T_{amb}}{T_{base}}}$$

(Equation 56)

Where:

p	is Ip/I_{base}
Ip	is continuous load current before the current is icreased to I Tamb = ambiant temperature. If temperature compensation is not used, Tamb = 20°C as fixed value,
T_{amb}	is ambient temperature and
T_{amb}	is 20° C as a fixed value if temperature compensation is not used.

For other parameters: see description in the setting table in the Technical Reference Manual

Setting example

Assume the following data:

- I1b: 5 A
- Temperature increase of the conductor : 90°C at continuous load current 4.5 A.
- Max. permissible temperature of the conductor: 125°C
- Time constant τ = 20 min
- Max. ambient temperature: 30°C
- Max. temperature increase due to radiant power from the sun: 5°C

Example 1: THOL with no temperature compensation

I_{base} = 4.5 A = 4.5/5 x 100 = 90 % of I1b

T_{base} = 90°C, τ = 20 min

The thermal function assumes 20°C ambient temperature as a fixed value instead of the actual value 30°C. Also, the 5°C temperature increase due to the sun radiant power is not included in the calculated temperature increase. Hence, the function calculates continous conductor temperature 20 + 90 = 110°C at 4.5 A whereas the max. value is 30 + 90 +5 = 125°C. Hence the setting should be TTrip = 125 - (125 - 110) = 110°C.

Example 2: THOL with temperature compensation

Assume temperature measuring elements with output 4 mA at -20°C and 20 mA at 100°C. Settings of Ibase, T_{base} and τ same as above

.MI11-I-Max= 20.00mA MI11-I-MaxValue = +100°C

CMI11-I-Min= 4.00mA MI11-I-MinValue = -20°C

The influence of the ambient temperature is included in the calculated values. The 5°C temperature increase due to the sun radiant power, however, is not included. Hence the setting should be T_{trip} = 125 - 5 = 120°C.

Chapter 6 Secondary system supervision

About this chapter

This chapter describes the secondary system supervision functions.

1 Current circuit supervision (CTSU)

1.1 Application

The correct operation of a protection depends on correct information about the primary value of currents and voltages. When currents from two independent 3-phase sets of CT's, or CT cores, measuring the same primary currents are available, a reliable current circuit supervision can be arranged by comparing the currents from the two sets. If an error in any CT circuit is detected, the protection functions concerned are to be blocked and an alarm given.

In case of large currents, unequal transient saturation of CT cores with different remanence or different saturation factor may result in differences in the secondary currents from the two CT sets. Unwanted blocking of protection functions during the transient period must be avoided.

The supervision function must be sensitive and have short operate time to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of errors in the current circuits.

Note that the same current input transformer (I5) in REx 5xx is used for the reference current I_{ref} of the CT supervision, the residual current from the parallel line for the fault locator and, dependent on setting I4 or I5, maybe for the earth-fault protection function. Hence, when the CT supervision function is used, the other functions mentioned can not be used. Also the settings Xm0 = 0 and Rm0 = 0 must be used for the fault locator.

1.2 Functionality

The supervision function compares the numerical value of the sum of the three phase currents $|\Sigma I_{phase}|$ (current inputs I1, I2 and I3) and the numerical value of the residual current $|I_{ref}|$ (current input I5) from another current transformer set, see figure 46.

The CTSU-FAIL output will be set to a logical one when the following criteria are fulfilled:

- The numerical value of the difference $|\Sigma I_{phase}| - |I_{ref}|$ is higher than 80% of the numerical value of the sum $|\Sigma I_{phase}| + |I_{ref}|$.
- The numerical value of the current $|\Sigma I_{phase}| - |I_{ref}|$ is equal to or higher than the set operate value IMinOp (5 - 100% of I1b).
- No phase current has exceeded 1.5 times rated relay current I1b during the last 10 ms
- The current circuit supervision is released by setting Operation = On.

The CTSU-FAIL output remains activated 100 ms after the AND-gate resets when being activated for more than 20 ms. If the CTSU-FAIL lasts for more than 150 ms a CTSU-ALARM will be issued. In this case the CTSU-FAIL and CTSU-ALARM will remain activated 1 s after the AND-gate resets. This prevents unwanted resetting of the blocking function when phase current supervision element(s) operate, e.g. during a fault.

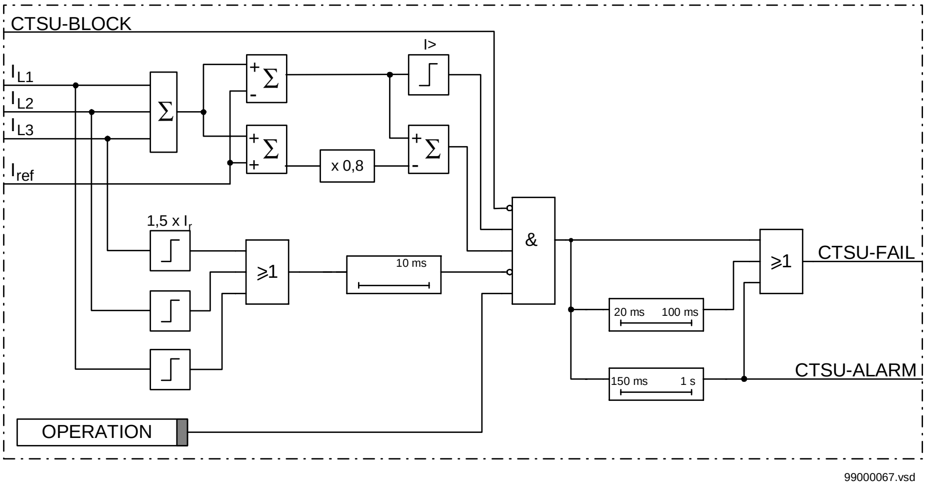


Figure 46: Simplified logic diagram for the current circuit supervision

The operate characteristic is percentage restrained, see figure 47.

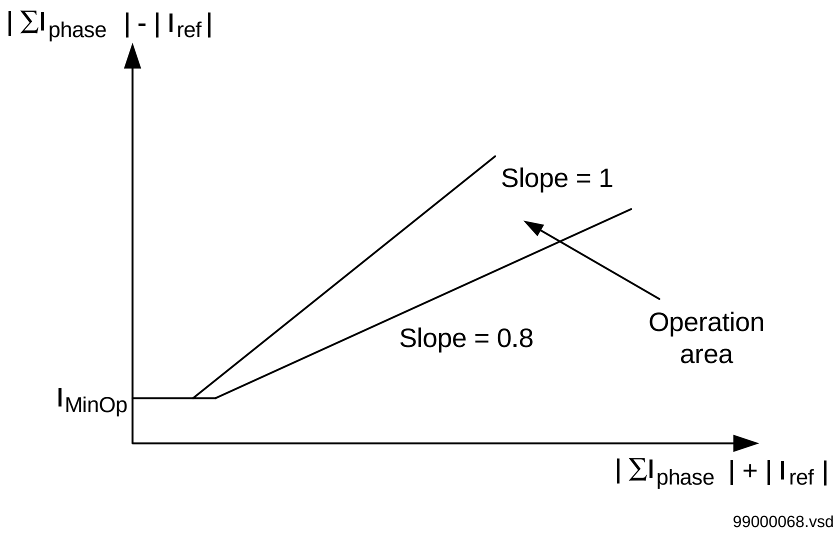


Figure 47: Operate characteristics

Note that due to the formulas for the axis compared, $|\Sigma I_{phase}| - |I_{ref}|$ and $|\Sigma I_{phase}| + |I_{ref}|$ respectively, the slope can not be above 1.

1.3 Calculations

1.3.1 Setting instructions

The function is activated by setting Operation = On.

The minimum operate current (IMinOp) should as a minimum be set to twice the residual current in the supervised CT circuits under normal service conditions and rated primary current. The setting range is 5 – 100% of I1b

The CTSU-FAIL and CTSU-ALARM outputs are connected to the blocking input of the actual protection function and output alarm relay respectively via the internal logic programming of the REx 5xx relay.

Chapter 7 Logic

About this chapter

This chapter describes the logic functions.

1 Trip logic (TR)

1.1 Application

All trip signals from the different protection functions shall be routed through the trip logic. In its most simple alternative the logic will only link the trip signal and assure a sufficient duration of the trip signal.

To meet the different single, double, 1 and 1/2 or other multiple circuit breaker arrangements, one or more identical TR function blocks may be provided within a single terminal. The actual number of these TR function blocks that may be included within any given terminal depends on the type of terminal. Therefore, the specific circuit breaker arrangements that can be catered for, or the number of bays of a specific arrangement that can be catered for, depends on the type of terminal.

One TR function block should be used for each breaker, if the line is connected to the substation via more than one breaker. Assume that single pole tripping and auto-reclosing is used for the line. The breaker chosen as master must in that case have single pole tripping, while the slave breaker could have three pole tripping and auto-reclosing. In case of a permanent fault only one of the breakers has to be operated at the second energising of the fault. In case of a transient fault the slave breaker reclosing is made as a three pole reclosing onto the non-faulted line.

The same philosophy can be used for two-pole tripping and auto-reclosing.

1.2 Functionality

The minimum duration of a trip output signal from the TR function is 150ms. This is to secure the fault clearance.

The three-pole TR function has a single input through which all trip output signals from the protection functions within the terminal, or from external protection functions via one or more of the terminal’s binary inputs, are routed. It has a single trip output for connection to one or more of the terminal’s binary outputs, as well as to other functions within the terminal requiring this signal.

In case of multi-breaker arrangement, one TR function block can be used for each breaker, if the breaker functions differ. This can be the case if single pole trip and auto-reclosing is used.

2 Event function (EV)

2.1 Application

When using a Substation Automation system, events can be spontaneously sent or polled from the terminal to the station level. These events are created from any available signal in the terminal that is connected to the event function block. The event function block can also handle double indication, that is normally used to indicate positions of high-voltage apparatuses. With this event function block, data also can be sent to other terminals over the interbay bus.

2.2 Functionality

The events can be created from both internal logical signals and binary input channels. The internal signals are time tagged in the main processing module, while the binary input channels are time tagged directly on each I/O module. The events are produced according to the set event masks. The event masks are treated commonly for both the LON and SPA channels. All events according to the event mask are stored in a buffer, which contains up to 1000 events. If new events appear before the oldest event in the buffer is read, the oldest event is overwritten and an overflow alarm appears.

The outputs from the event function block are formed by the reading of status and events by the station HMI on either every single input or double input. The user-defined name for each input is intended to be used by the station HMI.

Twelve of the event function blocks are executed with fast cyclicity. That means that the time-tagging resolution on the events that are emerging from internal logical signals, created from configurable logic, is the same as the cyclicity of this logic. The time tagging resolution on the events that are emerging from binary input signals have a resolution of 1 ms.

Two special signals for event registration purposes are available in the terminal, *Terminal restarted and Event buffer overflow*.

2.3 Design

General

As basic, 12 event function blocks EV01-EV12 running with a fast cyclicity, are available in REx 5xx. When the function Apparatus control is included in the terminal, additional 32 event function blocks EV13-EV44, running with a slower cyclicity, are available.

Each event function block has 16 connectables corresponding to 16 inputs INPUT1 to INPUT16. Every input can be given a name with up to 19 characters from the CAP 531 configuration tool.

The inputs can be used as individual events or can be defined as double indication events.

The inputs can be set individually from the Parameter Setting Tool (PST) under the Mask-Event function as:

- No events
- OnSet, at pick-up of the signal
- OnReset, at drop-out of the signal
- OnChange, at both pick-up and drop-out of the signal

Also an input PrColxx (xx=01-44) is available on the function block to define on which protocol the events shall be sent.

The event function blocks EV01-EV06 have inputs for information numbers and function type, which are used to define the events according to the communication standard IEC 60870-5-103.

Double indication

Double indications are used to handle a combination of two inputs at a time, for example, one input for the open and one for the close position of a circuit breaker or disconnector. The double indication consists of an odd and an even input number. When the odd input is defined as a double indication, the next even input is considered to be the other input. The odd inputs has a suppression timer to suppress events at 00 states.

To be used as double indications the odd inputs are individually set from the SMS under the Mask-Event function as:

- Double indication
- Double indication with midposition suppression

Here, the settings of the corresponding even inputs have no meaning.

These states of the inputs generate events. The status is read by the station HMI on the status indication for the odd input:

- 00 generates an intermediate event with the read status 0
- 01 generates a close event with the read status 1
- 10 generates an open event with the read status 2
- 11 generates an undefined event with the read status 3

Communication between terminals

The BOUND and INTERVAL inputs are available on the event function block.

The BOUND input set to 1 means that the output value of the event block is bound to another control terminal on the LON bus. The event function block is then used to send data over the LON bus to other REx 5xx terminals. The most common use is to transfer interlocking information between different bays. That can be performed by an event function block used as a send block and with a Multiple Command function block used as a receive block. The document *Apparatus Control* describes how to transfer the interlocking information. The configuration of the communication between control terminals is made by the LON Network Tool.

The INTERVAL input is applicable only when the BOUND input is set to 1. The INTERVAL is intended to be used for cyclic sending of data to other control terminals via the LON bus with the interval time as set. This cyclic sending of data is used as a backup of the event-driven sending, which always is performed. With cyclic sending of data, the communication can be supervised by a corresponding INTERVAL input on the Multiple Command function block in another control terminal connected to the LON bus. This INTERVAL input time is set a little bit longer than the interval time set on the event function block. With INTERVAL=0, only event-driven sending is performed.

2.4 Calculations

The event reporting can be set from the PST as:

- Use event masks
- Report no events
- Report all events

Use of event masks is the normal reporting of events, that is, the events are reported as defined in the database.

An event mask can be set individually for each available signal in the terminal. The setting of the event mask can only be performed from the PST.

All event mask settings are treated commonly for all communication channels of the terminal.

Report no events means blocking of all events in the terminal.

Report all events means that all events, that are set to OnSet/OnReset/OnChange are reported as OnChange, that is, both at set and reset of the signal. For double indications when the suppression time is set, the event ignores the timer and is reported directly. Masked events are still masked.

Parameters to be set for the event function block are:

- T_SUPRyy including the suppression time for double indications.
- NAMEyy including the name for each input.
- PrColxx including the type of protocol for sending the events.
- INTERVAL used for the cyclic sending of data.
- BOUND telling that the block has connections to other terminals over the LON bus.
- FuncTEVx (for EV01-EV06) including the function type for sending events via IEC 60870-5-103.
- InfoNoyy (for EV01-EV06) including the information number for the events sending via IEC 60870-5-103.

These parameters are set from the CAP 531 configuration tool. When the BOUND parameter is set, the settings of the event masks have no meaning.

Chapter 8 Monitoring

About this chapter

This chapter describes the monitoring functions.

1 Disturbance report (DRP)

1.1 Application

Use the disturbance report to provide the network operator with proper information about disturbances in the primary network. Continuous collection of system data and, at occurrence of a fault, storing of a certain amount of pre-fault, fault and post-fault data, contributes to the highest possible quality of electrical supply. The stored data can be used for analysis and decision making to find and eliminate possible system and equipment weaknesses.

The function comprises several sub functions enabling different users to access relevant information in a structured way.

1.2 Functionality

The disturbance report is a common name for several facilities to supply the operator with more information about the disturbances in the system. Some of the facilities are basic and some are optional in the different products. For some products not all facilities are available.

The facilities included in the disturbance report are:

- General disturbance information
- Indications
- Event recorder
- Fault locator
- Trip values (phase values)
- Disturbance recorder

The whole disturbance report can contain information for up to 10 disturbances, each with the data coming from all the parts mentioned above, depending on the options installed. All information in the disturbance report is stored in non-volatile flash memories. This implies that no information is lost in case of loss-of-power supply

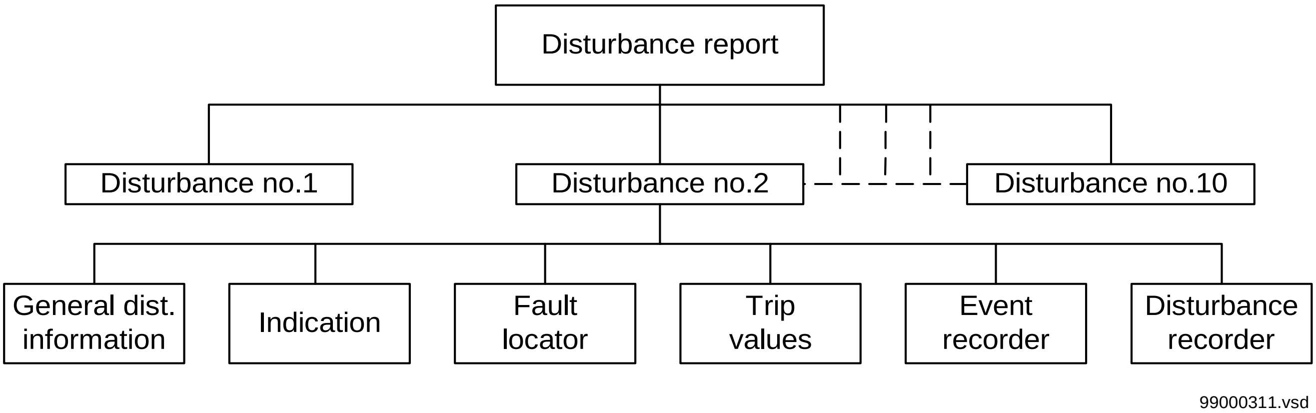


Figure 48: Disturbance report structure

Up to 10 disturbances can always be stored. If a new disturbance is to be recorded when the memory is full, the oldest disturbance is over-written by the new one. The nominal memory capacity for the disturbance recorder is measured with 10 analog and 48 binary signals recorded, which means that in the case of long recording times, fewer than 10 disturbances are stored. If fewer analog signals are recorded, a longer total recording time is available. This memory limit does not affect the rest of the disturbance report.

Disturbance information

The indications, the fault locator result (when applicable), and the trip values are available on the local HMI. For a complete disturbance report, front communication with a PC or remote communication with SMS is required.

Disturbance overview is a summary of all the stored disturbances. The overview is available only on a front-connected PC or via the Station Monitoring System (SMS). The overview contains:

- Disturbance index
- Date and time
- Trip signals
- Trigger signal that activated the recording
- Distance to fault (requires Fault locator)
- Fault loop selected by the Fault locator (requires Fault locator)

Disturbance Summary is automatically scrolled on the local human-machine interface (HMI). Here the two latest disturbances (DisturbSummary 1, which is the latest and DisturbSummary 2 which is the second latest) are presented with:

- Date and time
- Selected indications (set with the Indication mask)
- Distance to fault and fault loop selected by the Fault locator

Disturbance data on the HMI is presented at:

DisturbReport/Disturbances/Disturbance n (n=1 - 10)

The date and time of the disturbance, the trigger signal, the indications, the fault locator result and the trip values are available, provided that the corresponding functions are installed.

Indications

Indications is a list of signals that were activated during the fault time of the disturbance. A part (or all) of these signals are automatically scrolled on the local HMI after a disturbance.

Event recorder

The event recorder contains an event list with time-tagged events. In the Station Monitoring System, this list is directly connected to a disturbance.

Fault locator

The fault locator contains information about the distance to the fault and about the measuring loop that was selected for the calculation. After changing the system parameters in the terminal, a recalculation of the distance to the fault can be made in the protection

Trip values

Trip values includes phasors of currents and voltages before the fault and during the fault

Disturbance recorder

The disturbance recorder records analog and binary signal data before, during and after the fault.

Recording times

The disturbance report records information about a disturbance during a settable timeframe. The recording times are valid for the whole disturbance report. The disturbance recorder and the event recorder register disturbance data and events during *tRecording*, the total recording time. Indications are only registered during the fault time.

The total recording time, *tRecording*, of a recorded disturbance is:

tRecording = tPre + tFault + tPost or tPre + tLim, depending on which criterion stops the current disturbance recording

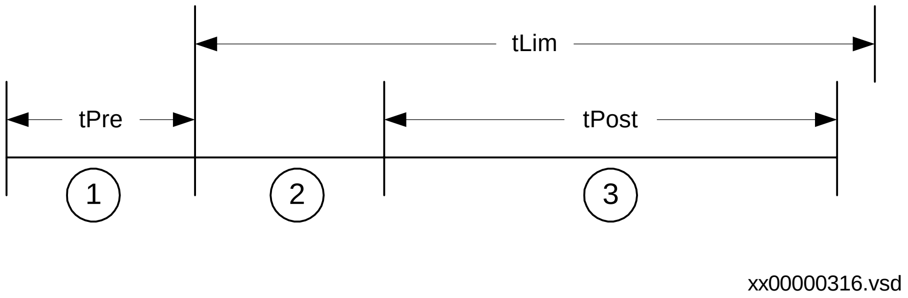


Table 7: Definitions

1	Pre-fault or pre-trigger recording time. The time before the fault including the operate time of the trigger. Use the setting tPre to set this time.
2	Fault time of the recording. The fault time cannot be set. It continues as long as any valid trigger condition, binary or analog, persists (unless limited by tLim the limit time).
3	Post fault recording time. The time the disturbance recording continues after all activated triggers are reset. Use the setting tPost to set this time.
tLim	Limit time. The maximum allowed recording time after the disturbance recording was triggered. The limit time is used to eliminate the consequences of a trigger that does not reset within a reasonable time interval. It limits the maximum recording time of a recording and prevents subsequent overwriting of already stored disturbances.Use the setting tLim to set this time.

Figure 49: The recording times definition

Analog signals

Up to 10 analog signals (five voltages and five currents from the transformer module) can be selected for recording and triggering if the disturbance recorder function is installed. If fewer than 10 signals are selected, the maximum storing capacity in the flash memories, regarding total recording time are increased.

A user-defined name for each of the signals can be programmed in the terminal.

For each of the 10 analog signals, *Operation* = *On* means that it is recorded by the disturbance recorder. The trigger is independent of the setting of *Operation*, and triggers even if operation is set to *Off*. Both undervoltage and overvoltage can be used as trigger condition. The same applies for the current signals.

The check of the trigger condition is based on peak-to-peak values. When this is found, the absolute average value of these two peak values is calculated. If the average value is above the threshold level for an overvoltage or overcurrent trigger, this trigger is indicated with a greater than (>) sign with the user-defined name.

If the average value is below the set threshold level for an undervoltage or undercurrent trigger, this trigger is indicated with a less than (<) sign with its name. The procedure is separately performed for each channel.

This method of checking the analog start conditions gives a function which is insensitive to DC offset in the signal. The operate time for this start is typically in the range of one cycle, 20 ms for a 50 Hz network.

The analog signals are presented only in the disturbance recording, but they affect the entire disturbance report when being used as triggers.

Binary signals

Up to 48 binary signals can be selected from the signal list, where all available signals are grouped under each function. The 48 signals can be selected from internal logical signals and binary input signals. Each of the 48 signals can be selected as a trigger of the disturbance report. It is also possible to set if the trigger should be activated on a logic 1 or a logic 0. A binary signal can be selected to activate the red LED on the local HMI.

A user-defined name for each of the signals can be programmed in the terminal.

The selected 48 signals are presented in the event list and the disturbance recording. But they affect the whole disturbance report when they are used as triggers.

The indications, that are to be automatically scrolled on the HMI when a disturbance has been recorded are also selected from these 48 signals with the HMI Indication Mask.

Trigger signals

The trigger conditions affect the entire disturbance report. As soon as a trigger condition is fulfilled, a complete disturbance report is recorded. On the other hand, if no trigger condition is fulfilled, there is no disturbance report, no calculation of distance to fault, no indications, and so on. This implies the importance of choosing the right signals as trigger conditions.

A trigger can be of type:

- Manual trigger
- Binary-signal trigger
- Analog-signal trigger (over/under function)

Manual trigger

A disturbance report can be manually triggered from the local HMI, a front-connected PC, or SMS. When the trigger is activated, the manual trigger signal is generated. This feature is especially useful for testing.

Manual trigger from the local HMI is found at:

DisturbReport
ManualTrig

Binary trigger

Any binary signal state (logic one or a logic zero) can be selected to generate a trigger. The binary signal must remain in a steady state for at least 15 ms to be valid.

When a binary signal is selected to generate a trigger from a logic zero, the selected signal will not be listed in the indications list of the disturbance report.

Analog trigger

All analog signals are available for trigger purposes, no matter if they are recorded in the disturbance recorder or not. But the disturbance recorder function must be installed in the terminal.

Retrigger

Under certain circumstances the fault condition may reoccur during the postfault recording, for instance by automatic reclosing to a still faulty network. In order to capture the new fault it is possible to allow retriggering during the PostFault recording.

1.3 Calculations

The main part of the settings for the Disturbance Report is found on the local human-machine interface (HMI) at:

Settings
DisturbReport

The settings include:

Operation	Disturbance Report (On/Off)
ReTrig	Re-trigger during post-fault state (On/Off)
SequenceNo	Sequence number (0-255) (normally not necessary to set)
RecordingTimes	Recording times for the Disturbance Report and the event/indication logging, including pre-fault time, post-fault time, and limit time for the entire disturbance
BinarySignals	Selection of binary signals, trigger conditions, HMI indication mask and HMI red LED option
AnalogSignals	Recording mask and trigger conditions
FaultLocator	Distance measurement unit (km/miles/%)
	km or miles selected under line reference

User-defined names of analog signals can be set at:

Configuration
AnalogInputs

The user-defined names of binary signals can be set at:

Configuration
DisturbReport
Input n (n=1-48)

The analog and binary signals appear with their user-defined names.

Settings during normal conditions

Table 8: How the settings affect different functions in the disturbance report

HMI Setting menu	Function	Distur-bance summary (on HMI)	Distur-bance recorder	Indica-tions	Event list (SMS)	Trip values	Fault loca-tor
Operation	Operation (On/Off)	Yes	Yes	Yes	Yes	Yes	Yes
Record-ing times	Recording times (tPre, tPost, tLim)	No	Yes	No	Yes	No	No
Binary sig-nals	Trigger operation and trigger level	Yes	Yes	Yes	Yes	Yes	Yes
	Indication mask (for automatic scrolling)	Yes	No	No	No	No	No
Analog signals	Operation (On/Off)	No	Yes	No	No	Yes	Yes
	Trigger over/under function	Yes	Yes	Yes	Yes	Yes	Yes
Fault Locator	Fault locator set-tings (Distance Unit)	No	No	No	No	No	Yes

Operation

HMI submenu:

Settings
DisturbReport
Operation

Operation can be set to On or Off. If Off is selected, note that no disturbance report is registered, including indications, fault locator, event recorder, and disturbance recorder.

Operation = Off:

- Disturbances are not stored.
- LED information (yellow - start, red - trip) is not stored or changed.
- No disturbance summary is scrolled on the local HMI.

Operation = On:

- Disturbances are stored, disturbance data can be read from the local HMI and from a front-connected PC or Station Monitoring System (SMS).
- LED information (yellow - start, red - trip) is stored.
- The disturbance summary is automatically scrolled on the local HMI for the two latest registered disturbances, until cleared.

Post re-trigger can be set to On or Off

Postretrig = On:

Re-trigger during the set post-fault time is enabled.

Postretrig = Off:

Re-trigger during the set post fault time is not accepted.

Sequence number

HMI submenu:

Settings
  DisturbReport
    SequenceNo

Normally, this setting option is seldom used. Each disturbance is assigned a number in the disturbance report. The first disturbance each day normally receives *SequenceNo = 0*. The value of *SequenceNo* that can be read in the service report is the number that will be assigned to the next disturbance registered during that day.

In normal use, the sequence number is increased by one for each new disturbance until it is reset to zero each midnight.

Recording times

HMI submenu:

Settings
DisturbReport
RecordingTimes

Under this submenu, the different recording times for the disturbance report are set (the pre-fault time, post-fault time, and limit time). These recording times affect the disturbance recorder and event recorder functions. The total recording time, tRecording, of a recorded disturbance is:

tRecording =	tPre + tFault + tPost, or tPre + tLim, depending on which criterion stops the current disturbance recording.

Binary signals

HMI submenu:

Configuration
DisturbReport
Input n (n=1-48)

Up to 48 binary signals can be selected from the signal list, where all available signals are grouped function by function. The 48 signals can be selected among internal logical signals and binary input signals. Each selected signal is registered by the disturbance recorder, event recorder, and indication functions during a recording.

A user-defined name for each of the signals can be entered. This name can comprise up to 13 characters.

HMI submenu:

Settings
DisturbReport
BinarySignals

For each of the 48 signals, it is also possible to select if the signal is to be used as a trigger for the start of the disturbance report (*TrigOperation*), and if the trigger should be activated at a logical 1 or 0 level (*TrigLevel*).

The indications in the disturbance summary, that are automatically scrolled on the HMI when a disturbance is registered, are also selected from these 48 signals using the indication mask.

Analog signals

HMI submenu:

> **Settings**
> **DisturbReport**
> **AnalogSignals**

This HMI submenu is only available when the disturbance recorder option is installed. For each of the 10 analog signals (five voltages and five currents), Operation = On means that it is recorded by the disturbance recorder. If fewer than 10 signals are selected, the maximum storing capacity in the flash memories for total recording time becomes longer.

Both undervoltage and overvoltage can be used as trigger condition. The same applies for the current signals. The trigger is independent of the setting of *Operation* and triggers even if *Operation = Off*.

A user-defined name for each of the signals can be entered. It can consist of up to 13 characters. It is found at:

> **Configuration**
> **AnalogInputs**

Behaviour during test mode

When the terminal is set to test mode, the behaviour of the disturbance report can be controlled by the test mode disturbance report settings **Operation** and **DisturbSummary** available on the local HMI under:

> **Test/Testmode/DisturbReport**

The impact of the settings are according to the following table:

Table 9: Disturbance report settings

Operation	**Disturb-Summary**	**Then the results are...**
Off	Off	• Disturbances are not stored. • LED information is not displayed on the HMI and not stored. • No disturbance summary is scrolled on the HMI.
Off	On	• Disturbances are not stored. • LED information (yellow - start, red - trip) are displayed on the local HMI but not stored in the terminal. • Disturbance summary is scrolled automatically on the local HMI for the two latest recorded disturbances, until cleared. • The information is not stored in the terminal.
On	On or Off	• The disturbance report works as in normal mode. • Disturbances are stored. Data can be read from the local HMI, a front-connected PC, or SMS.- LED information (yellow - start, red - trip) is stored. • The disturbance summary is scrolled automatically on the local HMI for the two latest recorded disturbances, until cleared. • All disturbance data that is stored during test mode remains in the terminal when changing back to normal mode.

2 Indications

2.1 Application

The indications from all the 48 selected binary signals are shown on the local human-machine interface (HMI) and on the Station Monitoring System (SMS) for each recorded disturbance in the disturbance report. The LEDs on the front of the terminal display start and trip indications.

2.2 Functionality

The indications shown on the HMI and SMS give an overview of the status of the 48 event signals during the fault. On the HMI, the indications for each recorded disturbance are presented at:

DisturbReport
    Disturbances
        Disturbance n (n=1-10)

All selected signals can be internally produced signals or emerge from binary input channels.

The indications are registered only during the fault time of a recorded disturbance, as long as any trigger condition is activated. A part or all of these indications can be automatically scrolled on the local HMI after a disturbance is recorded, until acknowledged with the C button on the HMI. They are selected with the indication mask.

The signal name for internal logical signals presented on the screen follows the signal name, which can be found in the signal list in each function description of the “Technical reference manual”. Binary input signals are displayed with their user-defined names.

The LED indications display this information:

Green LED:

- Steady light — In Service
- Flashing light — Internal fail, the INT--FAIL internal signal is high
- Dark — No power supply

Yellow LED:

- Steady light — A disturbance report is triggered
- Flashing light — The terminal is in test mode or in configuration mode

Red LED:

- Steady light — Trig on binary signal with HMI red LED option set
- Flashing light — The terminal is in configuration mode

2.3 Calculations

The signals to be displayed as indications are selected in the disturbance report setting. This can be found on the local HMI at:

Settings
  DisturbReport
    BinarySignals
      Input n (n=1-48)

3 Disturbance recorder

3.1 Application

Use the disturbance recorder to achieve a better understanding of the behavior of the power network and related primary and secondary equipment during and after a disturbance. An analysis of the recorded data provides valuable information that can be used to improve existing equipment. This information can also be used when planning for and designing new installations.

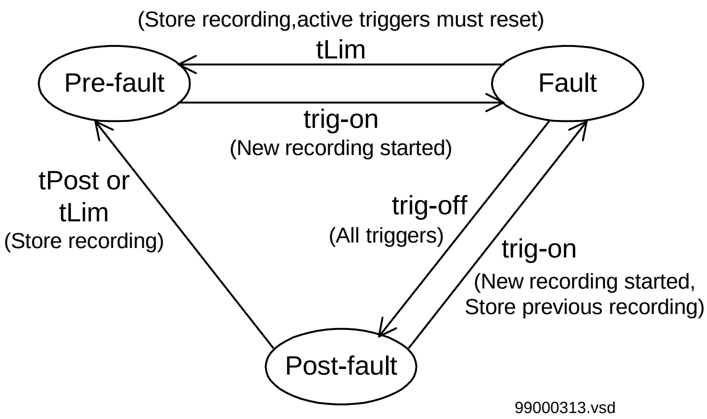
The disturbance recording function in the REx 5xx terminals is characterized by great flexibility as far as starting conditions and recording times, and large storage capacity are concerned. Thus, the disturbance recorders are not dependent on the operation of protective functions, and they can record disturbances that were not discovered by protective functions for one reason or another.

The disturbance recording function in the REx 5xx terminals is fully adequate for the recording of disturbances for the protected object.

Use available software tools to retrieve the recordings and the evaluation software REVAL to analyze, evaluate and print recordings.

3.2 Functionality

Disturbance recording is based on the continuous collection of network data, analog values and binary signals, in a cyclic buffer. The buffer operates according to the FIFO principle, old data will be overwritten as new data arrives when the buffer is full. The size of this buffer is determined by the set pre-fault recording time.



Upon detection of a fault condition (triggering), the data storage continues in another part of the memory. The storing goes on as long as the fault condition prevails - plus a certain additional time. The length of this additional part is called the post-fault time and it can be set in the disturbance report. The above mentioned two parts form a disturbance recording. The whole memory acts as a cyclic buffer and when it is full, the oldest recording is overwritten.

A user-defined name for each of the signals can be programmed in the terminal.

Recording Capacity

The recording function can record all analog inputs in the transformer module and up to 48 binary signals. To maximise the use of the memory, the number of analog channels to be recorded is user-selectable by programming and can be set individually for each analog input. The recorded binary signals can be either true binary input signals or internal logical signals created by the functions.

Memory capacity

The maximum number of recordings stored in the memory is 10. So depending on the set recording times and the recording of the enabled number of channels, the memory can contain a minimum of six and a maximum of 10 disturbance recordings comprising of both header part and data part. But the header part for the last 10 recordings is always available.

Time tagging

The terminal has a built-in, real-time clock and calendar. This function is used for time tagging of the recorded disturbances. The time tagging refers to the activation of the trigger that starts the disturbance recording.

Signal processing

The processing of analog signals is handled by a dedicated DSP (digital signal processor). Other functions are implemented in the main CPU. The memory is shared with other functions.

The numerical signals coming from the A/D conversion module in serial form are converted to parallel form in a dedicated DSP. The analog trigger conditions are also checked in the DSP.

A check of the start conditions is performed by searching for a maximum value. This is a positive peak. The function also seeks a minimum value, which is the negative peak.

When this is found, the absolute average value is calculated. If this value is above the set threshold level for the overfunction on the channel in question, an overfunction start on that channel is indicated. The overfunction is indicated with a greater than (>) sign.

Similarly, if the average value is below the set threshold level for underfunction on the channel in question, an underfunction start on that channel is indicated. The underfunction is indicated with a less than (<) sign.

The procedure is separately performed for each channel. This method of checking the analog start conditions gives a function that is insensitive to DC offset in the signal. The operating time for this start is typically in the range of one cycle, 20 ms in a 50 Hz network.

The numerical data, along with the result of the trigger condition evaluation, are transmitted to the main CPU. The main CPU handles these functions:

- Evaluation of the manual start condition
- Evaluation of the binary start condition, both for true binary input signals and for internally created logical signals
- Storage of the numerical values for the analog channels

The numerical data for the analog channels are stored in a cyclic pre-fault buffer in a RAM. When a trigger is activated, the data storage is moved to another area in the RAM, where the data for the fault and the subsequent post-fault period are stored. Thus, a complete disturbance recording comprises the stored data for the pre-fault, fault, and post-fault period.

The RAM area for temporary storage of recorded data is divided into sub-areas, one for each recording. The size of a subarea is governed by the sum of the set pre-fault (tPre) and maximum post-trigger (tLim) time. There is a sufficient memory capacity for at least four consecutive recordings with a maximum number of analog channels recorded and with maximum time settings. Should no such area be free at the time of a new trigger, the oldest recording stored in the RAM is overwritten.

When a recording is completed, a post recording processing occurs.

This post-recording processing comprises:

- Merging the data for analog channels with corresponding data for binary signals stored in an event buffer
- Compression of the data, which is performed without losing any data accuracy
- Storing the compressed data in a non-volatile memory (flash memory)

The recorded disturbance is now ready for retrieval and evaluation. The recording comprises the stored and time-tagged disturbance data along with relevant data from the database for configuration and parameter set-up.

Some parameters in the header of a recording are stored with the recording, and some are retrieved from the parameter database in connection with a disturbance. This means that if a parameter that is retrieved from the parameter database was changed between the time of recording and retrieval, the collected information is not correct in all parts. For this reason, all recordings should be transferred to the Station Monitoring System (SMS) workstation and then deleted in the terminal before any such parameters are changed.

3.3 Design

The recordings can be divided into two parts, the header and the data part. The data part contains the numerical values of recorded analog and binary channels. The header contains clearly written basic information about the disturbance. A part of this information is also used by REVAL to reproduce the analog and binary signals in a correct and user-friendly way. Such information is primary and secondary instrument transformer ratings.

Table 10: Disturbance header

Parameter	Parameter data-base	Stored with distur-ance
General		
Station, object and ID	x	
Date and time		x
Sequence number		x
CT earthing	x	
Time synchronization source	x	
Collection window parameters tPre, tPost, tLim		x
Prefault phase-to-phase voltage and current RMS values		x
Trig signal and test flag		x
Analog signals		
Signal name	x	
Primary and secondary instrument transformer rating	x	
Undertrig: level and operation	x	
Overtrig: level and operation	x	

Parameter	**Parameter data-base**	**Stored with distur-ance**
Undertrig status at time of trig		x
Overtrig status at time of trig		x
Instantaneous phase voltage at time of trig		x
Instantaneous phase current at time of trig		x
Phase voltage and phase current before trig (prefault)		x
Phase voltage and phase current after trig (fault)		x
Binary signals		
Signal name		x
Type of contact (trig level)	x	
Trig operation	x	
Signal status at time of trig		x
Trig status at time of trig		x

3.4 Calculations

The setting parameters specific for the disturbance recording function are available in the menu tree under:

Settings
DisturbReport
Operation
SequenceNo
RecordingTimes
BinarySignals
AnalogSignals

The list of parameters in the “Technical reference manual”, explains the meaning of the abbreviations used in connection with setting ranges.

Remember that values of parameters set elsewhere in the menu tree are linked to the information on a recording. Such parameters are, for example, station and object identifiers, CT and PT ratios.

The sequence number of the recordings is a specific parameter for the disturbance recorder and is used to identify the different recordings. By combining the date and the sequence number for a recording, the recording can be uniquely identified. The sequence number is also shown under:

Settings
DisturbReport
SequenceNo

The read value on the local human-machine interface (HMI) display is the sequence number that the next recorded disturbance receives. The number is automatically increased by one for each new recording and is reset to zero at each midnight. The sequence number can also be set manually.

4 Event recorder

4.1 Application

When using a front-connected PC or Station Monitoring System (SMS), an event list can be available for each of the recorded disturbances in the disturbance report. Each list can contain up to 150 time-tagged events. These events are logged during the total recording time, which depends on the set recording times (pre-fault, post-fault and limit time) and the actual fault time. During this time, the first 150 events for all the 48 selected binary signals are logged and time tagged. This list is a useful instrument for evaluating a fault and is a complement to the disturbance recorder.

To obtain this event list, the event recorder function (basic in some terminals and optional in others) must be installed.

4.2 Functionality

When one of the trig conditions for the disturbance report is activated, the events are collected by the main processing unit, from the 48 selected binary signals. The events can come from both internal logical signals and binary input channels. The internal signals are time tagged in the main processing module, while the binary input channels are time tagged directly on each I/O module. The events are collected during the total recording time, *tRecording*, and they are stored in the disturbance report memory at the end of each recording.

The name of the binary input signal that appears in the event list is the user-defined name that can be programmed in the terminal.

The time tagging of events emerging from internal logical signals and binary input channels has a resolution of 1 ms.

4.3 Calculations

The settings of the event recorder consist of the signal selection and the recording times. It is possible to select up to 48 binary signals, either internal signals or signals coming from binary input channels. These signals coincide with the binary signals recorded by the disturbance recorder. The disturbance summary indications that are to scroll automatically on the local human-machine interface (HMI), can only be selected from these 48 event channels.

The signal selection is found at:

Settings
DisturbReport
BinarySignals
Input n (n=1-48)

Each of the up to 48 event channels can be selected from the signal list, consisting of all available internal logical signals and all binary input channels.

For each of the binary input and output signals, a user-defined name can be programmed at:

Configuration
I/O
Slotnn-XXXX (ex. Slot15-BOM3)

5 Trip value recorder

5.1 Application

The main objective of line protection and monitoring terminals is fast, selective and reliable operation for faults on a protected object. Besides this, information on the values of the currents and voltages before and during the fault is valuable to understand the severity of the fault.

The trip value recorder in the REx 5xx series of terminals provides this information on the HMI and via SCS/SMS. The function is an optional software module in the terminal.

The function calculates the pre-fault and fault values of currents and voltages and presents them as phasors with amplitude and argument.

5.2 Design

Pre-fault and fault phasors of currents and voltages are filtered from disturbance data stored in digital sample buffers.

When the disturbance report function is triggered, the trip value recorder function starts to calculate the frequency of the analogue channel U1. If the calculation fails, a default frequency is read from database to ensure further execution of the function.

Then the sample for the fault interception is looked for by checking the non-periodic changes. The channel search order is U1, U2, U3, I1, I2, I3, I4, I5 and U5.

If no error sample is found, the trig sample is used as the start sample for the Fourier estimation of the complex values of currents and voltages. The estimation uses samples during one period before the trig sample. In this case the calculated values are used both as pre-fault and fault values.

If an error sample is found the Fourier estimation of the prefault values starts 1.5 period before the fault sample. The estimation uses samples during one period. The postfault values are calculated using the Recursive Least Squares (RLS) method. The calculation starts a few samples after the fault sample and uses samples during 1/2 - 2 periods depending on the shape of the signals.

The pre-fault time (tPre) should be at least 0.1 s to ensure enough samples for the estimation of pre-fault trip values.

5.3 Calculations

Customer specific names for all the ten analogue inputs (five currents and five voltages) can be entered. Each name can have up to 13 alphanumeric characters. These names are common for all functions within the disturbance report functionality.

The user-defined names for the analogue inputs are set under the menu:

Configuration
  AnalogInputs
    U1 (U2..U5, I1..I5)

6 Monitoring of AC analog measurements

6.1 Application

Fast, reliable supervision of different analogue quantities is of vital importance during the normal operation of a power system.

Operators in the control centres can, for example:

- Continuously follow active and reactive power flow in the network
- Supervise the busbar voltage and frequency

Different measuring methods are available for different quantities. Current and voltage instrument transformers provide the basic information on measured phase currents and voltages in different points within the power system. At the same time, currents and voltages serve as the input measuring quantities to power and energy meters, protective devices and so on.

Further processing of this information occurs within different control, protection, and monitoring terminals and within the higher hierarchical systems in the secondary power system.

6.2 Functionality

The REx 5xx protection, control, and monitoring terminals have as basic the functionality to measure and further process information about up to five input currents and five input voltages. The number of processed alternate measuring quantities depends on the type of terminal and built-in options. Additional information is also available:

- Mean values of measured currents I in the first three current measuring channels.
- Mean values of measured voltages U in the first three voltage measuring channels.
- Three-phase active power P as measured by the first three current and voltage measuring channels.
- Three-phase reactive power Q as measured by the first three current and voltage measuring channels.
- Three-phase apparent power S as measured by the first three current and voltage measuring channels.
- Frequency f.

The accuracy of measurement depends on the requirements. Basic accuracy satisfies the operating (information) needs. An additional calibration of measuring channels is necessary and must be ordered separately when the requirements on accuracy of the measurement are higher. Refer to the technical data and ordering particulars for the particular terminal.

The information on measured quantities is then available for the user at different locations:

- Locally by means of the local human-machine interface (HMI) unit.
- Locally by means of a front-connected personal computer (PC).
- Remotely over the LON bus to the station control system (SCS)
- Remotely over the SPA port to the station monitoring system (SMS).

User-defined measuring ranges

Each measuring channel has an independent measuring range from the others. This allows the users to select the most suitable measuring range for each measuring quantity on each monitored object of the power system. This gives a possibility to optimize the functionality of the power system.

Continuous monitoring of the measured quantity

Users can continuously monitor the measured quantity in each channel by means of four built-in operating thresholds (figure 50). The monitoring has two different modes of operating:

- Overfunction, when the measured current exceeds the HiWarn or HiAlarm pre-set values.
- Underfunction, when the measured current decreases under the LowWarn or LowAlarm pre-set values.

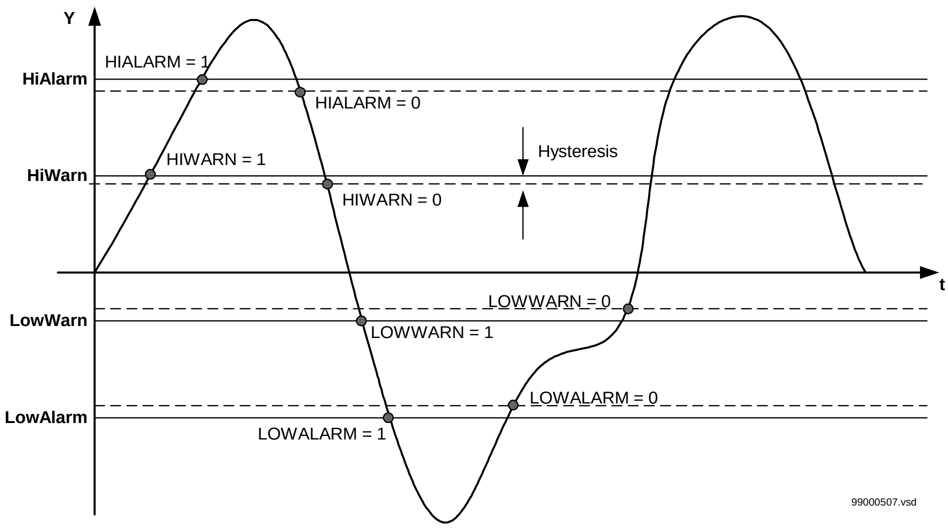


Figure 50: Presentation of the operating limits.

Each operating level has its corresponding functional output signal:

- HIWARN
- HIALARM
- LOWWARN
- LOWALARM

The logical value of the functional output signals changes according to Figure 50.

The user can set the hysteresis, which determines the difference between the operating and reset value at each operating point, in wide range for each measuring channel separately. The hysteresis is common for all operating values within one channel.

Continuous supervision of the measured quantity

The actual value of the measured quantity is available locally and remotely. The measurement is continuous for each channel separately, but the reporting of the value to the higher levels depends on the selected reporting mode. The following basic reporting modes are available:

- Periodic reporting.
- Periodic reporting with dead-band supervision in parallel.
- Periodic reporting with dead-band supervision in series.
- Dead-band reporting.

Users can select between two types of dead-band supervision:

- Amplitude dead-band supervision (ADBS).
- Integrating dead-band supervision (IDBS).

Amplitude dead-band supervision

If a measuring value is changed, compared to the last reported value, and the change is larger than the +/- ΔY predefined limits that are set by user, then the measuring channel reports the new value to a higher level, if this is detected by a new measuring sample. This limits the information flow to a minimum necessary. Figure 51 shows an example of periodic reporting with the amplitude dead-band supervision. The picture is simplified: the process is not continuous but the values are evaluated with a time interval of one second from each others.

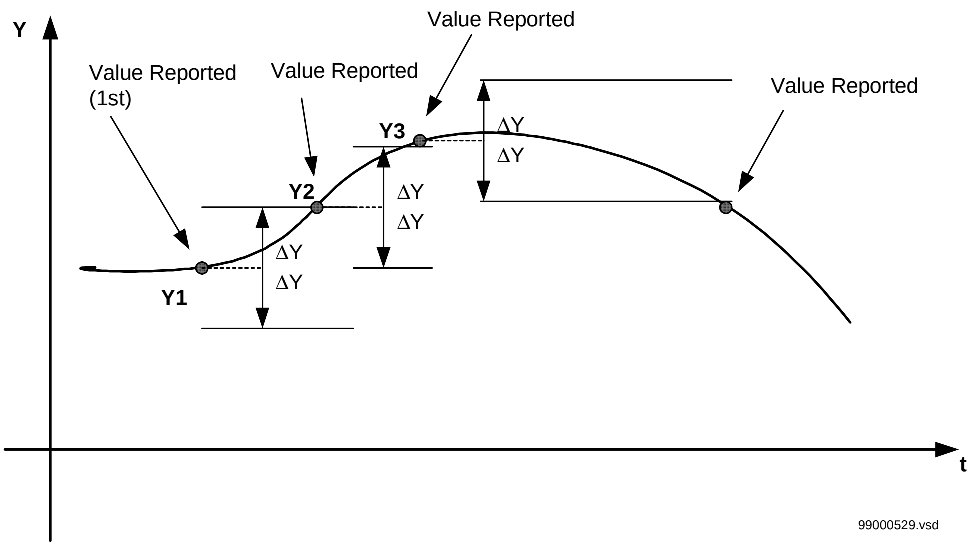


Figure 51: Amplitude dead-band supervision reporting

After the new value is reported, the +/- ΔY limits for dead-band are automatically set around it. The new value is reported only if the measured quantity changes more than defined by the +/- ΔY set limits.

Integrating dead-band supervision

The measured value is reported if the time integral of all changes exceeds the pre-set limit (figure 52), where an example of reporting with integrating dead-band supervision is shown. The picture is simplified: the process is not continuous but the values are evaluated with a time interval of one second from each other.

The last value reported (Y1 in figure 52) serves as a basic value for further measurement. A difference is calculated between the last reported and the newly measured value during new sample and is multiplied by the time increment (discrete integral). The absolute values of these products are added until the pre-set value is exceeded. This occurs with the value Y2 that is reported and set as a new base for the following measurements (as well as for the values Y3, Y4 and Y5).

The integrating dead-band supervision is particularly suitable for monitoring signals with small variations that can last for relatively long periods.

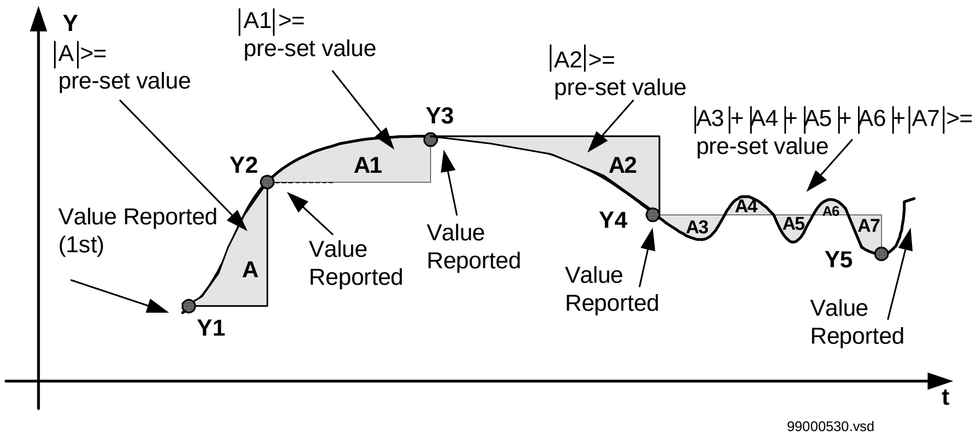


Figure 52: Reporting with integrating dead-band supervision.

Periodic reporting

The user can select the periodic reporting of measured value in time intervals between 1 and 3600 s. The measuring channel reports the value even if it has not changed for more than the set limits of amplitude or integrating dead-band supervision. To disable periodic reporting, set the reporting time interval to 0 s (figure 53).

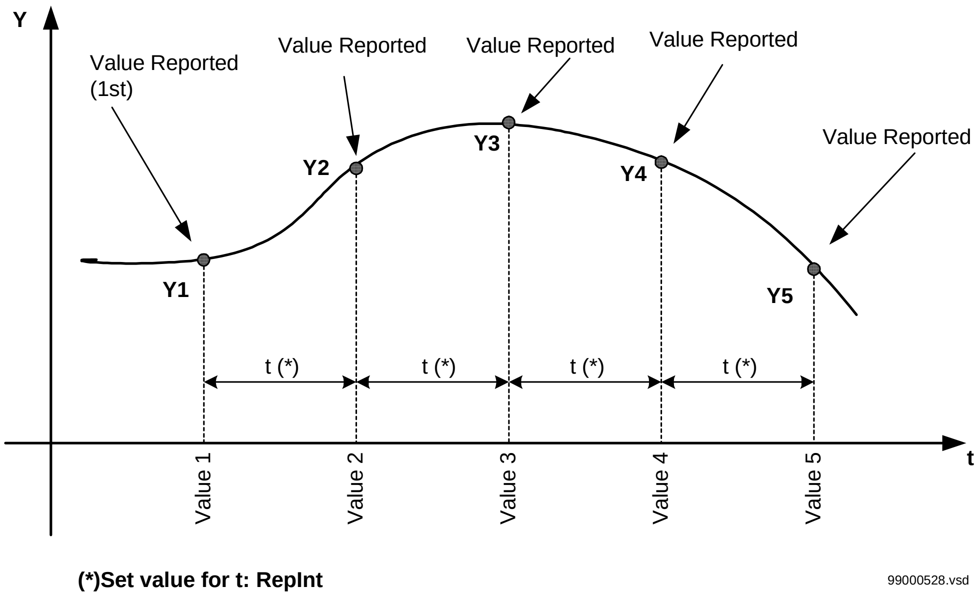


Figure 53: Periodic reporting.

Periodic reporting with parallel dead-band supervision

The newly measured value is reported:

- After each time interval for the periodic reporting expired or
- When the new value is detected by the dead-band supervision function.

The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.

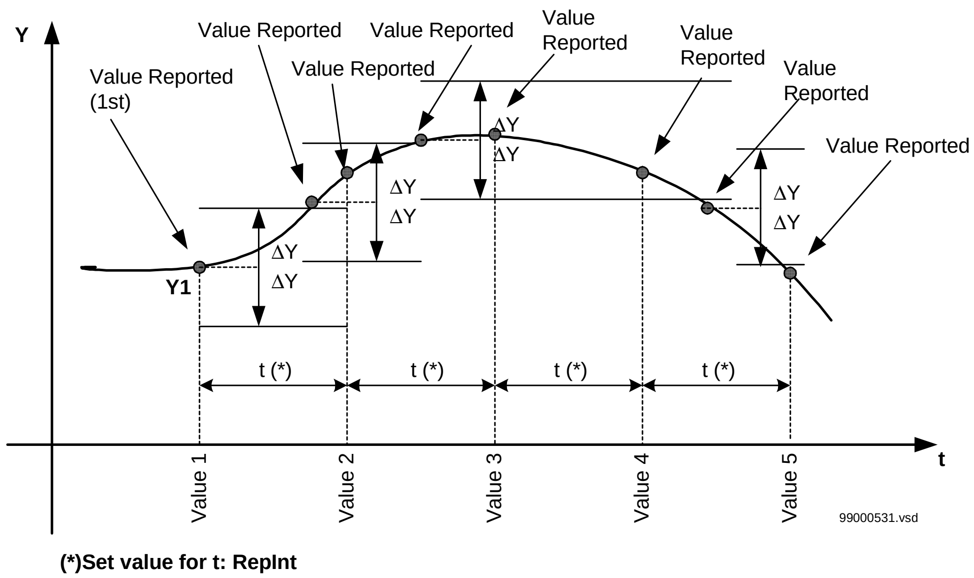
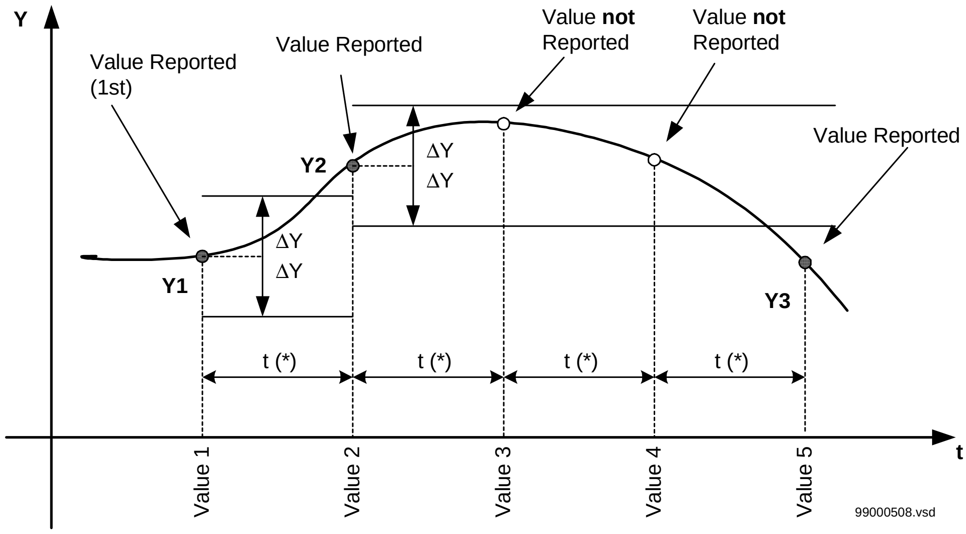


Figure 54: Periodic reporting with amplitude dead-band supervision in parallel.

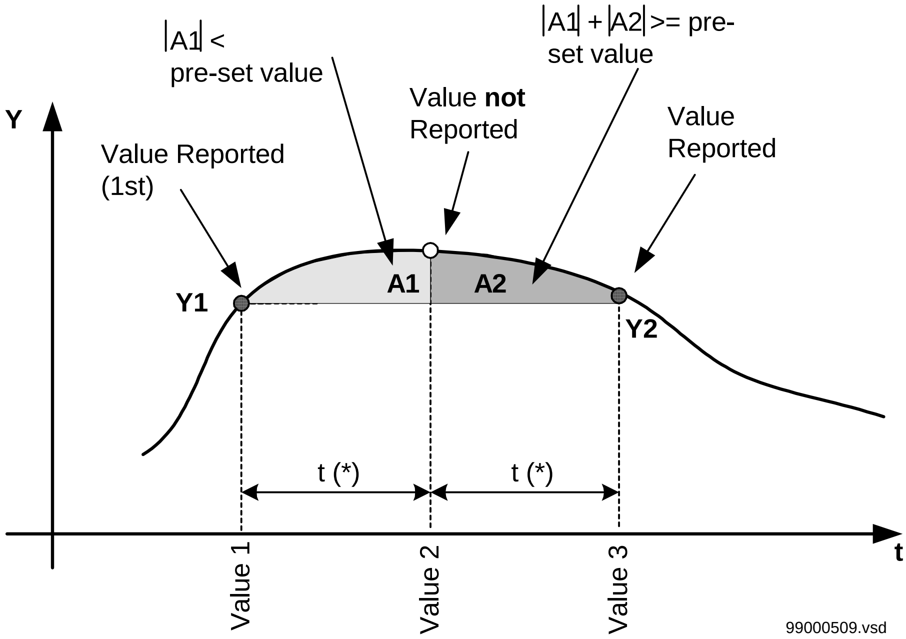
Periodic reporting with serial dead-band supervision

Periodic reporting can operate serially with the dead-band supervision. This means that the new value is reported only if the set time period expired and if the dead-band limit was exceeded during the observed time (figures 55 and 56). The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.



(*)Set value for t: RepInt

Figure 55: Periodic reporting with amplitude dead-band supervision in series.



(*)Set value for t: RepInt

Figure 56: Periodic reporting with integrating dead-band supervision in series

Combination of periodic reportings

The reporting of the new value depends on setting parameters for the dead-band and for the periodic reporting. Table 11 presents the dependence between different settings and the type of reporting for the new value of a measured quantity.

Table 11: Dependence of reporting on different setting parameters:

EnDeadB*	EnIDeadB*	EnDeadBP*	RepInt*	Reporting of the new value
Off	Off	Off	0	No measured values is reported.
Off	On	On	t>0	The new measured value is reported only if the time t period expired and if, during this time, the integrating dead-band limits were exceeded (periodic reporting with integrating dead-band supervision in series).
On	Off	On	t>0	The new measured value is reported only if the time t period has expired and if, during this time, the amplitude dead-band limits were exceeded (periodic reporting with amplitude dead-band supervision in series).
On	On	On	t>0	The new measured value is reported only if the time t period expired and if at least one of the dead-band limits were exceeded (periodic reporting with dead-band supervision in series).
Off	On	Off	0	The new measured value is reported only when the integrated dead-band limits are exceeded.
On	Off	Off	0	The new measured value is reported only when the amplitude dead-band limits were exceeded.
On	On	Off	0	The new measured value is reported only if one of the dead-band limits was exceeded.
x	x	Off	t>0	The new measured value is updated at least after the time t period expired. If the dead-band supervision is additionally selected, the updating also occurs when the corresponding dead-band limit was exceeded (periodic reporting with parallel dead-band supervision).
* Please see the setting parameters in the Technical reference manual for further explanation				

6.3 Design

The design of the alternating quantities measuring function follows the design of all REx 5xx-series protection, control, and monitoring terminals that have distributed functionality, where the decision levels are placed as closely as possible to the process.

The measuring function uses the same input current and voltage signals as other protection and monitoring functions within the terminals. The number of input current and voltage transformers depends on the type of terminal and options included. The maximum possible configuration comprises five current and five voltage input channels.

Measured input currents and voltages are first filtered in analogue filters and then converted to numerical information by an A/D converter, which operates with a sampling frequency of 2 kHz.

The numerical information on measured currents and voltages continues over a serial link to one of the built-in digital signal processors (DSP). An additional Fourier filter numerically filters the received information, and the DSP calculates the corresponding values for the following quantities:

- Five input measured voltages (U1, U2, U3, U4, U5), RMS values
- Five input measured currents (I1, I2, I3, I4, I5), RMS Values
- Mean RMS value, U, of the three phase-to-phase voltages calculated from the first three phase-to-earth voltages U1, U2 and U3
- Mean RMS value, I, of the first three measured RMS values I1, I2, and I3
- Three-phase active power, P, related to the first three measured currents and voltages (I1, U1, I2, U2, I3, U3)
- Three-phase, reactive power, Q, related to the first three measured currents and voltages (I1, U1, I2, U2, I3, U3)
- Three-phase apparent power, S, related to the first three measured currents and voltages (I1, U1, I2, U2, I3, U3)
- Mean value of frequencies, f, as measured with voltages U1, U2, and U3

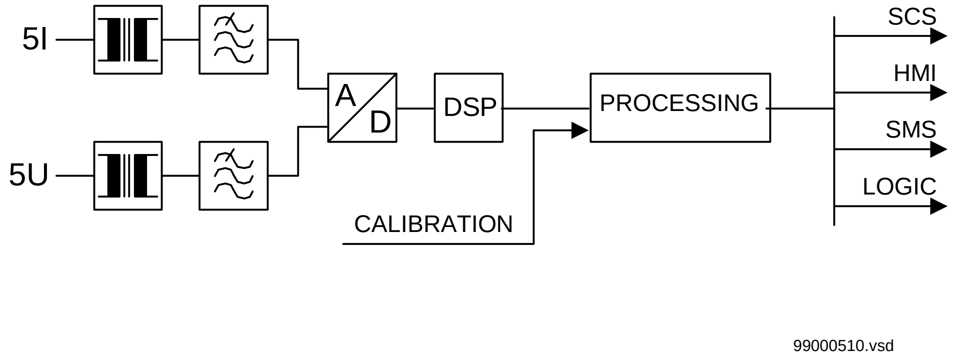


Figure 57: Simplified diagram for the function

This information is available to the user for operational purposes.

6.4 Calculations

The basic terminal parameters can be set from the HMI under the submenu:

Configuration
AnalogInputs
General
fr,CTEarth

So users can determine the rated parameters for the terminal:

- Rated frequency fr
- Position of the earthing point of the main CTs (CTEarth), which determines whether the CT earthing point is towards the protected object or the busbar

The other basic terminal parameters, related to any single analog input, can be set under the submenu:

Configuration
AnalogInputs
U1, U2, U3, U4, U5, I1, I2, I3, I4, I5, U, I, P, Q, S, f

So the users can determine the base values, the primary CTs and VTs ratios, and the user-defined names for the analog inputs of the terminal.

Under U1:

- ac voltage base value for analog input U1: U1b
- voltage transformer input U1 nominal primary to secondary scale value: U1Scale
- Name (of up to 13 characters) of the analog input U1: Name

Under U2:

- ac voltage base value for analog input U2: U2b
- voltage transformer input U2 nominal primary to secondary scale value: U2Scale
- Name (of up to 13 characters) of the analog input U2: Name

Under U3:

- ac voltage base value for analog input U3: U3b
- voltage transformer input U3 nominal primary to secondary scale value: U3Scale
- Name (of up to 13 characters) of the analog input U3: Name

Under U4:

- ac voltage base value for analog input U4: U4b
- voltage transformer input U4 nominal primary to secondary scale value: U4Scale
- Name (of up to 13 characters) of the analog input U4: Name

Under U5:

- ac voltage base value for analog input U5: U5b
- voltage transformer input U5 nominal primary to secondary scale value: U5Scale
- Name (of up to 13 characters) of the analog input U5: Name

Under I1:

- ac current base value for analog input I1: I1b
- current transformer input I1 nominal primary to secondary scale value: I1Scale
- Name (of up to 13 characters) of the analog input I1: Name

Under I2:

- ac current base value for analog input I2: I2b
- current transformer input I2 nominal primary to secondary scale value: I2Scale
- Name (of up to 13 characters) of the analog input I2: Name

Under I3:

- ac current base value for analog input I3: I3b
- current transformer input I3 nominal primary to secondary scale value: I3Scale
- Name (of up to 13 characters) of the analog input I3: Name

Under I4:

- ac current base value for analog input I4: I4b
- current transformer input I4 nominal primary to secondary scale value: I4Scale
- Name (of up to 13 characters) of the analog input I4: Name

Under I5:

- ac current base value for analog input I5: I5b
- current transformer input I5 nominal primary to secondary scale value: I5Scale
- Name (of up to 13 characters) of the analog input I5: Name

Under U:

- Name (of up to 13 characters) of the average voltage U: Name

Under I:

- Name (of up to 13 characters) of the average current I: Name

Under P:

- Name (of up to 13 characters) of the active power P: Name

Under Q:

- Name (of up to 13 characters) of the reactive power Q: Name

Under S:

- Name (of up to 13 characters) of the apparent power S: Name

Under f:

- Name (of up to 13 characters) of the frequency value f: Name

The names of the first 10 quantities automatically appears in the REVAL evaluation program for each reported disturbance.

The PST Parameter Setting Tool has to be used in order to set all remaining parameters that are related to different alternating measuring quantities.

In the settings menu it is possible to set all monitoring operating values and the hysteresis directly in the basic units of the measured quantities for each channel and for each quantity:

Settings
DisturbReport
AnalogSignals

The dead-band limits can be set directly in the corresponding units of the observed quantity for the:

- Amplitude dead-band supervision (ADBS)
- Integrating dead-band supervision (IDBS)

The IDBS area is defined by the following formula:

$$IDBS = \frac{IDeadB}{ReadFreq} = IDeadB \cdot ts$$

(Equation 57)

Where:

IDeadB	is a set operating value for IDBS in corresponding unit.
ReadFreq	is the reading frequency. It has a constant value of 1Hz.
ts = 1/ReadFreq	is the time between two samples (fixed to 1s).

The setting value for IDBS is IDeadB, and is expressed in the measuring unit of the monitored quantity (kV, A, MW, Mvar, MVA or Hz). The value is reported if the time integral area is greater than the value IDBS.

If a 0.1 Hz variation in the frequency for 10 minutes (600 s) is the event that should cause the reporting of the frequency monitored value, than the set value for IDeadB is 60 Hz.

The hysteresis can be set under the setting Hysteres.

Alarm and warning thresholds have to be set respectively under the settings HiAlarm (LowAlarm) and HiWarn (LowWarn).

See the Technical reference manual for a list of all the setting parameters.

Note!

It is important to set the time for periodic reporting and deadband in an optimized way to minimize the load on the station bus.

7 Monitoring of DC analog measurements

7.1 Application

Fast, reliable supervision of different analogue quantities is of vital importance during the normal operation of a power system. Operators in the control centres can, for example:

- Continuously follow active and reactive power flow in the network
- Supervise the busbar voltages
- Check the temperature of power transformers, shunt reactors
- Monitor the gas pressure in circuit breakers

Different measuring methods are available for different quantities. Current and voltage instrument transformers provide the basic information on measured phase currents and voltages in different points within the power system. At the same time, currents and voltages serve as the input measuring quantities to power and energy meters.

Different measuring transducers provide information on electrical and non-electrical measuring quantities such as voltage, current, temperature, and pressure. In most cases, the measuring transducers change the values of the measured quantities into the direct current. The current value usually changes within the specified mA range in proportion to the value of the measured quantity.

Further processing of the direct currents obtained on the outputs of different measuring converters occurs within different control, protection, and monitoring terminals and within the higher hierarchical systems in the secondary power system.

7.2 Functionality

The REx 5xx control, protection and monitoring terminal have a built-in option to measure and further process information from 6 up to 36 different direct current information from different measuring transducers. Six independent measuring channels are located on each independent mA input module and the REx 5xx terminals can accept from one up to six independent mA input modules, depending on the case size. Refer to the technical data and ordering particulars for the particular terminal.

Information about the measured quantities is then available to the user on different locations:

- Locally by means of the local human-machine-interface (HMI)
- Locally by means of a front-connected personal computer (PC)
- Remotely over the LON bus to the station control system (SCS)
- Remotely over the SPA port to the station monitoring system (SMS)

User-defined measuring ranges

The measuring range of different direct current measuring channels is settable by the user independent on each other within the range between -25 mA and +25 mA in steps of 0.01 mA. It is only necessary to select the upper operating limit I_Max higher than the lower one I_Min.

The measuring channel can have a value of 2 of the whole range I_Max - I_Min above the upper limit I_Max or below the lower limit I_Min, before an out-of-range error occurs. This means that with a nominal range of 0-10 mA, no out-of-range event will occur with a value between -0.2 mA and 10.2 mA.

User can this way select for each measuring quantity on each monitored object of a power system the most suitable measuring range and this way optimize a complete functionality together with the characteristics of the used measuring transducer.

Continuous monitoring of the measured quantity

The user can continuously monitor the measured quantity in each channel by means of six built-in operating limits (figure 58). Two of them are defined by the operating range selection: I_Max as the upper and I_Min as the lower operating limit. The other four operating limits operate in two different modes:

- Overfunction, when the measured current exceeds the HiWarn or HiAlarm pre-set values
- Underfunction, when the measured current decreases under the LowWarn or LowAlarm pre-set values

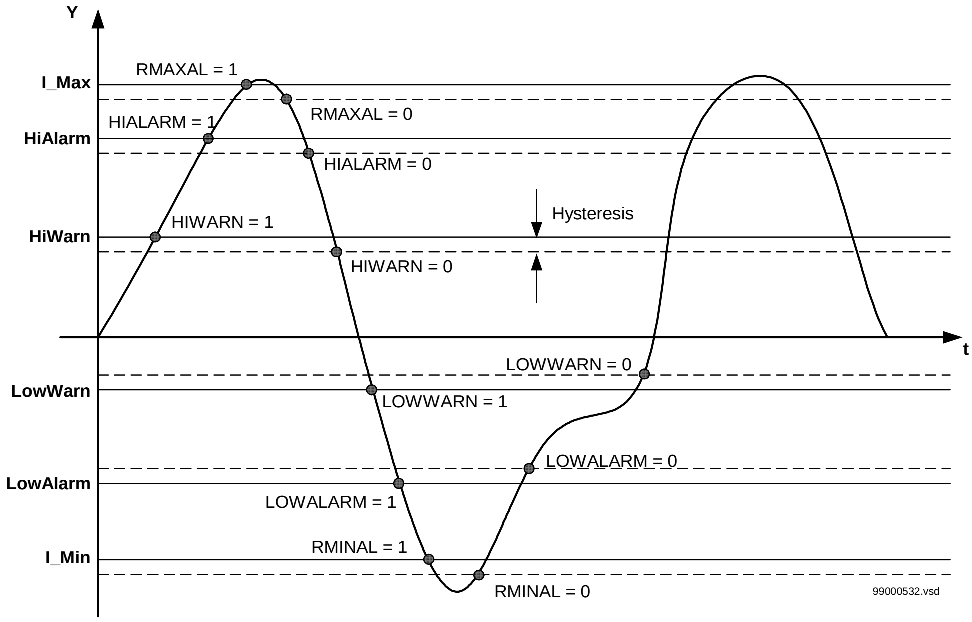


Figure 58: Presentation of the operating limits

Each operating level has its corresponding functional output signal:

- RMAXAL
- HIWARN
- HIALARM
- LOWWARN
- LOWALARM
- RMINAL

The logical value of the functional output signals changes according to figure 58.

The user can set the hysteresis, which determines the difference between the operating and reset value at each operating point, in wide range for each measuring channel separately. The hysteresis is common for all operating values within one channel.

Continuous supervision of the measured quantity

The actual value of the measured quantity is available locally and remotely. The measurement is continuous for each channel separately, but the reporting of the value to the higher levels (control processor in the unit, HMI and SCS) depends on the selected reporting mode. The following basic reporting modes are available:

- Periodic reporting
- Periodic reporting with dead-band supervision in parallel
- Periodic reporting with dead-band supervision in series
- Dead-band reporting

Users can select between two types of dead-band supervision:

- Amplitude dead-band supervision (ADBS).
- Integrating dead-band supervision (IDBS).

Amplitude dead-band supervision

If the changed value —compared to the last reported value— is larger than the +/- ΔY predefined limits that are set by users, and if this is detected by a new measuring sample, then the measuring channel reports the new value to a higher level. This limits the information flow to a minimum necessary. Figure 59 shows an example of periodic reporting with the amplitude dead-band supervision.

The picture is simplified: the process is not continuous but the values are evaluated at time intervals depending on the sampling frequency chosen by the user (SampRate setting).

After the new value is reported, the new +/- ΔY limits for dead-band are automatically set around it. The new value is reported only if the measured quantity changes more than defined by the new +/- ΔY set limits.

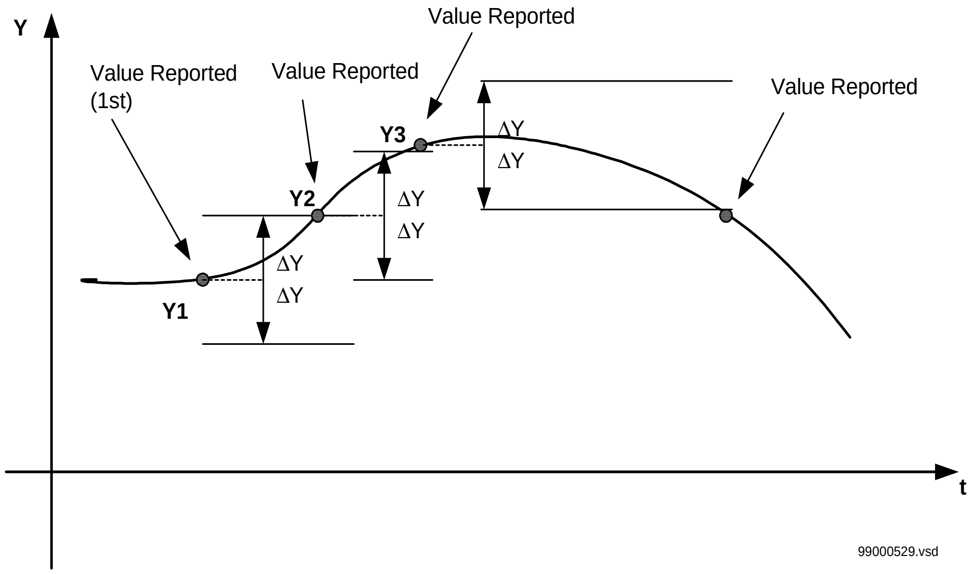


Figure 59: Amplitude dead-band supervision reporting

Integrating dead-band supervision

The measured value is updated if the time integral of all changes exceeds the pre-set limit (figure 60), where an example of reporting with integrating dead-band supervision is shown. The picture is simplified: the process is not continuous but the values are evaluated at time intervals depending on the sampling frequency chosen by the user (SampRate setting).

The last value reported (Y1 in figure 60) serves as a basic value for further measurement. A difference is calculated between the last reported and the newly measured value during new sample and is multiplied by the time increment (discrete integral). The absolute values of these products are added until the pre-set value is exceeded. This occurs with the value Y2 that is reported and set as a new base for the following measurements (as well as for the values Y3, Y4 and Y5).

The integrating dead-band supervision is particularly suitable for monitoring signals with low variations that can last for relatively long periods.

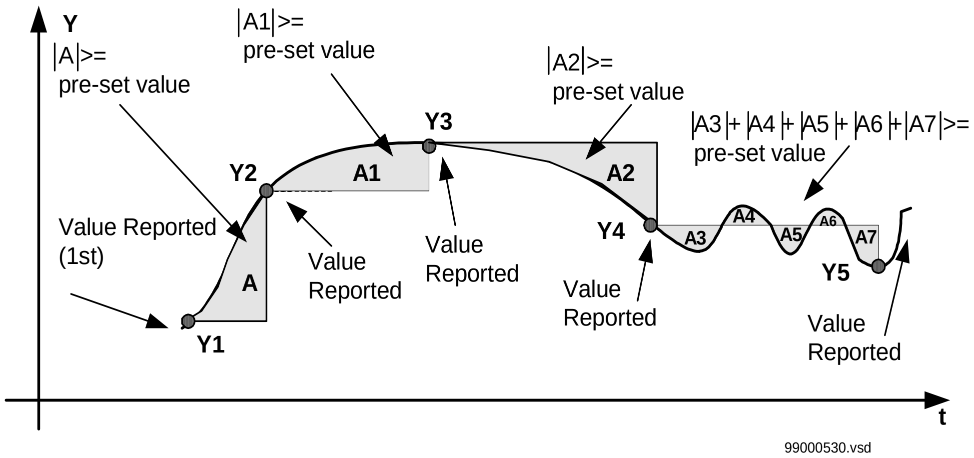


Figure 60: Reporting with integrating dead-band supervision

Periodic reporting

The user can select the periodic reporting of measured value in time intervals between 1 and 3600 s (setting RepInt). The measuring channel reports the value even if it has not changed for more than the set limits of amplitude or integrating dead-band supervision (figure 61). To disable periodic reporting, set the reporting time interval to 0 s.

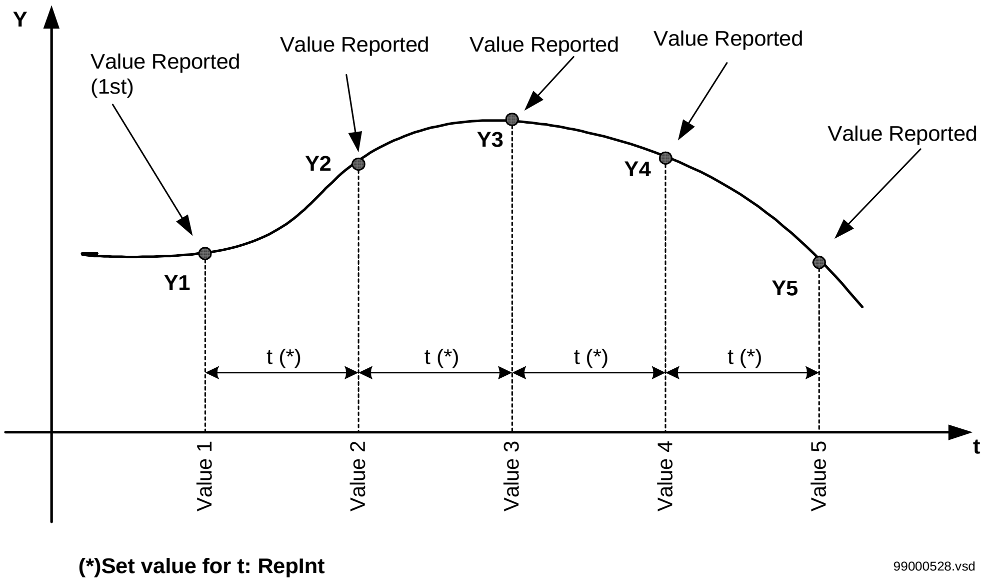


Figure 61: Periodic reporting

Periodic reporting with parallel dead-band supervision

The newly measured value is reported:

- After each time interval for the periodic reporting expired, **OR**;
- When the new value is detected by the dead-band supervision function.

The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.

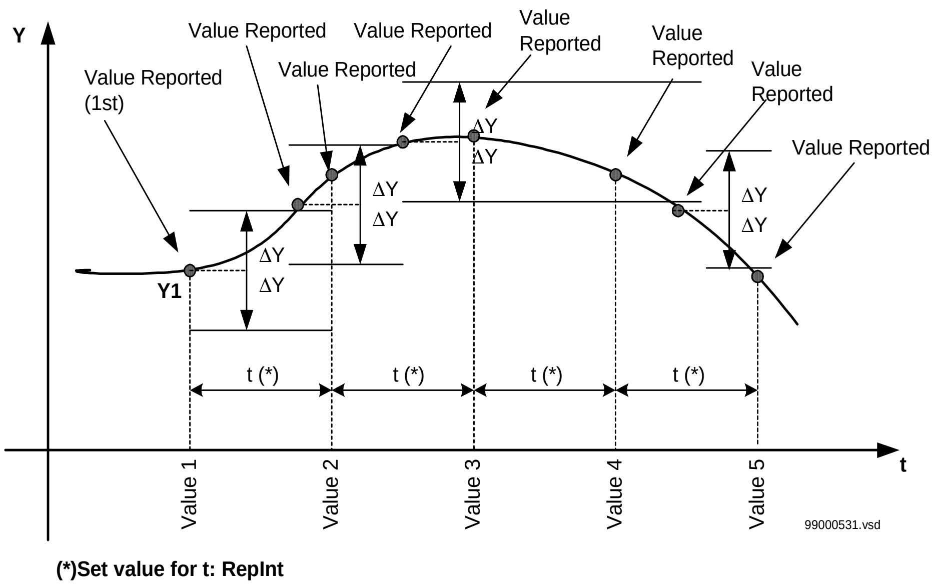
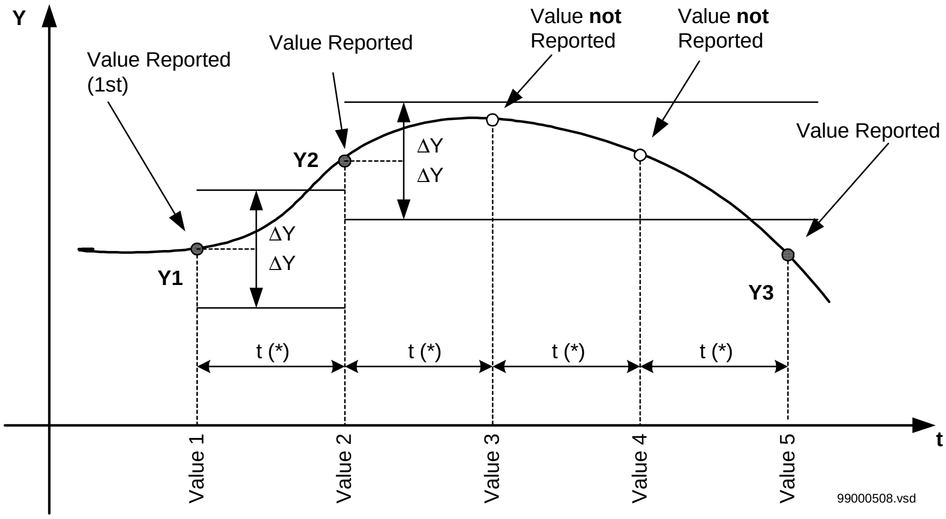


Figure 62: Periodic reporting with amplitude dead-band supervision in parallel.

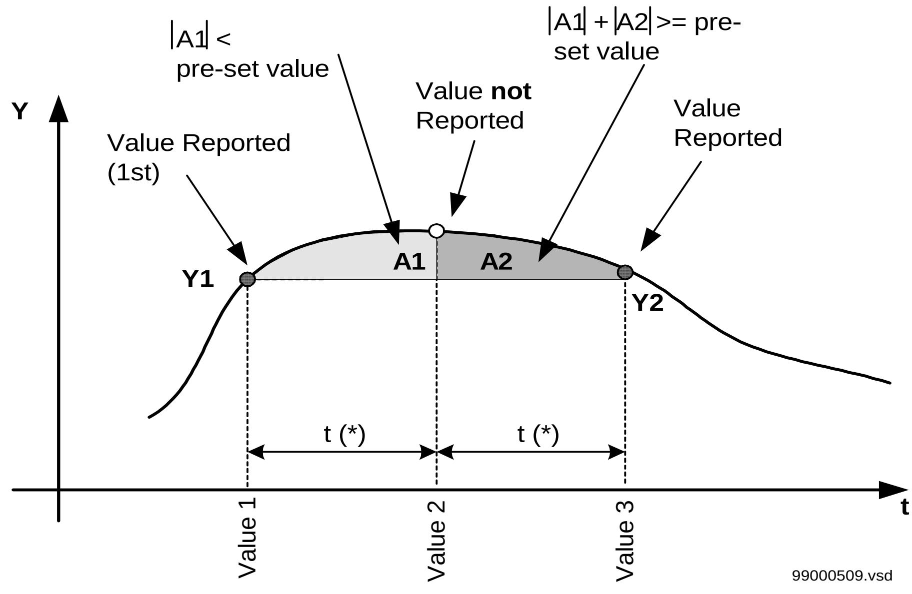
Periodic reporting with serial dead-band supervision

Periodic reporting can operate serially with the dead-band supervision. This means that the new value is reported only if the set time period expired **AND** if the dead-band limit was exceeded during the observed time (figures 63 and 64). The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.



(*)Set value for t: RepInt

Figure 63: Periodic reporting with amplitude dead-band supervision in series



(*)Set value for t: RepInt

Figure 64: Periodic reporting with integrating dead-band supervision in series

Combination of periodic reportings

The reporting of the new value depends on setting parameters for the dead-band and for the periodic reporting. Table 1 presents the dependence between different settings and the type of reporting for the new value of a measured quantity.

Table 12: Dependence of reporting on different setting parameters:

EnDeadB *	EnIDeadB *	EnDeadBP *	RepInt *	Reporting of the new value
Off	Off	Off	0	No measured values is reported
Off	On	On	t>0	The new measured value is reported only if the time t period expired and if, during this time, the integrating dead-band limits were exceeded (periodic reporting with integrating dead-band supervision in series)
On	Off	On	t>0	The new measured value is reported only if the time t period has expired and if, during this time, the amplitude dead-band limits were exceeded (periodic reporting with amplitude dead-band supervision in series)
On	On	On	t>0	The new measured value is reported only if the time t period expired and if at least one of the dead-band limits were exceeded (periodic reporting with dead-band supervision in series)
Off	On	Off	0	The new measured value is reported only when the integrated dead-band limits are exceeded
On	Off	Off	0	The new measured value is reported only when the amplitude dead-band limits were exceeded

EnDeadB *	EnIDeadB *	EnDeadBP *	RepInt *	Reporting of the new value
On	On	Off	0	The new measured value is reported only if one of the dead-band limits was exceeded
x	x	Off	t>0	The new measured value is updated at least after the time t period expired. If the dead-band supervision is additionally selected, the updating also occurs when the corresponding dead-band limit was exceeded (periodic reporting with parallel dead-band supervision)
* Please see the setting parameters in the Technical reference manual for further explanation				

7.3 Design

The design of the mA input modules follows the design of all REx 5xx-series protection, control, and monitoring terminals that have distributed functionality, where the decision levels are placed as closely as possible to the process.

Each independent measuring module contains all necessary circuitry and functionality for measurement of six independent measuring quantities related to the corresponding measured direct currents.

On the accurate input shunt resistor (R), the direct input current (from the measuring converter) is converted into a proportional voltage signal (the voltage drop across the shunt resistor is in proportion to the measured current). Later, the voltage signal is processed within one differential type of measuring channel (figure 65).

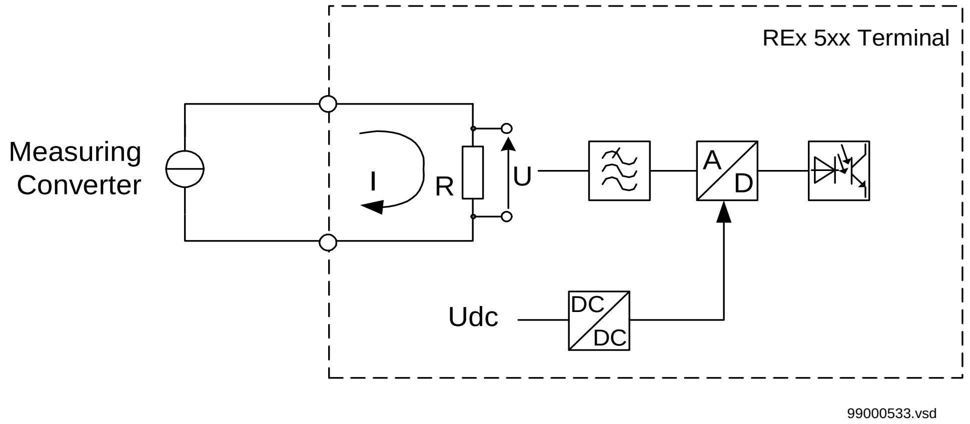


Figure 65: Simplified diagram for the function

The measured voltage is filtered by the low-pass analogue filter before entering the analogue to digital converter (A/D). Users can set the sampling frequency of the A/D converter between 5 Hz and 255 Hz to adapt to different application requirements as best as possible.

The digital information is filtered by the digital low-pass filter with the $(\sin x/x)^3$ response. The filter notch frequency automatically follows the selected sampling frequency. The relation between the frequency corresponding to the suppression of -3 dB and the filter notch frequency corresponds to the equation:

$$f_{-3dB} = 0,262 \cdot f_{notch}$$

(Equation 58)

Using optocouplers and DC/DC conversion elements that are used separately for each measuring channel, the input circuitry of each measuring channel is galvanically separated from:

- The internal measuring circuits
- The control microprocessor on the board

A microprocessor collects the digitized information from each measuring channel. The microprocessor serves as a communication interface to the main processing module (MPM).

All processing of the measured signal is performed on the module so that only the minimum amount of information is necessary to be transmitted to and from the MPM. The measuring module receives information from the MPM on setting and the command parameters; it reports the measured values and additional information—according to needs and values of different parameters.

Each measuring channel is calibrated very accurately during the production process. The continuous internal zero offset and full-scale calibration during the normal operation is performed by the A/D converter. The calibration covers almost all analogue parts of the A/D conversion, but neglects the shunt resistance.

Each measuring channel has built in a zero-value supervision, which greatly rejects the noise generated by the measuring transducers and other external equipment. The value of the measured input current is reported equal to zero (0) if the measured primary quantity does not exceed +/-0.5% of the maximum measuring range.

The complete measuring module is equipped with advanced self-supervision. Only the outermost analogue circuits cannot be monitored. The A/D converter, optocouplers, digital circuitry, and DC/DC converters, are all supervised on the module. Over the CAN bus, the measuring module sends a message to the MPM for any detected errors on the supervised circuitry.

7.4 Calculations

The PST Parameter Setting Tool has to be used in order to set all the parameters that are related to different DC analogue quantities.

Users can set the 13 character name for each measuring channel.

All the monitoring operating values and the hysteresis can be set directly in the mA of the measured input currents from the measuring transducers.

The measured quantities can be displayed locally and/or remotely according to the corresponding modules that are separately set for each measuring channel by the users (five characters).

The relation between the measured quantity in the power system and the setting range of the direct current measuring channel corresponds to this equation:

$$\mathrm{Value} = \mathrm{ValueMin} + (\mathrm{I} - \mathrm{IMin}) \cdot \frac{\mathrm{ValueMax} - \mathrm{ValueMin}}{\mathrm{IMax} - \mathrm{IMin}}$$

(Equation 59)

Where:

I_Min	is the set value for the minimum operating current of a channel in mA.
I_Max	is the set value for the maximum operating current of a channel in mA.
ValueMin	is the value of the primary measuring quantity corresponding to the set value of minimum operating current of a channel, I_Min.
ValueMax	is the value of the primary measuring quantity corresponding to the set value of maximum operating current of a channel, I_Max.
Value	is the actual value of the primary measured quantity.

Figure 66 shows the relationship between the direct mA current I and the actual value of the primary measured quantity, Value.

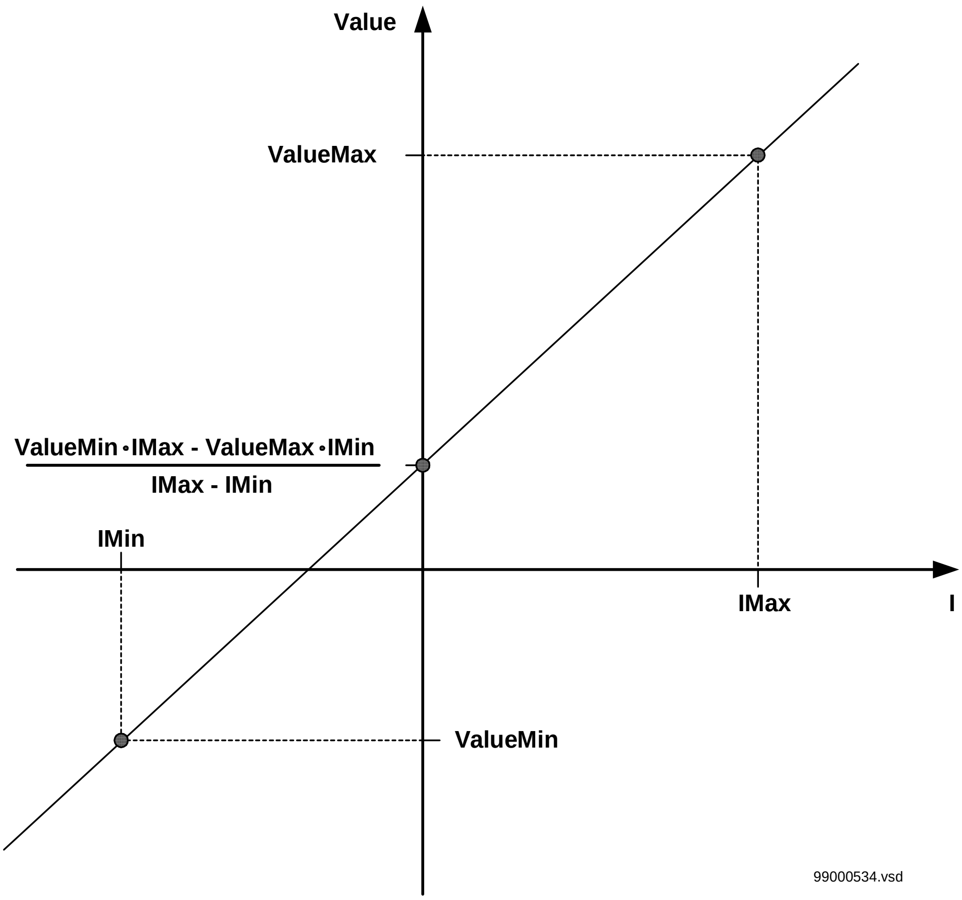


Figure 66: Relationship between the direct current (I) and the measured quantity primary value (Value)

The dead-band limits can be set directly in the mA of the input direct current for:

- Amplitude dead-band supervision ADBS
- Integrating dead-band supervision IDBS

The IDBS area [mAs] is defined by the following equation:

$$IDBS = \frac{IDeadB}{SampRate} = IDeadB \cdot ts$$

(Equation 60)

where:

IDeadB	is the set value of the current level for IDBS in mA.
SampRate	is the sampling rate (frequency) set value, in Hz.
ts = 1/SampRate	is the time between two samples in s.

If a 0.1 mA variation in the monitored quantity for 10 minutes (600 s) is the event that should cause the trigger of the IDBS monitoring (reporting of the value because of IDBS threshold operation) and the sampling frequency (SampRate) of the monitored quantity is 5 Hz, than the set value for IDBS (IDeadB) will be 300 mA:

$$IDBS = 0.1 \cdot 600 = 60[mA\ s]$$

(Equation 61)

$$IDeadB = IDBS \cdot SampRate = 60 \cdot 5 = 300[mA]$$

(Equation 62)

The polarity of connected direct current input signal can be changed by setting the ChSign to On or Off. This way it is possible to compensate by setting the possible wrong connection of the direct current leads between the measuring converter and the input terminals of the REx 5xx series unit.

The setting table lists all setting parameters with additional explanation.

Note:

It is important to set the time for periodic reporting and deadband in an optimized way to minimize the load on the station bus.

Chapter 9 Data communication

About this chapter

This chapter describes the data communication and the associated hardware.

1 Remote end data communication

1.1 Application

General

The hardware communication modules (or modems) for the Remote end data communication are available in basically three different versions:

- for optical communication
- for short range pilot wire communication
- for galvanic connection to communication equipment according to ITU (former CCITT) and EIA interface standards.

All systems are designed to be able to work at 64 kbit/s. Some of them can also work at North American standard of 56 kbit/s. This is especially pointed out in the description under each module.

If the protection terminal is located at a long distance (>100 m for V.36, X.21 and RS530 and >10m for G.703) from the communication equipment or multiplexer or if the cables run through a noisy area, optical communication should be used to interconnect the protection terminal and the communication equipment. In this case the protection terminal contains module used for optical fibre communication and a suitable optical to electrical converter is installed close to the communication equipment due to the fact that there exists no standard for optical connections to communication equipment. The optical-to-electrical converters that can be used are FOX6Plus (and FOX20) from ABB and 21-15xx or 21-16xx from FIBERDATA. The FOX6Plus together with optical fibre modem supports the G.703 co-directional interfacing and with restrictions for X.21 and V.36. 21-15xx supports V.35 and V.36 while 21-16xx supports X.21, G.703 and RS530 co-directional and contra-directional. For 21-15xx and 21-16xx short range optical fibre modem is needed.

NOTE!

When using galvanic connection between protection terminal and communication equipment or point to point galvanic connection between two protection terminals it is essential that the cable installation is carefully done. See Installation and commissioning manual for further information.

Optical connection of multiplexer is only possible if the multiplexer is of type FOX6Plus or FOX20 from ABB. The terminal can then be connected optically to the multiplexer, provided the protection is equipped with the optical fibre modem , not the short range fibre optical modem, and the FOX is equipped with an Optical Terminal Module of type N3BT.

1.2 Design

The Remote end data communication consists of two parts, one software part that handles the message structure, packing different pieces together, activate sending of the messages, unpacking received messages etc, and one hardware part forming the interface against external communication equipments. The hardware part, or built-in modems, can have either galvanic or optical connection. To ensure compatibility with a wide range of communication equipment and media, the terminal is designed to work within the signalling bandwidth of a standard CCITT PCM channel at 64 kbits/s. To enable the use in North American EIA PCM systems working at 56 kbits/s, some of the interfacing modules can be adapted to this bit rate.

The message is based on the HDLC protocol. This is a protocol for the flow management of the information on a data communication link that is widely used. The basic information unit on an HDLC link is a frame. A frame consists of:

- start (or opening) flag
- address and control fields (if included)
- data to be transmitted
- CRC word
- end (or closing) flag.

The start and stop flags are 8 bit each and the Cyclic Redundancy Check (CRC) 16 bits. The data field differs if between a message sent from a slave to a master and a message sent from a master to a slave. The principle design is according to figure 67.

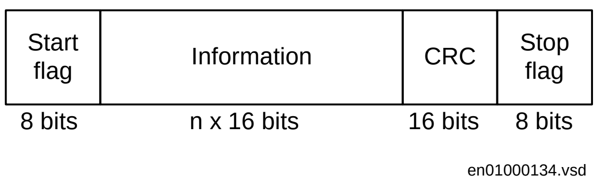


Figure 67: Data message structure

The start and stop flags are the 0111 1110 sequence (7E hexadecimal) defined in HDLC standard. The CRC is designed according to standard CRC16 definition.

The optional address field in the HDLC frame is not used, instead a separate addressing is included in the data field.

The address field is used for checking that the received message originates from the correct equipment. There is always a risk of multiplexers occasionally mixing up the messages. Each terminal is given different terminal numbers. The terminal is then programmed to accept messages only from a specific terminal number.

If the CRC function detects a faulty message, the message is thrown away and not used in the evaluation. No data restoration or retransmission are implemented.

The hardware, consisting of a Data communication module, is placed in an applicable slot in the terminal. To add or remove the module, a reconfiguration of the terminal is done from the graphical configuration tool, CAP 531.

1.2.1 Data message, line differential protection

The differential protection sends a data message every 5 ms. The slave to master message consists of information shown in figure 68 and the master to slave message according to figure 69.

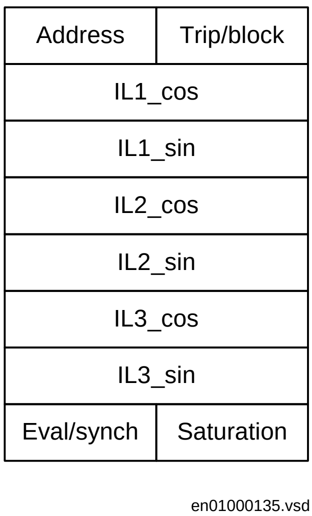


Figure 68: Slave to master message

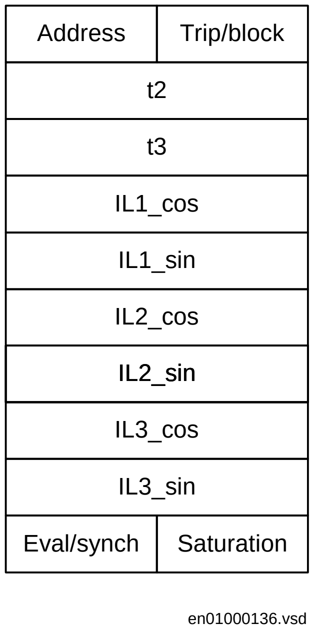


Figure 69: Master to slave message

The main difference between the two messages is the two times, t2 and t3, included in the master to slave message.

There is also included a check of the length of the received message. A slave is only accepts messages coming form a master and vice versa. This can be done since the length of the telegrams are different.

2 Optical fibre communication module

2.1 Application

Optical fibre modem

This module is designed for point to point optical communication, see figure 70, but can also be used for direct optical communication to a multiplexer of type FOX6Plus or FOX20, see figure 71 from ABB, provided it is equipped with an Optical Terminal Module of type N3BT. The FOX6Plus can also be used as an optical to electrical converter supporting the G.703 co-directional interfacing according to ITU (former CCITT), see figure 72. FOX6Plus can also in some cases be used for X.21 and V.36 interface but special attention must be paid to how to connect the signal. Used as an optical to electrical converter the FOX6Plus only supports 64 kbit/s data transmission.

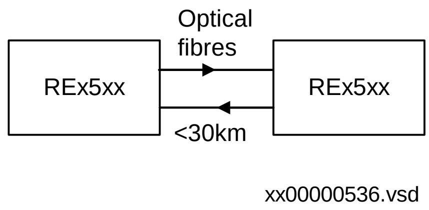


Figure 70: Dedicated link, opticalfibre connection.

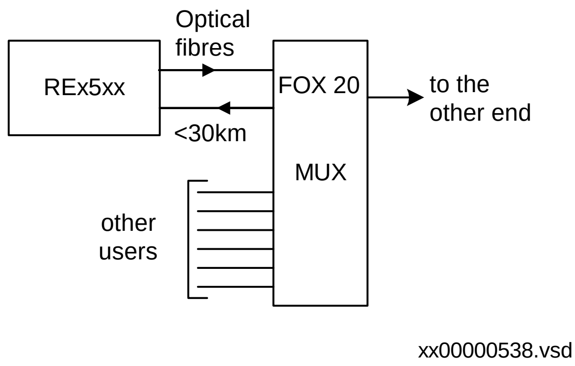


Figure 71: Multiplexed link, optical fibre connection.

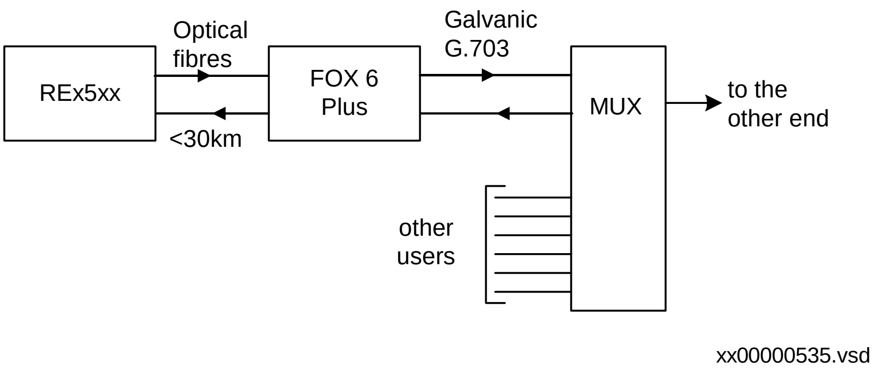


Figure 72: Multiplexed link, fibre optical-galvanic connection with FOX6Plus

2.2 Design

The optical communication module is designed to work with both 9/125 µm single-mode fibres and 50/125 or 62,5/125 µm multimode fibres at 1300 nm wavelength. The connectors are of type FC-PC (SM) or FC (MM) respectively. Two different levels of optical output power are used to cover distances from 0 to approximately 30 km. The leverl of optical power is selected with a setting. The attenation fibres is normally approximately 0.8 dB/km for multimode and 0.4 dB/km for single-mode. Additional attenuation due to installation can be estimated to be 0.2dB/km for multimode and 0.1 dB/km for single-mode fibres. For single-mode fibre and high output power this results in a maximum distance of 32km.

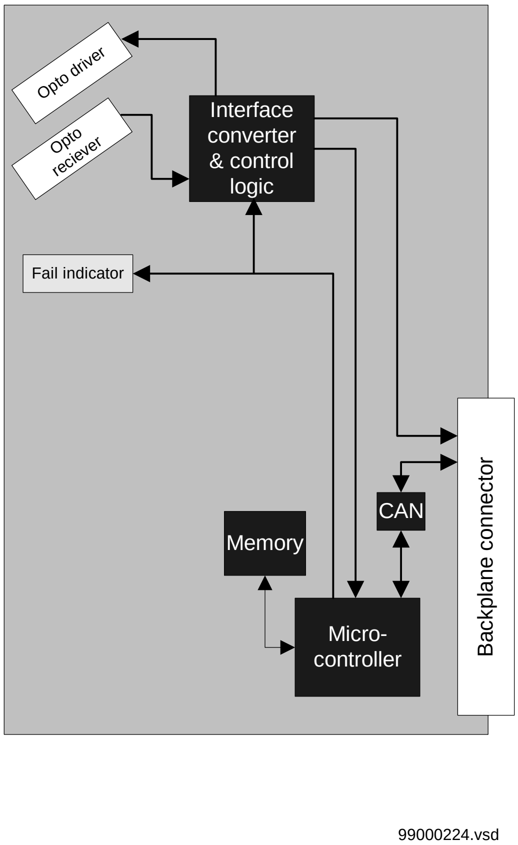


Figure 73: Block diagram for the optical communication module.

3 Galvanic data communication module

3.1 Application

Interface modules for V.36, X.21 and RS530

These interface modules are intended for connection to commercially available communication equipments or multiplexers and can be used both with 56 and 64 kbit/s data transmission.

Since the protection communicates continuously, a permanent communication circuit is required. Consequently, the call control and handshaking features specified for some interfacing recommendations are not provided.

Even if the standard claims that the reach for these interfaces are up to 1 km at 64 kbit/s it is not recommended to use that distance for protection purposes where the communication has to be reliable also under primary power system faults. This is due to the low level of the communication signals which gives low margin between signal and noise. If the protection terminal is in the same building as the multiplexing equipment and the environment is relatively free from noise, the protection terminal may be connected directly to the multiplexer via shielded and properly earthed cables with twisted pairs for distances less than 100 m.

Modules are available for the following interface recommendations, specifying the interconnection of the digital equipment to a PCM multiplexer:

- V.35/36 co-directional galvanic interface
- V.35/36 contra-directional galvanic interface
- X.21 galvanic interface
- RS530/422 co-directional galvanic interface
- RS530/422 contra-directional galvanic interface

Note!

Due to problems of timing co-directional operation for V.35/36 and RS530 is only recommended to be used for direct back-to-back operation, for example during laboratory testing!

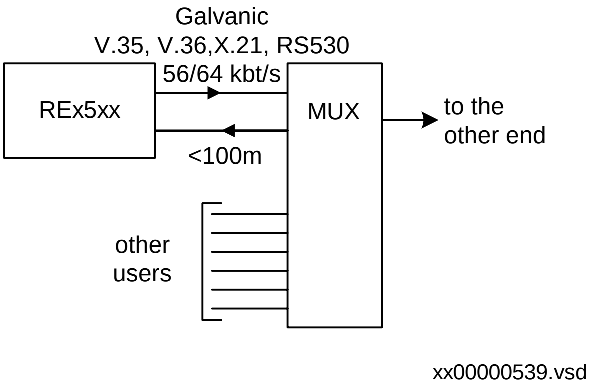


Figure 74: Multiplexed link, galvanic connection

3.2 Design

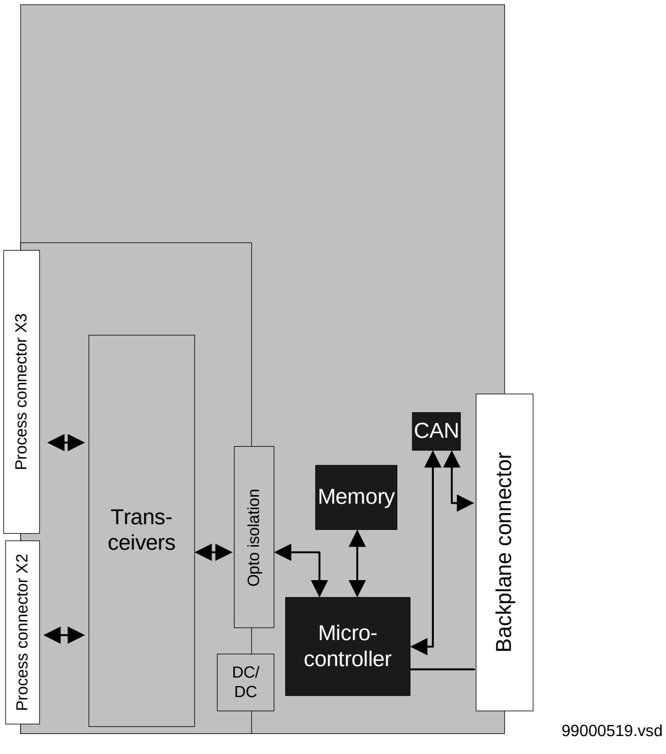


Figure 75: Block diagram for the galvanic communication module

4 Short range galvanic module

4.1 Application

Short range galvanic modem

The short range galvanic modem is used for point to point synchronous data transmission at 64 kbit/s at distances up to 4 km. Transmission is performed simultaneously in both directions, full duplex, over four wires in a communication (pilot wire) line according to figure 76.

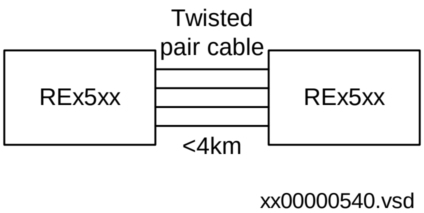


Figure 76: Dedicated link, short range galvanic modem

Compared to normal data transmission standards, for example V.36, X.21 etc., the short range modem increase the operational security and admits longer distances of transmission. This is achieved by a careful choice of transmission technology, modified M-3 balanced current loop and galvanic isolation between the transmission line and the internal logic of the protection terminal.

The reach will depend on the used cable. Higher capacitance between conductors and higher resistance will reduce the reach. The use of screened cables will increase the capacitance and thereby shorten the reach but this will often be compensated by the reduced noise giving a better operational security. Maximum ranges as a function of cable parameters are given in the diagram in figure 77.

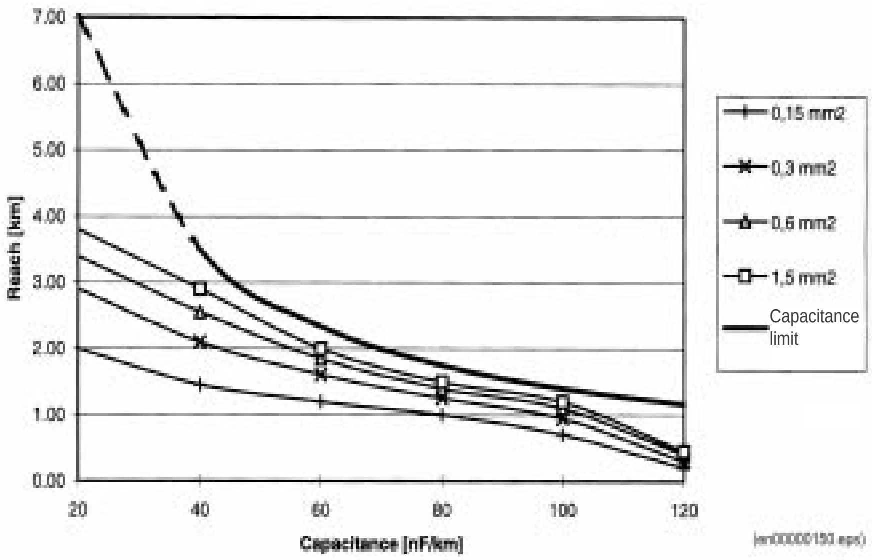


Figure 77: Maximum reach for short range galvanic modem

Note!

The reaches in the diagram, figure 77, are given for twisted-pair and double-screened cables, one screen for each pair and one common outer screen. For non twisted-pair cables, the reach has to be reduced by 20%. For non pair-screened cables, the reach also has to be reduced by 20%. For non twisted and single screened cables, one common outer screen, the reach will therefor be reduced by 40%.

5 Short range optical fibre module

5.1 Application

The short range optical fibre modem is used for point to point synchronous 64 kbit/s data transmission at distances up to 5 km, the principle is according to figure 78. It can also be used together with optic fibre transceiver type 21-15xx/16xx from FIBERDATA in order to get an optical link between the protection terminal and a remotely located communication equipment as in figure 79.

21-15xx supports interfaces according to ITU (former CCITT) standards V.35 and V.36 co- and contra-directional. 21-16xx supports interfaces standards X21 and G.703 according to ITU (former CCITT) and RS.530 according to EIA co- and contra-directional.

Transmission is performed simultaneously in both directions, full duplex, over two optical fibres. The fibres shall be of multi mode type, 50/125 µm or 62.5/125 µm.

The short range optical module has ST type connectors.

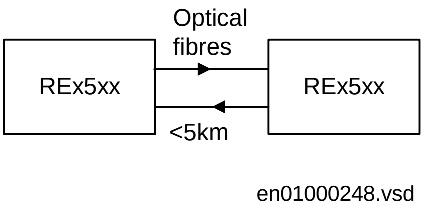


Figure 78: Dedicated link, optical fibre connection

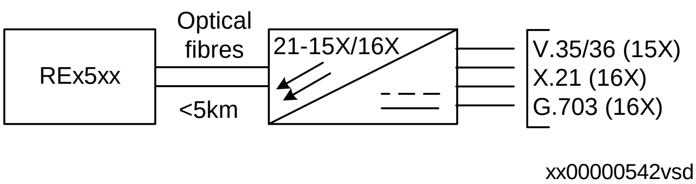


Figure 79: Multiplexed link, short range optical fibre connection

The reach will depend on the properties of the used optical fibre. In the optical budget has also to be accounted for losses in splices, connectors and also ageing of the cable. The connection to the protection terminal shall not be accounted for in the optical budget. 15 dB optical budget gives up to 5 km reach under normal conditions.

6 G.703 module

6.1 Application

Interface modules for G.703 co-directional

This interface module is intended for connection to commercially available communication equipments or multiplexers with G.703 interface. It can only be used with transmission rate of 64 kbit/s. Furthermore it only supports co-directional operation. Contra-directional and centralised clock are not supported.

Even if the standard claims that the reach can be rather long at 64 kbit/s, it is not recommended to use this for protection purposes where the communication has to be reliable also under primary power system faults. This is due to the low level of the communication, signals only 1 V, which gives low margin between signal and noise. If the protection and the communication equipment are located in the same room and the environment is free of noise, the protection terminal may be connected directly to the multiplexer via shielded and properly earthed cables with twisted pairs, same as shown in figure for V.36 etc, for distances up to 10 m.

7 Carrier module

7.1 Application

Use the carrier module with the appropriate galvanic or optical communication sub-module for short range communication of binary signals. Use the optical communication module when connecting a FIBERDATA 21-15X or FIBERDATA 21-16X optical-to-electric modem. The 21-15X model supports V.35 and V.36 standards, and the 21-16X model X.21, RS530 or G.703 standards.

7.2 Design

The carrier module is used to connect a communication sub-module to the platform. It adds the CAN-communication and the interface to the rest of the platform. By this the capability to transfer binary signals between for example two distance protection units is added.

The following three types of sub-modules can be added to the carrier module:

- Short range galvanic communication module
- Short range optical communication module
- G.703 communication module

The carrier module senses the type of sub-module via one of the two connectors.

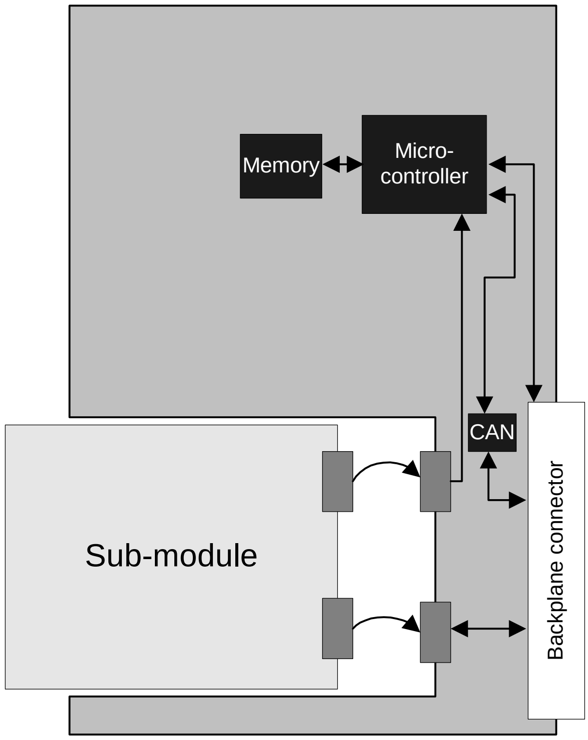


Figure 80: Block diagram for the carrier module.

8 Serial communication

8.1 Application

The serial communication can be used for different purposes, which enable better access to the information stored in the terminals. The serial communication is also used for communication directly between terminals (bay-to-bay communication).

The serial communication can be used with a station monitoring system (SMS) or with a substation control system (SCS). Normally, SPA communication is used for SMS and SCS; LON communication is used for SCS. Additionally, LON communication can also be used for SMS 510. SPA communication is also applied when using the front communication port, but for this purpose, no special serial communication function is required in the terminal. Only the software in the PC and a special cable for front connection is needed.

The rear SPA-port can alternatively be set up for IEC 60870-5-103 communication. IEC 60870-5-103 is a standard protocol for protection functions.

9 Serial communication, SPA

9.1 Application

The SPA communication is mainly used for SMS. It can include different numerical relays/terminals with remote communication possibilities. Connection to a personal computer (PC) can be made directly (if the PC is located in the substation) or by telephone modem through a telephone network with CCITT characteristics.

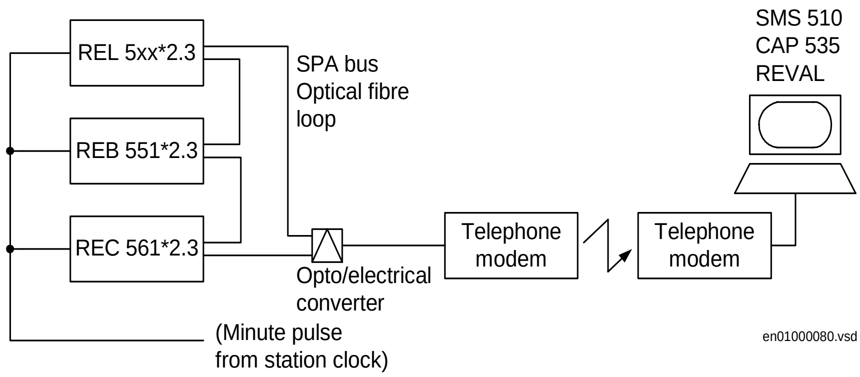


Figure 81: Example of SPA communication structure for a station monitoring system

9.2 Functionality

The SPA protocol V2.5 is an ASCII-based protocol for serial communication. The communication is based on a master-slave principle, where the terminal is a slave and the PC is the master. Only one master can be applied on each optic fibre loop. A program is needed in the master computer for interpretation of the SPA-bus codes and for translation of the settings sent to the terminal.

9.3 Design

When communicating locally with a Personal Computer (PC) in the station, using the rear SPA port, the only hardware needed for a station monitoring system is:

- Optical fibres
- Opto/electrical converter fo the PC
- PC

When communicating remotely with a PC using the rear SPA port, the same hardware is needed plus telephone modems.

The software needed in the PC, either local or remote, is:

- CAP 535 (Ver. 1.0 or higher) for configuration and parameter setting
- SMS 510 (Ver 1.0 or higher) for reading of disturbance records, events, distance to fault and trip value settings
- REVAL (Ver 2.0 or higher) for evaluation of the disturbance recorder data

When communicating to a front-connected PC, the only hardware required is the special front-connection cable. The software needed in a front connected PC is:

- CAP 535 (Ver. 1.0 or higher) for configuration and parameter setting
- SMS 510 (Ver 1.0 or higher) for reading of disturbance records, events, distance to fault and trip value settings
- REVAL (Ver 2.0 or higher) is also required if the same PC is used for evaluation of the disturbance recorder data.

9.4 Calculations

The SPA and the IEC use the same rear communication port. To define the protocol to be used, a setting is done on the local HMI under the menu:

Configuration
  TerminalCom
    SPA-IECPort

When the type of communication protocol is defined, the power to the terminal has to be switched off and on.

The most important settings in the terminal for SPA communication are the slave number and baud rate (communication speed). These settings are absolutely essential for all communication contact to the terminal.

These settings can only be done on the local HMI for rear channel communication at:

Configuration
TerminalCom
SPACOMM
Rear

and for front connection at:

Configuration
TerminalCom
SPACOMM
Front

The slave number can be set to any value from 1 to 899, as long as the slave number is unique within the used SPA loop.

The baud rate, which is the communication speed, can be set to between 300 and 38400 bits/s. The baud rate should be the same for the whole station, although different baud rates in a loop are possible. If different baud rates in the same fibre optical loop are used, consider this when making the communication setup in the communication master, the PC. The maximum baud rate of the front connection is limited to 9600 bit/s.

For local communication, 19200 or 38400 bit/s is the normal setting. If telephone communication is used, the communication speed depends on the quality of the connection and on the type of modem used. But remember that the terminal does not adapt its speed to the actual communication conditions, because the speed is set on the HMI of the terminal.

10 Serial communiction, IEC

10.1 Application

The IEC 60870-5-103 communication protocol is mainly used when a protection terminal communicates with a third party control or monitoring system. This system must have a software that can interpret the IEC 60870-5-103 communication messages.

10.2 Functionality

The IEC 60870-5-103 is an unbalanced (master-slave) protocol for coded-bit serial communication exchanging information with a control system. In IEC terminology a primary station is a master and a secondary station is a slave. The communication is based on a point to point principle. The master must have a software that can interpret the IEC 60870-5-103 communication messages. For detailed information about IEC 60870-5-103, refer to the IEC60870 standard part 5: Transmission protocols, and to the section 103: Companion standard for the informative interface of protection equipment.

10.3 Design

General

The protocol implementation in REx 5xx consists of the following functions:

- Event handling
- Report of analog service values (measurands)
- Fault location
- Command handling
  - Autorecloser ON/OFF
  - Teleprotection ON/OFF
  - Protection ON/OFF
  - LED reset
  - Characteristics 1 - 4 (Setting groups)
- File transfer (disturbance files)
- Time synchronization

Hardware

When communicating locally with a Personal Computer (PC) or a Remote Terminal Unit (RTU) in the station, using the SPA/IEC port, the only hardware needed is:

- Optical fibres, glass/plastic
- Opto/electrical converter for the PC/RTU
- PC/RTU

Events

The events created in the terminal available for the IEC 60870-5-103 protocol are based on the event function blocks EV01 - EV06. These function blocks include the function type and the information number for each event input, which can be found in the IEC-document. See also the description of the Event function.

Measurands

The measurands can be included as type 3.1, 3.2, 3.3, 3.4 and type 9 according to the standard.

Fault location

The fault location is expressed in reactive ohms. In relation to the line length in reactive ohms, it gives the distance to the fault in percent. The data is available and reported when the fault locator function is included in the terminal.

Commands

The commands defined in the IEC 60870-5-103 protocol are represented in a dedicated function block. This block has output signals according to the protocol for all available commands.

File transfer

The file transfer functionality is based on the Disturbance recorder function. The analog and binary signals recorded will be reported to the master. The eight last disturbances, that are recorded, are available for transfer to the master. A file that has been transferred and acknowledged by the master it cannot be transferred again.

The binary signals, that are reported, are those that are connected to the disturbance function blocks DRP1 - DRP3. These function blocks include the function type and the information number for each signal. See also the description of the Disturbance report.

The analog channels, that are reported, are the first four current inputs and the first four voltage inputs.

10.4 Calculations

Settings from the local HMI

The SPA and the IEC use the same rear communication port. To define the protocol to be used, a setting is done on the local HMI under the menu:

Configuration
TerminalCom
SPA-IECPort

When the type of communication protocol is defined, the power to the terminal has to be switched off and on.

The settings for IEC 60870-5-103 communication are the following:

- Individually blocking of commands
- Setting of measurand type
- Setting of main function type and activation of main function type
- Settings for slave number and baud rate (communication speed)
- Command for giving Block of information command

The settings for individually blocking of commands can be found on the local HMI at:

Configuration
TerminalCom
IECCom
Commands

Each command has its own blocking setting and the state can be set to OFF or ON. The OFF state corresponds to non-blocked state and ON corresponds to blocked state.

The settings for type of measurand can be found on the local HMI at:

Configuration
TerminalCom
IECCom
Measurands

The type of measurands can be set to report standardised types, Type 3.1, Type 3.2, Type 3.3, Type 3.4 or Type 9.

The use of main function type is to facilitate the engineering work of the terminal. The settings for main function type and the activation of main function type can be found on the local HMI at:

Configuration
TerminalCom
IECCom
FunctionType

The main function type can be set to values according to the standard, this is, between 1 and 255. The value zero is used as default and corresponds to not used.

The setting for activation of main function type can be set to OFF or ON. The OFF state corresponds to non-activated state and ON corresponds to activated state. Upon activated the main function type overrides all other settings for function type within the terminal, that is, function type settings for event function and disturbance recorder function. When set to OFF, function type settings for event function and disturbance recorder function use their own function type settings made on the function blocks for the event function and disturbance recorder respectively. Though for all other functions they use the main function type even when set to OFF.

The settings for communication parameters slave number and baud rate can be found on the local HMI at:

Configuration
TerminalCom
IECCom
Communication

The slave number can be set to any value between 0 to 255.

The baud rate, the communication speed, can be set either to 9600 bits/s or 19200 bits/s.

The settings for issuing a block-of-information command can be found on the local HMI at:

Configuration
TerminalCom
IECCom
BlockOfInfo

Information command with the value one (1) blocks all information sent to the master and abort any GI procedure or any file transfer in process. Thus issuing the command with the value set to zero (0) will allow information to be polled by the master.

The dialogue to operate the output from the BlockOfInformation command function is performed from different state as follows:

1. Selection active; select the:
   - C button, and then the No box activates.
   - Up arrow, and then New: 0 changes to New: 1. The up arrow changes to the down arrow.
   - E button, and then the Yes box activates.
2. Yes box active; select the:
   - C button to cancel the action and return to the BlockOfInfo window.
   - E button to confirm the action and return to the BlockOfInfo window.
   - Right arrow to activate the No box.
3. No box active; select the:
   - C button to cancel the action and return to the BlockOfInfo window.
   - E button to confirm the action and return to the BlockOfInfo window.
   - Left arrow to activate the Yes box.

Settings from the CAP 535 tool

Event

For each input of the Event function there is a setting for the information number of the connected signal. The information number can be set to any value between 0 and 255. In order to get proper operation of the sequence of events the event masks in the event function shall be set to ON_CHANGE. For single-command signals, the event mask shall be set to ON_SET.

In addition there is a setting on each event block for function type. Refer to description of the Main Function type set on the local HMI.

Commands

As for the commands defined in the protocol there is a dedicated function block with eight output signals. The configuration of these signals are made by using the CAP 531 tool.

To realise the BlockOfInformation command, which is operated from the local HMI, the output BLKINFO on the IEC command function block ICOM has to be connected to an input on an event function block. This input shall have the information number 20 (monitor direction blocked) according to the standard.

File transfer

For each input of the Disturbance recorder function there is a setting for the information number of the connected signal. The information number can be set to any value between 0 and 255.

Furthermore there is a setting on each input of the Disturbance recorder function for the function type. Refer to description of Main Function type set on the local HMI.

11 Serial communication, LON

11.1 Application

An optical network can be used within the Substation Automation system. This enables communication with the terminal through the LON bus from the operator’s workplace, from the control center and also from other terminals.

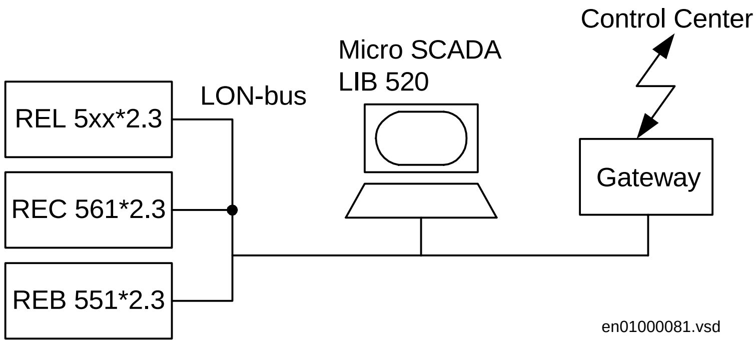


Figure 82: Example of LON communication structure for substation automation

11.2 Functionality

The LON protocol is specified in the LonTalkProtocol Specification Version 3 from Echelon Corporation. This protocol is designed for communication in control networks and is a peer-to-peer protocol where all the devices connected to the network can communicate with each other directly. For more information of the bay-to-bay communication, refer to the documents Event function and Multiple command function.

11.3 Design

The hardware needed for applying LON communication depends on the application, but one very central unit needed is the LON Star Coupler and optical fibres connecting the star coupler to the terminals. To communicate with the terminals from MicroSCADA, the application library LIB 520 is needed.

The HV/Control and the HV/REx 500 software modules are included in the LIB 520 high-voltage process package, which is a part of the Application Software Library within MicroSCADA applications.

The HV/Control software module is intended to be used for control functions in REx 5xx terminals. This module contains the process picture, dialogues and process database for the control application in the MicroSCADA.

The HV/REx 500 software module is used for setting and monitoring of the terminal via the MicroSCADA screen. At use of this function the PST Parameter Setting Tool (of v1.1 or higher) is required.

11.4 Calculations

Use the LNT, LON Network Tool to set the LON communication. This is a software tool applied as one node on the LON bus. In order to communicate via LON, the terminals need to know which node addresses the other connected terminals have, and which network variable selectors should be used. This is organised by the LNT.

The node address is transferred to the LNT via the local HMI at:

Configuration
  TerminalCom
    LONComm
      ServicePinMsg

By setting YES, the node address is sent to the LNT via the LON bus. Or, the LNT can scan the network for new nodes.

The speed of the LON bus is set to the default of 1.25 MHz. This can be changed by the LNT.

If the LON communication from the terminal stops, caused by setting of illegal communication parameters (outside the setting range) or by another disturbance, it is possible to reset the LON port of the terminal. This is performed at the local HMI at:

Configuration
  TerminalCom
    LONComm
      LONDefault

By setting YES, the LON communication is reset in the terminal, and the addressing procedure can start from the beginning again.

There are a number of session timers which can be set via the local HMI. These settings are only for advanced use and should only be changed after recommendation from ABB Automation Products AB. The time values below are the default settings. The settings can be found at:

Configuration
 TerminalCom
  LONComm
   SessionTimers

12 Serial communication modules (SCM)

12.1 SPA/IEC

The serial communication module for SPA/IEC is placed in a slot at the rear part of the main processing module. The serial communication module can have connectors for two plastic fibre cables or two glass fibre cables. The incoming optical fibre is connected to the RX receiver input and the outgoing optical fibre to the TX transmitter output. Pay special attention to the instructions concerning the handling, connection, etc. of the optical fibres.

12.2 LON

The serial communication module for LON is placed in a slot at the rear part of the Main processing module. The serial communication module can have connectors for two plastic fibre cables or two glass fibre cables. The incoming optical fibre is connected to the RX receiver input and the outgoing optical fibre to the TX transmitter output. Pay special attention to the instructions concerning the handling, connection, etc. of the optical fibres.

Chapter 10 Hardware modules

About this chapter

This chapter describes the different hardware modules.

1 Platform

1.1 General

The REx 5xx platform consists of a case, hardware modules and a set of basic functions.

The closed and partly welded steel case makes it possible to fulfill stringent EMC requirements. Three different sizes of the case are available to fulfill the space requirements of different terminals. The degree of protection is IP 40 according to IEC 529 for cases with the widths 1/2x19” and 3/4x19”. For case size 1/1x19” IP 30 applies for the top and bottom part. IP 54 can be obtained for the front area with accessories for flush and semiflush mounting. Mounting kits are available for rack, flush, semiflush or wall mounting.

All connections are made on the rear of the case. Screw compression type terminal blocks are used for electrical connections. Serial communication connections are made by optical fibre connectors type Hewlett Packard (HFBR) for plastic fibres or bayonet type ST for glass fibres

A set of hardware modules are always included in a terminal. Application specific modules are added to create a specific terminal type or family.

The basic functions provide a terminal with basic functionality such as self supervision, I/O-system configurator, real time clock and other functions to support the protection and control system of a terminal.

1.2 Platform configuration

Table 13: Basic, always included, modules

Module	Description
Combined backplane module (CBM)	Carries all internal signals between modules in a terminal. The size of the module depends on the size of the case. 1/1x19”: 13 slots available for I/O. 3/4x19”: 8 slots available for I/O. 1/2x19”: 3 slots available for I/O.
Power supply module (PSM)	Available in two different versions, each including a regulated DC/DC converter that supplies auxiliary voltage to all static circuits. • For case size 1/2x19” and 3/4x19” a version with four binary inputs and four binary outputs are used. An internal fail alarm output is also available. PSM output power 20W. • For case size 1/1x19” a version without binary I/O:s and increased output power is used. An internal fail alarm output is available. PSM output power 30W.
Main processing module (MPM)	Module for overall application control. All information is processed or passed through this module, such as configuration, settings and communication.
Human machine interface (LCD-HMI)	The module consist of LED:s, a LCD, push buttons and an optical connector for a front connected PC

Table 14: Application specific modules

Module	Description
Signal processing module (SPM)	Module for protection algorithm processing. Carries up to 12 digital signal processors, performing all measuring functions.
Milliampere input module (MIM)	Analog input module with 6 independent, galvanically separated channels.
Binary input module (BIM)	Module with 16 optically isolated binary inputs
Binary output module (BOM)	Module with 24 single outputs or 12 double-pole command outputs including supervision function
Binary I/O module (IOM)	Module with 8 optically isolated binary inputs, 10 outputs and 2 fast signalling outputs.
Data communication modules (DCMs)	Modules used for digital communication to remote terminal.
Transformer input module (TRM)	Used for galvanic separation of voltage and/or current process signals and the internal circuitry.
A/D conversion module (ADM)	Used for analog to digital conversion of analog process signals galvanically separated by the TRM.
Optical receiver module (ORM)	Used to interface process signals from optical instrument transformers.
Serial communication module (SCM)	Used for SPA/LON/IEC communication
LED module (LED-HMI)	Module with 18 user configurable LEDs for indication purposes

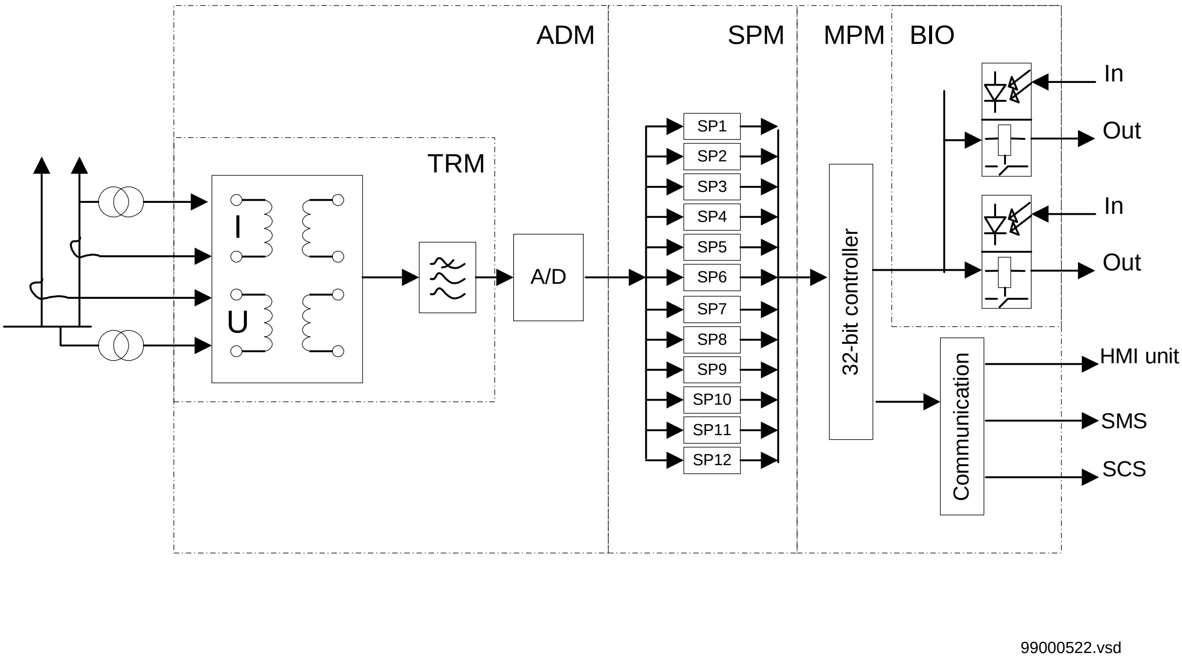


Figure 83: Basic block diagram

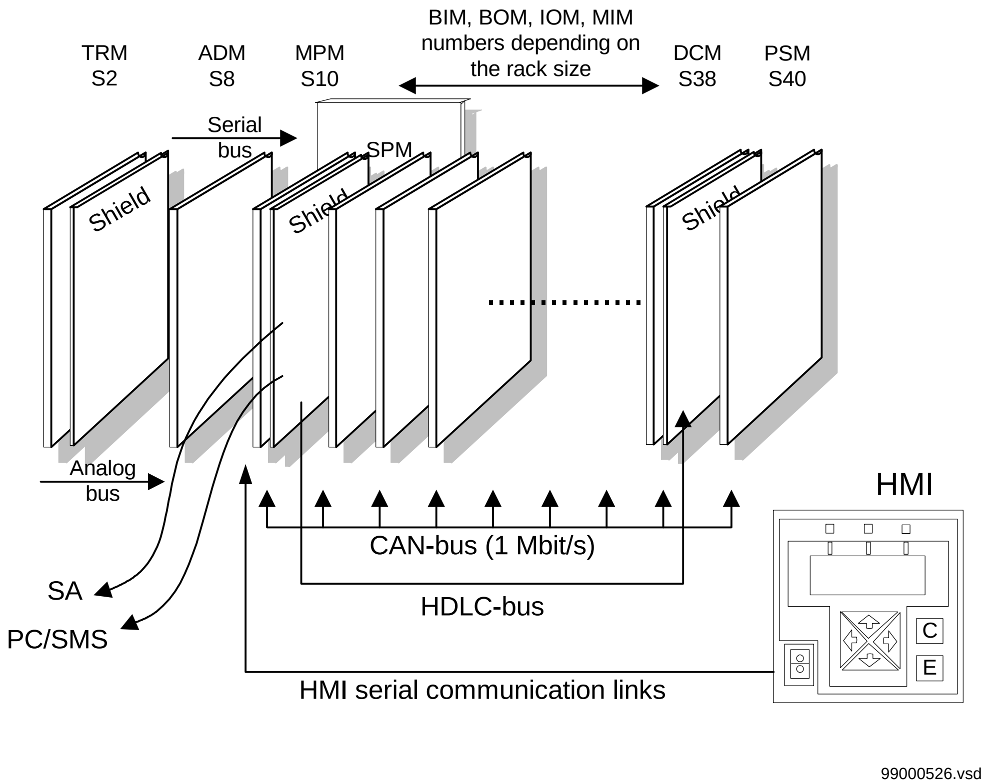


Figure 84: Internal hardware structure showing a full width case configuration

1.3 1/2x19" platform

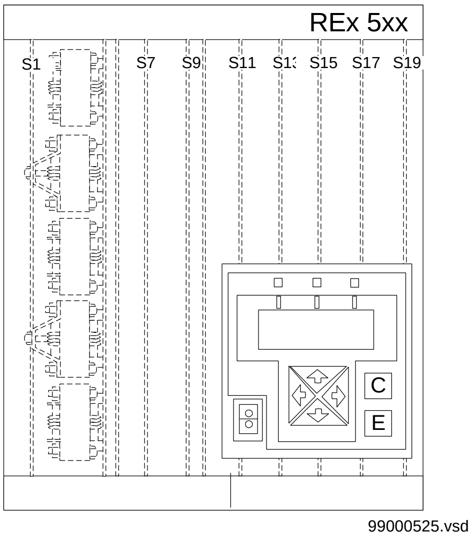


Figure 85: Hardware structure of the 1/2x19” case

2 Transformer input module (TRM)

Current and voltage input transformers form an insulating barrier between the external wiring and internal circuits of the terminal. They adapt the values of the measuring quantities to the static circuitry and prevent the disturbances to enter the terminal. Maximum 10 analog input quantities can be connected to the transformer module (TRM). A TRM with maximum number of transformers has:

- Five voltage transformers. The rated voltage is selected at order.
- Five current transformers. The rated currents are selected at order.

The input quantities are the following:

- Three phase currents
- Residual current of the protected line
- Residual current of the parallel circuit (if any) for compensation of the effect of the zero sequence mutual impedance on the fault locator measurement or residual current of the protected line but from a parallell core used for CT circuit supervision function or independent earthfault function.
- Three phase voltages
- Open delta voltage for the protected line (for an optional directional earth-fault protection)
- Phase voltage for an optional synchronism and energizing check.

The actual configuration of the TRM depends on the type of terminal and included functions. See figure 86 and figure 87.

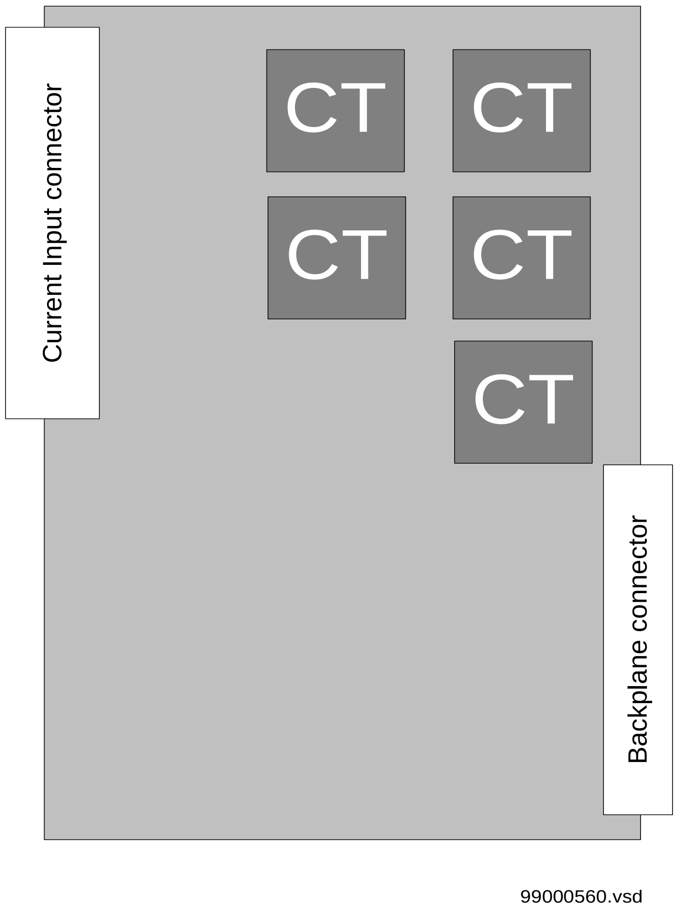


Figure 86: Block diagram of the TRM for REL 551, Line differential protection

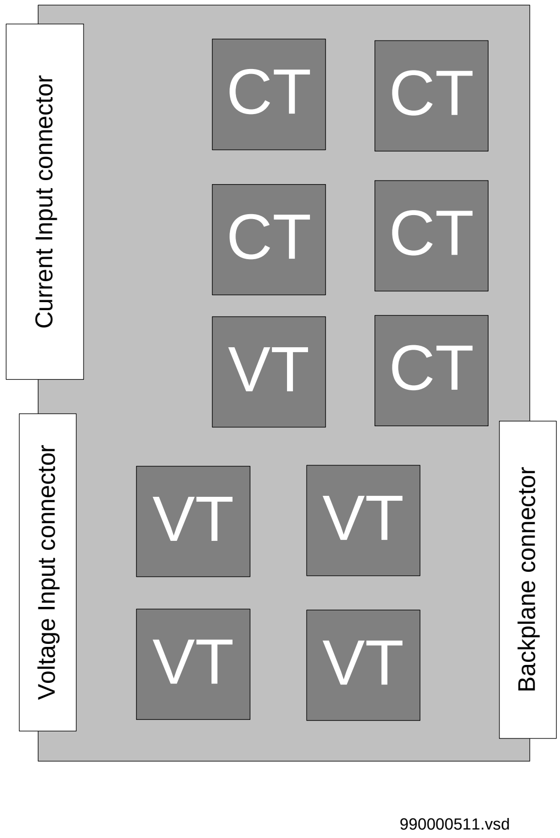


Figure 87: Block diagram of the TRM with maximum number of transformers used in most REx 5xx.

3 A/D-conversion module (ADM)

The incoming signals from the intermediate current transformers are adapted to the electronic voltage level with shunts. To gain dynamic range for the current inputs, two shunts with separate A/D channels are used for each input current. By that a 16-bit dynamic range is obtained with a 12 bits A/D converter.

The next step in the signal flow is the analogue filter of the first order, with a cut-off frequency of 500 Hz. This filter is used to avoid aliasing problems.

The A/D converter has a 12-bit resolution. It samples each input signal (5 voltages and 2x5 currents) with a sampling frequency of 2 kHz.

Before the A/D-converted signals are transmitted to the signal processing module, the signals are band-pass filtered and down-sampled to 1 kHz in a digital signal processor (DSP).

The filter in the DSP is a numerical filter with a cut-off frequency of 250 Hz.

The transmission of data between the A/D-conversion module and the signal processing module is done on a supervised serial link of RS485 type. This transmission is performed once every millisecond and contains information about all incoming analog signals.

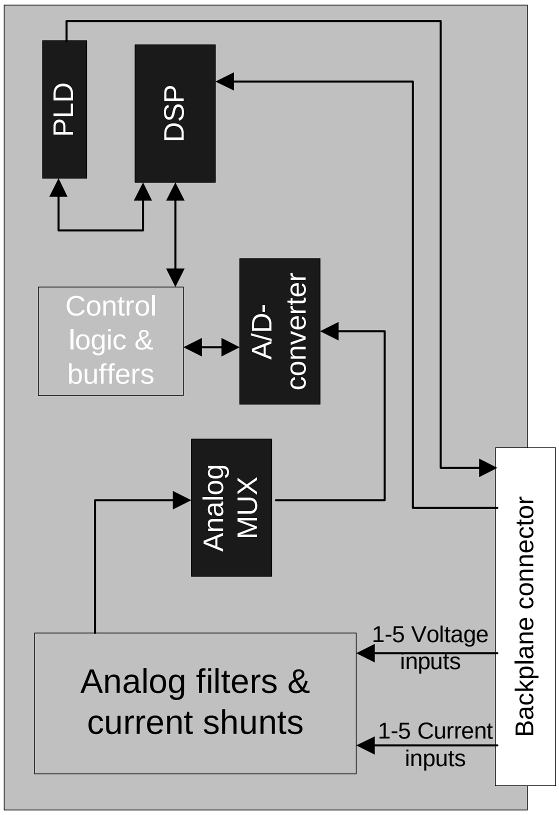


Figure 88: Block diagram for the ADM

4 Main processing module (MPM)

The terminal is based on a pipelined multi-processor design. The 32-bit main controller receives the result from the Signal processing module every millisecond.

All memory management are also handled by the main controller. The module has 8MB of disc memory and 1MB of code memory. It also has 8MB of dynamic memory.

The controller also serves four serial links: one high-speed CAN bus for Input/Output modules and three serial links for different types of HMI communication.

The main controller makes all decisions, based on the information from the Signal processing module and from the binary inputs. The decisions are sent to the different output modules and to these communication ports:

- Local HMI module including a front-connected PC, if any, for local human-machine communication.
- LON communication port at the rear (option).
- SPA/IEC communication port at the rear (option)

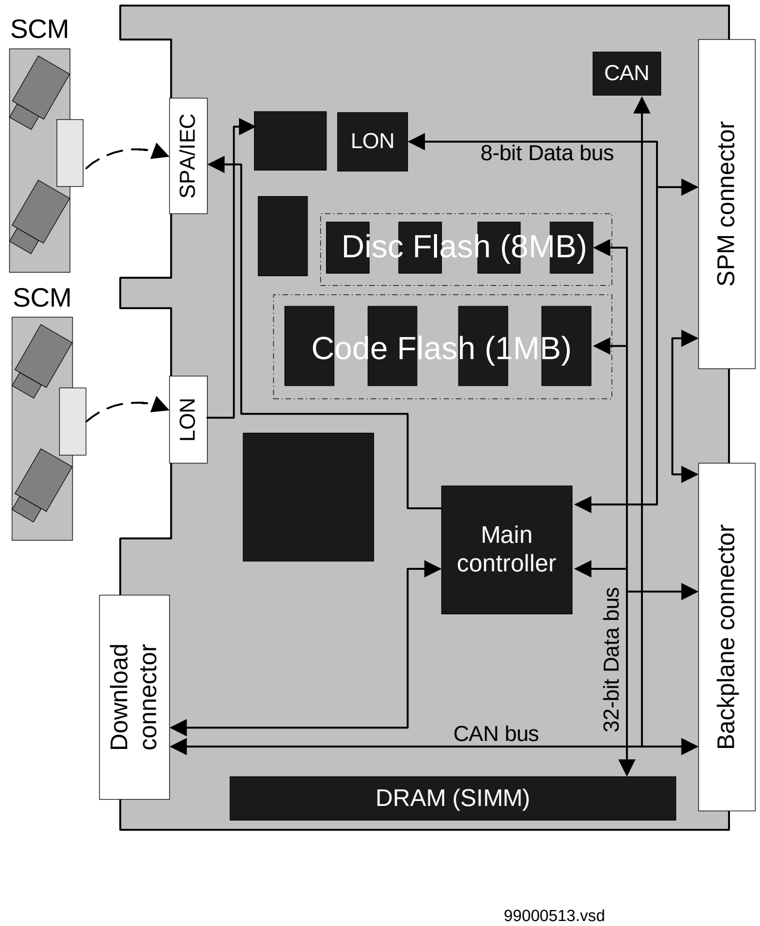


Figure 89: Block diagram for the MPM

To allow easy upgrading of software in the field a special connector is used, the Download connector.

5 Signal processing module (SPM)

All numerical data is received in all of the up to 12 (16 bits) digital signal processors (DSP). In these DSPs, the main part of the filtering and the calculations take place. The result from the calculations in the DSPs is sent every millisecond on a parallel bus to the (32 bit) main controller on the Main processing module.

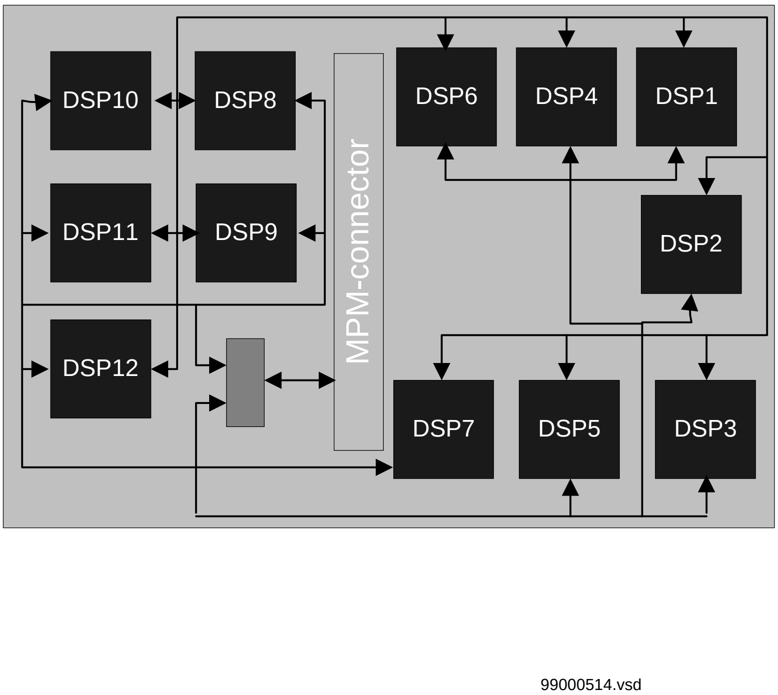


Figure 90: Block diagram of the SPM

6 Input/Output modules

6.1 General

The number of inputs and outputs in a REx 5xx terminal can be selected in a variety of combinations depending on the size of the rack. There is no basic I/O configuration of the terminal. The table below shows the number of available inputs or output modules for the different platform sizes.

Platform size	1/1x19”	3/4x19”	1/2x19”
I/O slots available	13	8	3

A number of signals are available for signalling purposes in the terminal and all are freely programmable. The voltage level of the input/output modules is selectable at order. Available versions are RL 48, 110, or 220 (48/60 V +/-20%, 110/125 V +/-20% or 220/250 V +/-20%). The Binary in/out module and the Binary input module are also available in an RL 24 version (24/30 V +/-20%).

Figure 91 shows the operating characteristics of the binary inputs of the four voltage levels.

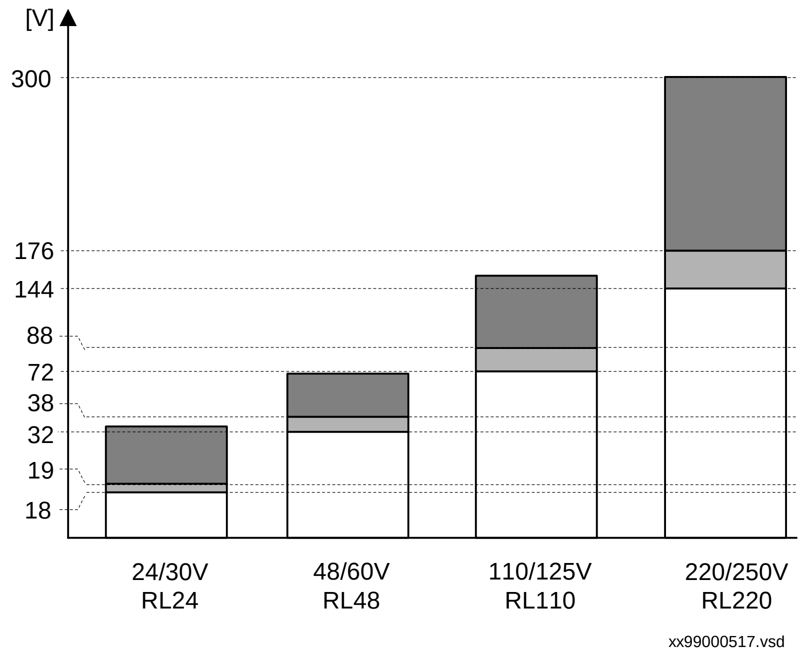


Figure 91: Voltage dependence for the binary inputs

Table 15: Input voltage ranges explained

	Guaranteed operation
	Operation uncertain
	No operation

The I/O modules communicates with the Main Processing Module via the CAN-bus on the backplane.

The design of all binary inputs enables the burn off of the oxide of the relay contact connected to the input, despite the low, steady-state power consumption, which is shown in figure 92.

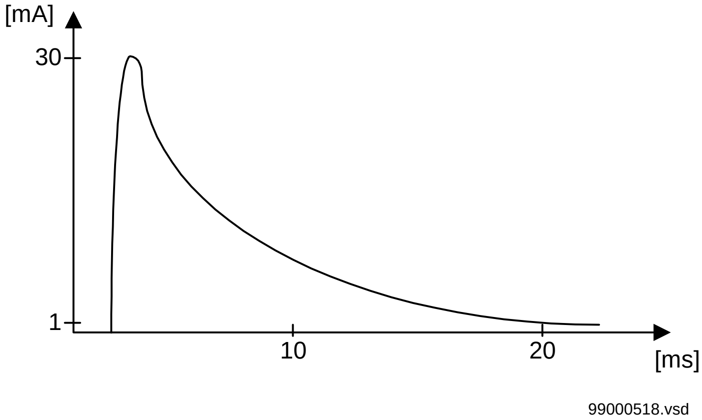


Figure 92: Current through the relay contact

6.2 Binary I/O module (IOM)

The binary in/out module contains eight optically isolated binary inputs and twelve binary output contacts. Ten of the output relays have contacts with a high-switching capacity (trip and signal relays). The remaining two relays are of reed type and for signalling purpose only. The relays are grouped together as can be seen in the terminal diagram.

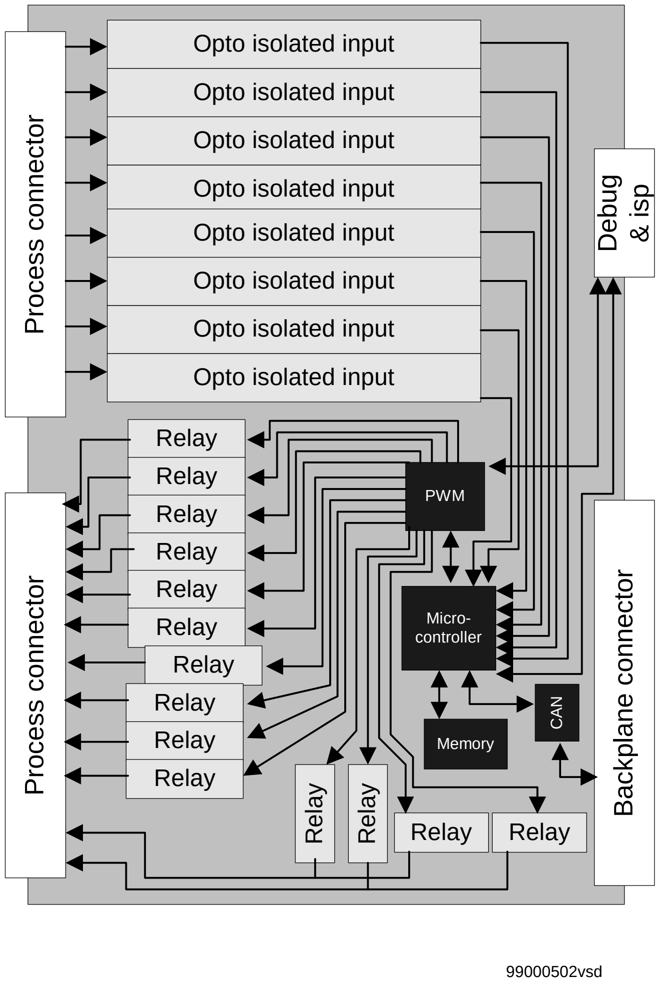


Figure 93: Block diagram for the binary input/output module

7 Power supply module (PSM)

The power supply module (PSM) contains a built-in, self-regulated DC/DC converter that provides full isolation between the terminal and the external battery system. The wide input voltage range of the DC/DC converter converts an input voltage range from 48 to 250V, including a +/-20% tolerance on the EL voltage. The output voltages are +5, +12 and -12 Volt.

The PSM, used in the 1/2x19” and 3/4x19” platforms, has built-in binary I/O with four optically isolated inputs and five outputs. One of the binary outputs is dedicated for internal fail. The PSM can provide power up to 20W.

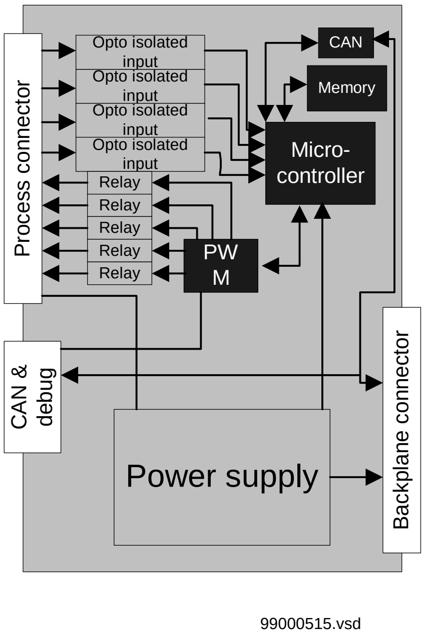


Figure 94: Block diagram for the PSM used in 1/2x19” and 3/4x19” cases.

8 Human-machine interface (HMI)

The local HMI module consists of three LEDs (red, yellow, and green), an LCD with four lines, each containing 16 characters, six buttons and an optical connector for PC communication.

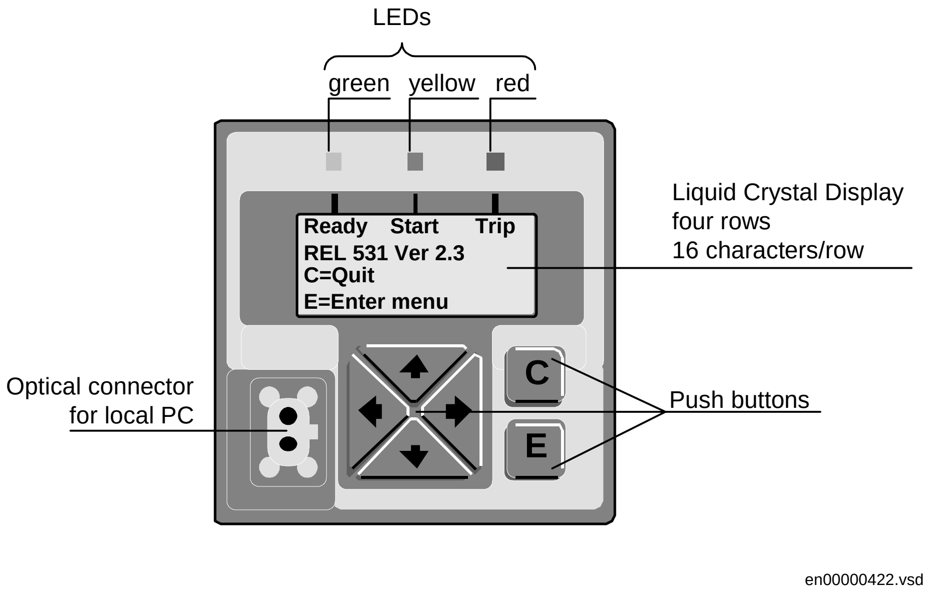


Figure 95: Local HMI

The PC is connected via a special cable, that has a built-in optical to electrical interface. Thus, disturbance-free local serial communication with the personal computer is achieved. Software tools are available from ABB for this communication. A PC greatly simplifies the communication with the terminal. It also gives the user additional functionality which is unavailable on the HMI because of insufficient space. The LEDs on the HMI display this information:

Table 16: The local HMI LED display

LED indication	Information
Green:	
Steady	In service
Flashing	Internal failure
Dark	No power supply
Yellow:	
Steady	Disturbance Report triggered
Flashing	Terminal in test mode
Red:	
Steady	Trip command issued from a protection function or disturbance recorder started
Flashing	Blocked