# Line differential relay

## for looped and meshed networks

## Specification

# 1 Line differential relay

This specification is valid for applications where, usually, the following criteria are applicable

- Dedicated line differential protection and circuit breaker control
- For looped and meshed networks
- Suitable for centralized and decentralized power generation
- Applicable to all network neutral earthing types

The specification highlights constructional features and software functions that are required within the specific relay application area.

The specification applies to design, manufacture, supply, testing and operation of protection, measuring and control functions intended for line differential protection applications in electrical power systems.

# 2 General

The provided relay shall work reliably and selectively as apart of a protection system. The relay must not operate at faults occurring outside the protection zone.

Internal faults or disturbances in the auxiliary supply or measurement circuits may not result in un-correct operation of the device.

Each start or trip provided by the relay must generate clear and reliable indications. These indications must be transferable to an upper level system over the station bus.

The relay shall be of a numerical communicating type offering extensive protection, control and measuring functions in one enclosed unit. The protection relay basic design and data modeling shall be based on the IEC 61850 standard.

Special attention has to be paid in minimizing the replacement time of a defective unit, preferably by means of "plug-in" units. The relay shall have full flexibility in terms of assigning any binary input and output signal to the internal logic circuits.

The following specification highlights the most important features of the relay. In no means the following shall be regarded as a complete specification for the relay. In addition the relay must fulfill the relevant IEC standards and be suitable for the intended applications, as described in the complete set of specifications, or otherwise communicated to the prospective bidders.

# 3 Mechanical design and mounting

The design shall be of "plug-in" type, where the plug-in unit can be withdrawn or inserted to a fixed mounted base unit. The withdrawal of the plug-in unit shall result automatic short-circuit in the supplying current transformers' secondary circuits. In other words, it shall be possible to safely extract the plug-in unit from the case (base unit) after disconnecting the auxiliary voltage without adding any external jumper wires or operating any additional switches or bridges.

Means shall be included to seal the plug-in unit into the base unit, to prevent accidental removal.

### 3.1.1 Current connections

For the current transformer secondary circuit lead connections both ring lug and compression type termination shall be supported. Each of the current terminals shall be capable of accepting at least two 2.5mm$^2$ size of wires, either solid or fine stranded.

### 3.1.2 Mounting

The protection relay wall, flush, semi-flush, rack and tilted semi-flush mounting options shall be possible using readily defined installation kits. The kits shall be from the same manufacturer to guarantee smooth installation and uniform outlook.

When the relays are flush or semi-flush mounted on a cabinet door, a degree of protection by enclosure of IP54 level must be reached, when the door is closed.

**Degree of protection of flush-mounted relay**

| Description | Value |
| --- | --- |
| Front side | IP 54 |
| Rear side, connection terminals | IP 20 |

When flush mounted on a cabinet door, the depth of the relay shall not exceed 160 mm, without any additional raising frame. Additionally, it shall be possible to mount at least two protection relays in parallel into a 4U high 19" rack.

## 3.2 LHMI

The LHMI shall support local measurement, single-line diagram, event and alarm views through its LCD display. It shall also enable the parameter settings. It shall be possible to choose either the main menu, single-line diagram or the measurement view as the default view. The LCD is to be fitted with at least eight rows of characters with easily readable font size.

### 3.2.1 Circuit-breaker, disconnector and earth-switch control

It shall be possible to control a circuit breaker, motor operated disconnectors or circuit breaker truck and motor operated earth-switch from <u>designated</u> control buttons. Additionally, primary devices shall easily be controlled and status shall clearly be indicated via single-line diagram view. It shall be possible to interlock the circuit breaker close command directly by a binary input, by a protection relay internal interlocking logic and by a thermal protection operation or by a protection relay trip command output operating in lock-out mode.

### 3.2.2  Indications and LEDs

Each start and trip from every protection function must be clearly indicated. It must also be possible to transfer the start and trip signals to the binary outputs if required and it must be possible to transfer them to an upper level system via communication link. The resetting of indications and alarm LEDs shall be easy, preferably by pressing one button only.

The LHMI shall include at least eleven (11) freely programmable alarm LEDs for status indication. It shall be possible to insert a written clarification on a paper strip beside each of the LEDs to indicate the assigned function of the LED.

### 3.2.3  Web server functionality

The relay shall be equipped with web server functionality to cater for remote HMI features, using commonly available web browser software. The web server functionality shall utilize the same user authority handling principles, as defined later on in this specification for the LHMI functionality. Activation of the web server shall need user intervention, thus the functionality shall be disabled as a default.

### 3.2.4  Local/Remote switch

The LHMI shall be equipped with a Local/Remote switch including status indication. The operation rights of the L/R switch shall be covered with the user authorization procedures of the relay. When in local mode, remote control commands to the circuit breaker shall be ignored and vice versa in remote mode.

## 3.3  Binary inputs and outputs

The number of inputs shall be enough to interface the relay to the external circuits in order to enable the full use of the protection relay functionality. The number of binary inputs shall not be less than ten (10). The threshold voltage of the binary inputs shall be settable using a dedicated parameter. Grouping of binary inputs under a common ground potential is allowed, as far as more than one common ground potential is available. The inputs shall be fully isolated from the protection relay internal circuits.

The total number of binary outputs shall not be less than nine (9), excluding the dedicated relay internal fault (IRF) output. In addition to the double pole trip output contacts, two other binary outputs shall be of heavy-duty type capable of tripping a circuit breaker (also see section 3.3.1)

The two binary trip outputs shall have a selectable "lock-out" operation mode, which locks the output relays after operation. The resetting of the lock-out state shall be possible via the LHMI, the binary input and the communication interface.

| Description | Value |
| --- | --- |
| Operating range | ± 20 % of the rated voltage |
| Rated voltage | 24...250 V DC |
| Threshold voltage | 18...175 V DC |
| Reaction time | < 5 ms |

It shall be possible, by software, to freely assign the binary inputs and outputs to the protection relay internal function logic. A possibility to introduce simple logic functions in the form of AND and OR gates, including signal inversion, in front of the binary inputs and outputs shall also be foreseen. As an example, a possibility to energize a binary output from a number of internal relay signals (OR gate) shall be available.

### 3.3.1 Trip outputs and master trip

Two binary outputs shall be dimensioned for circuit breaker trip purposes, introducing trip circuit supervision functionality and a possibility for double pole operation. It shall be possible to exclude the tripping circuit supervision functionality from the outputs physically by changing the protection relay terminal connections.

If required it must be possible to block all trip outputs by means of a single setting (master trip). In order to prevent the closing of a circuit breaker after a trip without resetting, there must be so called "lock-out" mode available.

The trip circuit must be supervised.

### 3.3.2 Self-supervision and IRF output

The relay shall be equipped with extensive self-supervision capabilities. In case of internal failure, the relay shall in no case issue a false trip signal. The failure code shall be visible on the protection relay LHMI (Local Human Machine Interface) display. The failure codes shall give detailed information about the situation. The end user documentation shall support the interpretation of the failure code in detail and by simple means.

A dedicated IRF (Internal Relay Fault) output must be available in order to provide IRF status to external systems.

## 3.4 Current input channels

The same hardware shall support both 5 A and 1 A nominal energizing currents. Selecting the nominal current shall be software based (settable). All the analog input channels shall have dedicated A/D converters to enable simultaneously sampling and elimination of skew.

Analogue to digital conversion shall be of such design that good linearity during the whole lifetime of the relay can be achieved. The analog signals shall be presented to the protection relay internal function blocks as no less than 32 samples per cycle with 18 bit resolution at 50 Hz base, with a signal to quantization noise ratio (NQSR) better than 110 db.

# 4   Protection

To handle periodic changes in the primary circuit switching conditions, i.e. the network topology, there shall be support for at least four (4) different setting banks for each of the protection functions. The change of setting bank shall take place commonly for all of the protection functions. It shall be possible to change the setting bank locally from the LHMI, using a binary input signal and remotely through the communication link. The change of setting bank shall happen rapidly and it shall not result in a protection relay restart, a relay malfunction or a communication break.

The protection functions listed below shall be regarded as the compulsory basic protection features. It shall be possible to either enable or disable each protection stage, depending on the requirements of the actual application.

## 4.1   Current protection

### 4.1.1   Line differential protection

The line differential function shall include low set, stabilized and high set, non-stabilized stages.

The stabilized low set stage shall provide a fast clearance of faults while remaining stability when high currents are passing through the protected zone increasing current measurement errors. The second harmonic restraint shall insure that the low set stage does not operate due to the start-up of a tapped transformer.

The high set stage shall provide a very fast clearance of severe faults including a high differential current regardless of harmonics.

The operating time characteristic for the low set stage shall be selectable, either definite time (DT) or inverse definite minimum time (IDMT). A direct inter-trip shall ensure that both ends are always operated, even without local criteria.

### 4.1.2   Non directional overcurrent protection

The protection shall consist of four separate freely settable non-directional overcurrent stages, covering setting ranges from 0.1 to 35 times pu (per unit). The operation characteristic of the low and high set stages shall be settable to either definite time or inverse time mode, supporting various types of inverse curves, including a user definable one.

The fourth stage shall work as an instantaneous stage. The instantaneous stage shall also support the peak-to-peak measurement mode and include a possibility to introduce a dedicated two times setting value peak detection for fast operation under conditions when the current transformers have saturated.

During an inrush current situation when large proportions of second harmonics are detected it shall be possible, for each of the stages, to raise the setting value by a freely settable multiplier. It shall be possible to select the number of started phases for operation between one, two or all three.

### 4.1.3   Non-directional earth-fault protection

In case the earth-fault protection is included it shall consist of four different non-directional earth-fault stages.

The earth-fault protection shall consist of three different stages and an additional sensitive stage. The stages shall cover setting ranges from 0.01 to 35 times pu.

The first two stages and the sensitive stage shall include both definite and inverse time characteristics, supporting various types of inverse curves, including a user-definable one. The fourth stage shall work as an instantaneous stage.

During an inrush current situation characterized by a large proportion of second harmonics it shall be possible, for each of the stages, to either block or raise the setting value by a freely settable multiplier. The third harmonic shall be attenuated at least by 40 dB.

### 4.1.4 Admittance based or directional earth-fault protection

The earth-fault protection shall consist of three different admittance based or directional earth-fault stages and an additional non-directional stage using a calculated $I_0$ value for cross-country faults .

The admittance stages shall cover voltage setting ranges from 0.05 to 5 times pu. The directional and non-directional stages shall cover current setting ranges from 0.01 to 35 times pu. They shall include both definite and inverse time characteristics, supporting various types of inverse curves, including a user definable one. It must be possible to operate the directional stages in non-directional mode. The operation mode must be selectable by means of a parameter.

During an inrush current situation characterized by large proportions of second harmonics it shall be possible, for each of the stages, to either block or raise the setting value by a freely settable multiplier. The third harmonic shall be attenuated at least by 40 dB.

### 4.1.5 Transient/Intermittent earth fault

In order to secure accurate operation, the transient/intermittent earth-fault protection must be based on a sampling function designed for the protection and clearance of intermittent and transient earth faults in distribution and sub-transmission networks. Fault detection should be done from the residual current and residual voltage signals by monitoring the transients using predefined criteria.

The sampling frequency shall be high enough for proper detection of transient / intermittent earth faults.

The operate time characteristic must be definite time (DT).

### 4.1.6 Negative sequence overcurrent protection

The negative phase-sequence current protection shall provide increased sensitivity to detect single phase and phase-to-phase faults, unbalanced loads due to, for example, broken conductors or to unsymmetrical feeder voltages.

The protection shall consist of two different stages. The operate time characteristics shall be selectable to be either definite time (DT) or inverse definite minimum time (IDMT).

The function shall contain a blocking feature. It shall be possible to block function outputs, timers, or the function itself, if desired.

### 4.1.7 Phase discontinuity protection

In order to achieve a capability to handle different load situations the protection shall be based on monitoring the negative sequence and the positive sequence current component ratio ($I_2/I_1$).

It shall be possible to block the operation of the stage by the starting signal from any of the earth-fault protection stages or by the inrush current detection.

## 4.2 Other protection functions

### 4.2.1 Thermal overload protection

Thermal overload protection for lines, cables and distribution transformers shall be included. The protection can utilize either one or two time constant principle.

### 4.2.2 Breaker failure protection

Breaker failure protection shall be included in the form of a dedicated function. It shall be possible to initiate the protection either from an internal signal of the protection relay or via a binary input. The protection shall facilitate re-tripping of its own breaker, and also back-up tripping of an up-stream breaker. In both cases the trip delays shall be adjustable.

The protection shall include different operation modes, where both the current flow and the circuit breaker position are monitored, or alternatively only either the current flow or the circuit breaker position is monitored. The current level for flow detection shall be separately adjustable for phase currents and residual current.

# 5 Measurements

There shall be measurement functions and indication in LHMI for analog inputs (current and voltage) connected to the relay, as per the following:

## 5.1 Phase currents

Momentary values for phases A, B and C selectable based on either true RMS or DFT (fundamental frequency only) values.

Maximum demand values for phases A, B and C with settable demand intervals of 1, 5, 10, 15, 30, 60 or 180 minutes.

Settable high and low warning thresholds (two of each), including selection of an initiating number of phases.

## 5.2 Residual current

Momentary value, selectable based on either true RMS or DFT (fundamental frequency only) values.

Settable high and low warning thresholds (two of each).

## 5.3 Current sequence components

The momentary values of the positive, negative and zero sequence current components shall be included.

## 5.4 Bias and differential currents ($I_{bias}$, $I_d$)

The momentary values for the bias and differential currents for phases A, B and C shall be included.

# 6 Disturbance, fault and event recording

The relay shall be capable of recording and storing at least the 1000 latest time-tagged events in a non-volatile memory.

The disturbance recorder shall be capable of recording at least 12 freely selectable analogue input signals and 64 freely selectable internal signals or binary inputs. The sample frequency shall be selectable, maximum sample frequency being no less than 1.6 kHz (32 samples per cycle at 50 Hz). The recording time shall be selectable, including the pre-trigger time. All analog and binary input channels must be capable of triggering the function.

There shall be a settable "quarantine" time for triggering channels, in order to prevent successive recordings triggered by the same source. Analogue channels must have an adjustable triggering level. For binary channels it shall be possible to choose triggering either from the rising or falling edge of the signal, or both. It shall be possible to record either wave-forms or trends of the analog channels. When the maximum number of channels is connected, utilizing the highest sampling frequency, at least two recordings, each with a length of 10 seconds, shall be supported.

For uploading the recorded disturbances records support for a suitable software tool shall be included. The uploaded recording shall be of a well-recognized format, preferably the COMTRADE format.

## 6.1 Event registration

The SoE (Sequence of Events) information must be accessible locally via the user interface on the relay front panel or remotely via the communication interface of the relay. The information should further be accessible, either locally or remotely, using the web browser based user interface.

To collect sequence-of-events (SoE) information, the relay must incorporate a non-volatile memory with a capacity of storing at least 1000 event codes with associated time stamps. The non-volatile memory must retain its data also in case the relay temporarily loses its auxiliary supply. The event log should facilitate detailed pre- and post-fault analyses of feeder faults and disturbances.

## 6.2 Fault records

The relay should have the capacity to store the records of at least 100 fault events. The records must enable the user to analyze the four most recent power system events. Each record must include the current and voltage values (if applicable), the start times of the protection blocks, time stamps, etc.

It must be possible to trigger the fault recording by the start signal or the trip signal of a protection block, or by both. The available measurement modes include DFT, RMS and peak-to-peak. In addition, the maximum demand current with time stamp should be separately recorded. By default, the records must be stored in a non-volatile memory.

## 6.3 Disturbance records

The relay must be provided with a disturbance recorder featuring up to 12 analog and 64 binary signal channels. From the analog channels it should be possible to record either the waveform or the trend of the currents and voltage measured.

It must be possible to trigger the recording function by an analog channel when the measured value falls below or exceeds the set triggering value. The binary signal channels should be capable of starting a recording on the rising or the falling edge of the binary signal or on both.

Binary relay signals such as a protection start or trip signal, or an external relay control signal over a binary input should be capable of triggering a recording. The recorded information must be stored in a non-volatile memory and be uploadable for subsequent fault analysis.

## 6.4  Time synchronization

The relay should support the following time synchronization methods with a time-stamping resolution of 1 ms.

- SNTP (Simple Network Time Protocol)
- IRIG-B (Inter-Range Instrumentation Group - Time Code Format B)

# 7  Condition monitoring

The condition monitoring functions of the device must constantly monitor the performance and the condition of the circuit breaker. When specified the monitoring should at least cover the spring charging time, $SF_6$ gas pressure, the travel-time and the inactivity time of the circuit breaker.

## 7.1  Self supervision

The device built-in self-supervision system must continuously monitor the state of the relay hardware and the operation of the relay software. Any fault or malfunction detected must be used for alerting the operator. A permanent device fault must block the protection functions of the relay to prevent incorrect operation.

## 7.2  Circuit breaker condition monitoring

A circuit breaker condition monitoring function shall be available for monitoring different parameters of the circuit breaker.

At least the following parameter should be monitored:

- circuit-breaker operation
- spring-charge indication
- breaker wear, travel time
- number of operation cycles

Alarms are generated when the calculated values exceed the threshold settings. The condition monitoring function contains a blocking feature. On request, the function outputs can be blocked.

# 8   Communication interfaces

The relay shall be of "native" IEC 61850 design thus offering optimal connection interface to a substation automation systems based on the 61850-8-1 standard. The physical communication connection shall be based on an Ethernet bus with galvanic 100BaseTX (RJ45) interface.

For increasing station bus communication availability and reliability, the relay shall have support for Ethernet redundancy. At minimum, support for RSTP (Rapid Spanning Tree Protocol) redundancy shall be available, but more preferably HSR (High-availability Seamless Redundancy) or PRP (Parallel Redundancy Protocol) shall be supported.

Other communication possibilities shall cover Modbus over WAN and Modbus serial. On the front side of the relay there shall be a local communication interface with an RJ45 connector. This connection shall be dedicated for the protection relay local user interface allowing parameterization, disturbance recorder upload, etc using software tools.

## 8.1   IEC 61850 GOOSE messaging

In applications where the IEC 61850 protocol is used for horizontal communication the relays must be capable of utilizing GOOSE messages, as described in the IEC 61850-8-1 standard.

The GOOSE message presentation and mapping shall be carried out in the relay in a user-friendly way, exposing the GOOSE incoming and outgoing signals to a similar manner as the physical binary inputs and outputs. The GOOSE signal performance has to be in accordance with type 1A and fulfill the requirements of class P1.

## 8.2   Protection communication and supervision

The communication between the relays shall rely on a dedicated fiber-optic communication channel. Multi-mode or single-mode fibers with LC connectors shall be used for line differential communication and shall support distances up to 20 km.

No external devices such as GPS clocks shall be needed for the line differential protection communication.

The protection communication supervision shall continuously monitor the protection communication link. The relay must immediately block the line differential protection function in case of severe interference on the communication link, which may risk the correct operation of the function.

An alarm signal shall be issued if the interference causes a permanent protection communication failure.

## 8.3   Signal exchange between local and remote relay (Binary Signal Transfer, BST)

A signal exchange function shall be available for transferring binary signals between the local and remote end line differential protection relays. The function shall include eight binary signals that are transferred in the protection communication telegram and that can be freely configured and used for any purpose in the line differential application.

Each of the eight signals shall be bidirectional and the binary data sent locally shall be available remotely as a received signal.

The exchange of signals between the relays shall be fast enough for inter tripping purposes and shall not exceed 7 ms excluding output relay delays.

## 8.4 User authorization

The relay shall support user authorization at least on four different levels. The authorization within the different levels shall start from basic viewer only functionality, ending with the highest authorization level having all rights, including password management.

There shall be settable separate passwords for each user level. The password shall be different for local and remote access.

# 9 Setting and configuration software

All necessary setting and configuration software, including cables, must be included. The software must be delivered together with the protection relays.

# 10 Environmental conditions

The relay must fulfill the environmental conditions listed below.

| Description | Value |
| --- | --- |
| Operating temperature range | -25...+55⁰C (continuous) |
| Short-time service temperature range | -40...+70⁰C (<16 h) |
| Relative humidity | <93%, non-condensing |

Electromagnetic compatibility tests

The EMC immunity test level meets the requirements listed below:

| Description | Value |
| --- | --- |
| 1 MHz burst disturbance test, class III: | According to IEC 61000-4-18 and IEC 60255-22-1, level 3 |

Electromagnetic compatibility tests

| | |
| --- | --- |
| Fast transient disturbance tests: | According to IEC 61000-4-4 and IEC 60255-22-4, class A |
| All ports | 4 kV |

Mechanical tests

| Description | Value |
| --- | --- |
| Vibration tests (sinusoidal) | According to IEC 60255-21-1, class 2 |
| Shock and bump test | According to IEC 60255-21-2, class 2 |

# 11 Quality assurance and standards

The provider of the device must have a quality system in place, which aims at securing a high quality of the manufactured device.

The product has to comply with RoHS directive 2002/95/EC.