

PARAMETERIZATION OF PROTECTION RELAYS IN POWER SYSTEMS

PROTECTION SYSTEMS IN THE POWER SYSTEM

SEL - 751/751A
SEL - 700G/GT
SEL - 787
SEL - 387E
SEL - 421

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TECHNICKÁ UNIVERZITA
V KOŠICIACH



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This textbook describes detailed procedures for the parameterization of SEL overcurrent, differential and distance digital relays, together with the theoretical background, the description and the wiring of the individual parts of digital relays.

The textbook is intended for electrical engineering students in study programmes focused on power engineering, for users of power equipment and for the professional public.

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Theory of electrical protection

The main task of protecting electrical equipment is to ensure that the equipment or the section is not exposed to adverse conditions, e.g. overloading of the equipment and the resulting reduction of its service life, or to random fault conditions caused by a short circuit.

For these reasons it is necessary to know the interactions between the equipment or the section and its surroundings, which have a very significant influence on the equipment itself. The effects of the equipment on its surroundings and of the surroundings on the equipment must therefore be known. The setting and the design should be based on the most detailed information available on these aspects.

If the information is incomplete or unclear, the calculation for the protection of the equipment or the section should not be started at all, or the influence of the surroundings on the equipment should be assessed more conservatively.



Theory of electrical protection

– overcurrent protection



Protection theory – overcurrent protection

Time-graded protection – selective tripping requires current and time grading, which provides mutual back-up between the protective relays. For this reason these relays contain a starting element and a timing element, which, together with the measuring and directional elements, identify the fault condition; the relay then responds to these changes according to the set times and pickup currents. Time-graded protection includes overcurrent and distance protection.

Overcurrent protection works on a simple principle and is used as back-up protection, or as main protection on MV lines and on less important low-voltage lines. As the name implies, the relay responds to current values above the set pickup current I_r , during line overload or short circuits.



Theory of electrical protection

– overcurrent protection

Časovo závislá – má klesajúcu závislosť podobnú poistkám, podľa rovnice

$$t = \frac{K}{\frac{I}{I_N} - 1} \text{ pre } I/I_N > 1 \text{ a } t = \infty \text{ pre } I/I_N \leq 1,$$

Polozávislá – má charakteristiku rovnakú do veľkosti I_0 . Pre väčšie prúdy $I/I_N > I_0$ už má konštantnú dobu pôsobenia a nezávisí od zmeny prúdu.

P_d - dovolená oblasť; P_z - zakázaná oblasť; h_0 - hranica pôsobenia

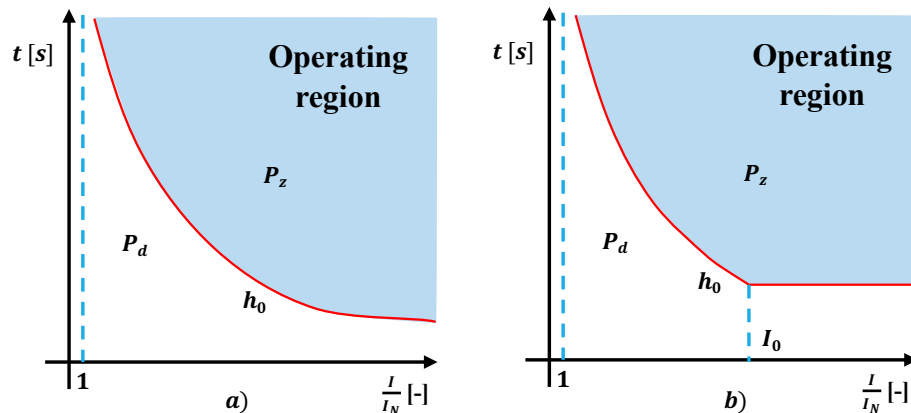


Fig. 1 Operating-time characteristics a) inverse-time; b) semi-inverse-time



Theory of electrical protection

– overcurrent protection

Definite-time – operates after the set time $t_>$ if the current exceeds $kI_>$. For higher currents $I/I_N > kI_>$ the characteristic has a constant operating time given by $t_>$ and no longer depends on the change of current.

Instantaneous – operates when the set current $kI_>$ is exceeded, almost without delay. The delay corresponds to the response time of the relay itself, about 20 ms.

P_d - permissible region; P_z - prohibited region; h_0 - operating boundary; $t_>$ - time delay; $kI_>$ - current pickup setting

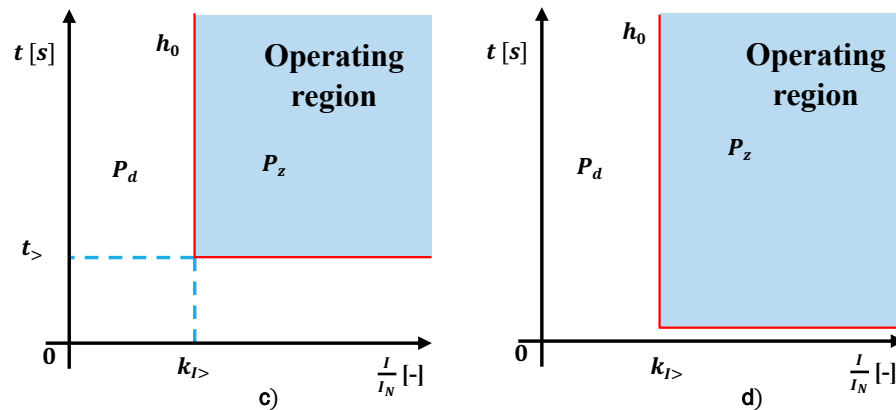


Fig. 2 Operating-time characteristics c) definite-time; d) instantaneous



Theory of electrical protection – overcurrent protection

The time settings are generally based on the assumption that the most remote relay trips fastest, for which the equation $t_2 = t_1 + \Delta t$ applies. The coordination time interval Δt depends on the design of the timing relay and of the circuit breaker and is most often in the range 0.2 to 0.5 s. The current settings of the relays must also be chosen so that the relays back each other up. Correct setting of the pickup currents I_r requires knowledge of the current levels of the short-circuit currents, of the overloads and of the rated currents. The short-circuit conditions must therefore be known.

If the network topology changes, it is necessary to verify that the existing relay settings are still adequate; if required, a different setting group can be used, since digital relays have four setting groups as standard, between which it is possible to switch.



Setting of overcurrent protection

Určenie veľkosti časového koordinačného intervalu Δt :

- maximálnymi chybami časového relé,
- dobou vypnutia výkonových vypínačov,
- záložným bezpečnostným časom, ktorý sa volí cca 0.1 s.

Nastavenie rozbehového prúdu I_r :

$$I_r \geq I_n * \frac{k_b}{k_p * p_i} \quad (1)$$

kde k_b je koeficient bezpečnosti a vyberá sa z intervalu 1.1 až 1.35

k_p je prídržný pomer relé a je udávaný výrobcovi v rozsahu 0.94 až 0.98

p_i je menovitý prevod prúdových transformátorov.



I_{kmax} – maximum short-circuit current (3-ph); I_{kmin} – minimum short-circuit current; I_r – pickup current; I_0 – dropout current; I_{zmaxOZ} – maximum inrush current for auto-reclosing; I_{zmaxM} – maximum motor starting current; I_n – rated current; I_{pmax} – maximum operating current

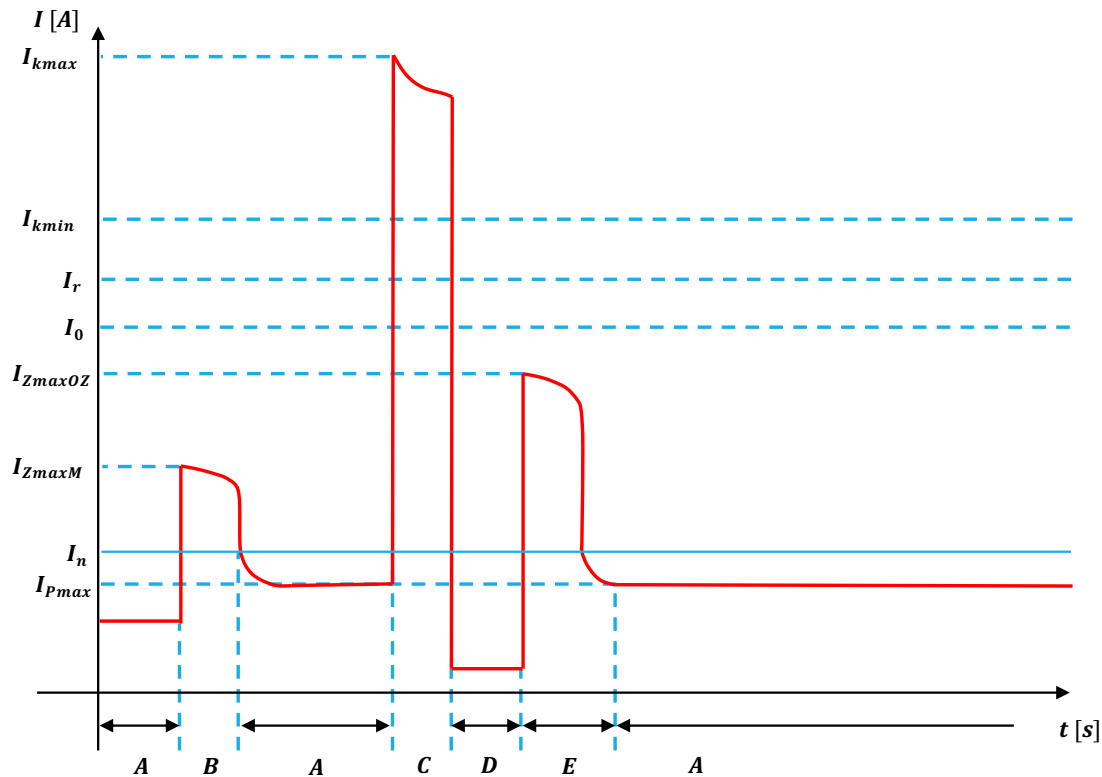


Fig. 3 Current levels under various operating and fault conditions



Setting of overcurrent protection

Ďalej rozbehový prúd nadprúdovej ochrany musí byť menší ako minimálny vypočítaný skratový prúd I_{k2fmin} na konci chráneného úseku.

$$I_r \leq I_{k2fmin} * \frac{1}{k_c * p_i} \quad (2) \quad k_c = \frac{I_{k2fmin}}{I_r * p_i} \quad (3)$$

kde k_c je koeficient citlivosti najmenej pre okamžité pôsobiacie 2 a ostatné 1.5

p_i je menovitý prevod prúdových transformátorov.

V prípade, že koeficient citlivosti k_c vyjde menší ako 1.5 u nadprúdových nezávislých časových ochrán, potom sa citlivosť ochrany zvýši tak, že znížime hodnotu rozbehového prúdu I_r . Týmto prestavením ochrany bude rozbiehať pri nižších prúdoch.



Setting of overcurrent protection

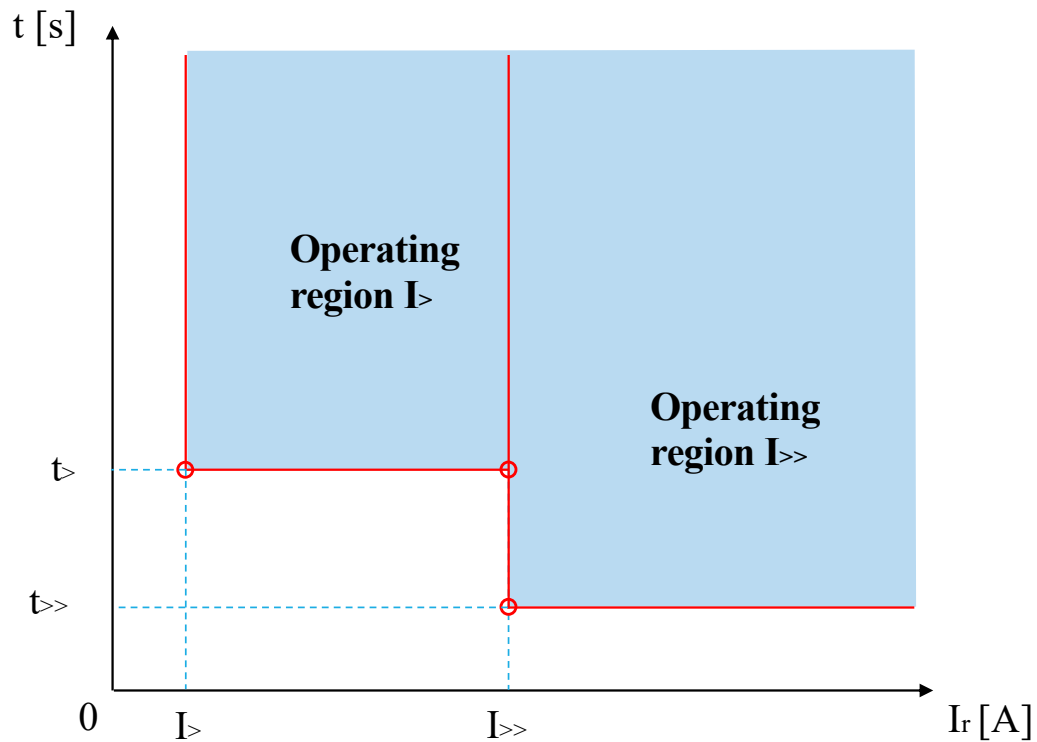
The three-phase short-circuit current is usually the largest. In the case of a short circuit close to a transformer with an earthed neutral, the single-phase short-circuit current can be larger than the three-phase one. This applies mainly to transformers with Yz, Dy and Dz connections when the y or z winding on the low-voltage side of the transformer is earthed. For this reason, the two-phase short-circuit current is used in the calculation of the pickup currents.

Electrical equipment is rated for the highest short-circuit current, which in most cases is the three-phase short-circuit current. Unlike overhead lines, cable lines suffer three-phase faults in almost all cases, because the arc destroys the insulation of all three phases. Two-phase faults on lines can cause increased stress on single-phase transformers connected to three-phase busbars.



Overcurrent protection characteristic

$t_{>}$ - time delay for overload; $t_{>>}$ - time delay for short circuits; $I_{>}$ - current pickup setting for overload; $I_{>>}$ - short-circuit current pickup setting



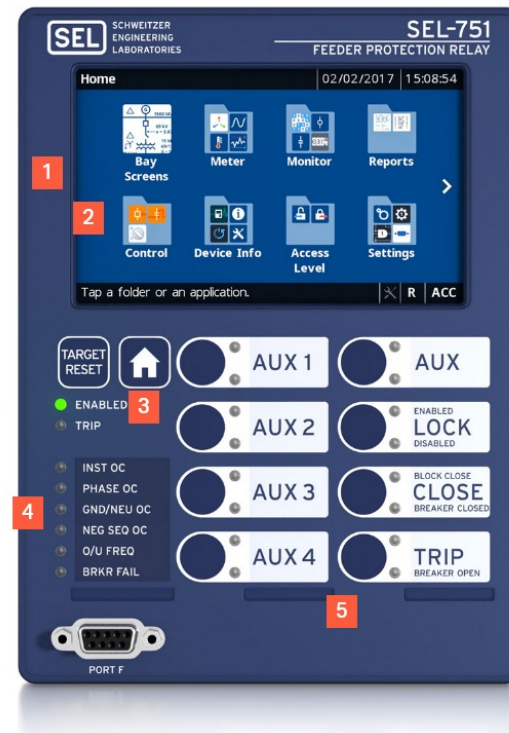
Overcurrent protection

- 1 The 2*16-character LCD display provides navigation, relay control, data and diagnostics through default messages or up to 32 customizable display messages
- 2 Programmable front-panel LEDs with user-configurable labels alert the operator to faults and to basic operations
- 3 Programmable operator pushbuttons with user-configurable labels allow customization of the front panel



Overcurrent protection

- 1 The 12.7 cm capacitive touchscreen with a resolution of 800x480 offers direct navigation via the touch display
- 2 Directories and applications provide quick access to the bay screen, to metering and real-time data, to reports, to settings and to other functions.
- 3 The home button always returns you to the main home screen
- 4 Programmable front-panel LEDs with user-configurable labels alert the operator to faults and to basic operations
- 5 Programmable operator pushbuttons with user-configurable labels allow customization of the front panel



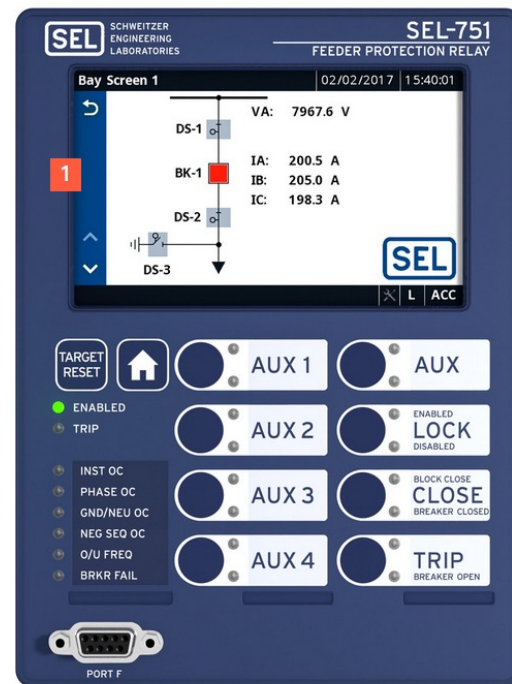
Overcurrent protection

1 Bay screen and device control

Choose from predefined bay screens or configure up to five custom bay screens using acSElerator® Bay Screen Builder SEL-5036 and acSElerator QuickSet® SEL-5030 software.

You can control one circuit breaker, eight two-position disconnectors and two three-position disconnectors, and analogue and digital data can also be shown on the context display.

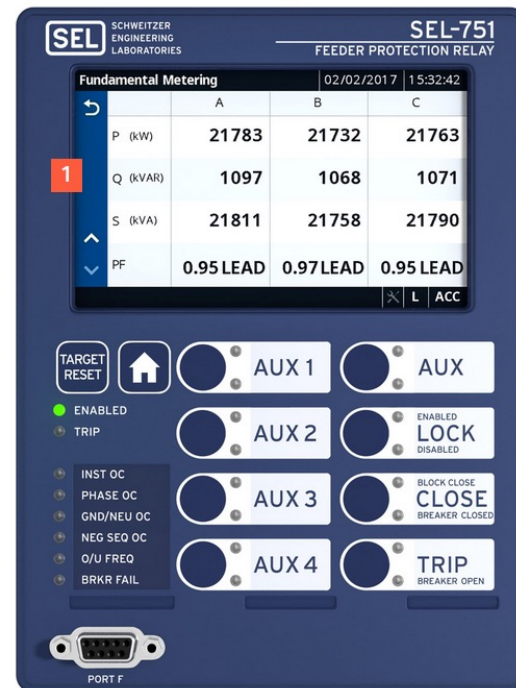
To control a circuit breaker or a disconnector, simply tap the Bay Screens application on the home screen and then the circuit breaker or disconnector you want to control.



Overcurrent protection

1 Basic metering

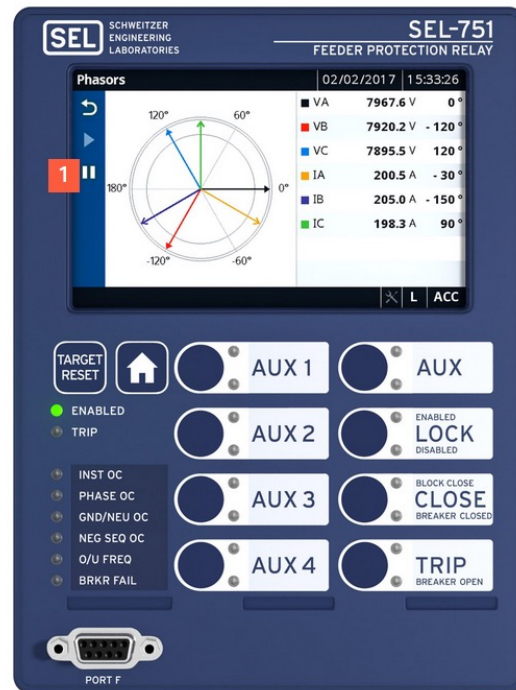
Displays the active, reactive and apparent power of each phase in the system and also shows power factor information, so that you can determine whether the phase current leads or lags the phase voltage.



Overcurrent protection

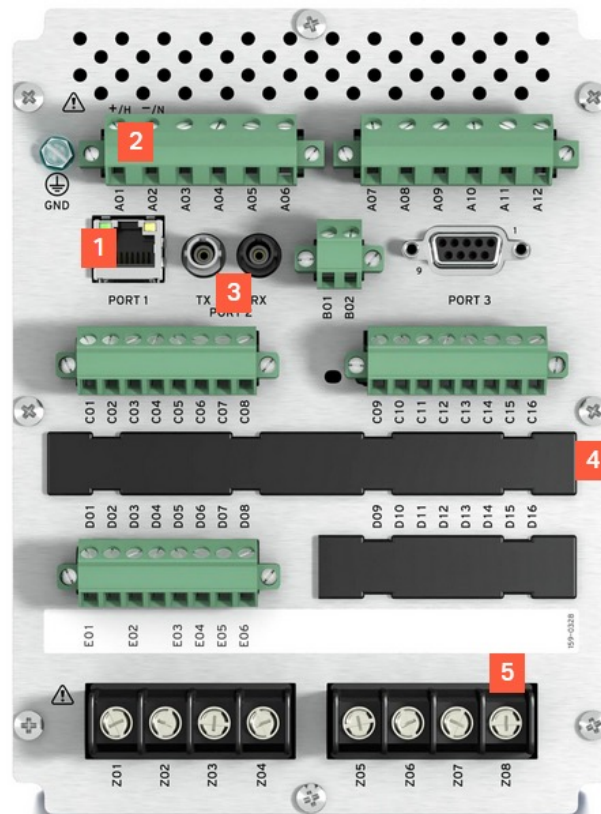
1 Display of the measured phasors

Graphical and textual display of the voltages and currents in the power system in real time, under balanced and unbalanced conditions.



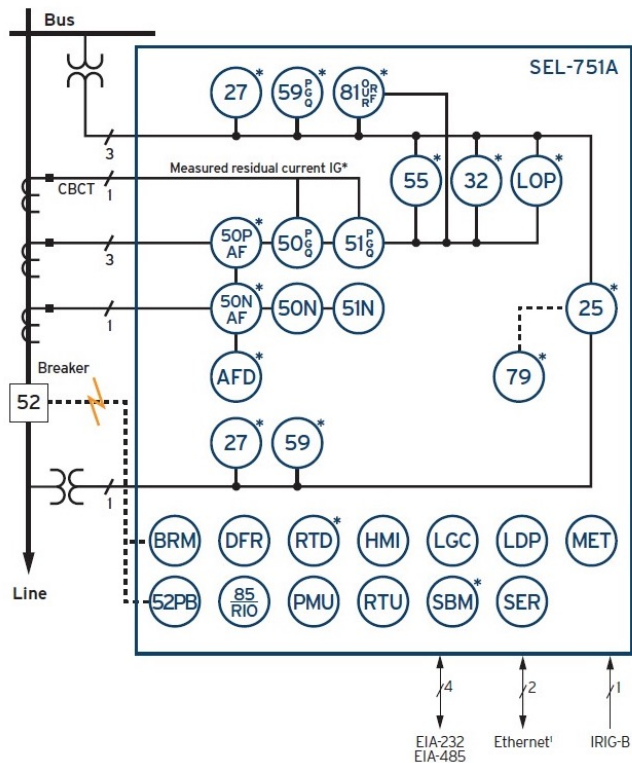
Overcurrent protection

- 1 A wide range of communication protocols and media provides flexibility in communication with other devices and control systems
- 2 Power supply option 24 - 48 V DC or 110 - 250 V DC/110 - 240 V AC
- 3 An optional optical serial port provides fast and easy engineering access
- 4 The card slots accommodate positions for optional inputs/outputs, a voltage input card or an arc-flash detection card with sensors, which help to increase safety and to prevent damage.
- 5 The phase current inputs and the optional phase voltage inputs are on a single card, which frees space for further optional input/output cards



Overcurrent protection

Tab. 1 Protection functions of the SEL-751A feeder relay



ANSI Numbers/Acronyms and Functions

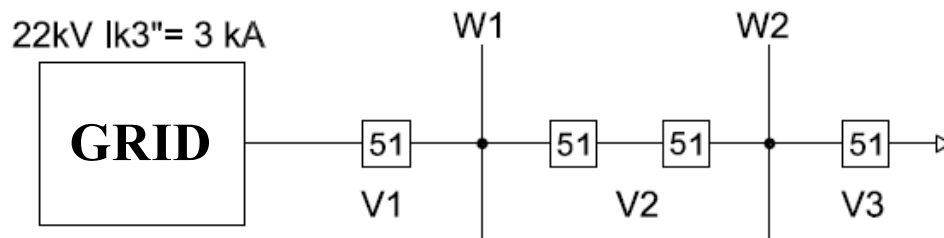
25	Synchronism Check*
27	Undervoltage*
32	Directional Power*
50	Adaptive Overcurrent
50 (P,G,Q)	Overcurrent (Phase, Ground, Neg. Seq.)
50N	Neutral Overcurrent
50N AF	Arc-Flash Neutral Overcurrent*
50P AF	Arc-Flash Phase Overcurrent*
51 (P,G,Q)	Time Overcurrent (Phase, Ground, Neg. Seq.)
51N	Neutral Time Overcurrent
52PB	Trip/Close Pushbuttons
55	Power Factor*
59	Overvoltage*
79	Autoreclosing*
81 (O,U,R,RF)	Over-/Underfrequency (Rate, Fast Rate)*
85 RIO	SEL MIRRORED BITS® Communications
AFD	Arc-Flash Detector*
BRM	Breaker Wear Monitor
DFR	Event Reports
LOP	Loss-of-Potential Logic*

Additional Functions

HMI	Operator Interface
LDP	Load Data Profiling
LGC	SELogic® Control Equations
PMU	Synchrophasors
RTD	Temperature
RTU	Remote Terminal Unit
SBM	Station Battery Monitor*
SER	Sequential Events Recorder



Overcurrent protection – selective tripping



Scheme parameters:

V1: 240 AlFe $R_{M1} = 0.121 \Omega/\text{km}$, $X_{M1} = 0.392 \Omega/\text{km}$, $I_N = 579 \text{ A}$, $l = 5 \text{ km}$

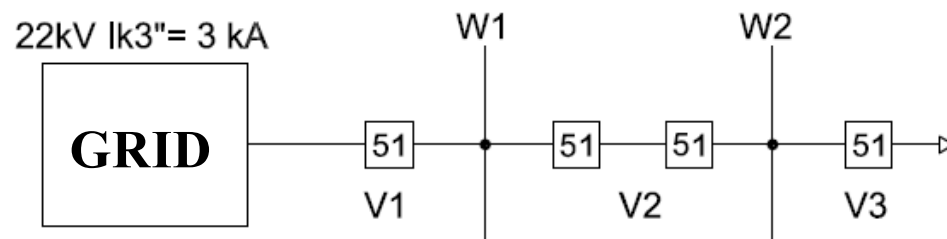
V2: 185 AlFe $R_{M1} = 0.156 \Omega/\text{km}$, $X_{M1} = 0.4 \Omega/\text{km}$, $I_N = 486 \text{ A}$, $l = 3 \text{ km}$

V3: 185 AlFe $R_{M1} = 0.156 \Omega/\text{km}$, $X_{M1} = 0.4 \Omega/\text{km}$, $I_N = 486 \text{ A}$, $l = 1 \text{ km}$

CT used = 600 A / 5 A; a line loading of 80 % is assumed



Overcurrent protection – selective tripping



Calculated parameters:

End of line V3

$$Z_{k1_V3} = 1.6503 + 7.7727i \, \Omega; I_{k2_V3} = 1.3843 \text{ kA}$$

Busbar W2

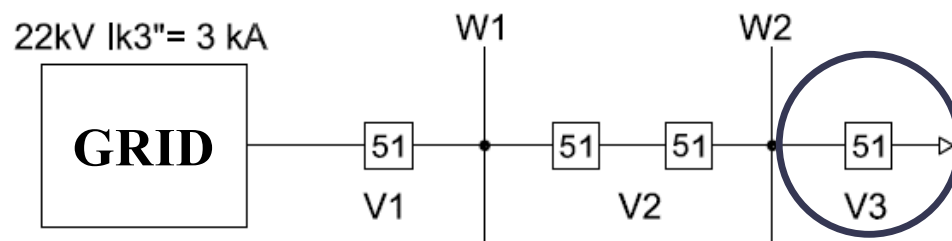
$$Z_{k1_V2} = 1.4943 + 7.3727i \, \Omega; I_{k2_V2} = 1.4623 \text{ kA}$$

Busbar W1

$$Z_{k1_V1} = 1.0263 + 6.1727i \, \Omega; I_{k2_V1} = 1.7579 \text{ kA}$$



Overcurrent protection – selective tripping



Calculated parameters:

End of line V3

$$I_{>} = 3.7516 \text{ A} \leq I_{R>} = 3.8 \text{ A};$$

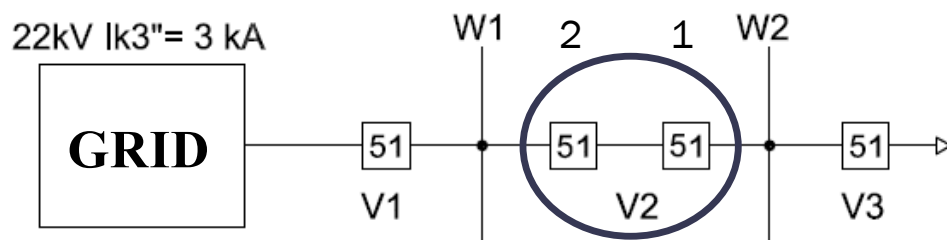
$$I_{>>} = 6.1526 \text{ A} \geq I_{R>>} = 5 \text{ A} > I_{R>} = 4 \text{ A}$$

$$t_{>} = 0.35 \text{ s}$$

$$t_{>>} = 0.1 \text{ s}$$



Overcurrent protection – selective tripping



$I_{R>} = 3.8 \text{ A};$
 $t_{>} = 0.35 \text{ s}$
 $I_{R>>} = 5 \text{ A};$
 $t_{>>} = 0.1 \text{ s}$

Calculated parameters:

End of line V2

$$I_{R>} = 3.8 \text{ A} < I_{R1>} = 4.3 \text{ A} < I_{R2>} = 4.8 \text{ A}$$

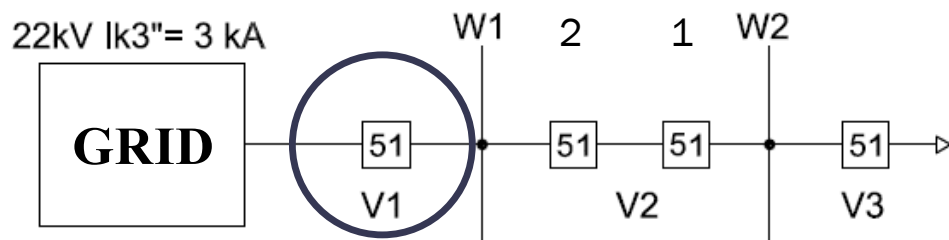
$$I_{>>} = 6.4989 \text{ A} \geq I_{R2>>} = 6 \text{ A} > I_{R1>} = 5.5 \text{ A} > I_{R>}$$

$$t_{1>} = 0.55 \text{ s}; t_{2>} = 0.75 \text{ s}; t_{2>} > t_{1>} > t_{>}$$

$$t_{1>>} = 0.15 \text{ s}; t_{2>>} = 0.2 \text{ s}; t_{2>>} > t_{1>>} > t_{>>}$$



Overcurrent protection – selective tripping



Calculated parameters:

End of line V1

$$I_{R2>} = 4.8 \text{ A} < I_{R>} = 5.3 \text{ A}$$

$$I_{>>} = 7.8129 \text{ A} \geq I_{R3>>} = 6.5 \text{ A} > I_{R2>} = 6 \text{ A}$$

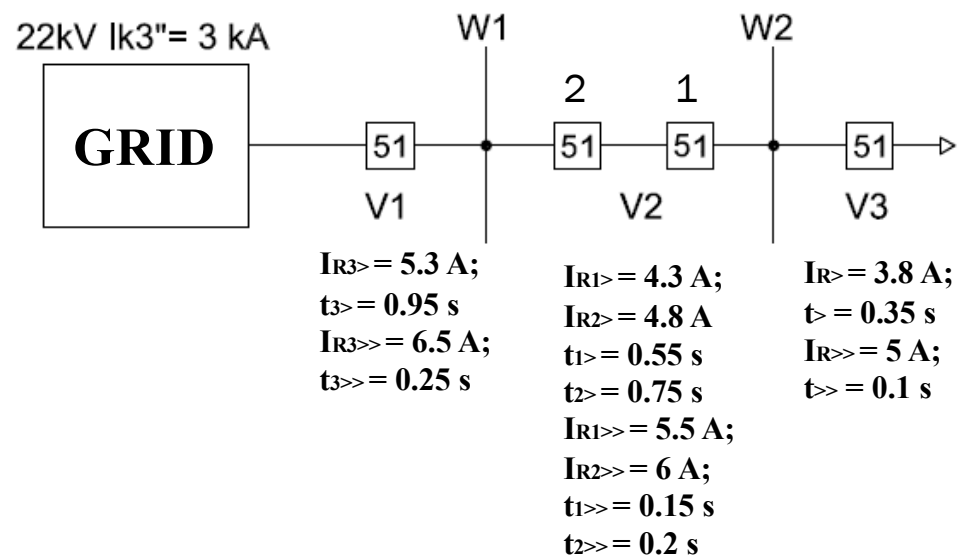
$$t_{3>} = 0.95 \text{ s}; t_{3>} > t_{2>}$$

$$t_{3>>} = 0.25 \text{ s}; t_{3>>} > t_{2>>}$$

$$\begin{aligned} I_{R1>} &= 4.3 \text{ A}; & I_{R>} &= 3.8 \text{ A}; \\ I_{R2>} &= 4.8 \text{ A}; & t_{>} &= 0.35 \text{ s} \\ t_{1>} &= 0.55 \text{ s} & I_{R>>} &= 5 \text{ A}; \\ t_{2>} &= 0.75 \text{ s} & t_{>>} &= 0.1 \text{ s} \\ I_{R1>>} &= 5.5 \text{ A}; \\ I_{R2>>} &= 6 \text{ A}; \\ t_{1>>} &= 0.15 \text{ s} \\ t_{2>>} &= 0.2 \text{ s} \end{aligned}$$



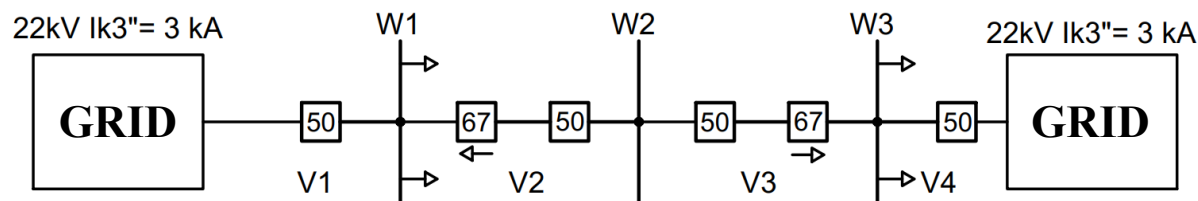
Overcurrent protection – selective tripping



Protection of the parts downstream of line V3 is provided by fuses only.



Overcurrent protection – selective tripping



Scheme parameters:

V1: 240 AlFe $R_{M1} = 0.121 \Omega/\text{km}$, $X_{M1} = 0.392 \Omega/\text{km}$, $I_N = 579 \text{ A}$, $l = 5 \text{ km}$

V2: 185 AlFe $R_{M1} = 0.156 \Omega/\text{km}$, $X_{M1} = 0.4 \Omega/\text{km}$, $I_N = 486 \text{ A}$, $l = 3 \text{ km}$

V3: 185 AlFe $R_{M1} = 0.156 \Omega/\text{km}$, $X_{M1} = 0.4 \Omega/\text{km}$, $I_N = 486 \text{ A}$, $l = 1 \text{ km}$

V4: 240 AlFe $R_{M1} = 0.121 \Omega/\text{km}$, $X_{M1} = 0.392 \Omega/\text{km}$, $I_N = 579 \text{ A}$, $l = 5 \text{ km}$

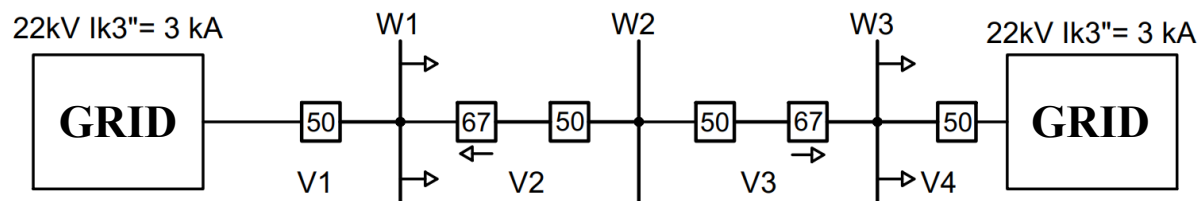
CT used = 600 A / 5 A; a line loading of 80 % is assumed

Substation W2 is a switching station only

Substations W1 and W3 contain a feeder to consumers



Overcurrent protection – selective tripping



Calculated parameters:

Busbar W1

$$Z_{k1_W1_right} = 1.6503 + 7.7727i \, \Omega; I_{k2_W1_right} = 1.3843 \, \text{kA}$$

$$Z_{k1_W1_left} = 1.0263 + 6.1727i \, \Omega; I_{k2_W1_left} = 1.7579 \, \text{kA}$$

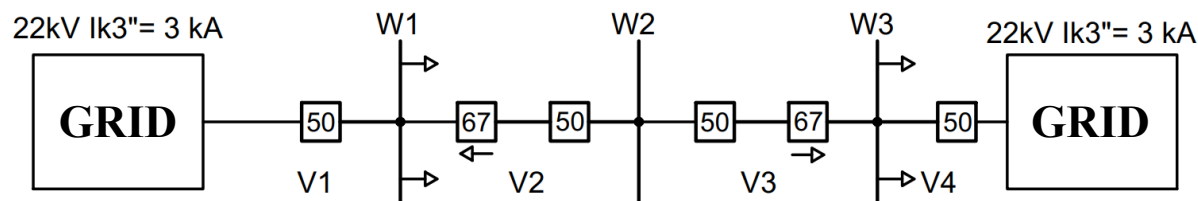
Busbar W2

$$Z_{k1_W2_right} = 1.1823 + 6.5727i \, \Omega; I_{k2_W2_right} = 1.6471 \, \text{kA}$$

$$Z_{k1_W2_left} = 1.4943 + 7.3727i \, \Omega; I_{k2_W2_left} = 1.4623 \, \text{kA}$$



Overcurrent protection – selective tripping



Calculated parameters:

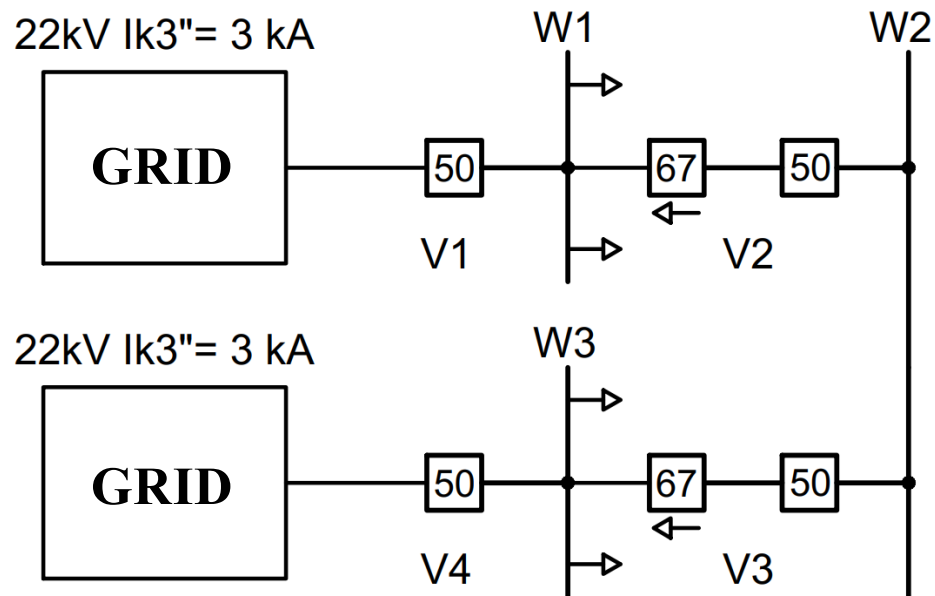
Busbar W3

$$Z_{k1_W3_right} = 1.0263 + 6.1727i \, \Omega; I_{k2_W3_right} = 1.7579 \, \text{kA}$$

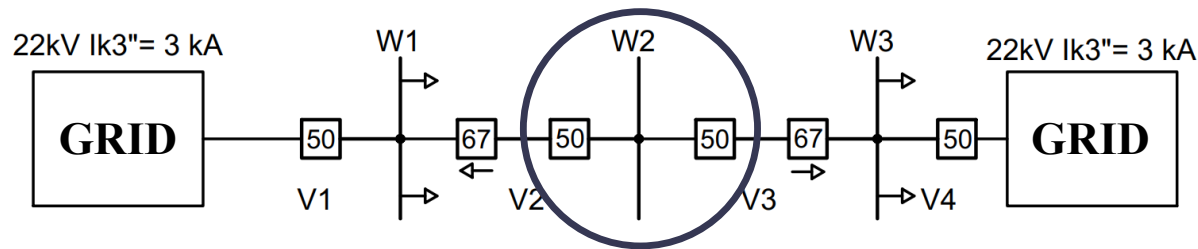
$$Z_{k1_W3_left} = 1.6503 + 7.7727i \, \Omega; I_{k2_W3_left} = 1.3843 \, \text{kA}$$



Overcurrent protection – selective tripping



Overcurrent protection – selective tripping



Calculated parameters:

W2_left

$$I_{>} = 3.7516 \text{ A} \leq I_{R>} = 4 \text{ A};$$

$$I_{>>} = 8.1236 \text{ A} \geq I_{R>>} = 6 \text{ A} > I_{R>} = 4 \text{ A}$$

$$t_{>} = 0.35 \text{ s}$$

$$t_{>>} = 0.1 \text{ s}$$

Calculated parameters:

W2_right

$$I_{>} = 3.7516 \text{ A} \leq I_{R>} = 4 \text{ A};$$

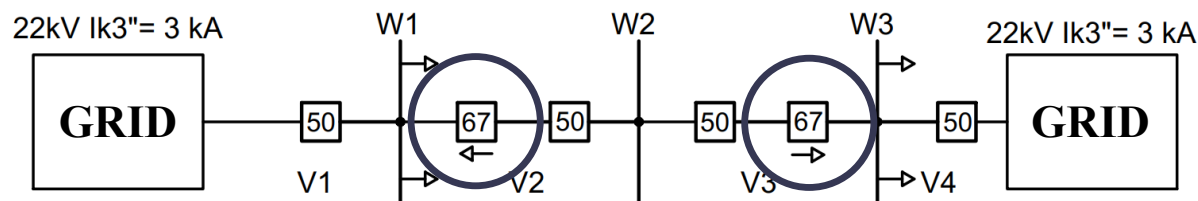
$$I_{>>} = 9.1508 \text{ A} \geq I_{R>>} = 6 \text{ A} > I_{R>} = 4 \text{ A}$$

$$t_{>} = 0.35 \text{ s}$$

$$t_{>>} = 0.1 \text{ s}$$



Overcurrent protection – selective tripping



Calculated parameters:

W1_right

$$I_{>>} = 7.6908 \text{ A} \geq I_{R>>} = 7 \text{ A} > I_{R_W2>} = 6 \text{ A}$$

$$t_{>>} = 0.15 \text{ s}$$

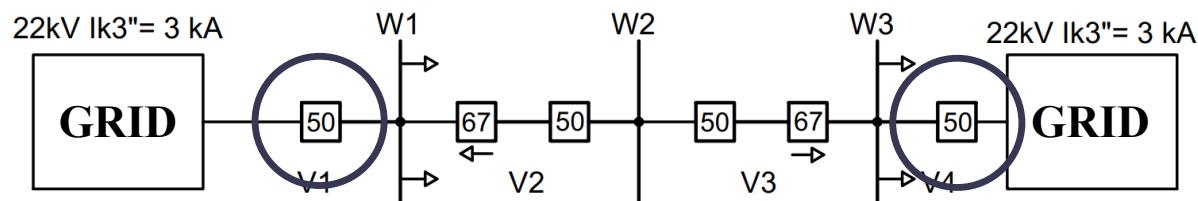
W3_left

$$I_{>>} = 7.6908 \text{ A} \geq I_{R>>} = 7 \text{ A} > I_{R_W2>} = 6 \text{ A}$$

$$t_{>>} = 0.15 \text{ s}$$



Overcurrent protection – selective tripping



Calculated parameters:

W1_left

$$I_{>} = 4.4695 \text{ A} \leq I_{R>} = 5 \text{ A};$$

$$I_{>>} = 9.7661 \text{ A} \geq I_{R>>} = 8 \text{ A} > I_{R>} = 6 \text{ A}$$

$$t_{>} = 0.55 \text{ s}$$

$$t_{>>} = 0.2 \text{ s}$$

Calculated parameters:

W3_right

$$I_{>} = 4.4695 \text{ A} \leq I_{R>} = 5 \text{ A};$$

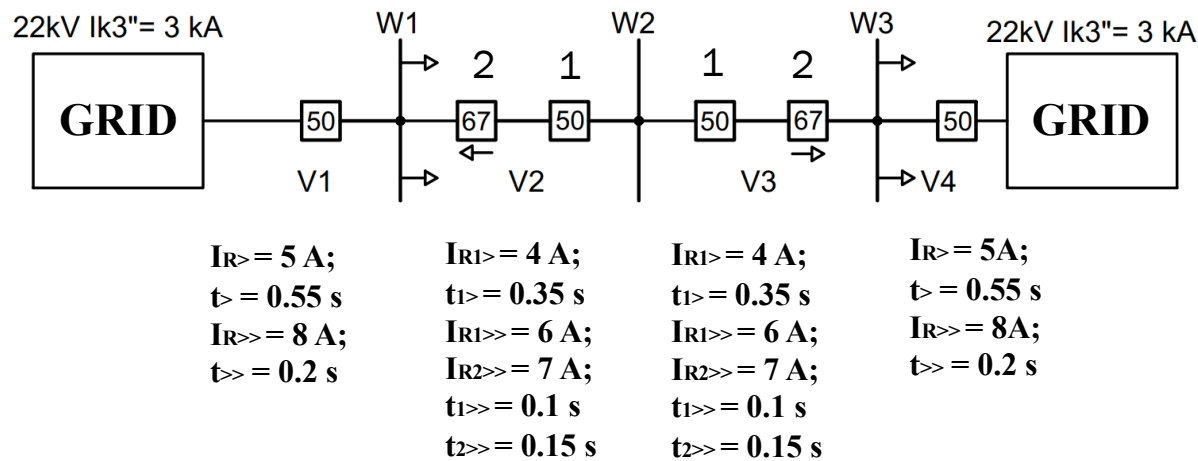
$$I_{>>} = 9.7661 \text{ A} \geq I_{R>>} = 8 \text{ A} > I_{R>} = 6 \text{ A}$$

$$t_{>} = 0.55 \text{ s}$$

$$t_{>>} = 0.2 \text{ s}$$



Overcurrent protection – selective tripping



Theory of electrical protection – differential protection



Theory of electrical protection – differential protection

Comparison-based protection – operates on the principle of comparing measured physical quantities at the input and at the output of the protected section or object. As the name of this group of relays implies, two measured quantities from two locations are compared; these are usually measured at the beginning and at the end of the protected section or object.

In order for comparison protection, otherwise called differential protection, to be able to compare these quantities between input and output, the two ends must be linked by a pilot connection. This type of connection is a typical feature of such relays. If the protected section or object inside this zone is healthy, the values of the compared quantities are equal. When the compared values differ, the relay evaluates whether the fault lies inside the protected zone, and for an internal fault it issues a trip command. *Comparison protection monitors only its own protected object or section, does not need to be time-coordinated with other relays and belongs to the basic fast protection.*



Differential protection is intended to protect electrical machines sensitively and selectively. Most often these are transformers, generators or large motors. Differential protection is now also commonly used for lines.

Differential protection is used quite frequently to protect alternators, namely as stator protection. Differential relays are connected before and after the winding. For this reason the generator must have the neutral point of the stator winding brought out.

The calculation of the operating characteristics is based on the measurement errors caused by the individual deviations of the devices used. Information on all devices used is therefore required, i.e. complete information on the operation and the parameters of all instruments used.

The same principles apply to every instrument current transformer as to an ordinary transformer; in the linear range the deviations are minimal, depending on the CT type. The error increases significantly mainly in the saturation range, where the measurement inaccuracies are large. Compensation of such errors is calculated as the sum of all error factors.



Calculation of total fault current:

$$I_{d2} = CT_{fault} + \text{excitation current} + TR_{fault} + \text{safety reserve} + \text{relay errors} \quad (4)$$

$$I_{d2} = 2 * 5 \% + 1 \% + 5 \% + 5 \% + 5 \% = 26 \%$$

Calculation of first slope setting:

$$SLP_1 = CT_{fault} + \text{excitation current} + TR_{fault} + \text{safety reserve} + \text{relay errors} \quad (5)$$

$$SLP_1 = 2 * 7 \% + 1 \% + 5 \% + 5 \% + 5 \% = 30 \%$$

Calculation of second slope setting:

$$SLP_2 = 2 * SLP_1 = 60 \% \quad (6)$$

To ensure safety at high fault currents outside the protected zone, CT saturation may occur. For this reason, it is recommended to set the slope to double the first one.



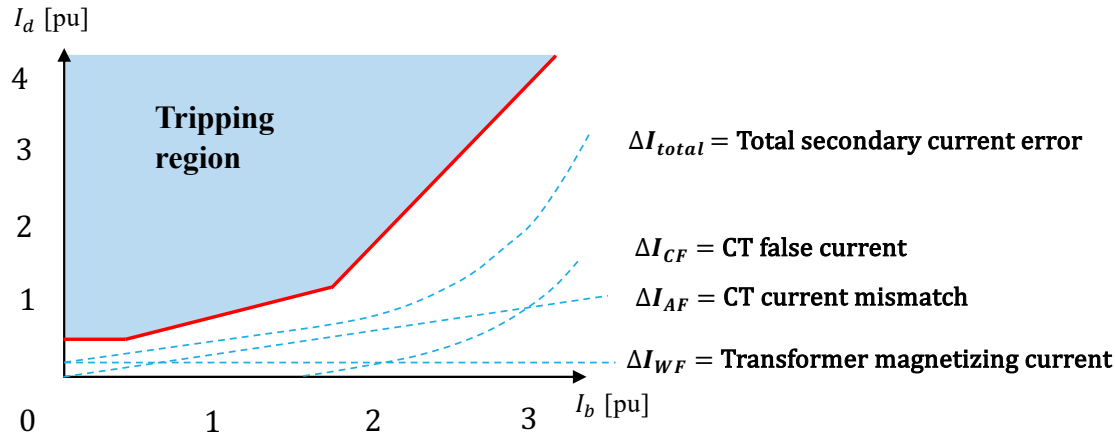


Fig. 4 Operating characteristic of the differential protection

Remaining missing points are calculated according to the relationship:

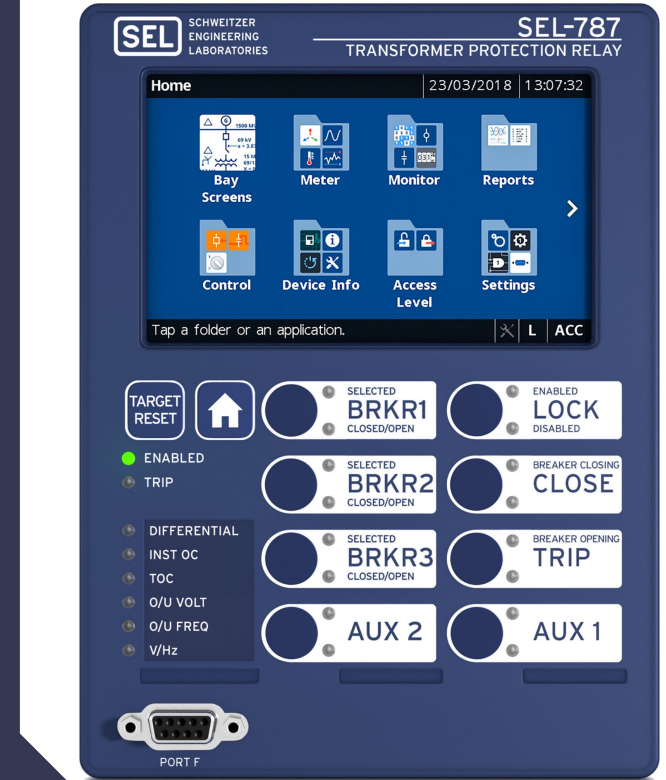
$$SLPx = \frac{I_{di} - I_{di-1}}{I_{bi} - I_{bi-1}} \quad (7)$$

Compensation factor CT TAP is calculated according to the relationship:

$$TAP = \frac{S \cdot 1000}{\sqrt{3} \cdot U_{L-L}} * PT = \frac{10.5 \text{ MVA}}{\sqrt{3} \cdot 11 \text{ kV}} * \frac{5}{600} = 4.593 \quad (8)$$

Verification of correct CT dimensioning is calculated according to the relationship:

$$\frac{TAP_{max}}{TAP_{min}} \leq 7.5 \quad (9)$$



Differential protection

1 Front-panel LEDs alert the operator to faults and to basic operations

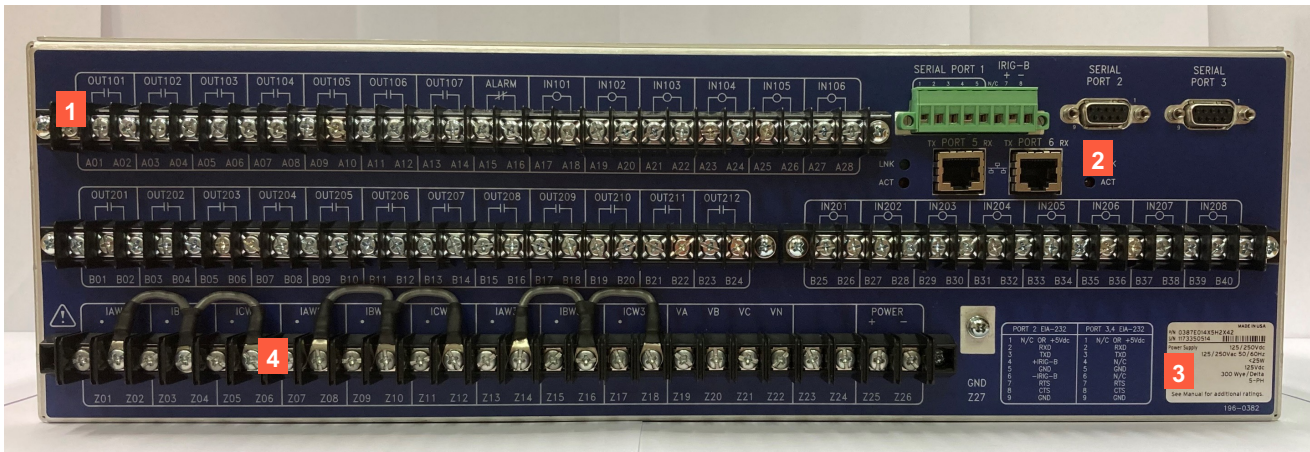
2 The 2*16-character LCD display provides navigation, relay control, data and diagnostics through default messages or up to 32 customizable display messages

3 Pushbuttons for controlling the differential relay



Differential protection

- 1 The card slots accommodate positions for inputs/outputs
- 2 A wide range of communication protocols and media provides flexibility in communication with other devices and control systems
- 3 Label indicating the permitted supply voltage of the differential relay
- 4 Slots for the voltage and current input card



Theory of electrical protection – differential protection

Factors affecting CT saturation:

- *Remanent magnetism in the CT core*
- *Mismatch of the CT characteristics*
- *Overloading of the CT circuit*

The breakpoint is determined for a restraint current I_b in the range 1.5 to 2.5, to ensure stability and sensitivity of the protected section.

It defines the end of the first slope and the beginning of the second slope of the operating characteristic.

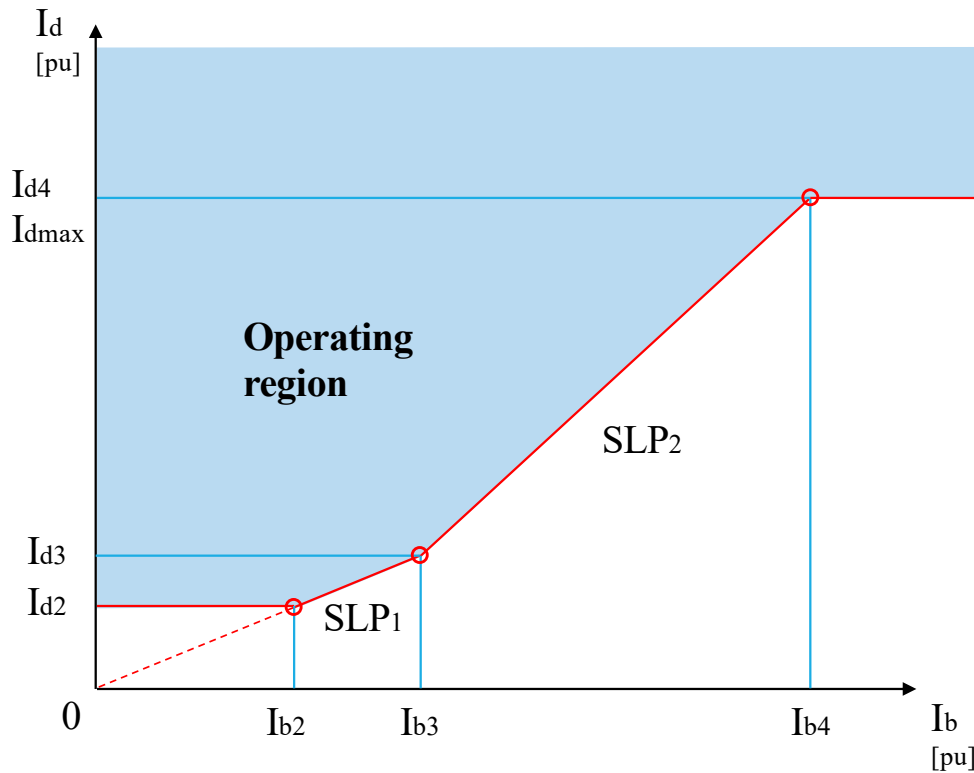
The upper limit of the differential current I_{dmax} is chosen in the range 8 to 10.



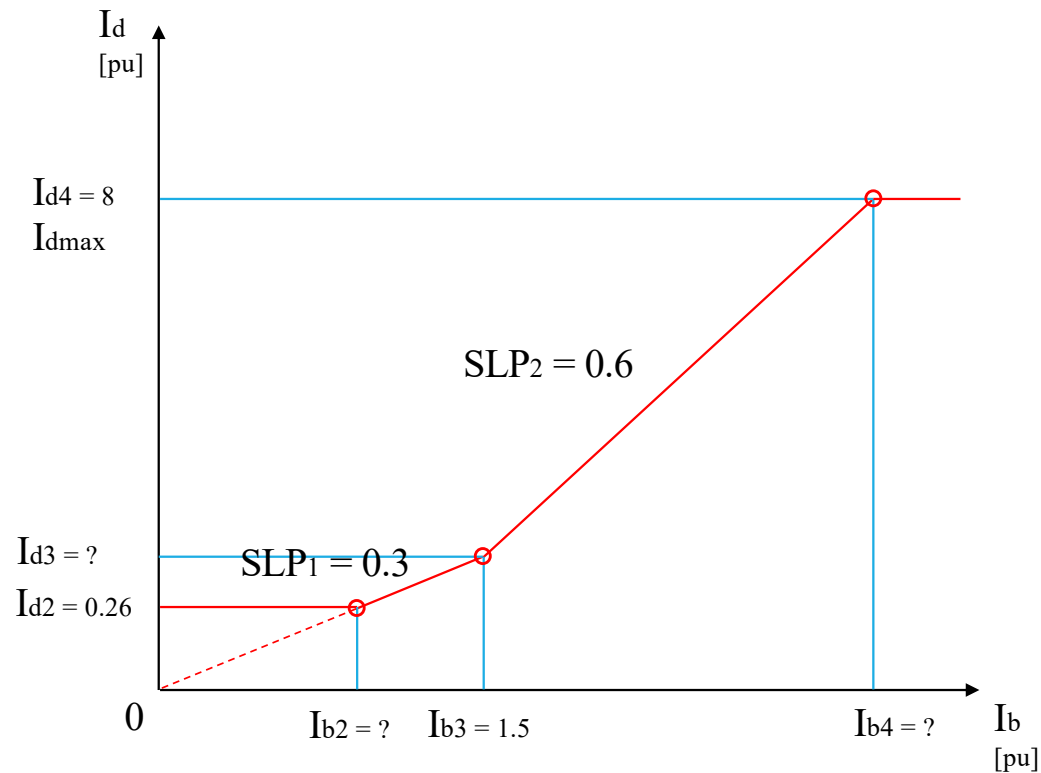
Differential protection characteristic

I_{s*} – Secondary side current of CT

$$I_d = \left| \vec{I}_{1s*} * TAP + \vec{I}_{2s*} * TAP \right| \quad (9) \quad I_b = \frac{|\vec{I}_{1s*} * TAP| + |\vec{I}_{2s*} * TAP|}{2} \quad (10)$$

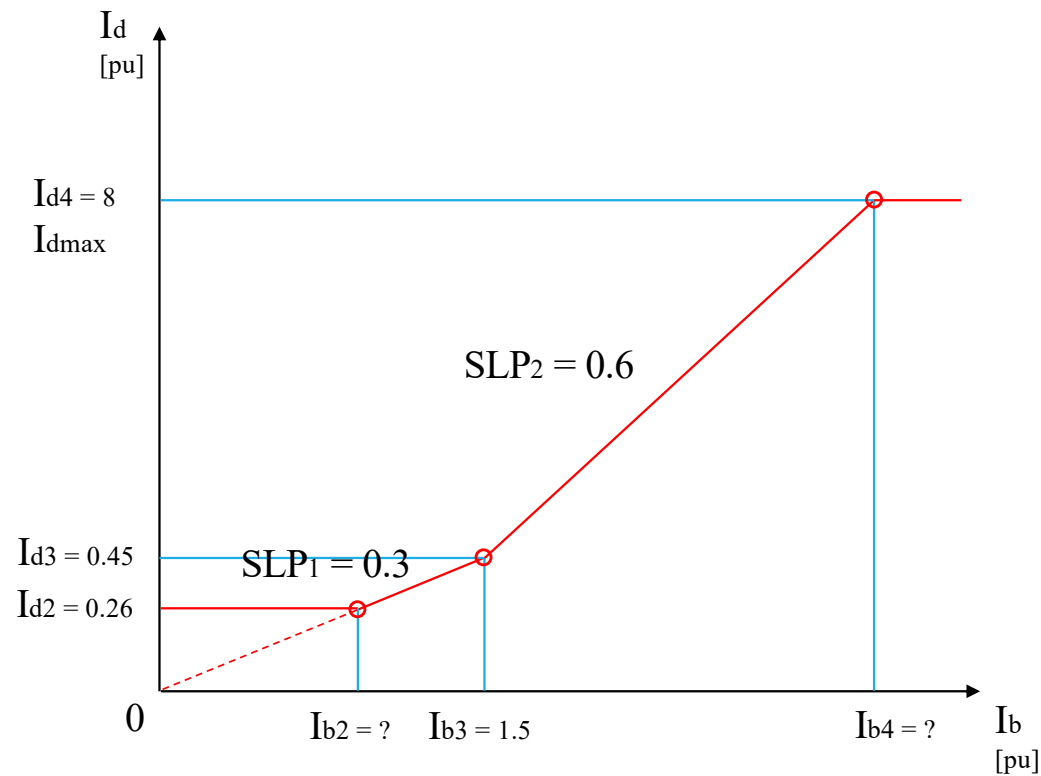


Differential protection characteristic



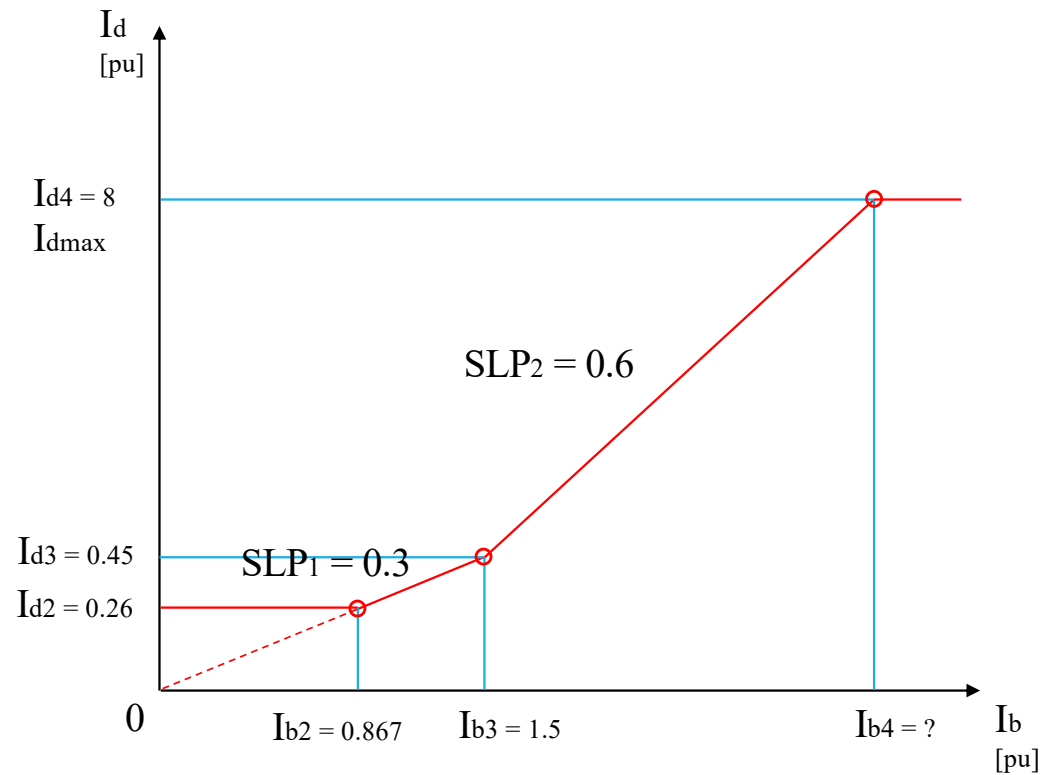
Differential protection characteristic

$$0.3 = \frac{I_{d3}-0}{1.5-0} \Rightarrow I_{d3} = 0.3*1.5 = 0.45$$



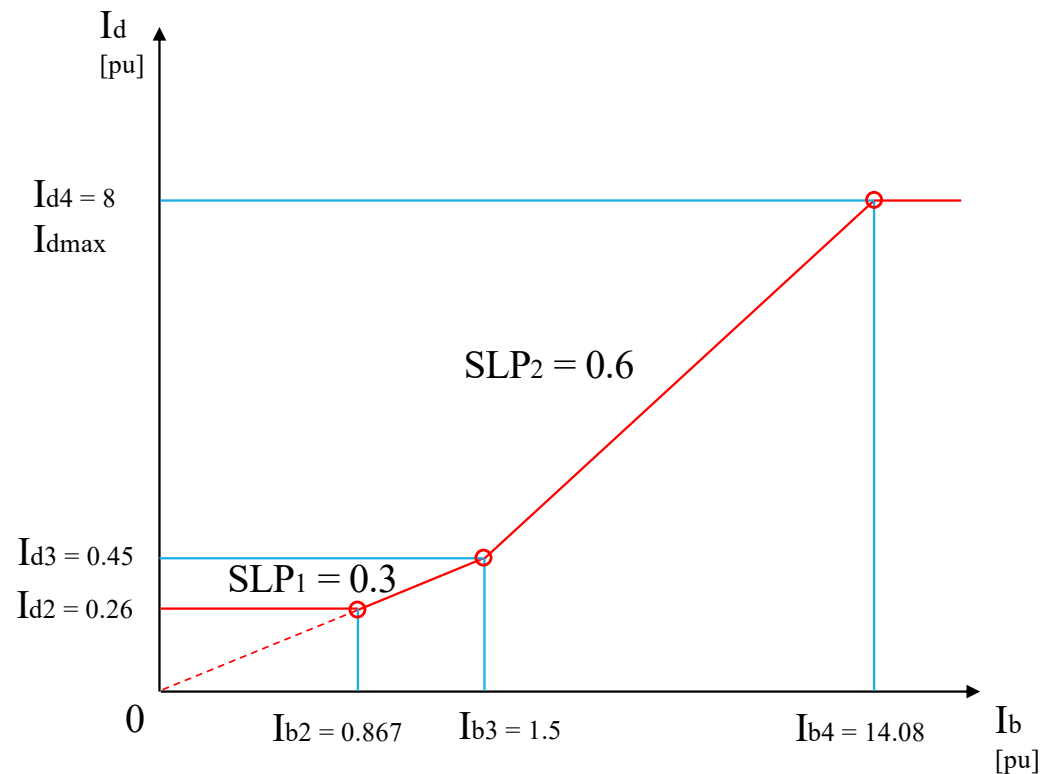
Differential protection characteristic

$$0.3 = \frac{0.45 - 0.26}{1.5 - I_{b2}} \Rightarrow I_{b2} = (0.45 - 0.19) / 0.3 = 0.867$$

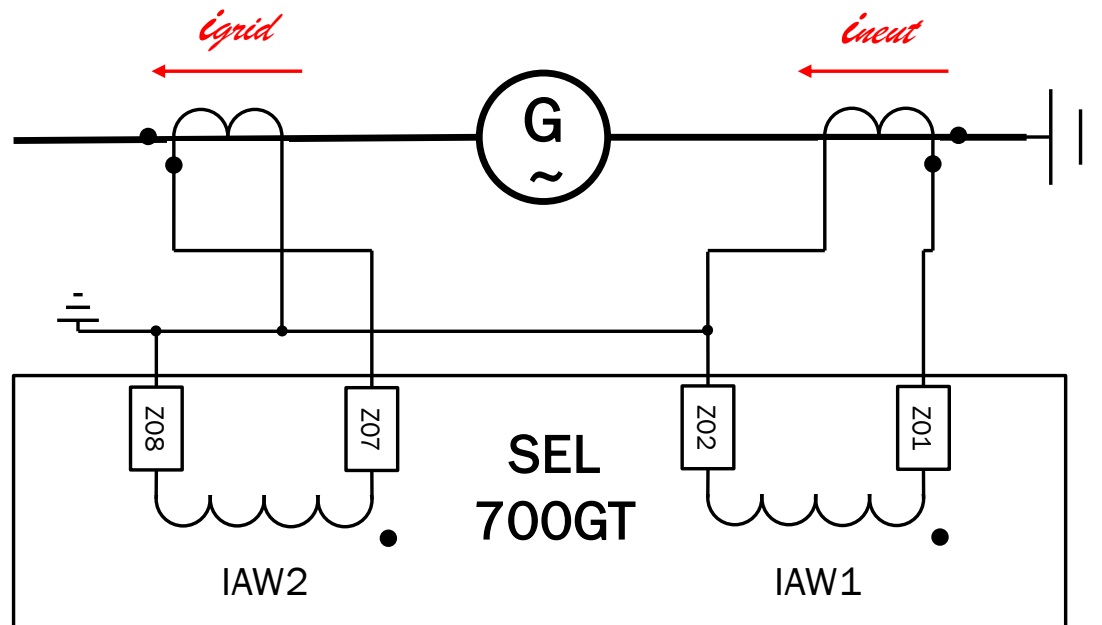


Differential protection characteristic

$$0.6 = \frac{8 - 0.45}{I_{b4} - 1.5} \Rightarrow I_{b4} = (7.55 + 0.9) / 0.6 = 14.08$$

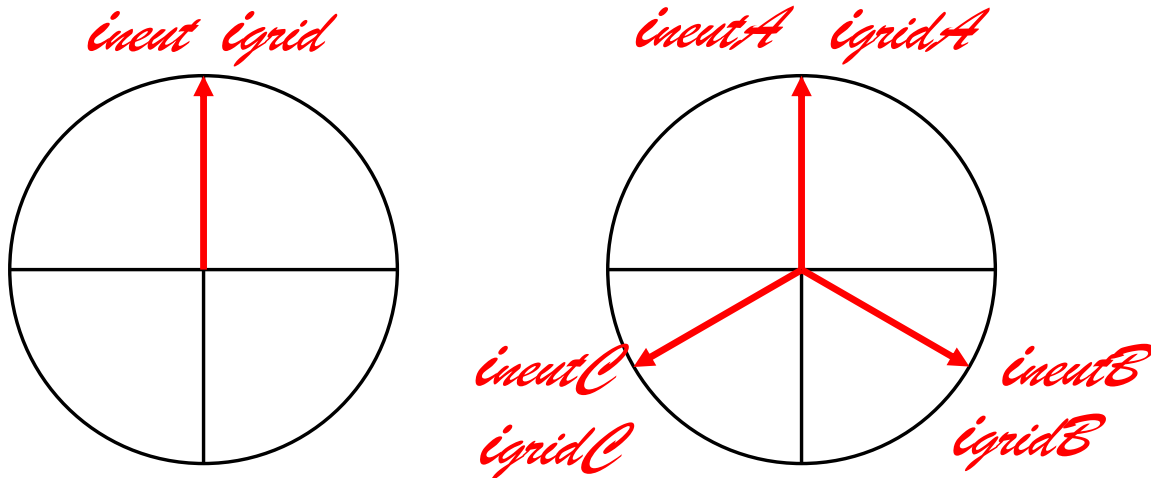


Generator differential protection



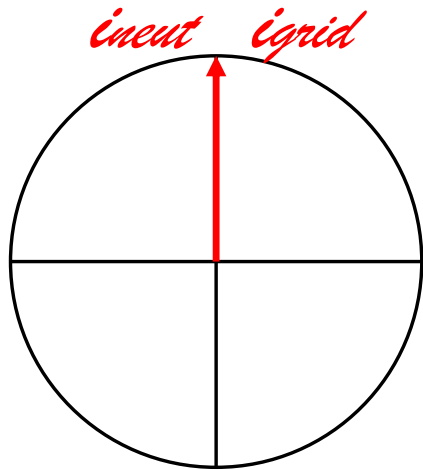
Generator differential protection

Phasor representation of the generator currents

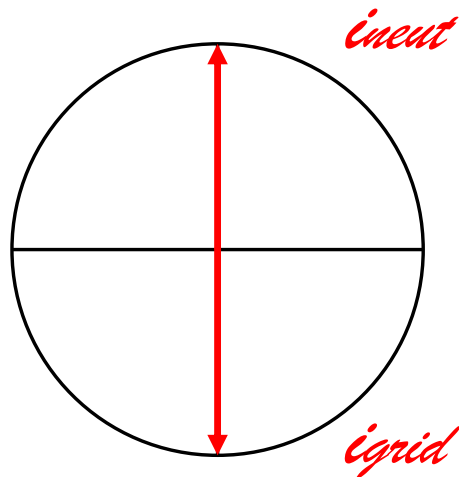


Generator differential protection

QuickCMC test



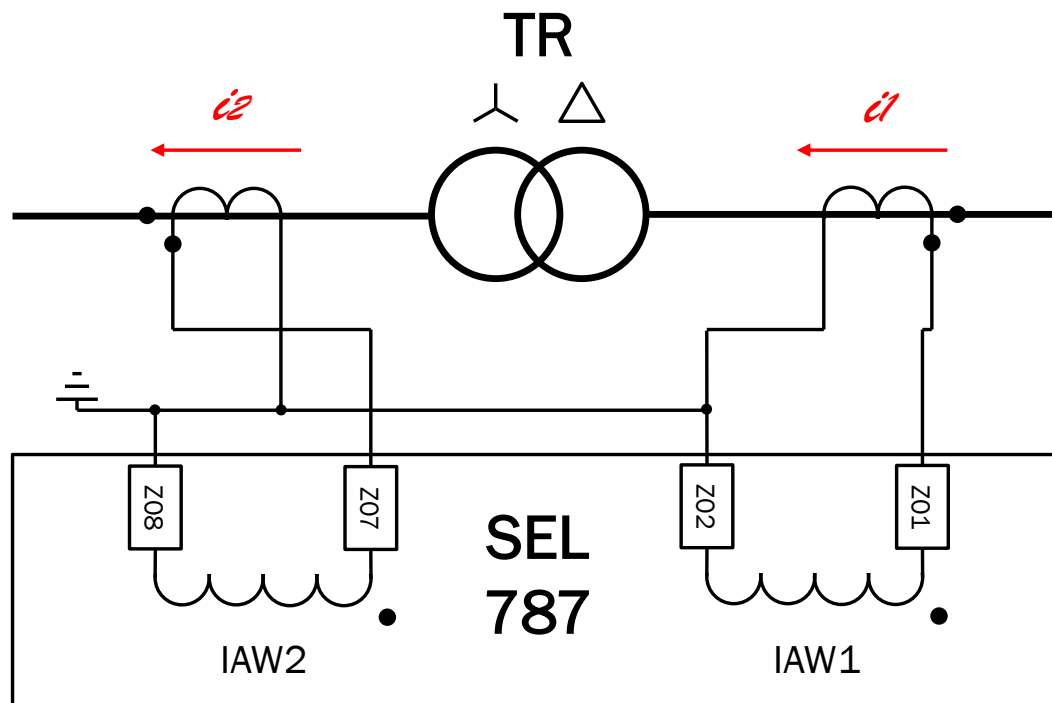
Instability test



Stability test

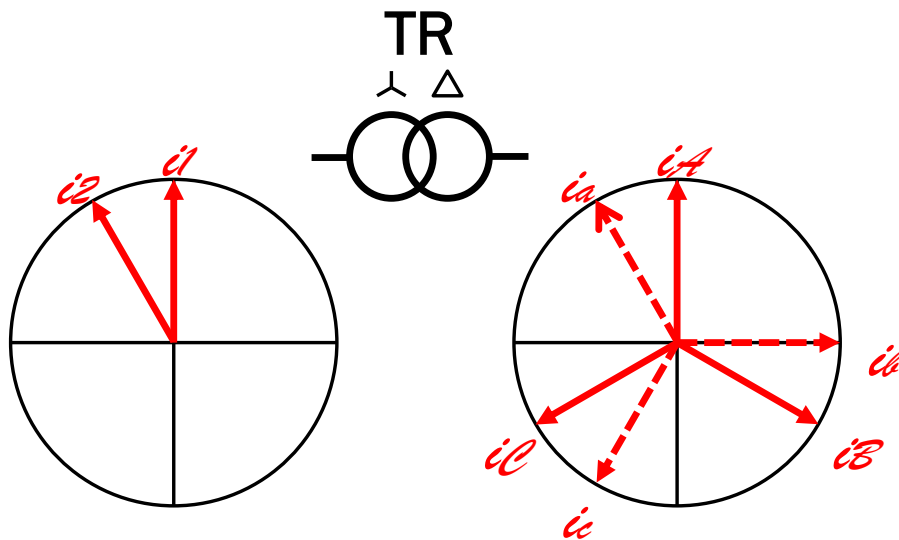


Transformer differential protection



Transformer differential protection

Phasor representation of the transformer currents

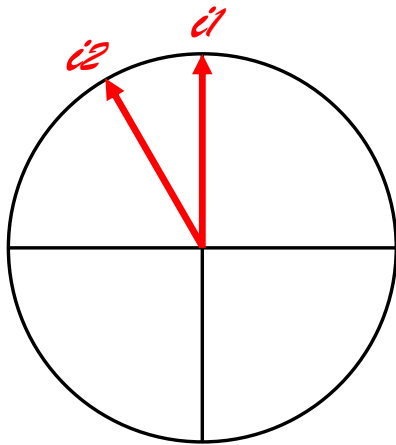


Vector group (clock number) of the Dyn11 transformer

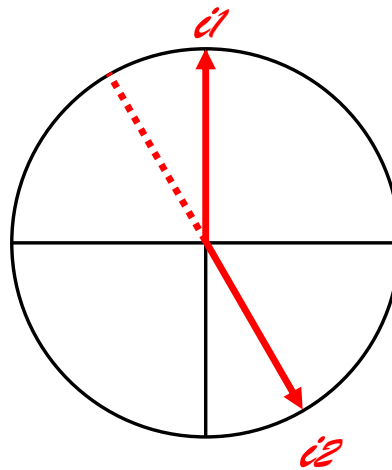


Transformer differential protection

QuickCMC test



Instability test



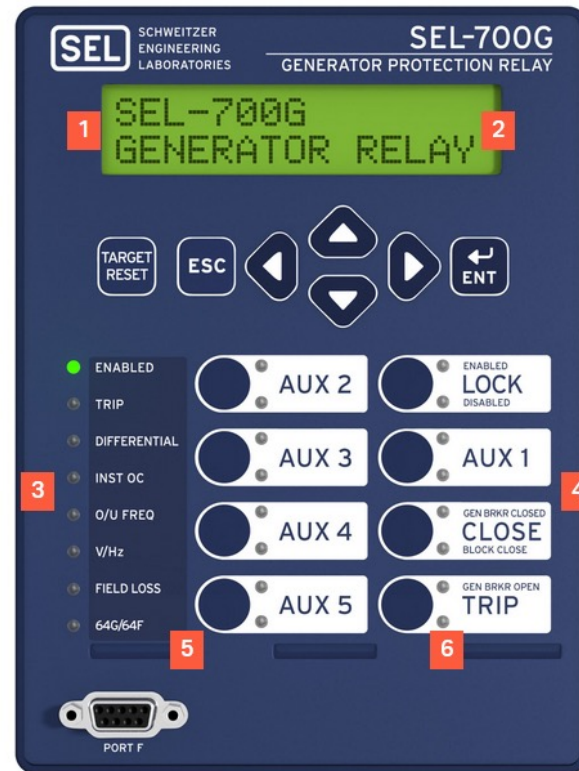
Stability test

The vector angle depends on how the test set is connected to the relay and on the test set itself.



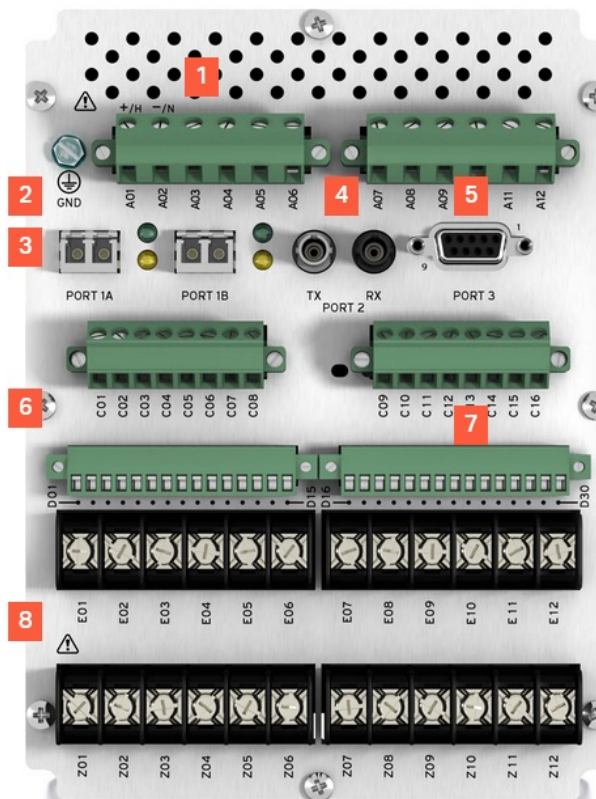
Generator differential protection

- 1 Large 2*16-character LCD display
- 2 Default messages or up to 32 customizable display labels inform personnel about power system events or about the relay status
- 3 Programmable three-colour front-panel LEDs
- 4 Programmable pushbuttons and labels
- 5 User-configurable label kit
- 6 Two programmable three-colour LEDs per pushbutton



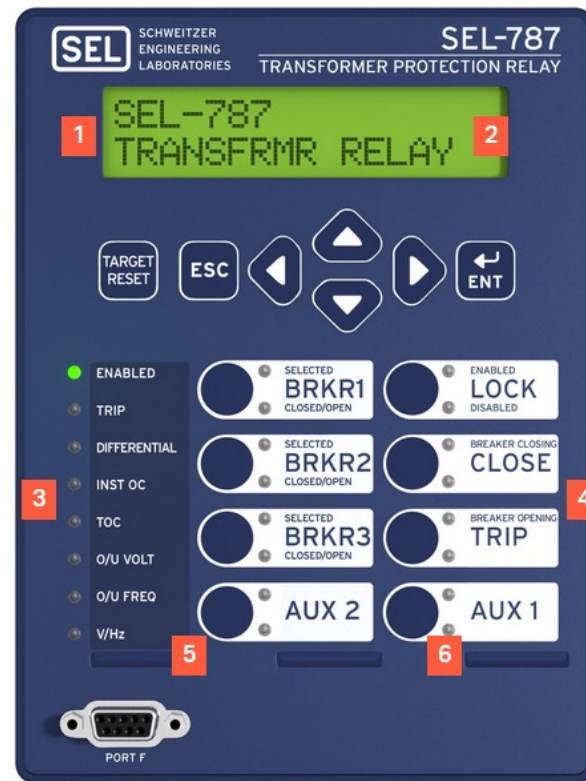
Generator differential protection

- 1 Power supply options 110 - 250 V DC/110 - 240 V AC or 24 - 48 V DC
- 2 The built-in web server allows direct transfer of metering and monitoring data without the need for external PC software
- 3 A wide range of communication protocols and media provides flexibility in communication with other devices and control systems
- 4 Optical serial port
- 5 MIRRORING BITS communication provides fast and reliable communication between relays
- 6 Slot for optional expansion cards
- 7 Optional resistance temperature detector (RTD) inputs
- 8 The current transformer and phase voltage transformer inputs are located on a single card, which allows more inputs/outputs in the other slots



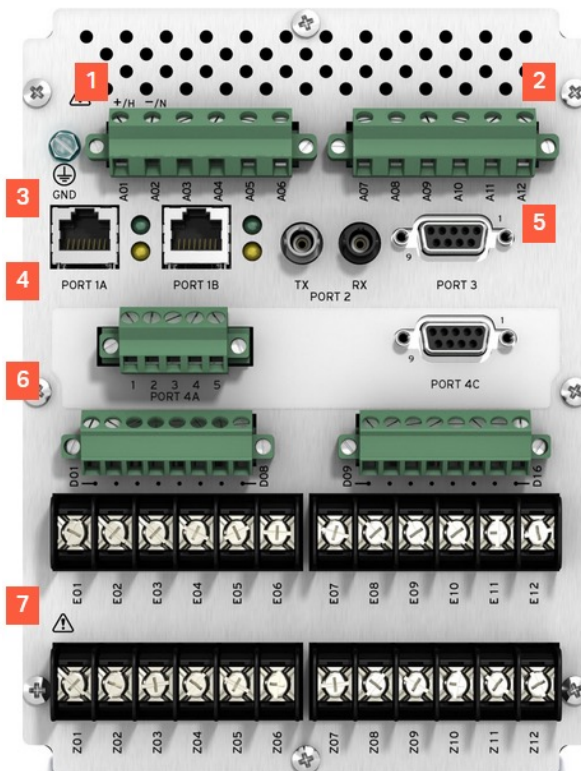
Transformer differential protection

- 1 Large 2*16-character LCD display
- 2 Default messages or up to 32 customizable display labels inform personnel about power system events or about the relay status
- 3 Programmable three-colour front-panel LEDs
- 4 Programmable pushbuttons and labels
- 5 User-configurable label kit
- 6 Two programmable three-colour LEDs per pushbutton



Transformer differential protection

- 1 Power supply options 110 - 250 V DC/110 - 240 V AC or 24 - 48 V DC
- 2 2 digital inputs and 3 digital outputs
- 3 A wide range of communication protocols and media provides flexibility in communication with other devices and control systems
- 4 The built-in web server allows direct transfer of metering and monitoring data
- 5 EIA-232 serial port and EIA-232 optical serial port with IRIG-B input
- 6 Slot for optional expansion cards
- 7 Slots for the current and voltage options



Theory of electrical protection – frequency protection



Theory of electrical protection – frequency protection

To protect an important global parameter such as frequency, a frequency relay (81) must be used to respond to frequency deviations.

Underfrequency protection (81U):

- Setting range: 45 – 50 Hz

Overfrequency protection (81O):

- Setting range: 50 – 55 Hz

Frequency protection setting (81):

- Underfrequency (81U): $f_{<} = 48 \text{ Hz}$; $t_{>} = 0.1 \text{ s}$
- Overfrequency (81O): $f_{>} = 52 \text{ Hz}$; $t_{>} = 0.1 \text{ s}$

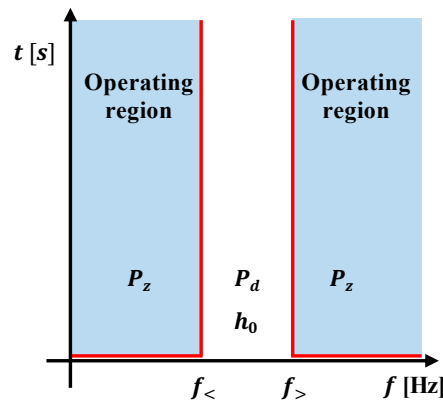


Fig. 5 Operating characteristic of the frequency protection

P_d - permissible region
 P_z - prohibited region
 h_0 - operating boundary
 $t_{>}$ - time delay



Theory of electrical protection – overvoltage/undervoltage protection



Protection theory – overvoltage/undervoltage protection

Before setting up, it is always necessary to determine the actual PT ratio. The most common PT secondary voltage is 100V or 110V. To set multiple stages, we must comply with $\Delta U \geq 0.1 * U_n$. Undervoltage protection is used in practice with overcurrent protection and mutual blocking, that is, as overcurrent protection with undervoltage blocking (50/27).

Overvoltage protection (27/59):

- *Setting range kc: $(0.8 - 2) * U_n$*
- *Time delay range: $(0.1 - 10) s$*

Seting calculation:

$$U_r = \frac{kc * U_n}{PTN} = \frac{1 * 15.75kV}{\frac{15000V}{100V}} = 105 V \quad (11)$$

$$\text{Time delay } t_r = 0.5 s$$

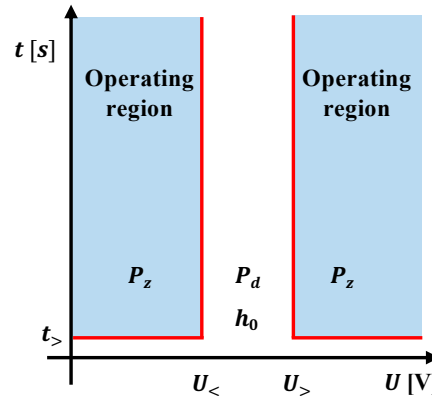


Fig. 6 Operating characteristic of the voltage protection

P_d - permissible region; P_z - prohibited region
 h_0 - operating boundary; t_r - time delay



Theory of electrical protection

– distance protection



Distance protection

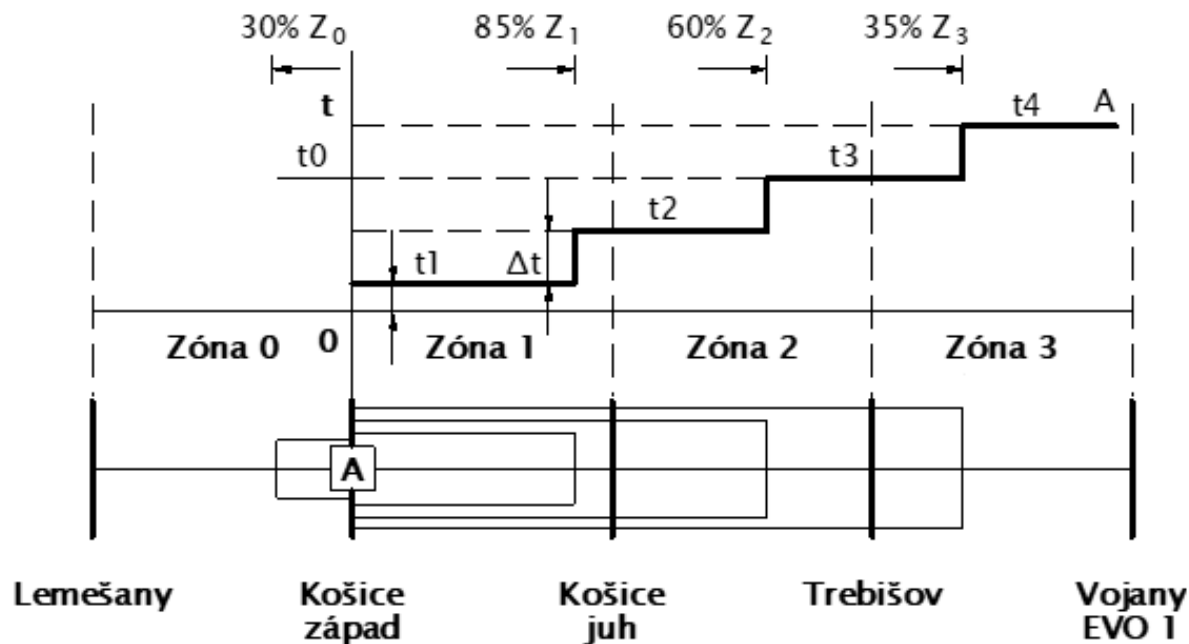


Fig. 7 Schematic designation of the distance protection zones

The zone designation diagram of the distance protection shows the operation of the individual zones: zones 1, 2 and 3 for the forward direction and zone 0 for the reverse direction.

Zone 1 covers protection of line no. 1 up to 85 %.

Zone 2 covers protection of line no. 2 up to 60 % and of line no. 1 up to 100 %.

Zone 3 covers protection of line no. 3 up to 35 % and of sections no. 1 and no. 2 up to 100 %.

Zone 0 covers protection of line no. 0 up to 30 %. This zone protects the reverse direction.

The time delays of the individual zones are graded by the constant Δt with a value of 0.4 s, while the time t_1 is chosen in the range 20 to 50 ms plus the breaker operating time.

Distance protection

Tab. 2 Line type table (specific parameters per 1 km of line)

Type	Rm ₁	Xm ₁	Bm ₁	I _{perm}	Rm ₀	Xm ₀	Bm ₀	Voltage
	[Ω/km]	[Ω/km]	[mS/km]	[A]	[Ω/km]	[Ω/km]	[mS/km]	[kV]
150 AlFe 3.6	0.201	0.403	2.810	420	0.603	1.209	8.430	110
185 AlFe	0.156	0.400	2.860	486	0.468	1.200	8.580	110
240 AlFe	0.121	0.392	2.920	579	0.363	1.176	8.760	110
450 AlFe	0.067	0.387	3.150	825	0.201	1.161	9.450	110
AAAC182-AL3	0.183	0.400	?	490	0.548	1.200	?	110
AAAC243-AL3	0.137	0.400	?	585	0.412	1.200	?	110
AAAC299-AL3	0.111	0.400	?	670	0.334	1.200	?	110



AAAC (All Aluminium Alloy
Conductors)

Distance protection

Calculation of the line impedance

$$Z_{line1} = l_1 * (R_m + jX_m)$$

Ratio from the specified current and voltage transformers

$$p = CT / VT = (300 \text{ A} / 5 \text{ A}) / (22000 \text{ V} / 100 \text{ V})$$

Calculation of the impedance for zone 1

Positive-sequence impedance component

$$Z1_{zone1} = p * 0.85 * Z_{line1}$$

Zero-sequence impedance component

$$Z0_{zone1} = p * 0.85 * Z_{line0}$$

Line impedance angle = $\angle Z_{line1}$

Calculation procedure:

Zone 1: set to 85 % of the impedance of line no. 1.

Instrument transformer ratios: the current transformer in the substation where the distance relay is installed is 300 A / 5 A and the voltage transformer is 22000 V / 100 V. The current transformer must withstand a 20x overload with an accuracy of $\pm 10 \%$ (saturation limit).

The impedance for zone 1 is calculated for the positive-sequence and zero-sequence impedance components according to the parameters of the given line.

Distance protection

Calculation of the line impedance

$$Z_{line2} = I_2 * (R_m + jX_m)$$

Ratio from the specified current and voltage transformers

$$p = CT/VT = (300\text{ A} / 5\text{ A}) / (22000\text{ V} / 100\text{ V})$$

Calculation of the impedance for zone 2

Positive-sequence impedance component

$$Z_{1zone2} = p * (0.6 * Z_{line2} + Z_{line1})$$

Zero-sequence impedance component

$$Z_{0zone2} = p * (0.6 * Z_{line2} + Z_{line1})$$

An analogous calculation applies to the other zones.

Calculation procedure:

Zone 2: set to 60 % of the impedance of line no. 2 and 100 % of line no. 1.

Instrument transformer ratios: the current transformer in the substation where the distance relay is installed is 300 A / 5 A and the voltage transformer is 22000 V / 100 V. The current transformer must withstand a 20x overload with an accuracy of $\pm 10\%$ (saturation limit).

The impedance for zone 2 consists of the impedance of line no. 1 and of line no. 2, for the positive-sequence and zero-sequence impedance components according to the parameters of the given lines.

Distance protection

This type of characteristic is created by combining the directional, reactance and resistance characteristics.

Quadrilateral characteristics consist of two straight lines that pass through the origin of the coordinate system and form angles of $\alpha_1 = 115$ to 125 degrees and $\alpha_2 = -15$ to -25 degrees with the $+R$ axis.

These lines divide the R - X characteristic into four quadrants; the forward direction is used in the first quadrant and the reverse direction in the third quadrant.

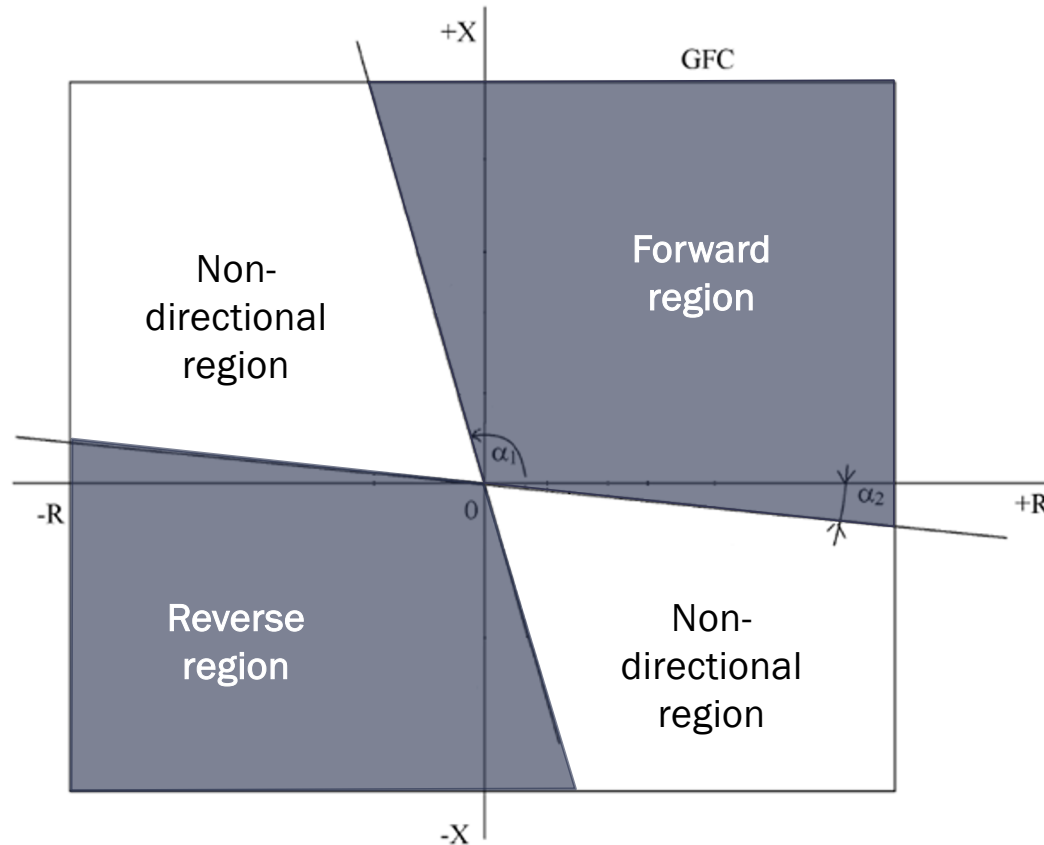


Fig. 8 Directional characteristic of the distance protection in the R-X diagram

Distance protection

The quadrilateral shape of the characteristic is further bounded by lines parallel to the real and imaginary axes.

To ensure selectivity, the characteristics are arranged in five stages with the possibility of different time settings. Usually the first four characteristics are set in the line direction and the fifth characteristic in the busbar direction.

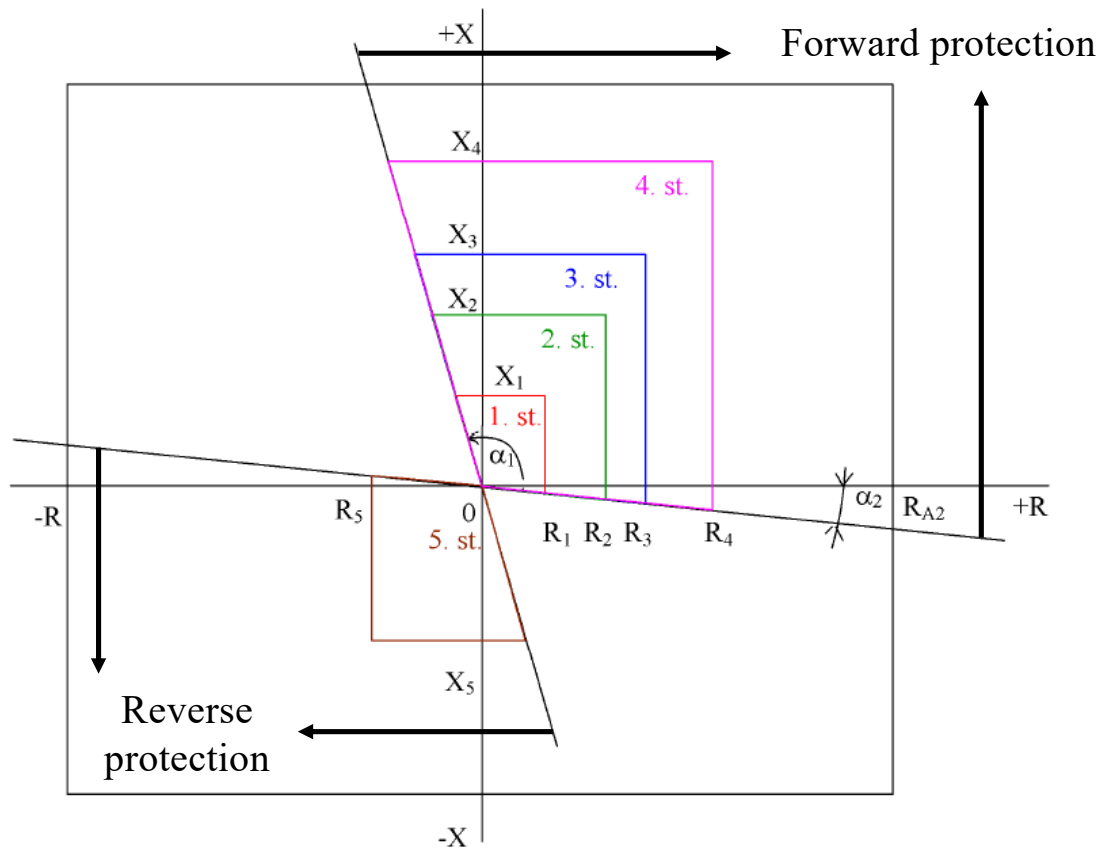


Fig. 9 Quadrilateral impedance characteristic of the distance protection

Distance protection

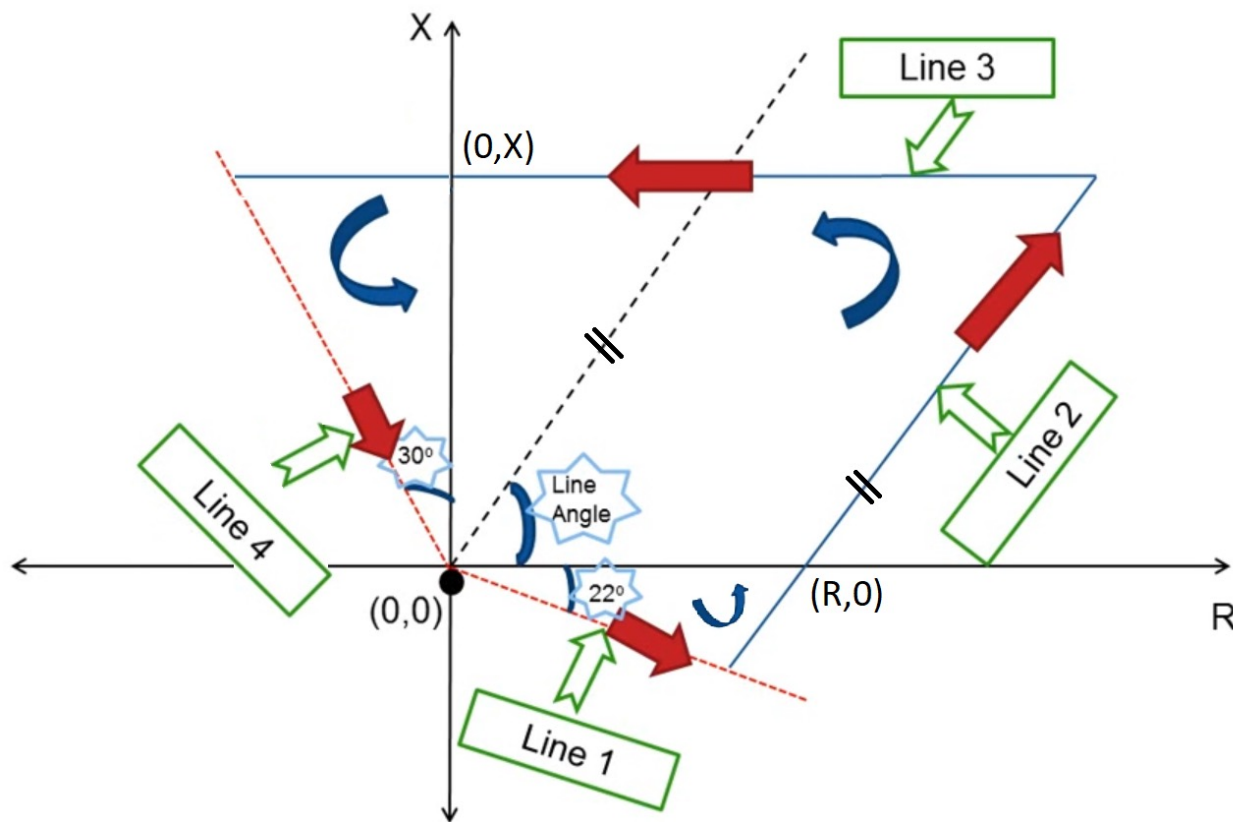


Fig. 10 Quadrilateral characteristic of the distance protection

Procedure for drawing the quadrilateral characteristic:

Line 1: the length of the segment follows from the calculation of the sides of the triangle with known angles (Line Angle and $\alpha_2 = 22^\circ$) and the coordinates $(R,0)$.

Line 2: the length of the segment follows from the calculation of the sides of the right triangle with known angles (Line Angle and 90°) and the coordinates $(0,X)$.

Line 3: the length of the segment follows from the calculation for Line 2 and the coordinates $(0,0)$.

Line 4: the length of the segment follows from the calculation of the sides of the right triangle with known angles (90° and 30°) and the coordinates $(0,0)$.

*Sample calculation of the
protection settings*



*Setting calculation for the
feeder overcurrent protection*



Overcurrent protection

Grid supply impedance

$$Z_{lgrid} = \frac{c \cdot U_n}{\sqrt{3} \cdot I_{k3siet}} = \frac{1 \cdot 22 \text{ kV}}{\sqrt{3} \cdot 3,2328 \text{ kA}} = 3.929 \Omega$$

$$X_{lgrid} = 0.995 \cdot Z_{lsiet} = 0.995 \cdot 3.929 \Omega = 3.909 \Omega$$

$$R_{lgrid} = 0.1 \cdot X_{lsiet} = 0.1 \cdot 3.909 \Omega = 0.391 \Omega$$

$$Z_{lgrid} = R_{lsiet} + 1j \cdot X_{lsiet} = 0.391 + j3.909 \Omega$$

Nominal branch current

$$I_N = \frac{S_n}{\sqrt{3} \cdot U_{n1}} = \frac{1000 \text{ kVA}}{\sqrt{3} \cdot 22 \text{ kV}} = 26.243 \text{ A}$$

Cable line impedance

$$R_l = \frac{\rho}{q_n} \cdot 1000 = \frac{1}{\frac{54}{35}} \cdot 1000 = 0.529 \Omega/\text{km}$$

$$X_l = 0.14 \Omega/\text{km}$$

$$Z_{lline} = l \cdot (R_l + 1j \cdot X_l) = 1 \cdot (0.529 + j0.14) = 0.529 + j0.14 \Omega$$

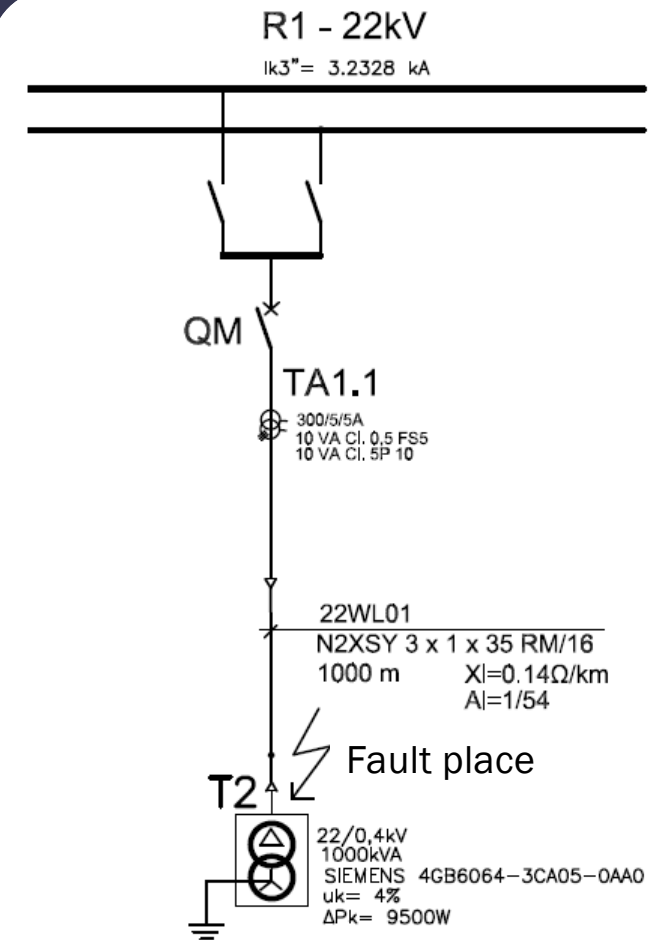


Fig. 11 Worked example

Overcurrent protection

Short-circuit current calculation

$$Z_{1fault} = Z_{1grid} + Z_{1line} = (0.391 + j3.909) + (0.529 + j0.14) = 0.92 + j4.049 \Omega$$

$$I_{k3R1} = \frac{c \cdot U_n}{\sqrt{3} \cdot |Z_{k1fault}|} = \frac{1 \cdot 22 \text{ kV}}{\sqrt{3} \cdot |0.92 + j4.049|} = 3.059 \text{ kA}$$

$$I_{k2R1} = \frac{\sqrt{3}}{2} \cdot I_{k3R1} = \frac{\sqrt{3}}{2} \cdot 3.059 \text{ kA} = 2.649 \text{ kA}$$

Calculation of pickup current for overload protection

$$I_{>} = \frac{k_b \cdot I_n}{k_p \cdot pp} = \frac{1.1 \cdot 26.243 \text{ A}}{0.95 \cdot \frac{300 \text{ A}}{5 \text{ A}}} = 0.506 \text{ A}$$

Calculation of pickup current for short-circuit protection

$$I_{>>} = \frac{0.8 \cdot I_{k2R1}}{k_c \cdot pp} = \frac{0.8 \cdot 2.649 \text{ kA}}{1.5 \cdot \frac{300 \text{ A}}{5 \text{ A}}} = 23.547 \text{ A}$$

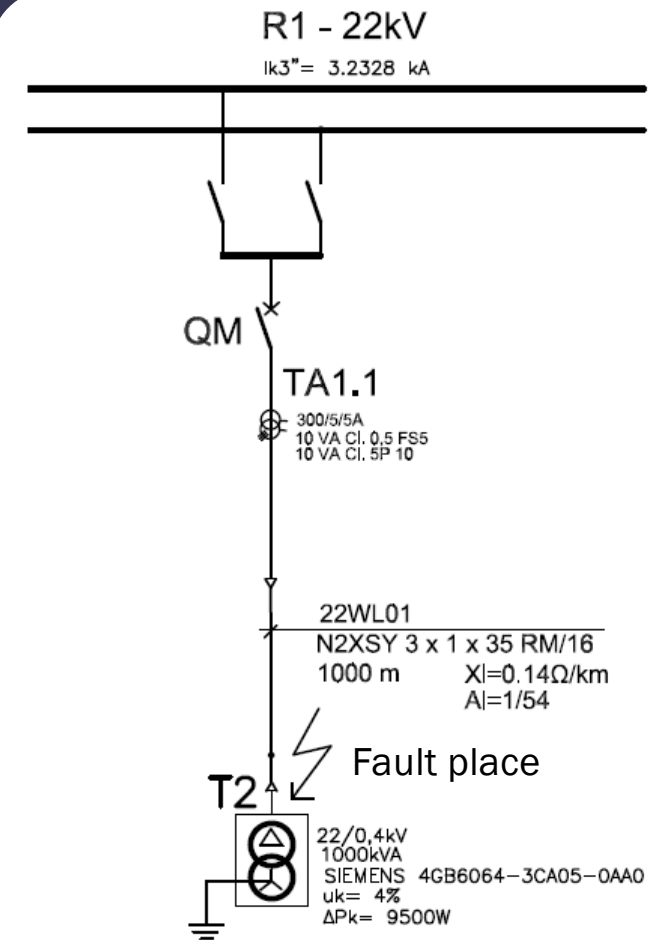


Fig. 11 Worked example

Overcurrent protection

Value of pickup current for overload protection

$$I_{>} \leq I_{R>}$$

$$0.506 \text{ A} \leq I_{R>}$$

$$I_{R>} = 1 \text{ A}$$

Value of pickup current for short-circuit protection

$$I_{\gg} \geq I_{R\gg} > I_{R>}$$

$$23.547 \text{ A} \geq I_{R\gg} > 1 \text{ A}$$

$$I_{R\gg} = 3.5 \text{ A}$$

Time delay is selected for overload at $t > 0.25 \text{ s}$ and for short-circuits at $t \gg 0 \text{ s}$, taking into account the protection of further sections only by the use of fuses and circuit breakers.

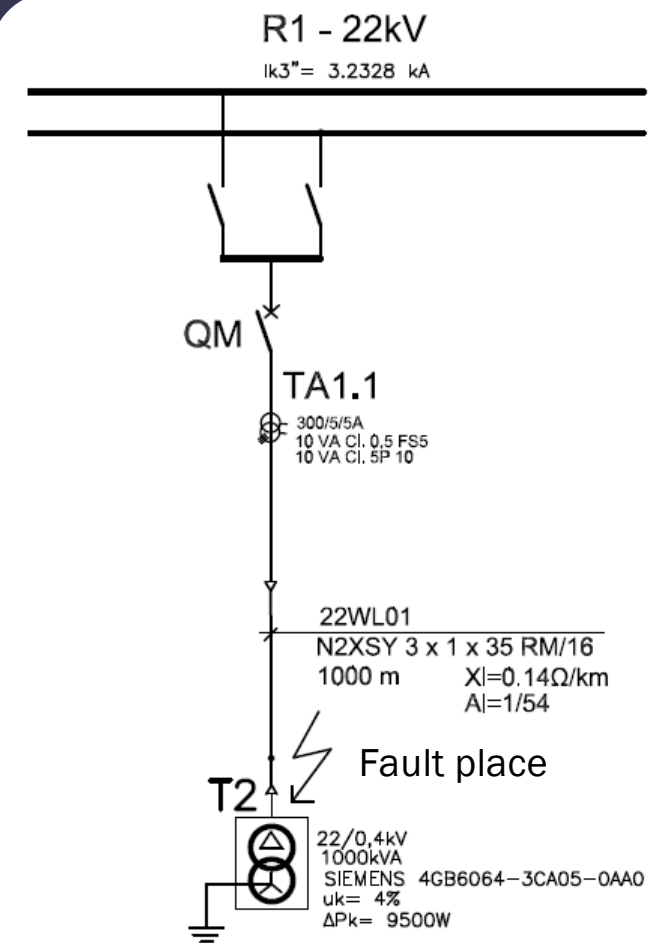


Fig. 11 Worked example

*Setting calculation for the
generator overcurrent
protection*



Generator overcurrent protection

For generator overcurrent protection, with respect to the protected equipment - in this example a generator - this relay must trip last if further relays are located upstream of it. This principle is very important for correct selective disconnection of the faulty section or device: since the generator acts in the network as a supply element, its time delays for short circuits and overloads are among the slowest (longest), so that the stability of the power system is maintained and the worst condition, a **BLACKOUT** caused by incorrectly set protection, does not occur.

***BLACKOUT** - this term denotes a large-scale interruption of the electricity supply over a large area, lasting tens of hours or days, which affects a large number of inhabitants. => Break-up of the transmission system into separate islands => cascading propagation of faults => **BLACKOUT**.*

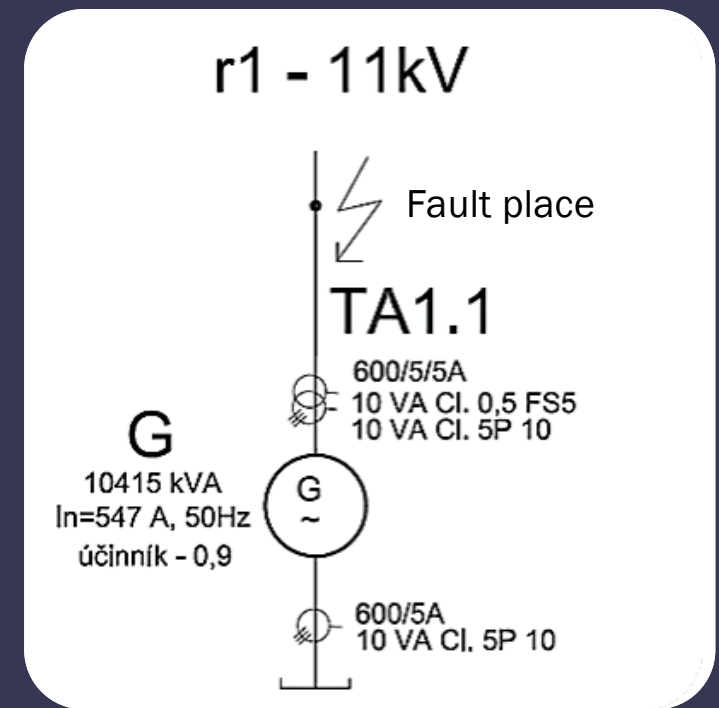


Fig. 12 Worked example

Generator overcurrent protection

When calculating R_g , we use a proportional coefficient that converts reactance to approximate resistance according to the size of reactance. Thus it takes into account the resistance of the conductor used in the winding according to the size of the reactor power and generator voltage.

$R_g = 0.05 * X_d''$ for generators with $U_{rg} > 1 \text{ kV}$ and $S_g \geq 100 \text{ MVA}$.

$R_g = 0.07 * X_d''$ for generators with $U_{rg} > 1 \text{ kV}$ and $S_g < 100 \text{ MVA}$.

$R_g = 0.15 * X_d''$ for generators with $U_{rg} \leq 1000 \text{ V}$.

Generator impedance

$$X_d = x_d'' * Z_{rG} = 0.165 * 11.618 = 1.917 \Omega$$

$$R_g = 0.07 * X_d'' = 0.07 * 1.917 = 0.134 \Omega$$

$$K_g = \frac{U_n}{U_{rG}} * \frac{c}{1 + x_d'' * \sin \varphi_{rG}} = \frac{11 \text{ kV}}{11 \text{ kV}} * \frac{1}{1 + 0.165 * \sin(\arccos(0.9))} = 0.933$$

$$Z_{lg} = K_g * (R_g + j * X_d'') = 0.933 * (0.134 + j1.917) = 0.125 + j1.788 \Omega$$

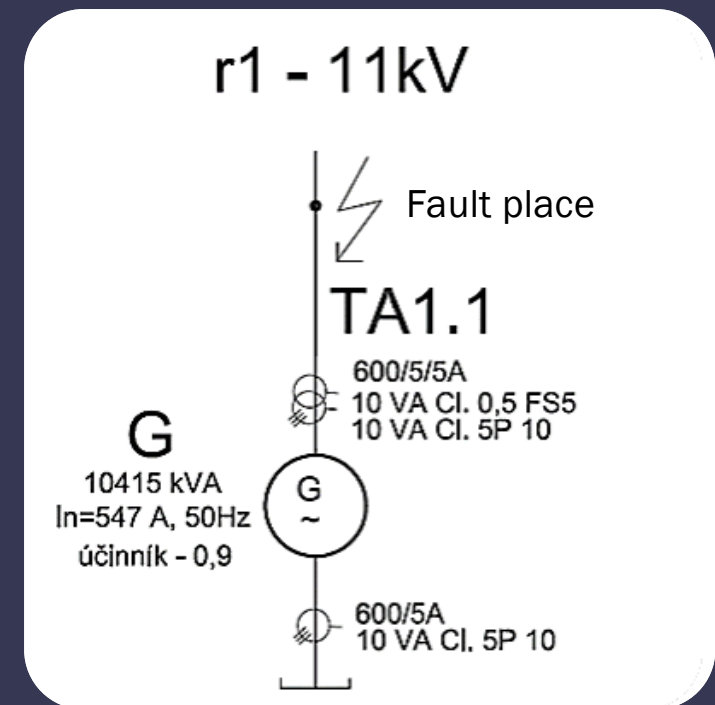


Fig. 12 Worked example

Generator overcurrent protection

Short-circuit current calculation

$$I_{k3g} = \frac{c \cdot U_n}{\sqrt{3} \cdot |Z_{1g}|} = \frac{1 \cdot 11 \text{ kV}}{\sqrt{3} \cdot |0.125 + j1.788|} = 3542.569 \text{ A}$$

$$I_{k2g} = \frac{\sqrt{3}}{2} \cdot I_{k3g} = \frac{\sqrt{3}}{2} \cdot 3542.569 \text{ A} = 3067.956 \text{ A}$$

$$I_n = 547 \text{ A}$$

Calculation of pickup current for overload protection

$$I_{>} = \frac{k_b \cdot I_n}{k_p \cdot pp} = \frac{1.1 \cdot 547 \text{ A}}{0.95 \cdot \frac{600 \text{ A}}{5 \text{ A}}} = 5.28 \text{ A}$$

Calculation of pickup current for short-circuit protection

$$I_{>>} = \frac{0.8 \cdot I_{k2g}}{k_c \cdot pp} = \frac{0.8 \cdot 3067.956 \text{ A}}{1.5 \cdot \frac{600 \text{ A}}{5 \text{ A}}} = 13.635 \text{ A}$$

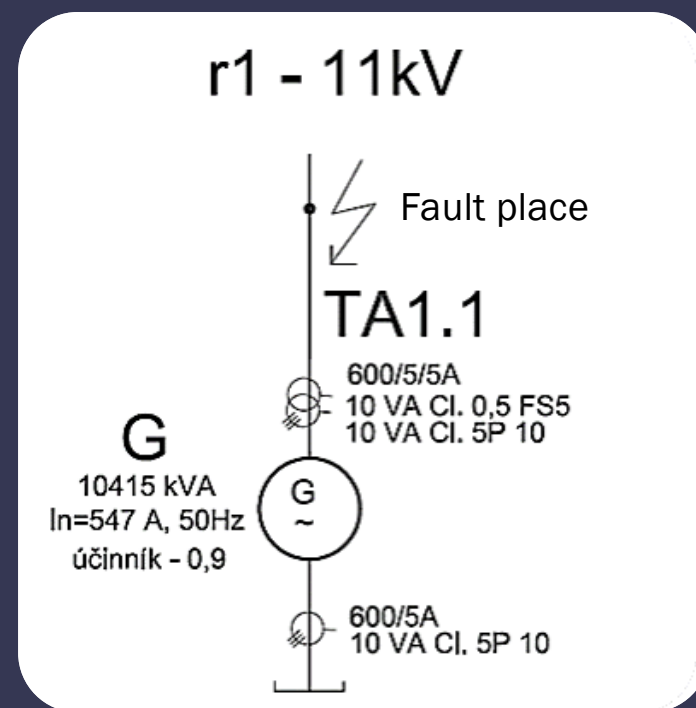


Fig. 12 Worked example

Generator overcurrent protection

Value of pickup current for overload protection

$$I_{>} \leq I_{R>}$$

$$5.28 A \leq I_{R>}$$

$$I_{R>} = 5.7 A$$

Value of pickup current for short-circuit protection

$$I_{\gg} \geq I_{R\gg} > I_{R>}$$

$$13.635 A \geq I_{R\gg} > 5.7 A$$

$$I_{R\gg} = 10 A$$

Time delay is selected for overload at $t > 5$ s and for short-circuits at $t \gg 2$ s, since the generator will be connected to the network through a transformer.

In case of measurement on the SEL AMS test set-up, it is necessary to reduce the tripping times below 250 ms.

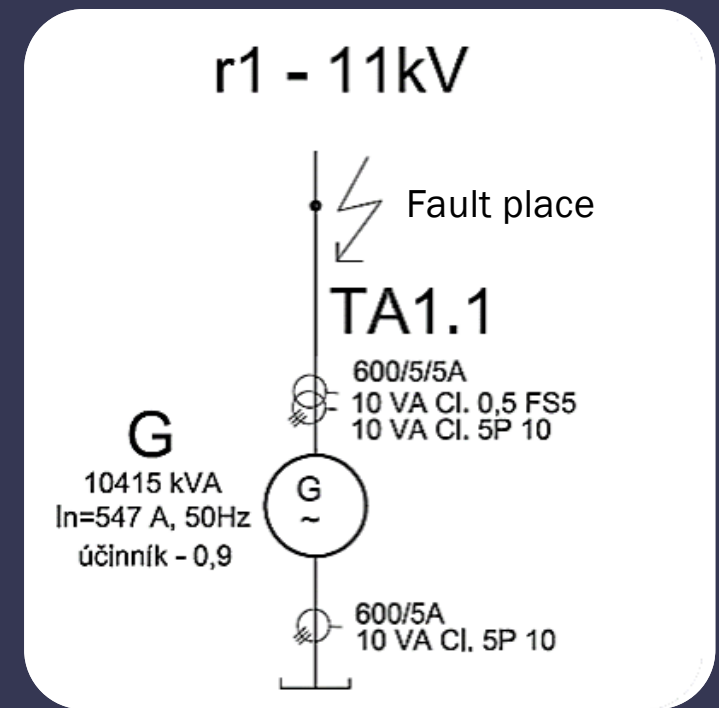


Fig. 12 Worked example

*Setting calculation for the
transformer overcurrent
protection*



Transformer overcurrent protection

The current transformer has a ratio of $pp = 300 \text{ A} / 5 \text{ A}$ and is connected to the primary winding of the transformer, with a rated primary-winding current for the given section $I_N = 209.5 \text{ A}$.

The current transformer has a ratio of $pp = 600 \text{ A} / 5 \text{ A}$ and is connected to the secondary winding of the transformer, with a rated secondary-winding current for the given section $I_N = 419 \text{ A}$.

The difference is that the overcurrent setting for the primary winding is calculated with a short circuit on the secondary side of the transformer, and for the secondary winding of the transformer the other way round, i.e. with a short circuit on the primary side of the transformer.

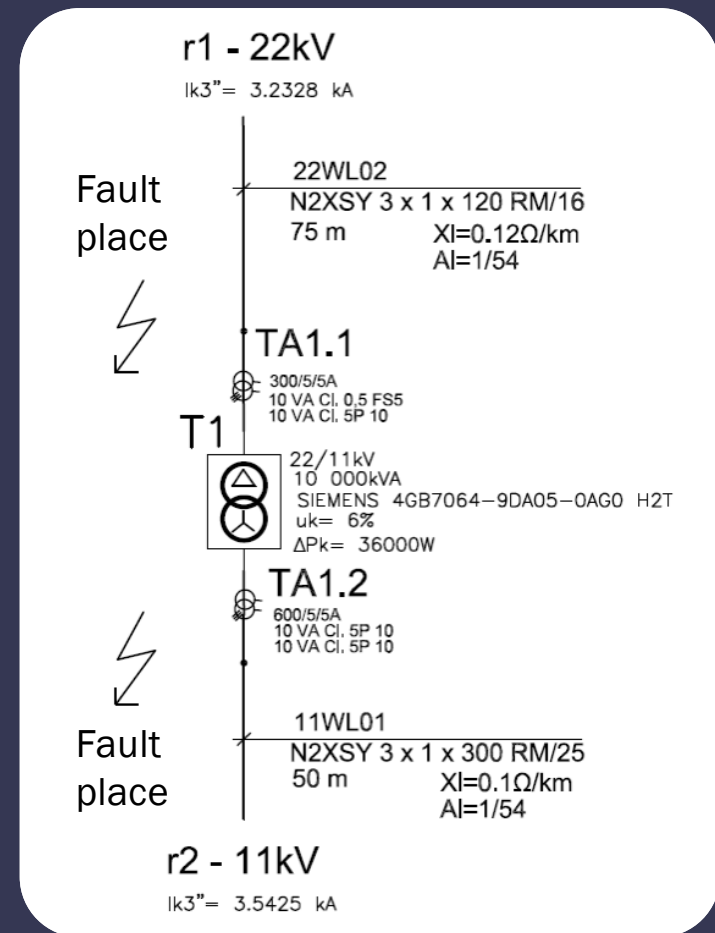


Fig. 14 Worked example

Transformer overcurrent protection

Grid supply impedance - primary winding of TR

$$Z_{Pgrid} = \frac{c \cdot U_n}{\sqrt{3} \cdot I_{k3grid}} = \frac{1 \cdot 22 \text{ kV}}{\sqrt{3} \cdot 3.2328 \text{ kA}} = 3.929 \Omega$$

$$X_{Pgrid} = 0.995 \cdot Z_{Pgrid} = 0.995 \cdot 3.929 = 3.909 \Omega$$

$$R_{Pgrid} = 0.1 \cdot X_{Pgrid} = 0.1 \cdot 3.909 = 0.391 \Omega$$

$$Z_{Pgrid} = R_{Pgrid} + j \cdot X_{Pgrid} = 0.391 + j3.909 \Omega$$

Grid supply impedance - secondary winding of TR

$$Z_{Sgrid} = \frac{c \cdot U_n}{\sqrt{3} \cdot I_{k3grid}} = \frac{1 \cdot 11 \text{ kV}}{\sqrt{3} \cdot 3.5425 \text{ kA}} = 1.793 \Omega$$

$$X_{Sgrid} = 0.995 \cdot Z_{Sgrid} = 0.995 \cdot 1.793 = 1.784 \Omega$$

$$R_{Sgrid} = 0.1 \cdot X_{Sgrid} = 0.1 \cdot 1.784 = 0.178 \Omega$$

$$Z_{Sgrid} = R_{Sgrid} + j \cdot X_{Sgrid} = 0.178 + j1.784 \Omega$$

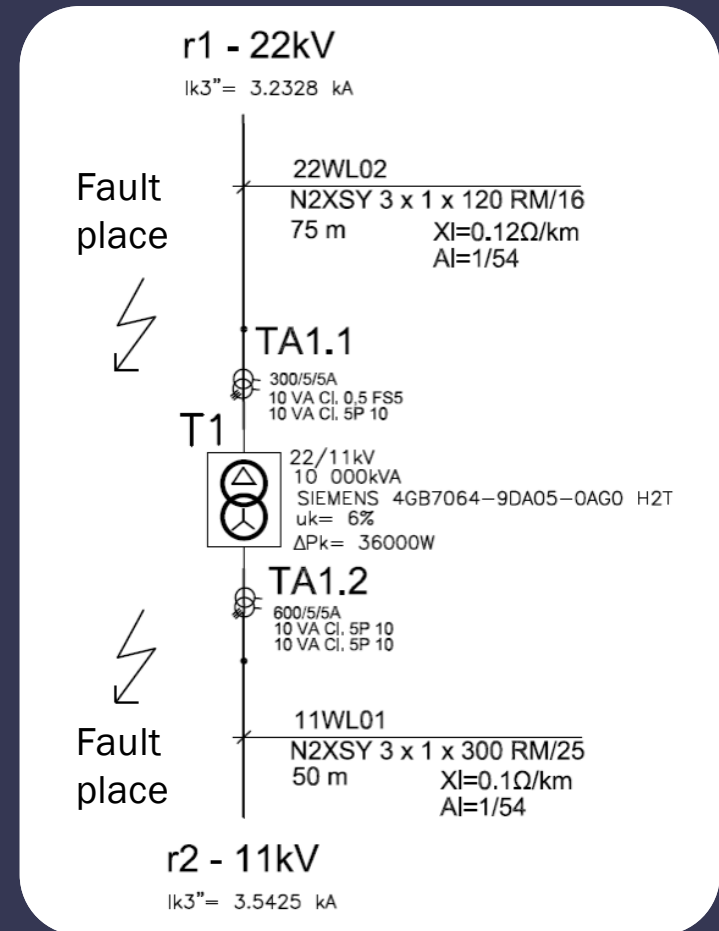


Fig. 14 Worked example

Transformer overcurrent protection

Nominal current of individual TR windings

$$I_{NP} = 209.5 \text{ A}$$

$$I_{NS} = 419 \text{ A}$$

Cable line impedance - primary winding of TR

$$R_{IP} = \frac{\rho}{q_n} * 1000 = \frac{1}{120} * 1000 = 0.154 \text{ } \Omega/\text{km}$$

$$X_{IP} = 0.12 \text{ } \Omega/\text{km}$$

$$Z_{Pline} = l * (R_{IP} + j * X_{IP}) = 0.075 * (0.154 + j0.12) = 0.012 + j0.009 \text{ } \Omega$$

Cable line impedance - secondary winding of TR

$$R_{IS} = \frac{\rho}{q_n} * 1000 = \frac{1}{300} * 1000 = 0.062 \text{ } \Omega/\text{km}$$

$$X_{IS} = 0.1 \text{ } \Omega/\text{km}$$

$$Z_{Sline} = l * (R_{IS} + j * X_{IS}) = 0.05 * (0.062 + j0.1) = 0.003 + j0.005 \text{ } \Omega$$

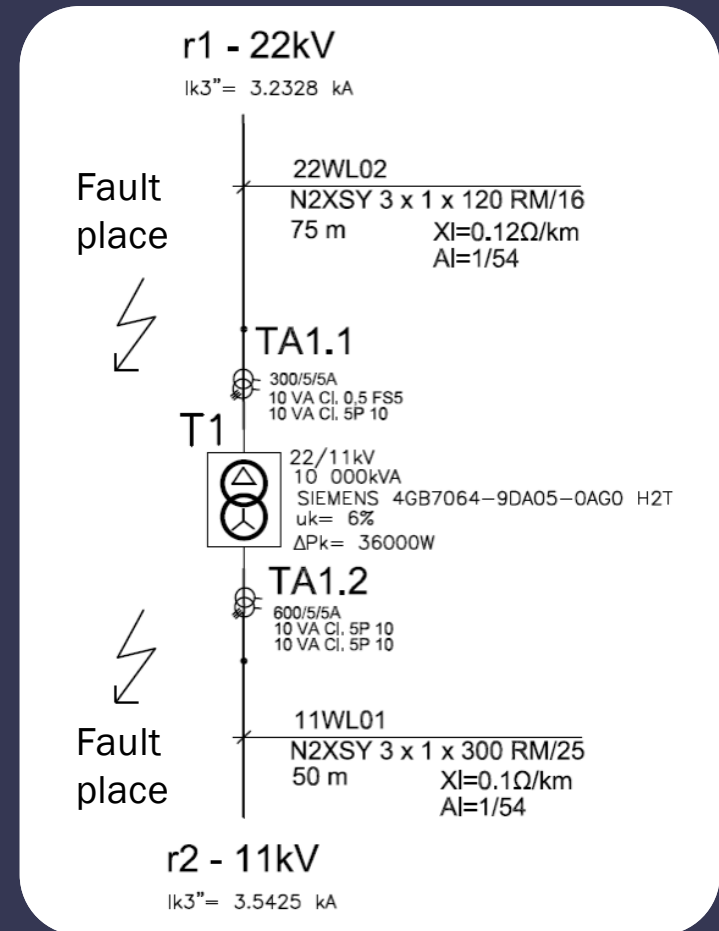


Fig. 14 Worked example

Transformer overcurrent protection

Calculation of transformer impedance

$$u_r = \frac{\Delta P_k}{S_n} = \frac{36000 \text{ W}}{10000 \text{ kVA}} = 0.0036$$

$$R_t = \frac{u_r * U_{n1}^2}{S_n} = \frac{0.0036 * 22 \text{ kV}^2}{10000 \text{ kVA}} = 0.174 \Omega$$

$$u_x = \sqrt{u_k^2 - u_r^2} = \sqrt{0.06^2 - 0.0036^2} = 0.0599$$

$$X_t = \frac{u_x * U_{n1}^2}{S_n} = \frac{0.0599 * 22 \text{ kV}^2}{10000 \text{ kVA}} = 2.899 \Omega$$

$$K_{t1} = \frac{0.95 * c}{1 + 0.6 * \frac{X_t}{\frac{U_{n1}^2}{S_n}}} = \frac{0.95 * 1}{1 + 0.6 * \frac{2.899}{\frac{22 \text{ kV}^2}{10000 \text{ kVA}}}} = 0.917$$

$$Z_{IT1} = K_{t1} * (R_t + j * X_t) = 0.917 * (0.174 + j2.899) = 0.16 + j2.658 \Omega$$

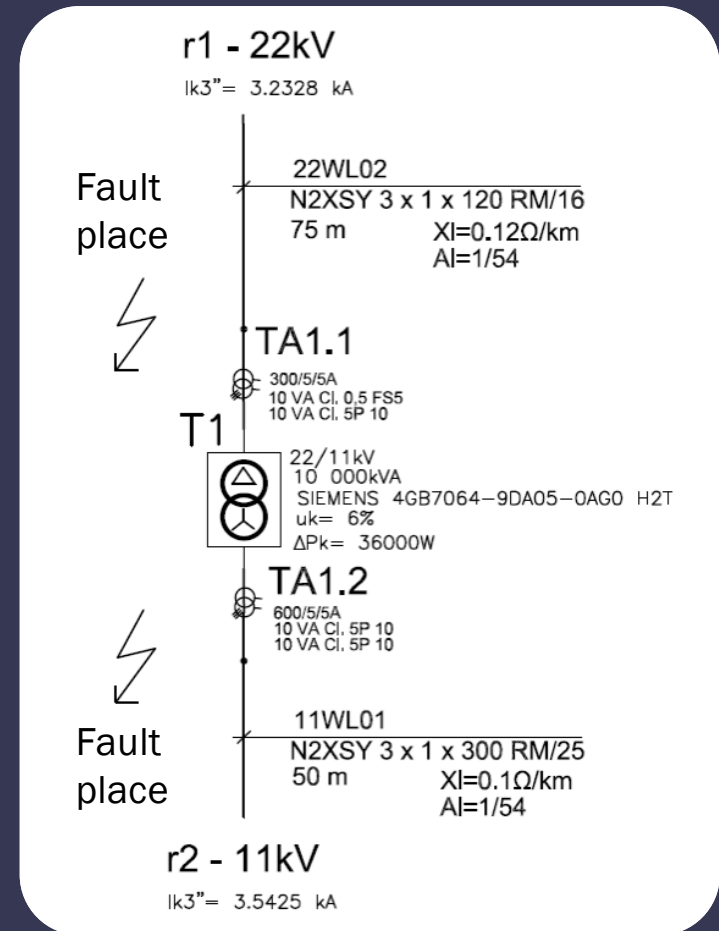


Fig. 14 Worked example

Transformer overcurrent protection

Short-circuit current calculation - primary winding of TR

$$Z_{1P} = Z_{Sgrid} * \left(\frac{U_{n1}}{U_{n2}} \right)^2 + Z_{Sline} * \left(\frac{U_{n1}}{U_{n2}} \right)^2 + Z_{1T1}$$

$$= (0.178 + j1.784) * \left(\frac{22 \text{ kV}}{11 \text{ kV}} \right)^2 + (0.003 + j0.005) * \left(\frac{22 \text{ kV}}{11 \text{ kV}} \right)^2 + (0.16 + j2.658) = 0.884 + j9.814 \Omega$$

$$I_{k3P} = \frac{c * U_n}{\sqrt{3} * |Z_{1P}|} = \frac{1 * 22 \text{ kV}}{\sqrt{3} * |0.884 + j1.784|} = 1.289 \text{ kA}$$

$$I_{k2P} = \frac{\sqrt{3}}{2} * I_{k3P} = \frac{\sqrt{3}}{2} * 1.289 \text{ kA} = 1.116 \text{ kA}$$

Short-circuit current calculation - secondary winding of TR

$$Z_{1S} = Z_{Pgrid} * \left(\frac{U_{n2}}{U_{n1}} \right)^2 + Z_{Pline} * \left(\frac{U_{n2}}{U_{n1}} \right)^2 + Z_{1T1} * \left(\frac{U_{n2}}{U_{n1}} \right)^2$$

$$= (0.391 + j3.909) * \left(\frac{11 \text{ kV}}{22 \text{ kV}} \right)^2 + (0.012 + j0.009) * \left(\frac{11 \text{ kV}}{22 \text{ kV}} \right)^2 + (0.16 + j2.658) * \left(\frac{11 \text{ kV}}{22 \text{ kV}} \right)^2$$

$$= 0.141 + j1.644 \Omega$$

$$I_{k3S} = \frac{c * U_n}{\sqrt{3} * |Z_{1S}|} = \frac{1 * 11 \text{ kV}}{\sqrt{3} * |0.141 + j1.644|} = 3.849 \text{ kA}$$

$$I_{k2S} = \frac{\sqrt{3}}{2} * I_{k3S} = \frac{\sqrt{3}}{2} * 3.849 \text{ kA} = 3.333 \text{ kA}$$

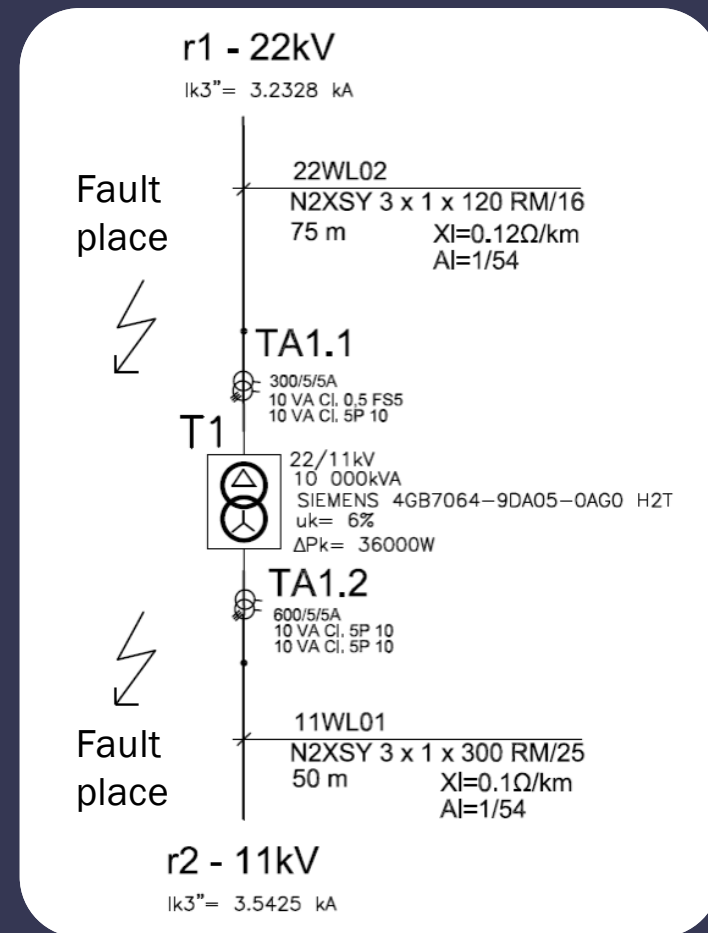


Fig. 14 Worked example

Transformer overcurrent protection

Calculation of pickup current for overload protection - primary winding

$$I_{>P} = \frac{k_b * I_{NP}}{k_p * pp} = \frac{1.1 * 209.5 \text{ A}}{0.95 * \frac{300 \text{ A}}{5 \text{ A}}} = 4.043 \text{ A}$$

Calculation of pickup current for overload protection - secondary winding

$$I_{>S} = \frac{k_b * I_{NS}}{k_p * pp} = \frac{1.1 * 419 \text{ A}}{0.95 * \frac{600 \text{ A}}{5 \text{ A}}} = 4.043 \text{ A}$$

Calculation of pickup current for short-circuit protection - primary winding

$$I_{>>P} = \frac{0.8 * I_{k2S}}{k_c * pp} = \frac{0.8 * 3.333 \text{ kA}}{1.5 * \frac{300 \text{ A}}{5 \text{ A}}} = 29.627 \text{ A}$$

Calculation of pickup current for short-circuit protection - secondary winding

$$I_{>>S} = \frac{0.8 * I_{k2P}}{k_c * pp} = \frac{0.8 * 1.116 \text{ kA}}{1.5 * \frac{600 \text{ A}}{5 \text{ A}}} = 4.96 \text{ A}$$

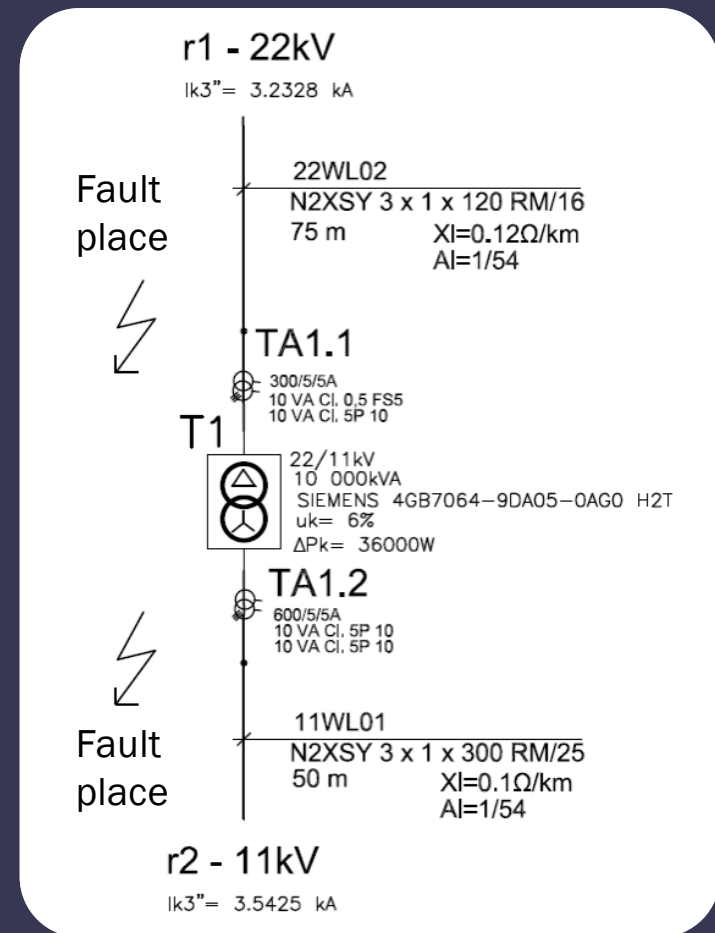


Fig. 14 Worked example

Transformer overcurrent protection

Value of pickup current for overload protection - primary TR

$$I_{>} \leq I_{R>}$$

$$4.043 \text{ A} \leq I_{R>}$$

$$I_{R>} = 4.5 \text{ A}$$

Value of pickup current for short-circuit protection - primary TR

$$I_{>>} \geq I_{R>>} > I_{R>}$$

$$29.627 \text{ A} \geq I_{R>>} > 4.5 \text{ A}$$

$$I_{R>>} = 7 \text{ A}$$

Time delay is selected for overload at $t > 0.7 \text{ s}$ and for short-circuits at $t >> 0.3 \text{ s}$, taking into account the protection of further sections using digital protection devices.

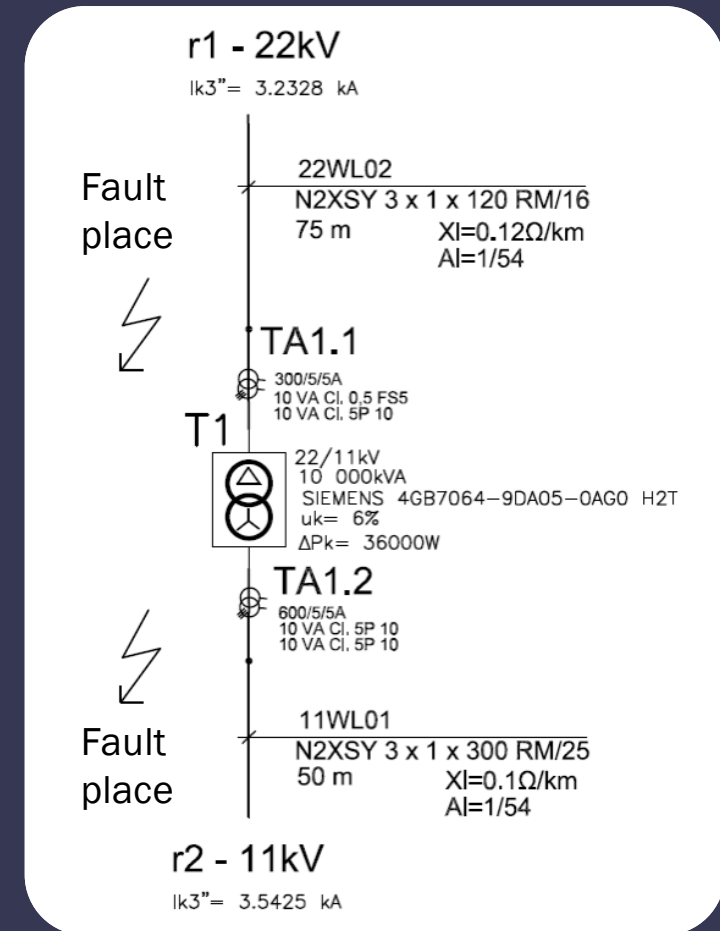


Fig. 14 Worked example

Transformer overcurrent protection

Value of pickup current for overload protection - secondary TR

$$I_{>} \leq I_{R>}$$

$$4.043 \text{ A} \leq I_{R>}$$

$$I_{R>} = 4.1 \text{ A}$$

Value of pickup current for short-circuit protection - secondary TR

$$I_{>>} \geq I_{R>>} > I_{R>}$$

$$4.96 \text{ A} \geq I_{R>>} > 4.1 \text{ A}$$

$$I_{R>>} = 4.8 \text{ A}$$

Time delay is selected for overload at $t > 0.5 \text{ s}$ and for short-circuits at $t >> 0.15 \text{ s}$, taking into account the protection of further sections only by the use of fuses and circuit breakers.

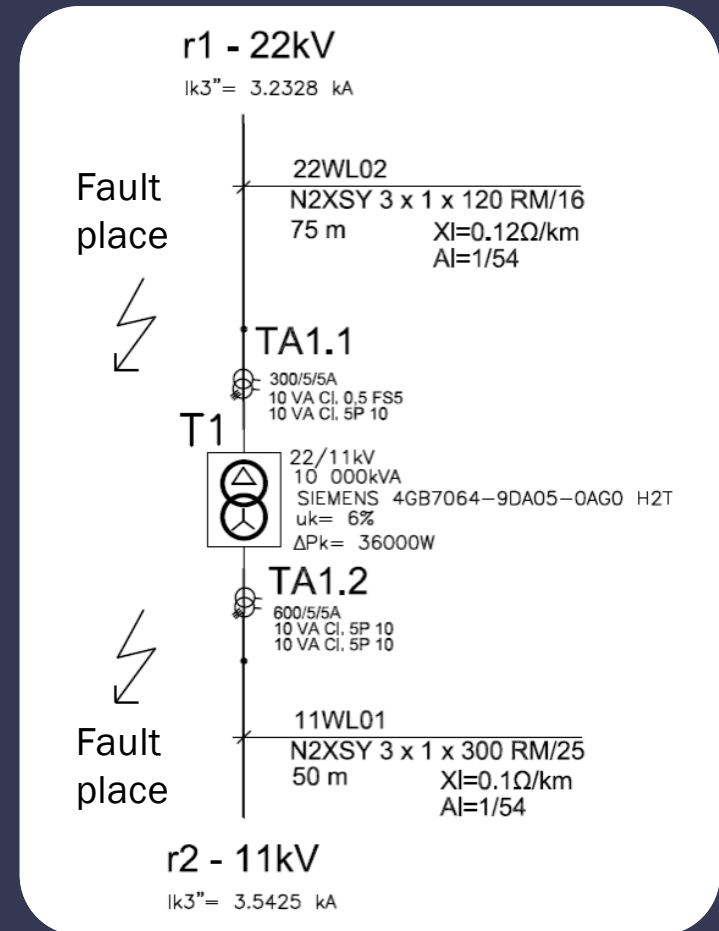


Fig. 14 Worked example

*Setting calculation for the
generator differential
protection*



Generator differential protection

Calculation of total fault current for O87P:

$I_{d2} = CT_{fault} + \text{excitation current} + TR_{fault} + \text{safety reserve} + \text{relay errors}$

$$I_{d2} = 2 * 5 \% + 1 \% + 5 \% + 5 \% + 5 \% = 26 \%$$

Calculation of first slope setting:

$SLP_1 = CT_{fault} + \text{excitation current} + TR_{fault} + \text{safety reserve} + \text{relay errors}$

$$SLP_1 = 2 * 7 \% + 1 \% + 5 \% + 5 \% + 5 \% = 30 \%$$

Calculation of second slope setting:

$$SLP_2 = 2 * SLP_1 = 60 \%$$

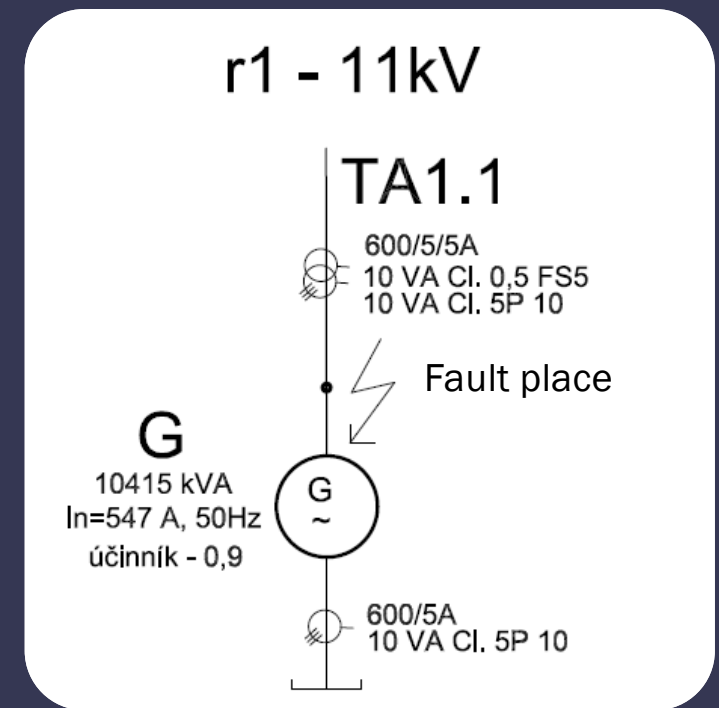


Fig. 13 Worked example

Generator differential protection

Calculation of current transformer ratio:

$$CTR_1 = \frac{600 \text{ A}}{5 \text{ A}} = 120$$

$$CTR_2 = \frac{600 \text{ A}}{5 \text{ A}} = 120$$

The knee point IRS1 is determined for the stabilizing current I_b in the range of 1.5 to 2.5. In this example, we consider 1.5. The upper limit U_{87P} of the differential current I_{dmax} is selected in the range of 8 to 10. For this example, we select 8. The second harmonic is set to 20% and the fifth harmonic is set to 40%.

Compensation factor PT TAP is calculated according to the relationship:

$$TAP = \frac{S \cdot 1000}{\sqrt{3} \cdot U_{L-L}} \cdot CT = \frac{10415 \text{ kVA}}{\sqrt{3} \cdot 11 \text{ kV}} \cdot \frac{5 \text{ A}}{600 \text{ A}} = 4.555$$

Pick-up test of differential protection

$$I_{d_{Prim.}} = I_{d_{Sek.}} = TAP \cdot SLP_1 = 4.555 \cdot 0.3 = 1.367 \text{ A}$$

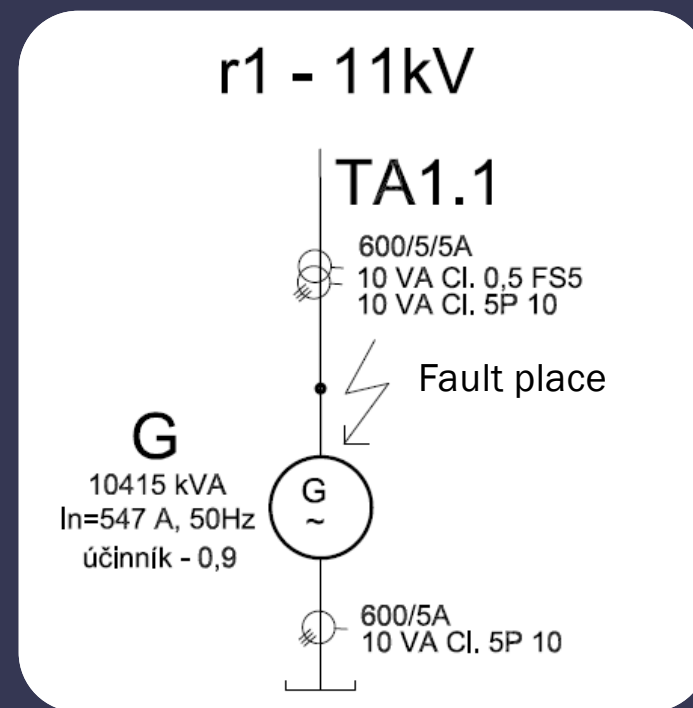


Fig. 13 Worked example

*Setting calculation for the
transformer differential
protection*



Transformer differential protection

Calculation of total fault current for O87P:

$I_{d2} = CT_{fault} + \text{excitation current} + TR_{fault} + \text{safety reserve} + \text{relay errors}$

$$I_{d2} = 2 * 5 \% + 1 \% + 5 \% + 5 \% + 5 \% = 26 \%$$

Calculation of first slope setting:

$SLP_1 = CT_{fault} + \text{excitation current} + TR_{fault} + \text{safety reserve} + \text{relay errors}$

$$SLP_1 = 2 * 7 \% + 1 \% + 5 \% + 5 \% + 5 \% = 30 \%$$

Calculation of second slope setting:

$$SLP_2 = 2 * SLP_1 = 60 \%$$

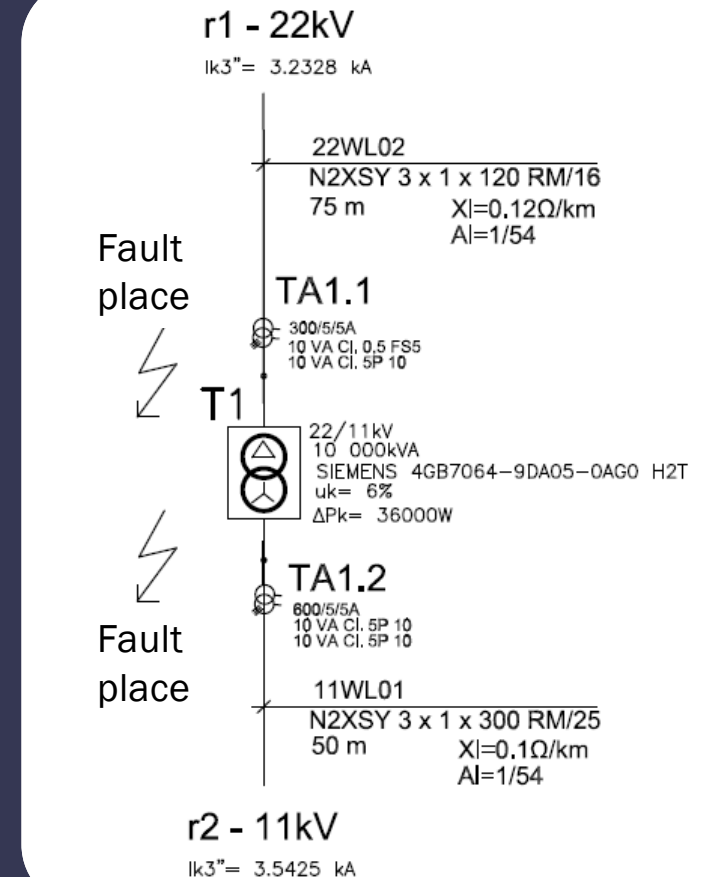


Fig. 15 Worked example

Transformer differential protection

Calculation of current transformer ratio:

$$CT_1 = \frac{300 \text{ A}}{5 \text{ A}} = 60$$

$$CT_2 = \frac{600 \text{ A}}{5 \text{ A}} = 120$$

The knee point IRS1 is determined for the stabilizing current I_b in the range of 1.5 to 2.5. For this example, we select 1.5.

The upper limit U87P of the differential current I_{dmax} is selected in the range of 8 to 10. For this example, we select 8.

The second harmonic is set to 20% and the fifth harmonic is set to 40%.

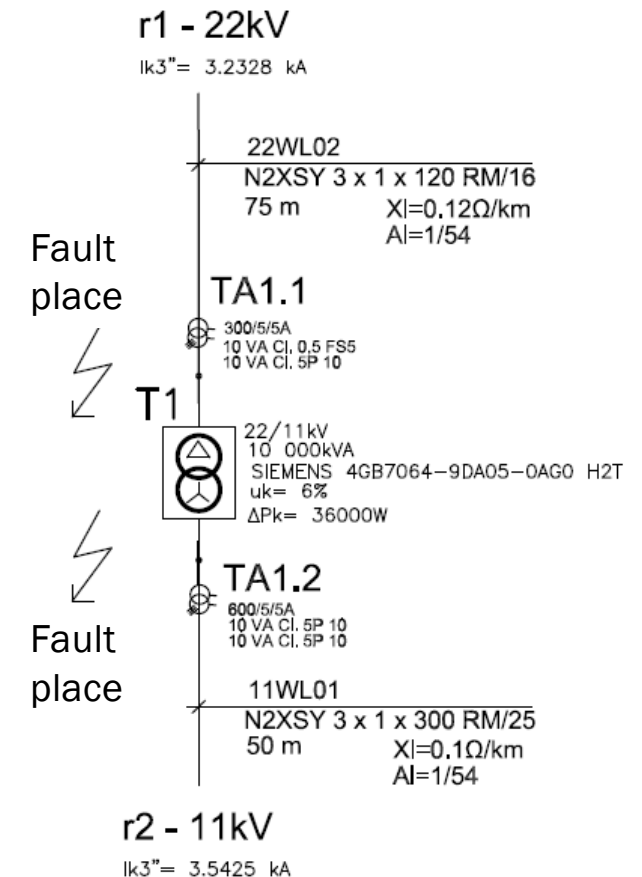


Fig. 15 Worked example

Transformer differential protection

Compensation factor PT TAP is calculated according to the relationship:

$$TAP = \frac{S \cdot 1000}{\sqrt{3} \cdot U_{L-L}} * CT = \frac{10000 \text{ kVA}}{\sqrt{3} \cdot 22 \text{ kV}} * \frac{5 \text{ A}}{300 \text{ A}} = 4.374$$

Compensation factor PT TAP is calculated according to the relationship:

$$TAP = \frac{S \cdot 1000}{\sqrt{3} \cdot U_{L-L}} * CT = \frac{10000 \text{ kVA}}{\sqrt{3} \cdot 11 \text{ kV}} * \frac{5 \text{ A}}{600 \text{ A}} = 4.374$$

Pick-up test of differential protection

$$Id_{prim.} = Id_{sek.} = TAP * SLP_1 = 4.374 * 0.3 = 1.312 \text{ A}$$

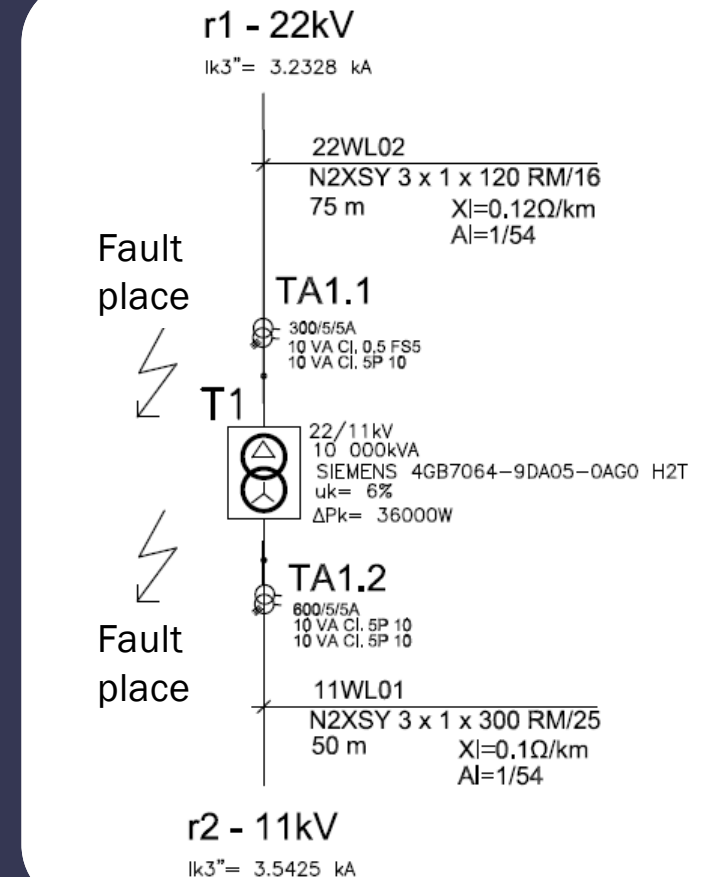


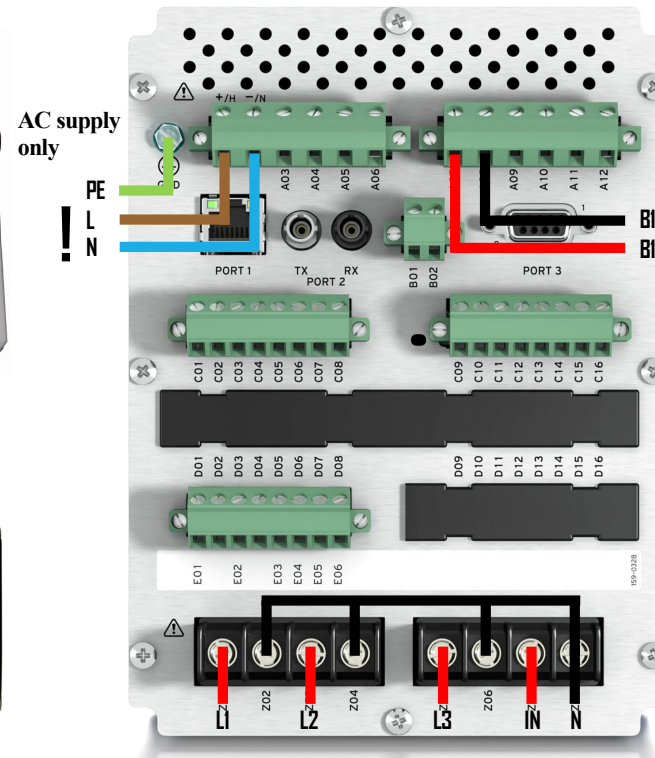
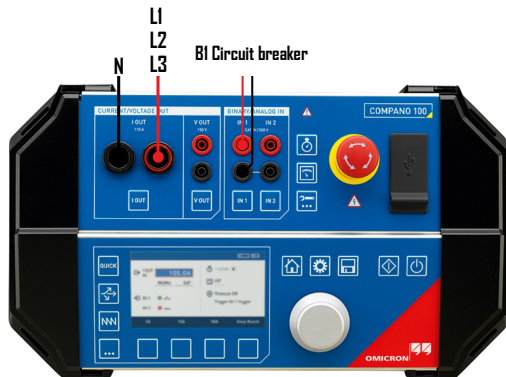
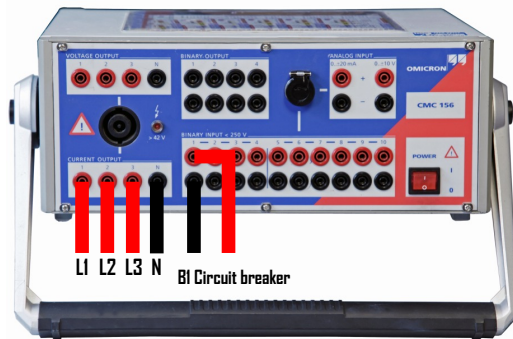
Fig. 15 Worked example

*Sample wiring and testing of
the configured digital relays*



Overcurrent protection SEL-751/751A

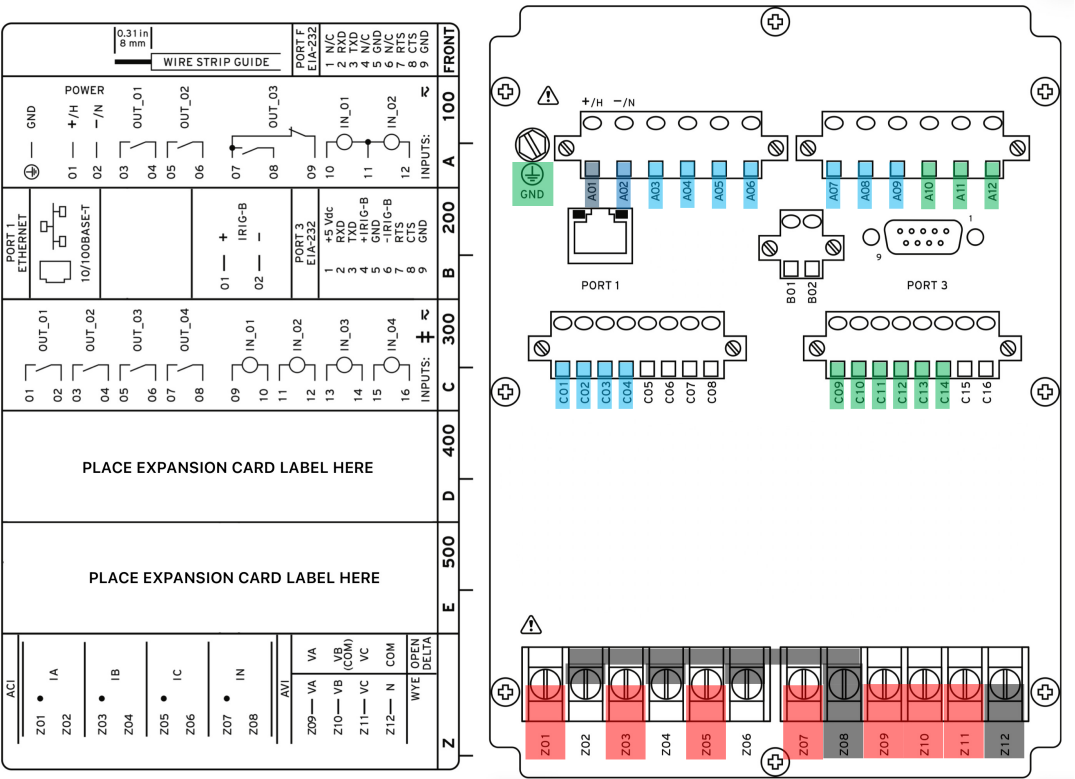
*Wiring diagram for the measurement of the SEL-751A
overcurrent protection*



Overcurrent protection

SEL-751

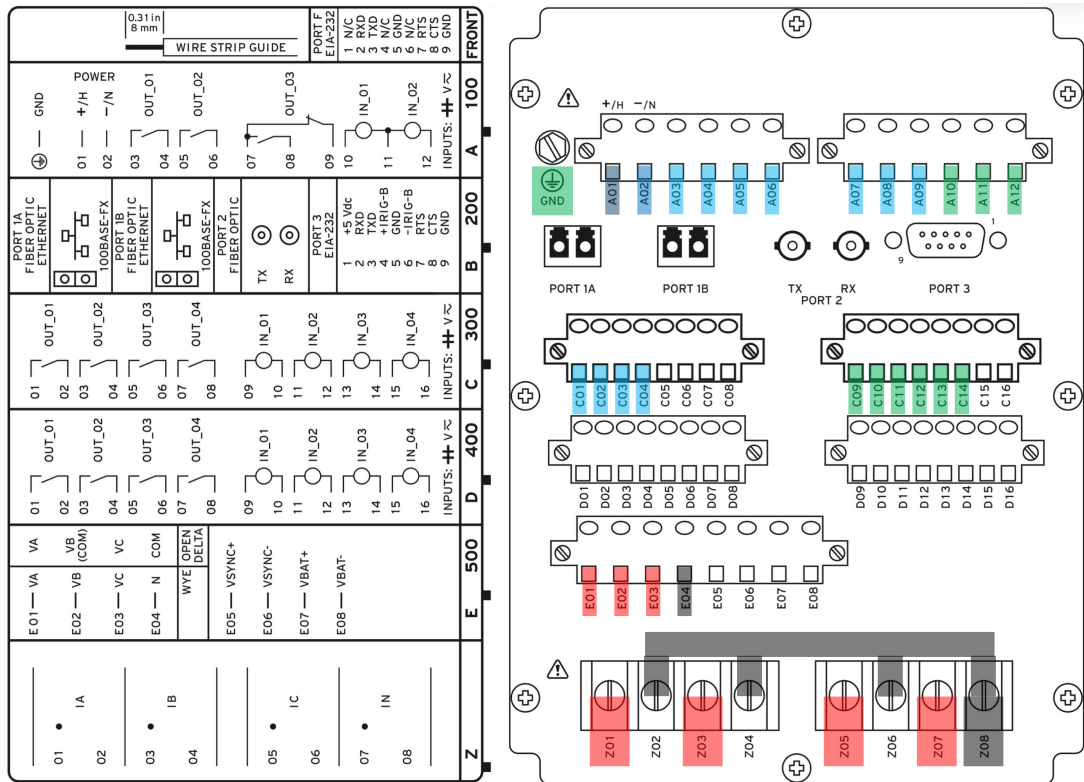
Wiring diagram of the digital relay for Bench 1



Overcurrent protection

SEL-751A

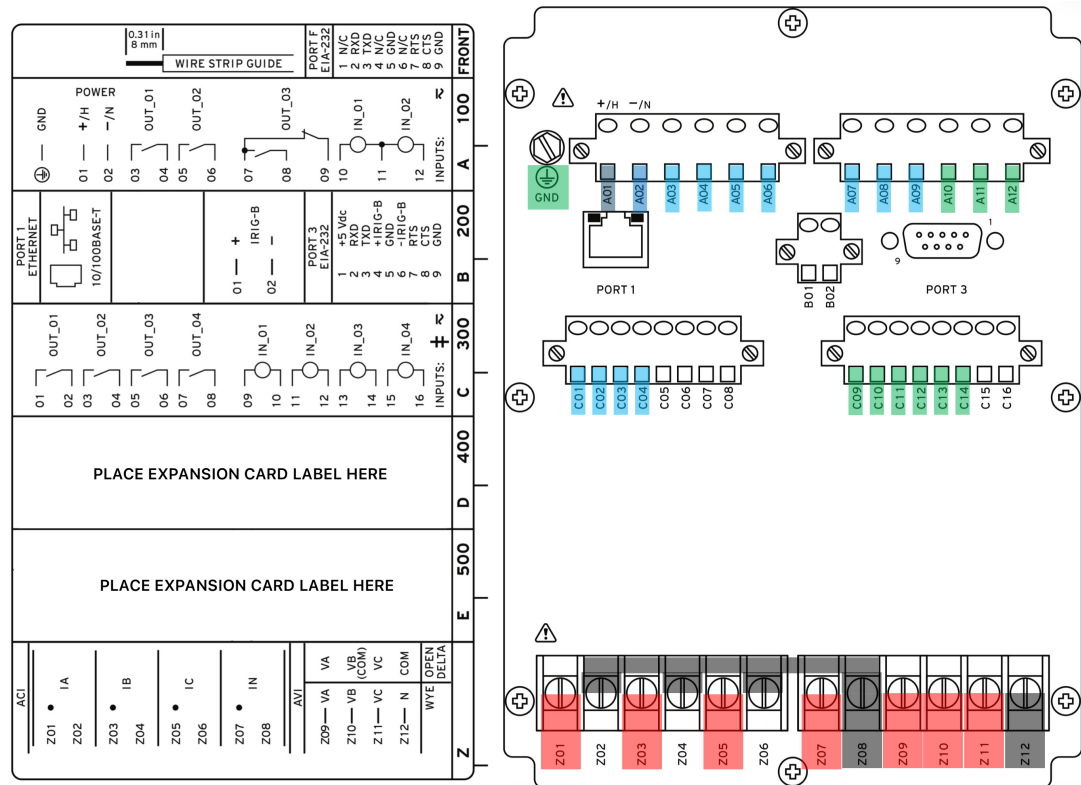
Wiring diagram of the digital relay for Bench 2



Overcurrent protection

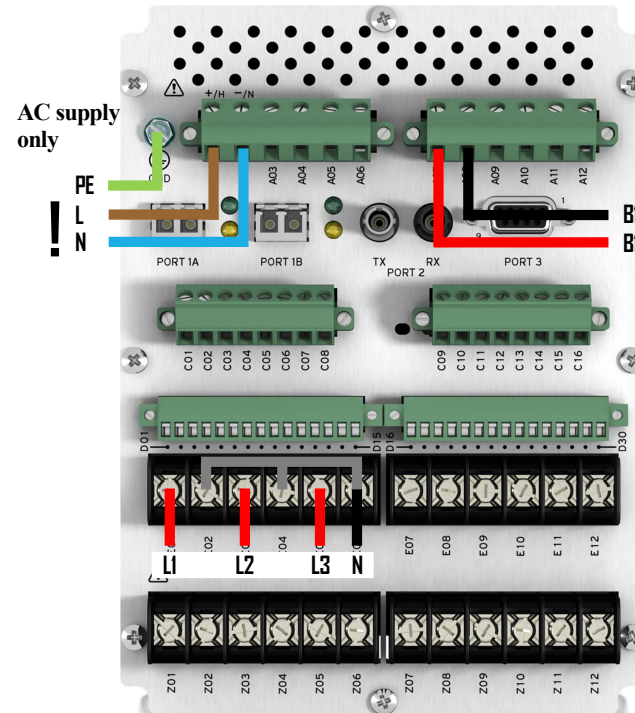
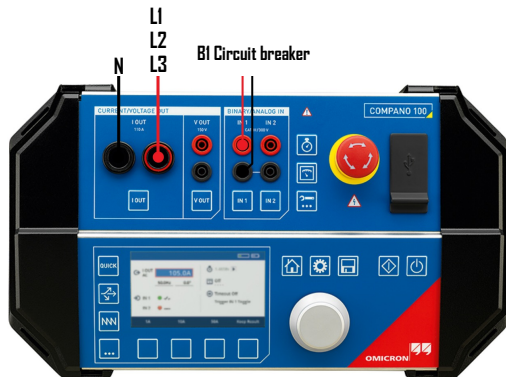
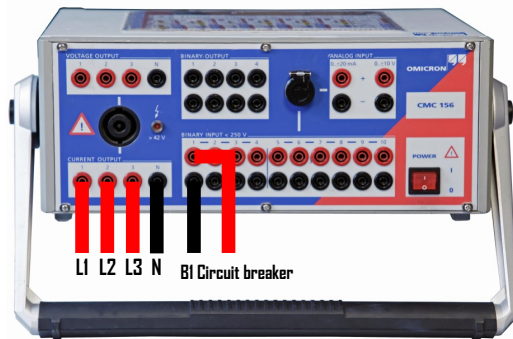
SEL-751A

Wiring diagram of the digital relay for Bench 3



Generator protection SEL-700G/700GT

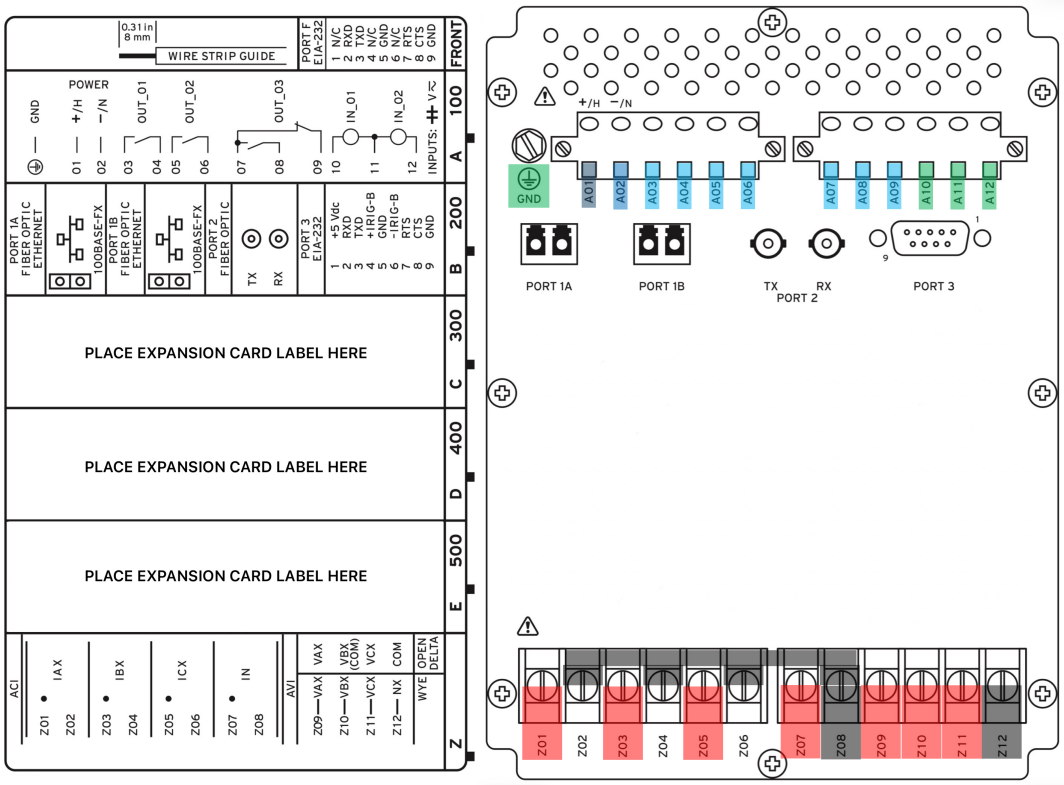
Wiring diagram for the measurement of the SEL-700GT
overcurrent protection



Generator protection

SEL-700G

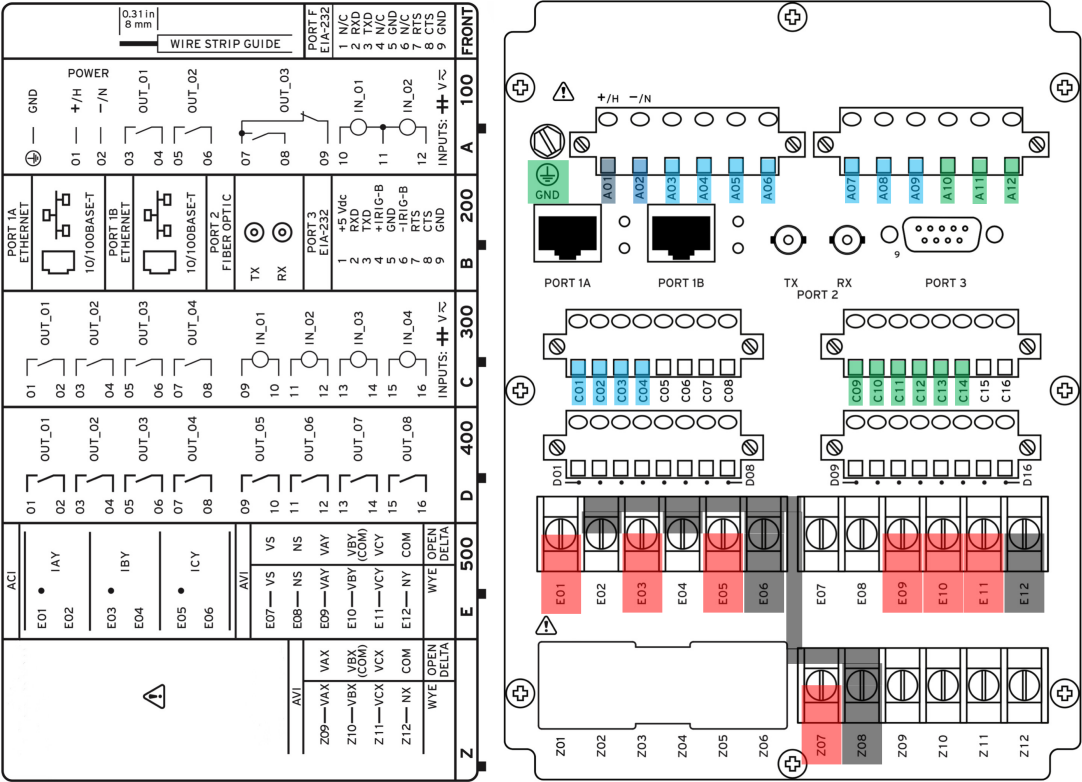
Wiring diagram of the digital relay for Bench 1



Generator protection

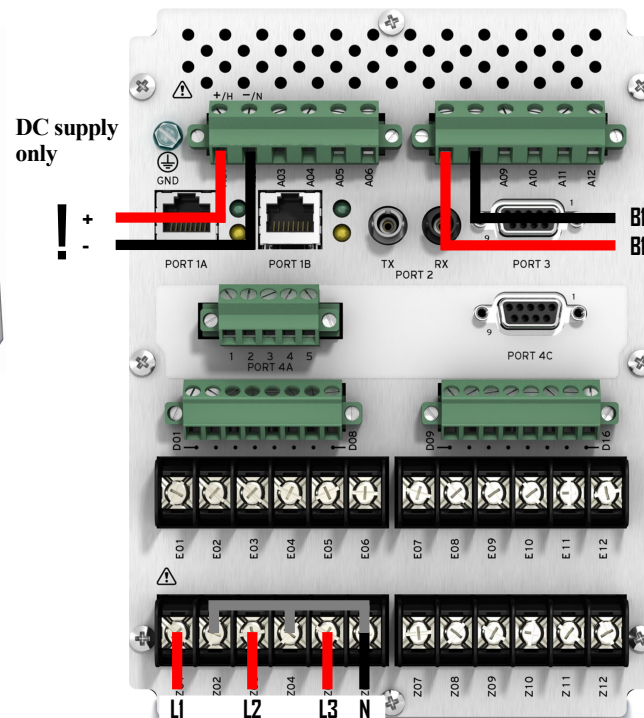
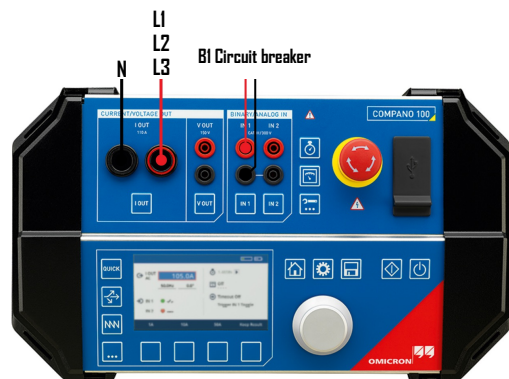
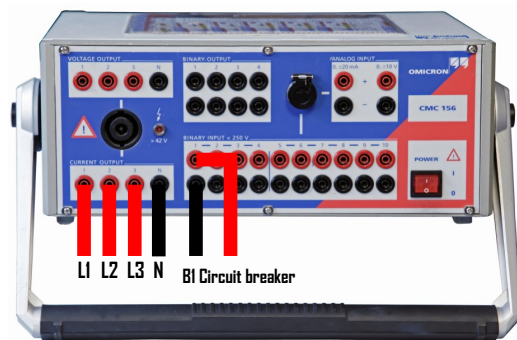
SEL-700GT

Wiring diagram of the digital relay for Bench 2



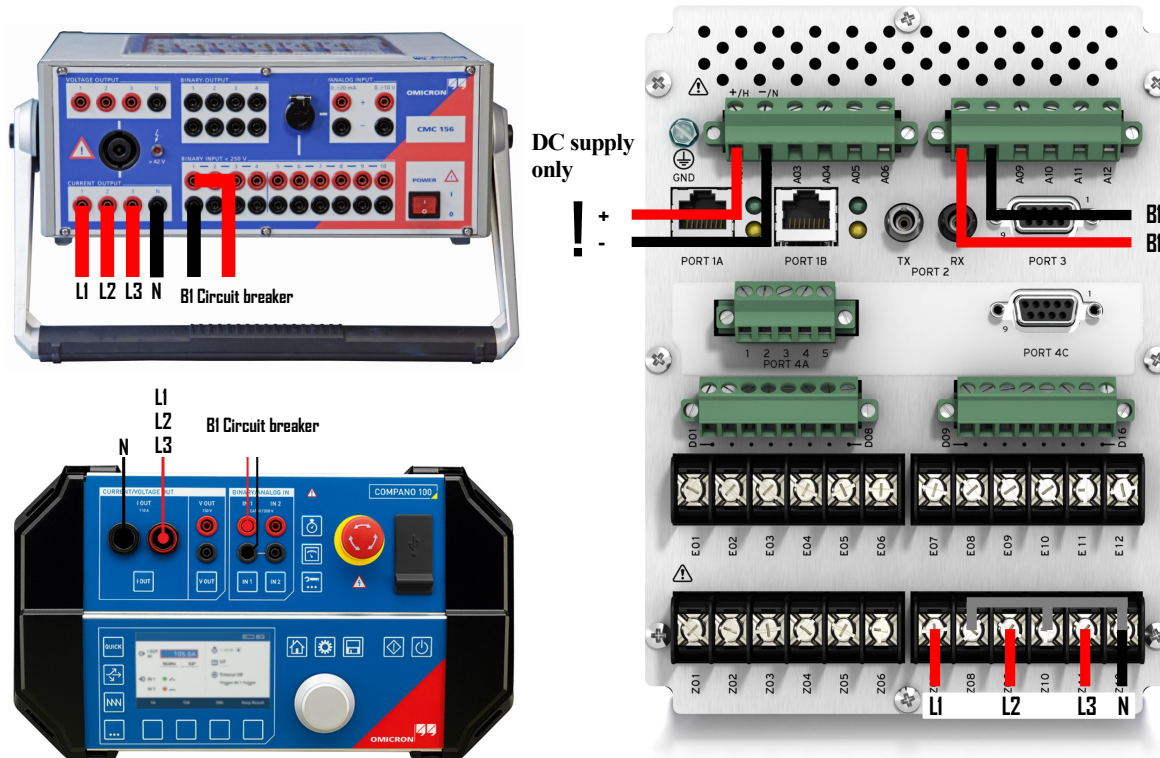
Transformer protection SEL-787 - overcurrent, primary

Wiring diagram for the measurement of the SEL-787 overcurrent protection



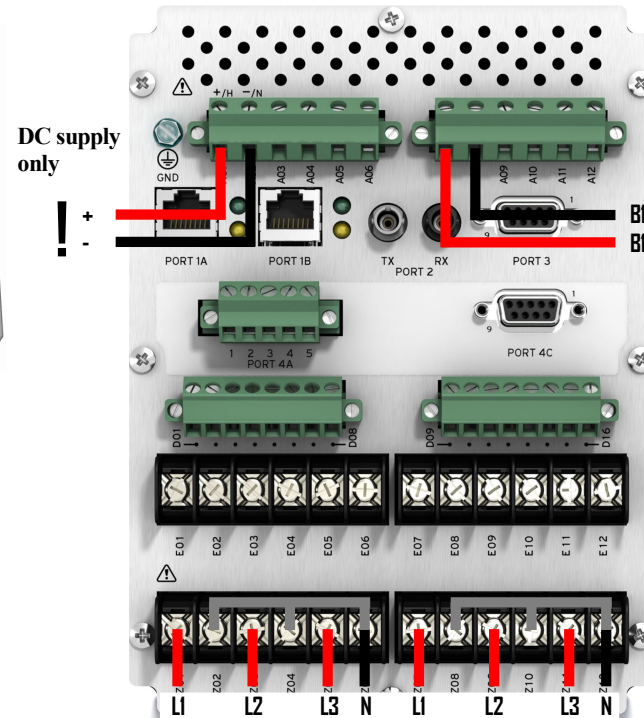
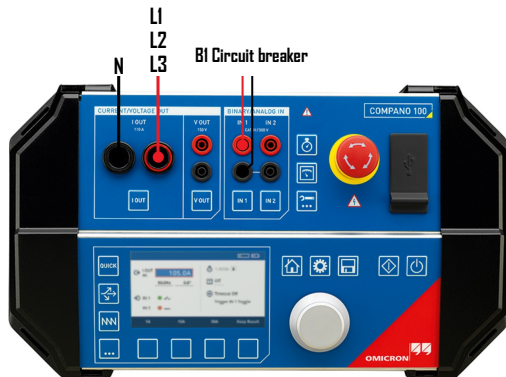
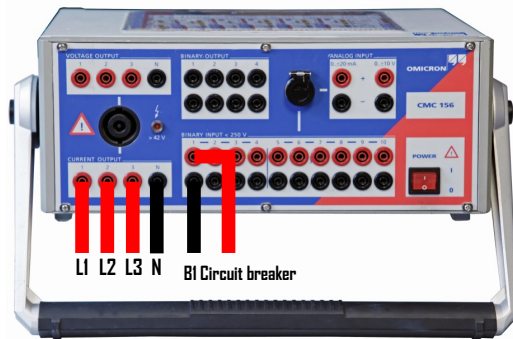
Transformer protection SEL-787 - overcurrent, secondary

Wiring diagram for the measurement of the SEL-787
overcurrent protection



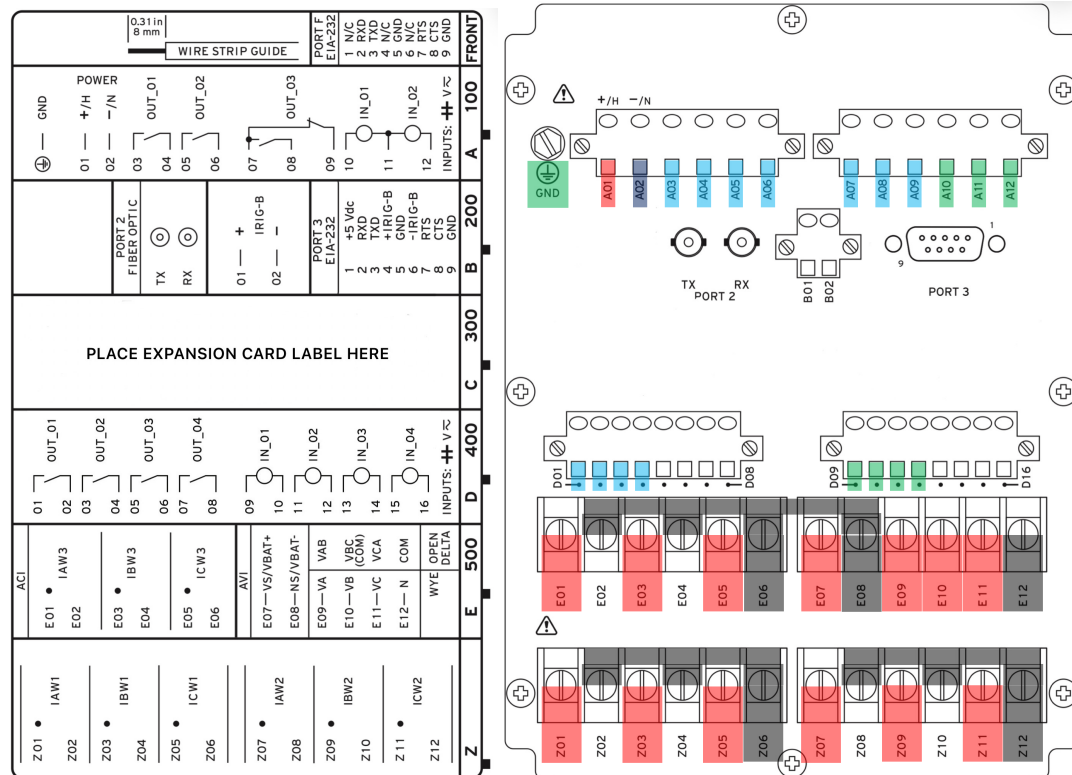
Transformer protection SEL-787

*Wiring diagram for the measurement of the SEL-787
overcurrent protection*



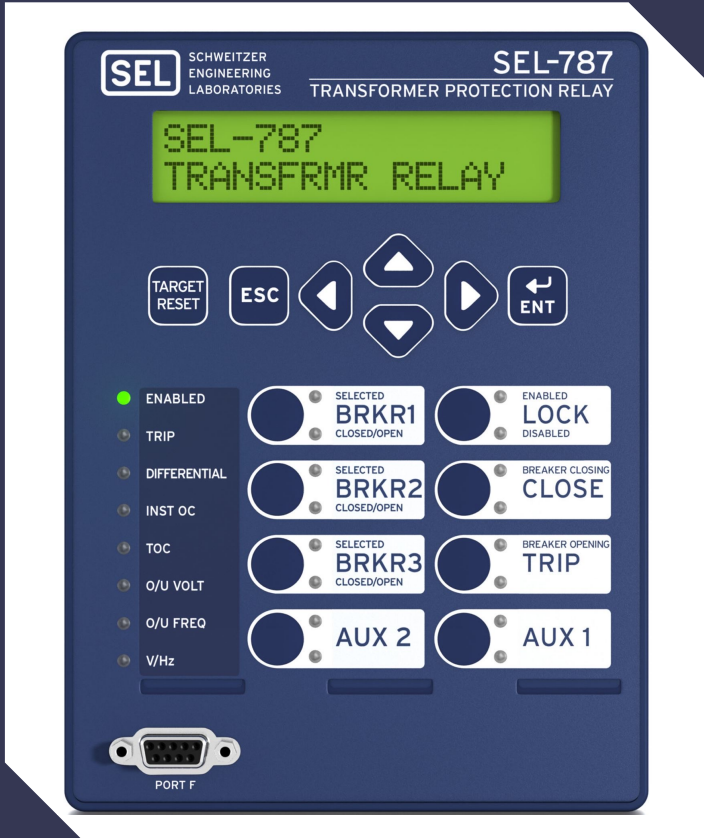
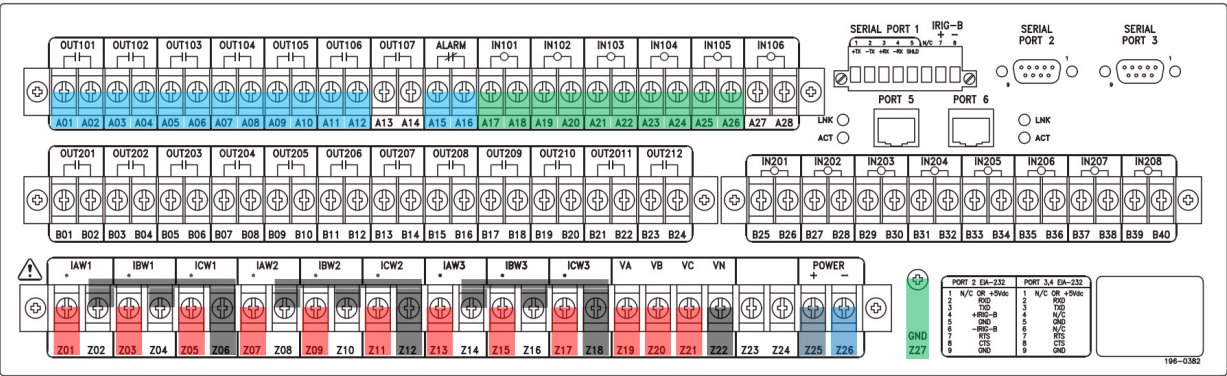
Transformer protection SEL-787

Wiring diagram of the digital relay for Bench 3



Transformer protection SEL-387E

Wiring diagram of the digital relay for Bench 1

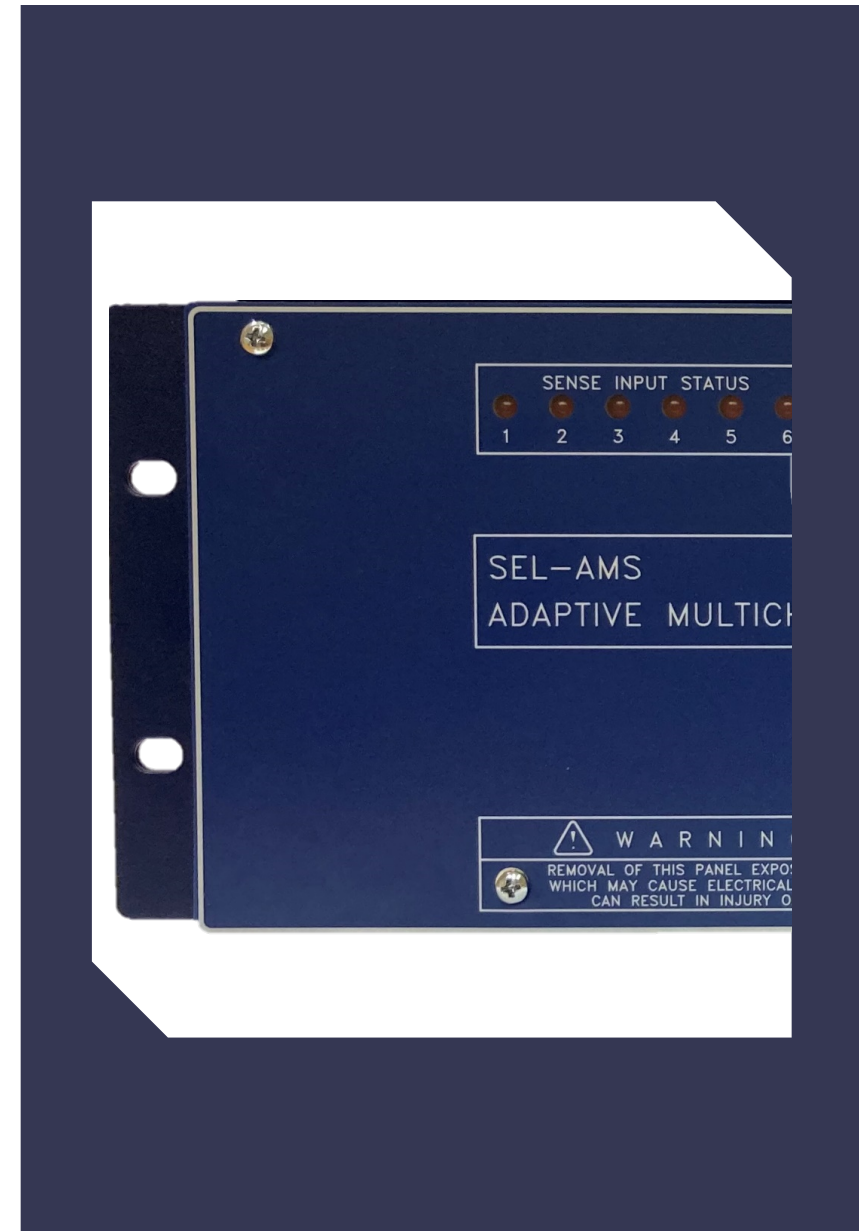
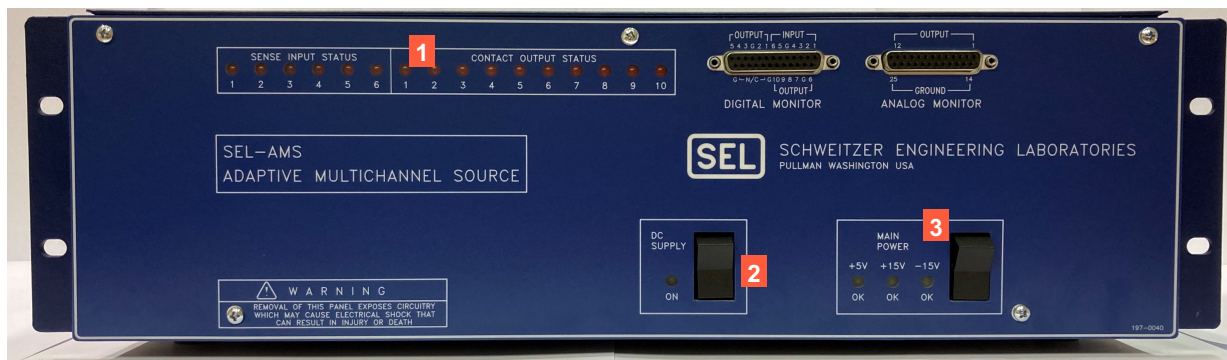


*Sample wiring
and testing with the SEL-
AMS*



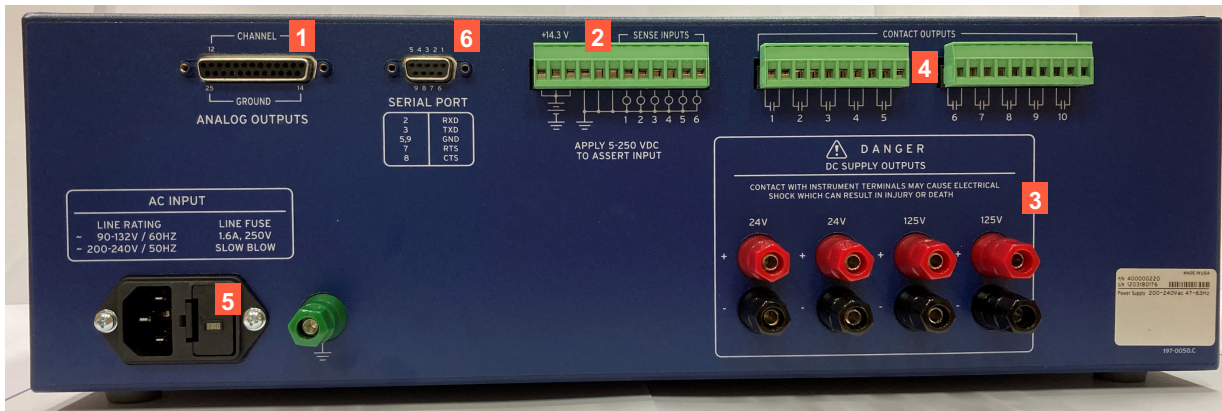
SEL-AMS test system

- 1** Front-panel LEDs show the status of the inputs and outputs of the test set
- 2** Switch for turning the 24 V and 125 V DC power supply on/off.
- 3** Switch for turning the SEL-AMS (4000) test set on/off



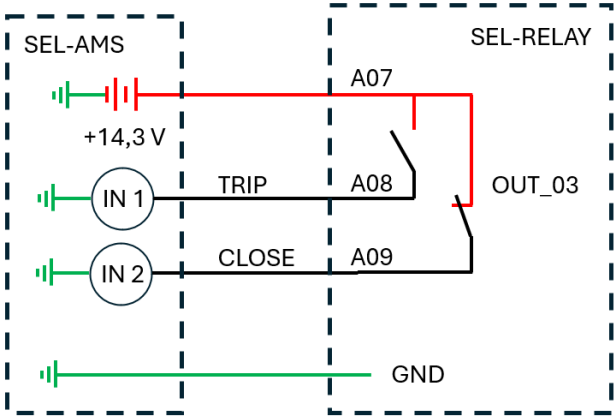
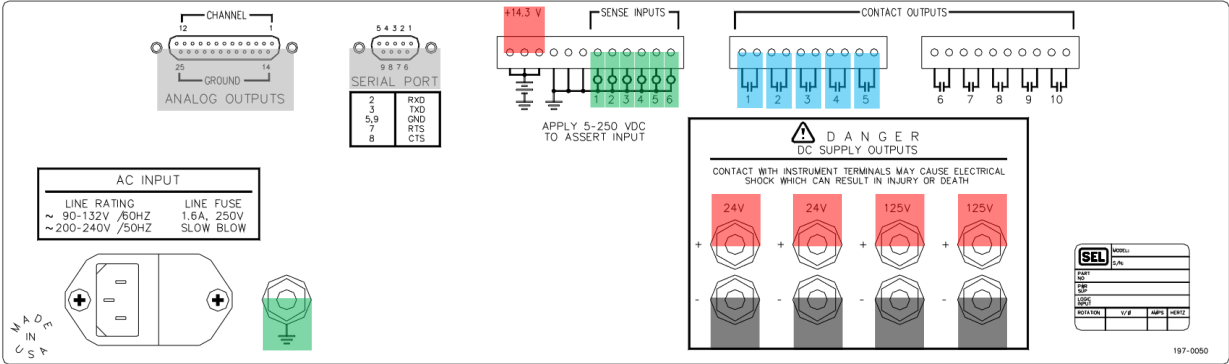
SEL-AMS test system

- 1** Analogue outputs for feeding the current and voltage inputs of the protective relay.
- 2** Input terminal strip and earthing terminal strip
- 3** DC supply outputs for 24 V and 125 V
- 4** Output terminal strip of the switching contacts
- 5** Connector for supplying the SEL-AMS (4000) test set, and earthing terminal
- 6** Port for communication with a PC



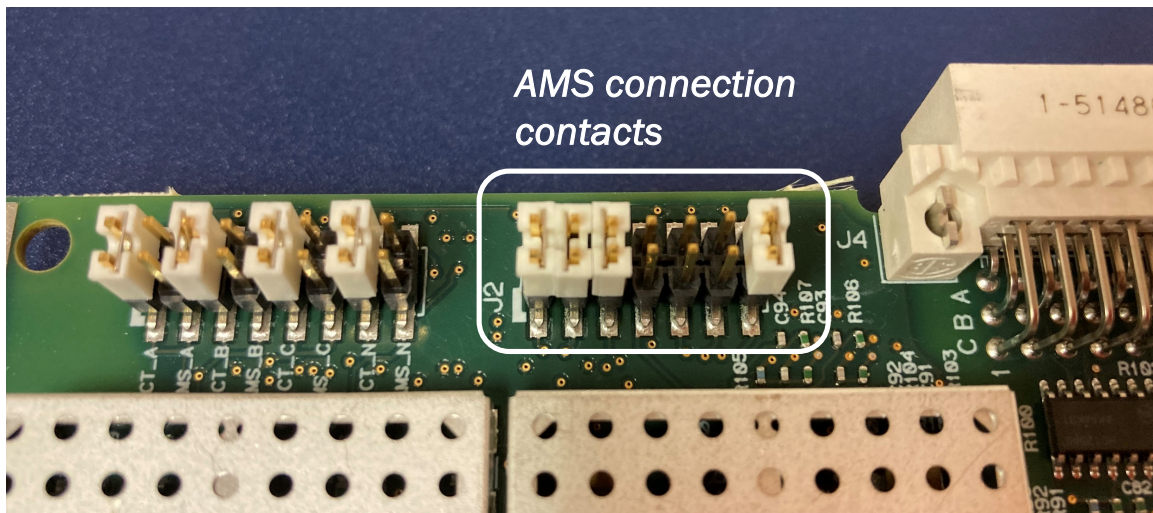
SEL-AMS test system

Wiring diagram of the test set for Bench 1



SEL-AMS test system

A condition for the use of this SEL-AMS test system is compatibility with the relay under test. This can be checked simply by looking at board E (the CT and VT input board), where the inputs for connecting the ribbon cable and the contacts for the AMS interconnection must be available.



SEL-AMS test system

Parameters of the SEL-AMS test system

Frequency range 10 – 300 Hz

The input delay time must not exceed 255 milliseconds.

The voltage and current ranges must not exceed 3.535 times the default output values for the individual protective relays.

Example for the SEL-787

Voltage range 0 – 720 V

Current range 0 – 374.5 A

The SEL-5401 software is required to control the test set.



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