PARAMETERIZATION OF PROTECTION RELAYS IN POWER SYSTEMS

PROTECTION SYSTEMS IN ELECTRIC POWER SYSTEM

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

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SCHWEITZER ENGINEERING LABORATORIES

The First edition published in 2022
Technical University of Košice
Letna 9, 04001 Košice

Title	**Parameterization of protection relays in power systems**
Author	**Ing. Robert Stefko**
Publisher	**Technical University of Košice**
The Year	**2022**
Issue	**First**
Pages	**115**
Copyright	**Technical University of Košice**
ISBN	**978-80-553-4067-8**
Edition	**Teaching texts**

The teaching text describes complex procedures for parameterization of overcurrent, differential, and distance protection relays from the company SEL, a theoretical basis for protection relays, description, and connection of individual parts of protection relays. The following obtains instructional videos along with wiring for Omicron testing.

The teaching text is intended for students of electrical engineering faculties in study programs focused on electric power engineering, users of electric power equipment, and the professional public.

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This teaching text was supported by the Agency for the Support of Research and Development under contract No. APVV-19-0576 and the grant agency of culture and education of the Ministry of Education, Science, Research and Sports of the Slovak Republic within the project VEGA No. 1/0757/21.

Thanks also go to SEL for donating various protection relays.

Theory of protections

The main task of equipment protection is to ensure the equipment or section is unexposed to adverse conditions, e.g., overloading of the device and thus reducing the service life of the device or an accidental fault condition due to a short circuit on the device.

For these reasons, it is necessary to know the relationship between the device or section in relation to the surrounding space, which has a very significant impact on the device. Therefore, we need to know the interactions of the device on the environment and the surroundings on the device. When setting up and designing, we should have as detailed information as possible for the reasons mentioned. *In the case of incomplete or unclear information, we should not even start with a calculation to protect the facility or section, or more rigorously assess the impact of the environment on the facility.*

Theory of protections – overcurrent protection

Theory of protections – overcurrent protection

Stepped protections - to ensure the selected shutdown, we need to ensure action with a time delay, which will be suitably graduated and thus ensure mutual backup protection. For this reason, they contain a start-up and time element which, if necessary, will switch off the protection with the measuring and directional element determined by the fault condition and, depending on the set times. Tiered protections include overcurrent and distance protections.

Overcurrent protections work on a simple principle and are used as backups or for HV lines and less important lines of lower voltage levels than the main ones. As already follows, the protection responds to the adjusted current value with the adjusted starting current adjustment Ir, in the case of lines or short circuits.

Theory of protections – overcurrent protection

<u>Time-dependent</u> - has a decreasing dependence similar to fuses, according to the equation $t = K/(I/I_N - I)$ for $I/I_N > I$ and $t = \infty$ for $I/I_N \leq I$,

<u>Semi-dependent</u> - has the same characteristics up to size I_0. For larger currents $I/I_N > I_0$ it already has a constant operating time and does not depend on the current change.

P_d – permitted area; P_z – forbidden area; h_0 – limit of action

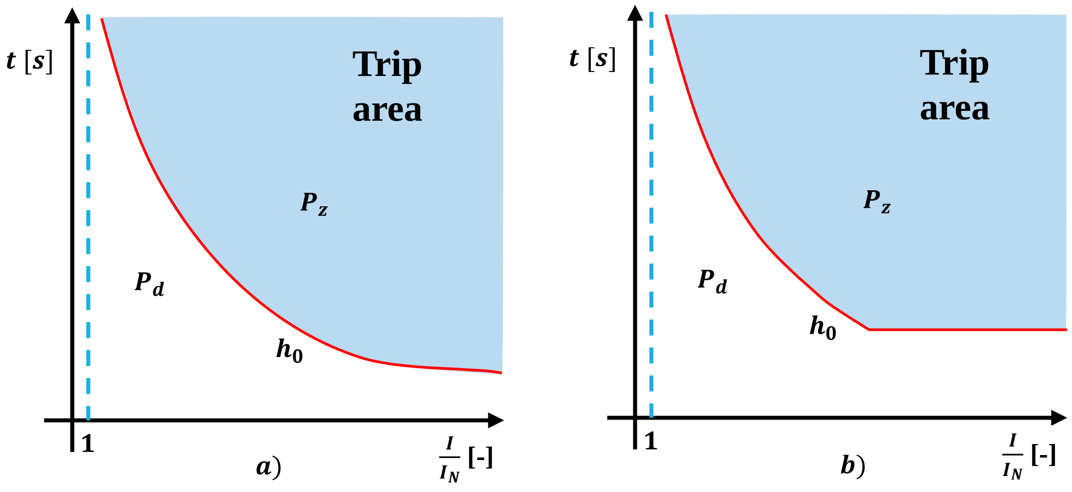


Fig. 1 Speed characteristics a) time-dependent; b) semi-dependent

Theory of protections – overcurrent protection

Definite time - acts according to the set time $t_>$ when the current $k_{I>}$ is reached. For larger currents $I/I_N > k_{I>}$ already has a constant operating time and does not depend on the current change.

Immediate - acts when the set current $k_{I>}$ is exceeded, almost without delay. The delay represents a protection response time of up to 10 ms.

P_d – permitted area; P_z – forbidden area; h_0 – limit of action; $t_>$ - time delay; $k_{I>}$ - current extension

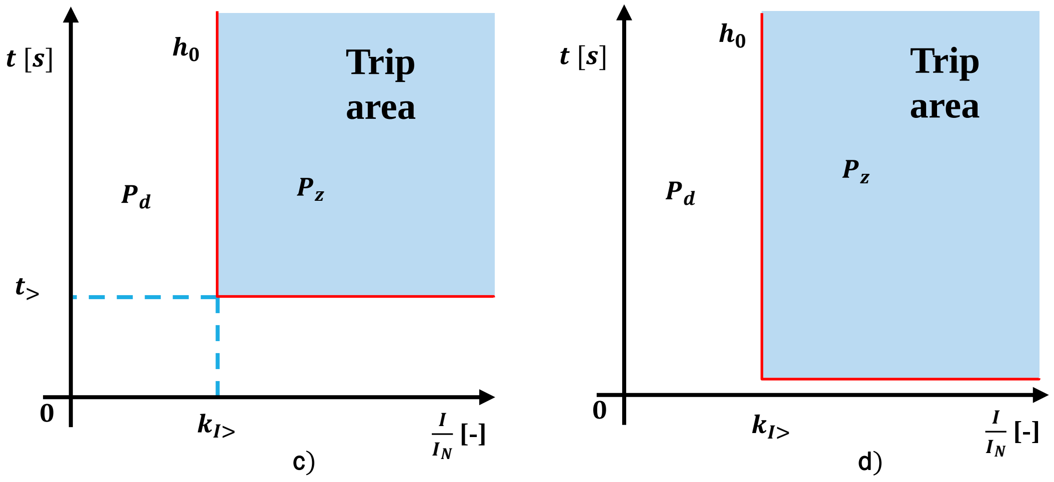


Fig. 2 Speed characteristics c) definite time; d) immediately acting

Theory of protections – overcurrent protection

The setting of independent times is generally based on the assumption that the farthest protection switches off the fastest, for which the equation $t_2 = t_1 + \Delta t$ applies. The coordination time interval Δt depends on the design of the time relay and switch, while it is most often in the range of 0.2 to 0.5 s. Simultaneously, it is important to forget the current setting of the relay so that the protections back up. To set the starting currents I_r correctly, I need to know the current ratios of short-circuit currents, overloads, and rated currents. The size of the short-circuit currents may vary for unique operating times. For these reasons, it is necessary to know the maximum and minimum short-circuit current.

When changing the network scheme, it is necessary to check whether the given protection settings suit and, if necessary, it is possible to use another set of protection settings, as digital protections have 4 sets by default, between which it is possible to switch.

Setting of overcurrent protections

Determining the size of the time coordination interval Δt:

- **maximum time relay errors,**
- **the time of switching off the circuit breakers,**
- **backup safety time, which is selected at about 0.1 s.**

Setting the starting current I_r:

- **the starting current of the relay I_r must be greater than I_n :**

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

where k_b is the safety factor and is selected from the range 1.1 to 1.35

k_p is the holding ratio of the relay and is specified by the manufacturer in the range 0.94 to 0.98

p_i is the rated conversion of current transformers.

I_{kmax} - maximum short-circuit current (3f); I_{kmin} - minimum short-circuit current; I_r - starting current; I_0 - waste current; I_{zmaxOZ} - maximum inrush current for reconnection; I_{zmaxM} - maximum starting current of motors; I_n - nominal current; I_{pmax} - maximum operating current

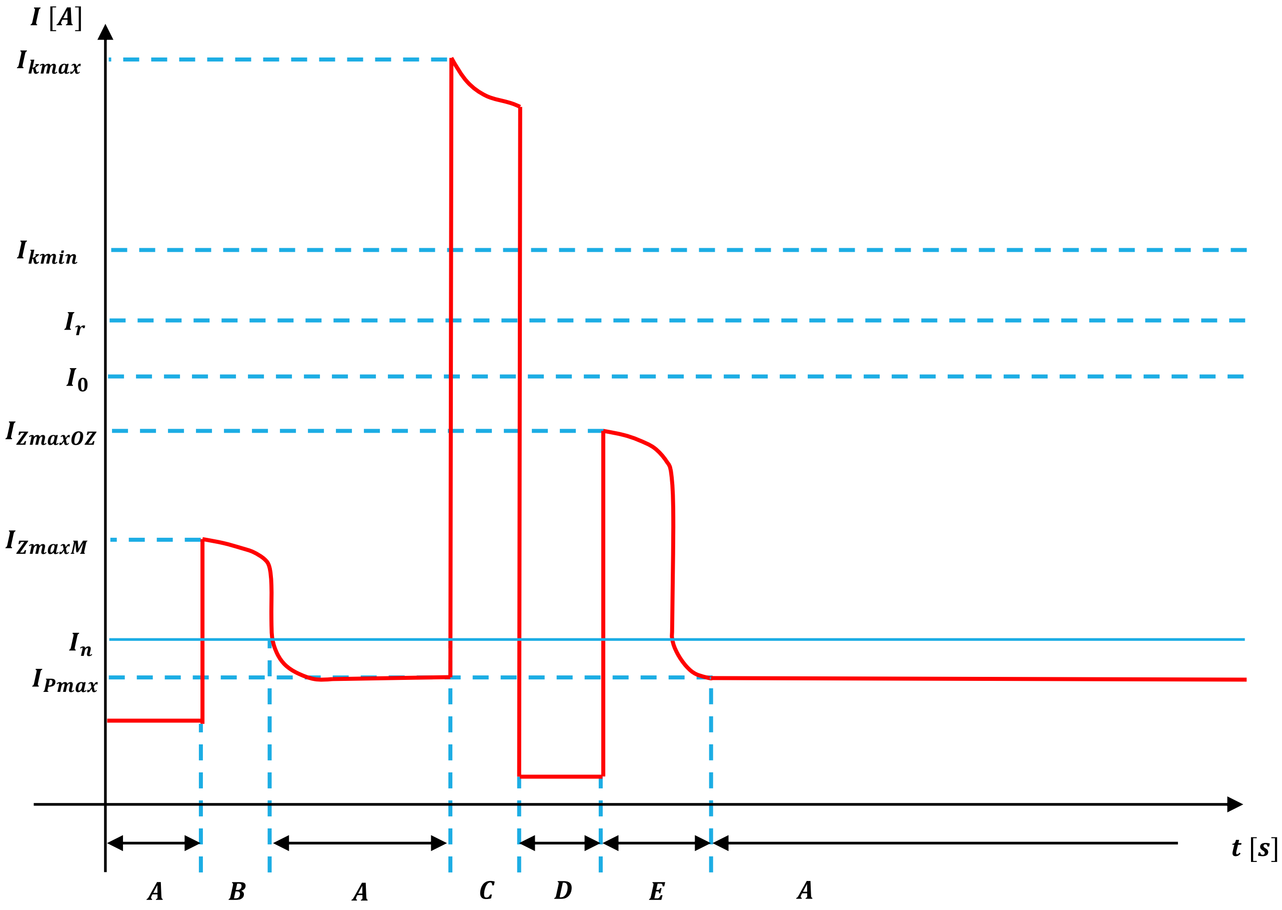


Fig. 3 Current ratios for various operating and fault conditions

Setting of overcurrent protections

Furthermore, the starting current of the overcurrent relay must be less than the minimum calculated short-circuit current I_{k2fmin} at the end of the backup section.

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

Where k_c is the sensitivity coefficient for at least the immediate 2 and the other 1.5.

p_i is the rated conversion of current transformers.

If the sensitivity coefficient kc is less than 1.5 for overcurrent independent time protections, then the sensitivity of the protection is increased by reducing the value of the starting current Ir. This change in protection will start at lower currents.

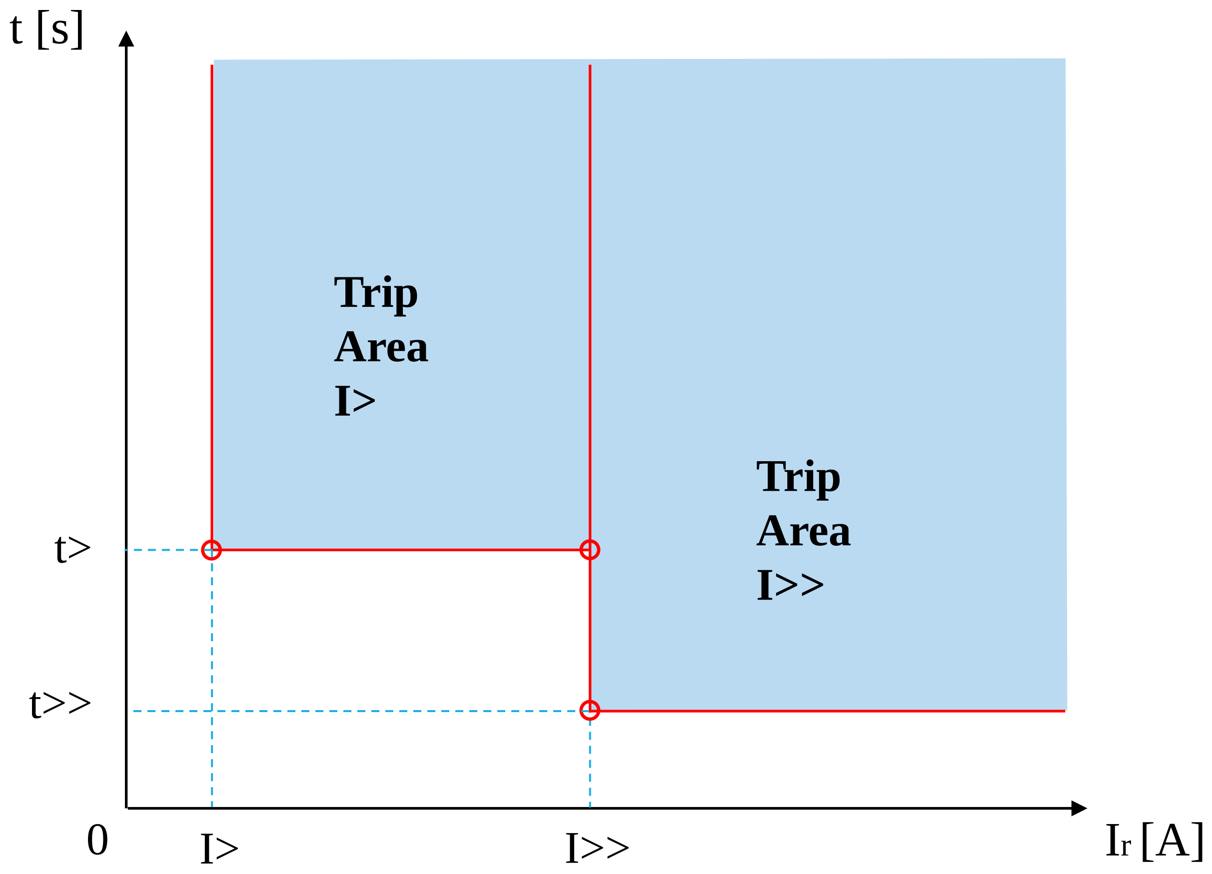
Setting of overcurrent protections

The three-phase short-circuit current is usually the largest. In the event of a short circuit in the vicinity of a transformer with a grounded node or a grounding transformer, the single-phase short-circuit current may be greater than the three-phase. This is especially true for transformers with Yz, Dy, and Dz connections to ground the winding y or z on the lower voltage side of the transformer. For this reason, a two-phase short-circuit current is considered when calculating the starting short-circuit currents.

Since electrical devices are rated for the highest short-circuit current, in most cases it is just a three-phase short-circuit current. Unlike overhead lines, cable lines have almost three-phase shorts in almost all cases, with the arc breaking the insulation of all three phases. Two-phase short-circuits on the lines can cause increased stress for single-phase transformers that are connected to three-phase busbars.

Characteristics of overcurrent relays

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



Overcurrent protection relay

1. The 2 × 16 character LCD provides navigation, relay control, data, and diagnostics via default messages or up to 32 customizable display messages

2. Programmable front-panel LEDs with user-configurable labels alert operators to faulted phases and element operation

3. Programmable operator pushbuttons with user-configurable labels allow front-panel customization

Overcurrent protection relay

1. The 5-inch, 800 × 480 display offers direct navigation via a capacitive touchscreen
2. Folders and applications provide quick access to bay screens, metering and monitoring data, reports, settings, and more
3. The home pushbutton allows you to easily return to the default home screen
4. Programmable front-panel LEDs with user-configurable labels alert operators to faulted phases and element operation
5. Programmable operator pushbuttons with user-configurable labels allow front-panel customization

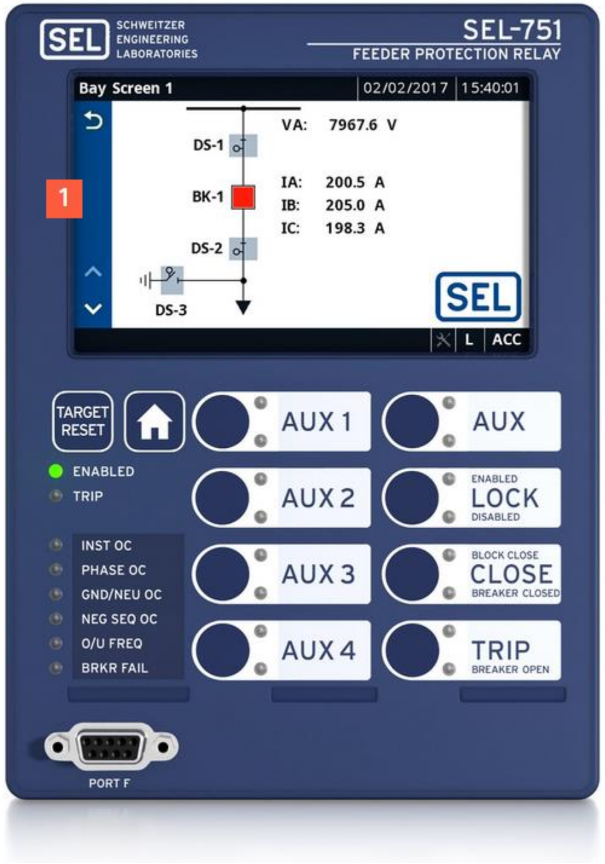
Overcurrent protection relay

1 **Outlet diagram and element control**

Choose from predefined wiring diagrams or configure up to five custom wiring diagrams using the acSELerator® Bay Screen Builder SEL-5036 software and the acSELerator QuickSet® SEL-5030 software.

You can control one circuit breaker, eight two-position disconnectors, and two three-position disconnectors, as well as analog and digital data on the context display.

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



Overcurrent protection relay

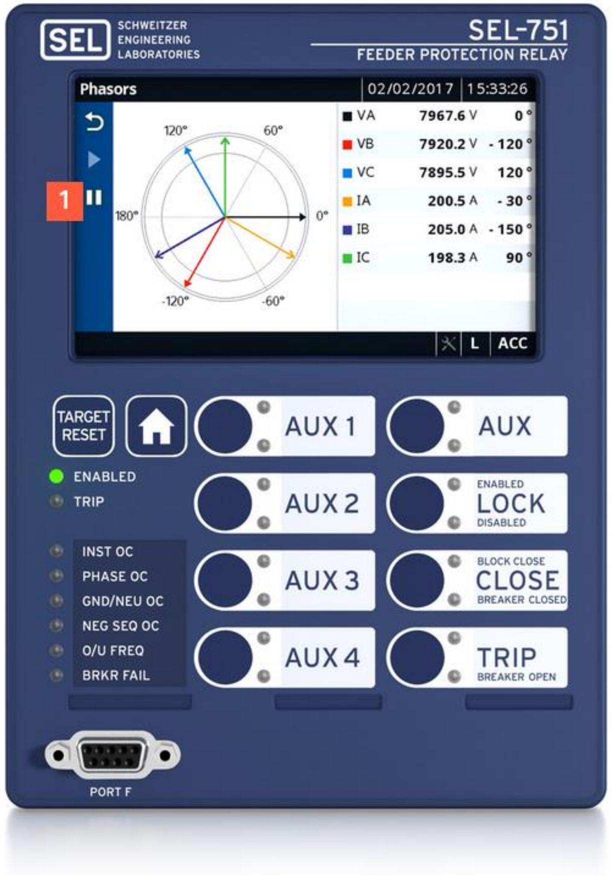
1 Basic measurement

It shows the real, reactive and apparent power of each phase in the system, as well as power factor information to see if the phase current is ahead or lagging the phase voltage.

Overcurrent protection relay

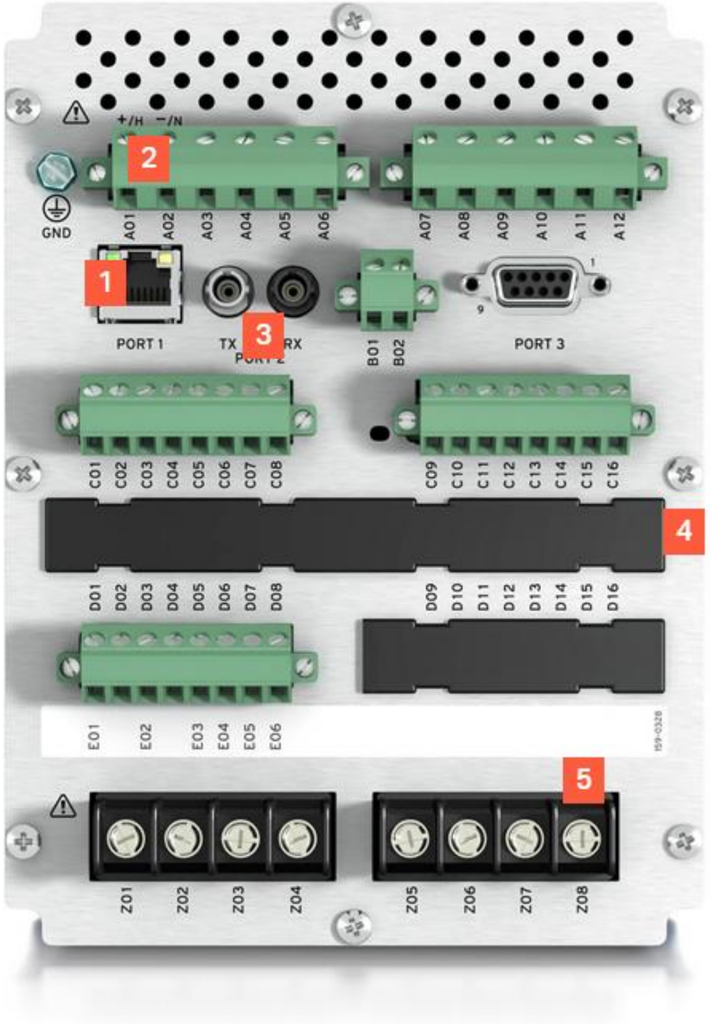
1 **Display of measured phasors**

Display of graphical and textual representation of voltages and currents in the power system in real-time during balanced and unbalanced conditions.

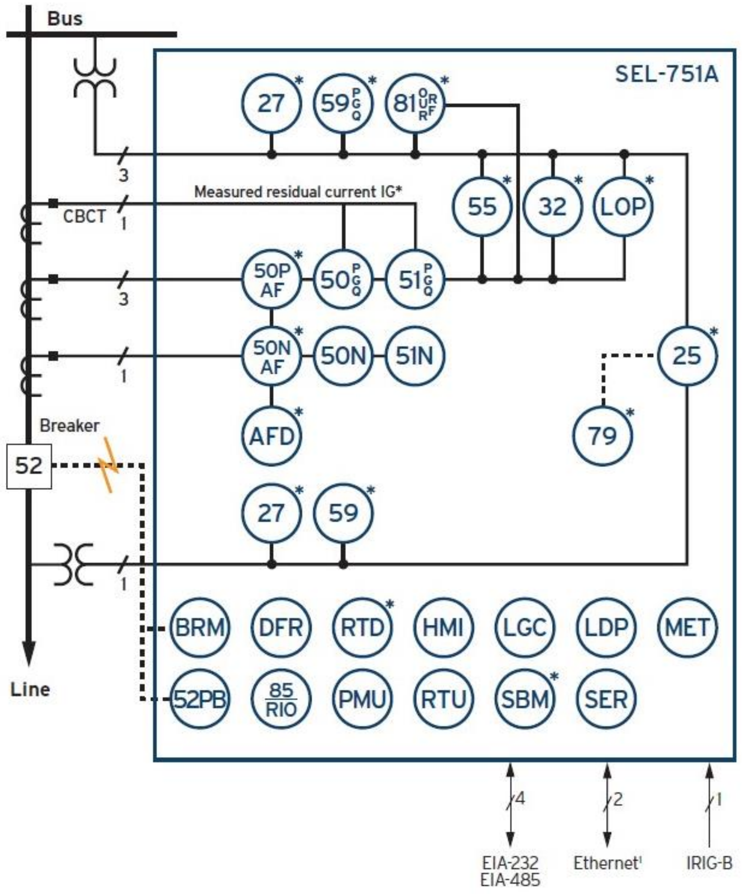


Overcurrent protection relay

1. A wide variety of communications protocols and media provide flexibility to communicate with other devices and control systems
2. Power supply options include 24–48 Vdc or 110–250 Vdc/110–240 Vac
3. The optional fiber-optic serial port provides quick and easy engineering access
4. Card slots include positions for optional I/O, a voltage input card, or an arc-flash detection card with sensors that help improve safety and prevent damage
5. Phase current and optional phase voltage inputs are on one card, freeing up space for additional SELECT™ I/O card options



Overcurrent protection relay

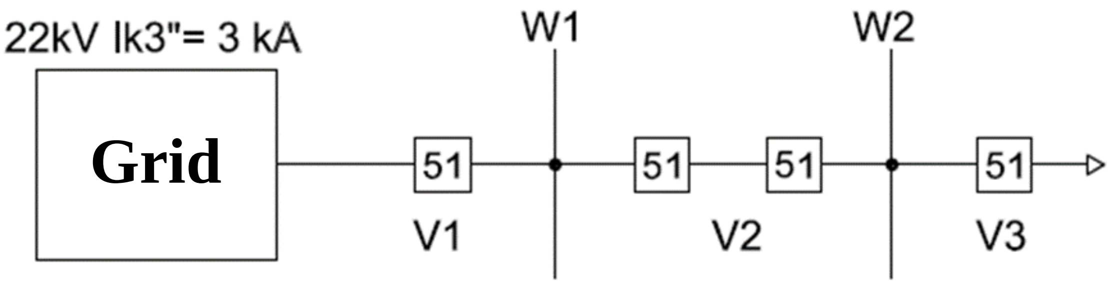


Tab. 1 Terminal protection functions SEL-751A

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 relay selective tripping



Schema parameters:

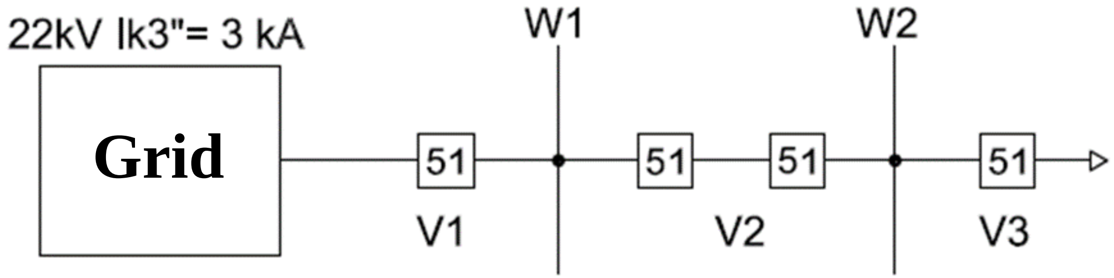
V1: 240 AlFe R_{M1} = 0.121Ω/km, X_{M1} = 0.392Ω/km, I_N = 579A, l = 5km

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

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

Used CT = 600A/5A; we are considering an 80% load on the line.

Overcurrent protection relay selective tripping



Calculated parameters:

End of the line V3

Zk1_V3 = (1.6503 + 7.7727i) Ω; Ik2_V3 = 1.3843kA

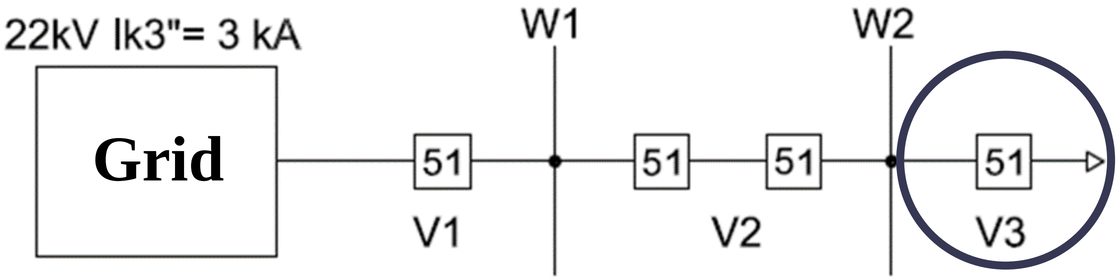
Bus W2

Zk1_V2 = (1.4943 + 7.3727i) Ω; Ik2_V2 = 1.4623kA

Bus W1

Zk1_V1 = (1.0263 + 6.1727i) Ω; Ik2_V1 = 1.7579kA

Overcurrent protection relay selective tripping



Calculated parameters:

End of the line V3

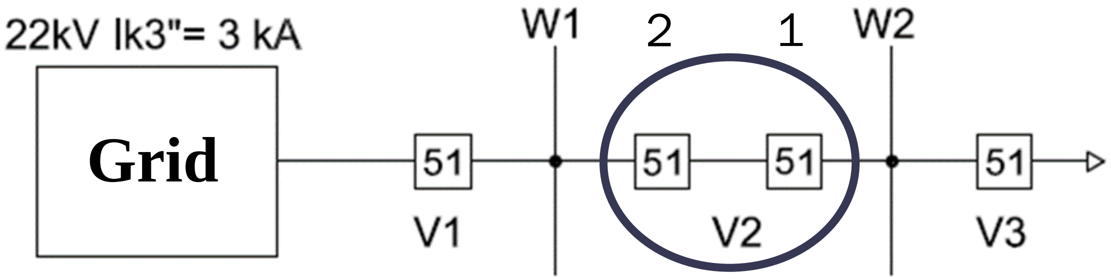
I> = 3.7516A ≤ IR> = 4A;

I>> = 7.6908A ≥ IR>> = 6A > IR> = 4A

t> = 0.35s

t>> = 0.1s

Overcurrent protection relay selective tripping



IR> = 4A;
t> = 0.35s
IR>> = 6A;
t>> = 0.1s

Calculated parameters:

Bus W2

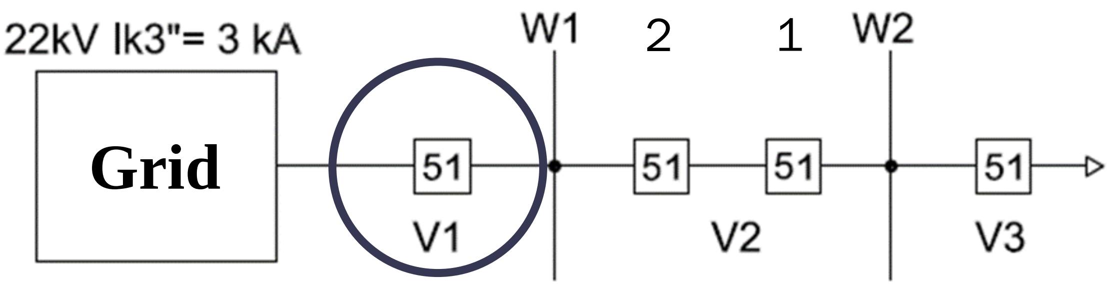
I> = 4A < IR> = 5A & 6A

I>> = 8.1236A ≥ IR2>> = 8A > IR1> = 7A

t1> = 0.55s; t2> = 0.75s; t2> > t1>

t1>> = 0.15s; t2>> = 0.2s; t2>> > t1>>

Overcurrent protection relay selective tripping



IR1> = 5A;
IR2> = 6A
t1> = 0.55s
t2> = 0.75s
IR1>> = 7A;
IR2>> = 8A;
t1>> = 0.15s
t2>> = 0.2s

IR> = 4A;
t> = 0.35s
IR>> = 6A;
t>> = 0.1s

Calculated parameters:

Bus W1

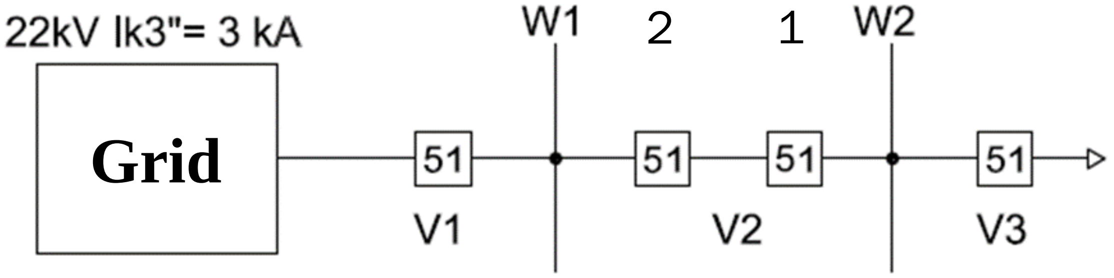
I> = 6A < IR> = 7A

I>> = 9.7661A ≥ IR3>> = 9A > IR2> = 8A

t3> = 0.95s; t3> > t2>

t3>> = 0.25s; t3>> > t2>>

Overcurrent protection relay selective tripping

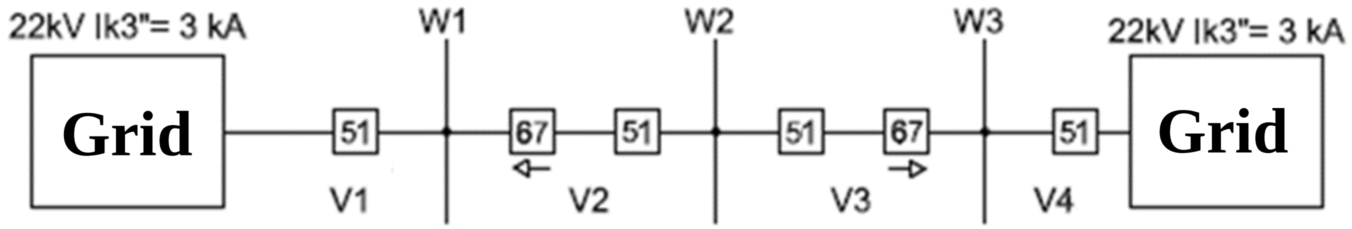


IR> = 7A;
t> = 0.95s
IR>> = 9A;
t>> = 0.25s

IR1> = 5A;
IR2> = 6A
t1> = 0.55s
t2> = 0.75s
IR1>> = 7A;
IR2>> = 8A;
t1>> = 0.15s
t2>> = 0.2s

IR> = 4A;
t> = 0.35s
IR>> = 6A;
t>> = 0.1s

Overcurrent protection relay selective tripping



Schema parameters:

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

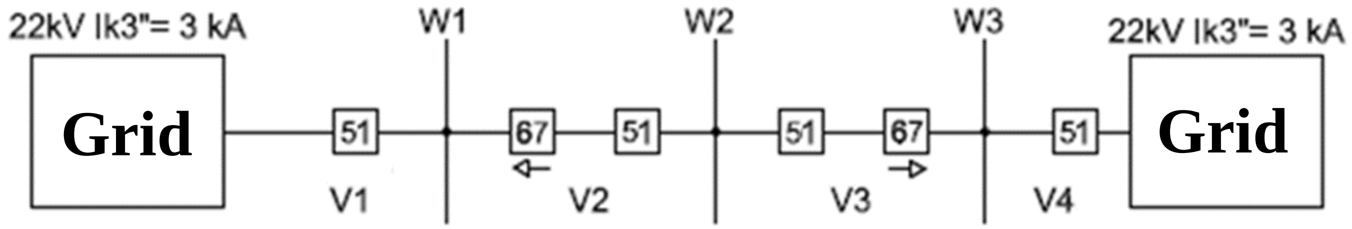
V2: 185 AlFe R_{M1} = 0.156Ω/km, X_{M1} = 0.4Ω/km, I_N = 486A, l = 3km

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

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

Used CT = 600A/5A; we are considering an 80% load on the line.

Overcurrent protection relay selective tripping



Calculated parameters:

Bus W1

Zk1_w1_right = (1.6503 + 7.7727i) Ω; Ik2_W1_right = 1.3843kA

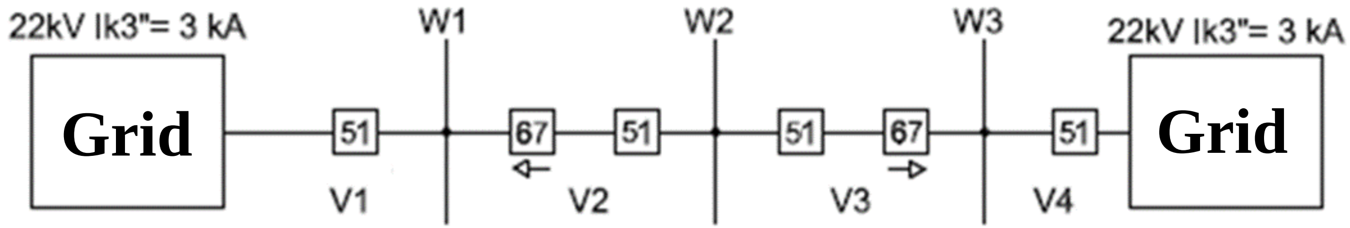
Zk1_w1_left = (1.0263 + 6.1727i) Ω; Ik2_W1_left = 1.7579kA

Bus W2

Zk1_w2_right = (1.1823 + 6.5727i) Ω; Ik2_W2_right = 1.6471kA

Zk1_w2_left = (1.4943 + 7.3727i) Ω; Ik2_W2_left = 1.4623kA

Overcurrent protection relay selective tripping



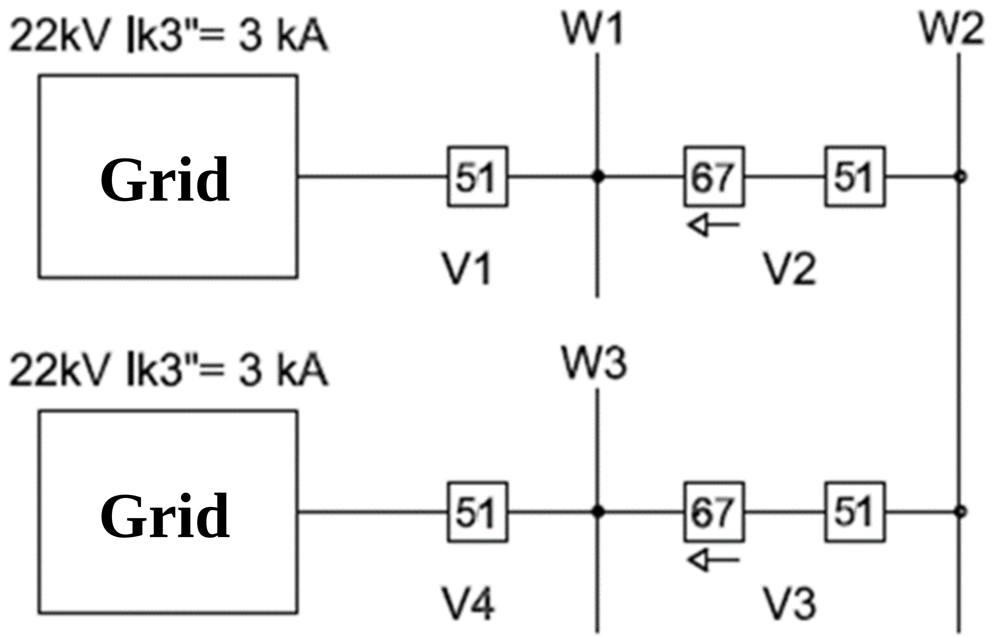
Calculated parameters:

Bus W3

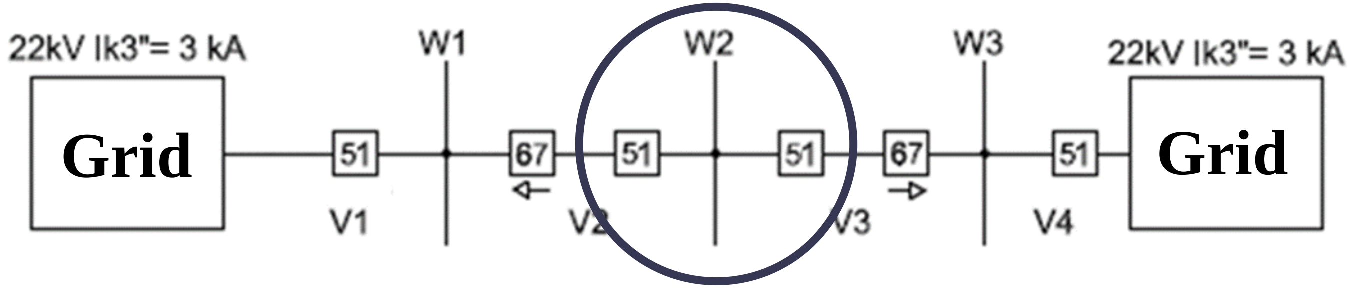
Zk1_w1_right = (1.0263 + 6.1727i) Ω; Ik2_W1_right = 1.7579kA

Zk1_w1_left = (1.6503 + 7.7727i) Ω; Ik2_W1_left = 1.3843kA

Overcurrent protection relay selective tripping



Overcurrent protection relay selective tripping



Calculated parameters:

W2_left

I>= 3.7516A ≤ IR> = 4A;

I>> = 8.1236A ≥ IR>> = 6A > IR> = 4A

t> = 0.35s

t>> = 0.1s

Calculated parameters:

W2_right

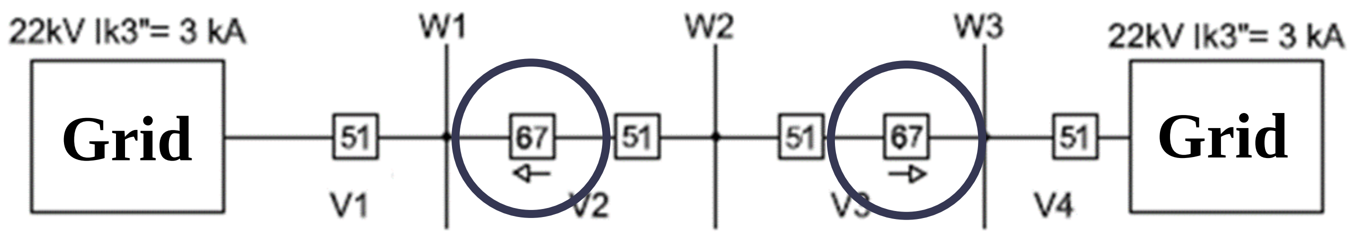
I>= 3.7516A ≤ IR> = 4A;

I>> = 9.1508A ≥ IR>> = 6A > IR> = 4A

t> = 0.35s

t>> = 0.1s

Overcurrent protection relay selective tripping



Calculated parameters:

W1_right

I>> = 7.6908A ≥ IR>> = 7A > IR_W2> = 6A

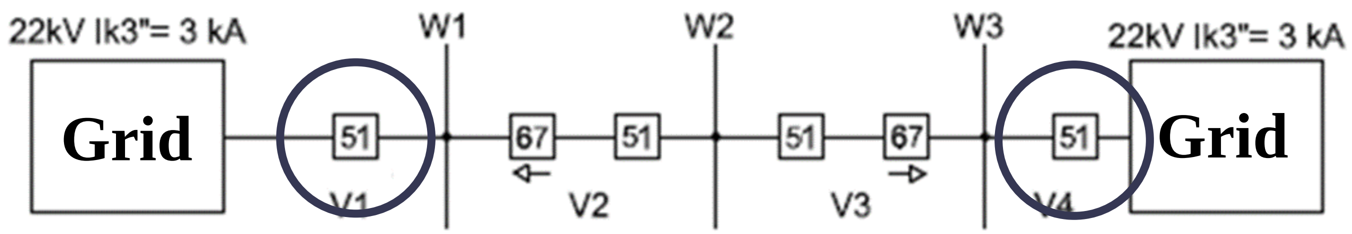
t>> = 0s

W3_left

I>> = 7.6908A ≥ IR>> = 7A > IR_W2> = 6A

t>> = 0s

Overcurrent protection relay selective tripping



Calculated parameters:

W1_left

I>= 4.4695A ≤ IR> = 5A;

I>> = 9.7661A ≥ IR>> = 8A > IR> = 6A

t> = 0.55s

t>> = 0.2s

Calculated parameters:

W3_right

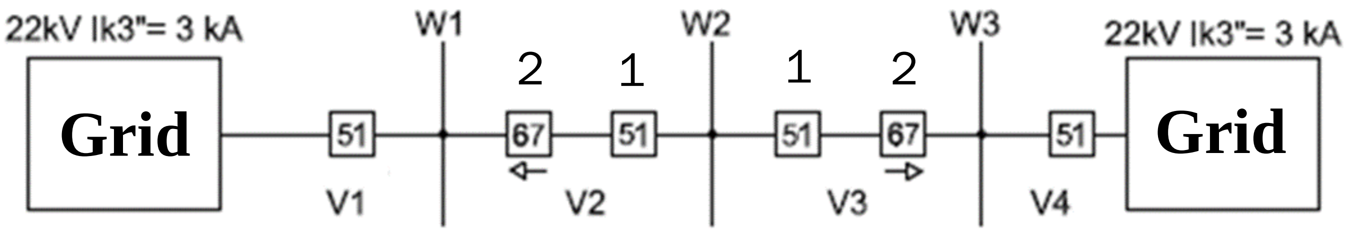
I>= 4.4695A ≤ IR> = 5A;

I>> = 9.7661A ≥ IR>> = 8A > IR> = 6A

t> = 0.55s

t>> = 0.2s

Overcurrent protection relay selective tripping



IR> = 5A;
t> = 0.55s
IR>> = 8A;
t>> = 0.2s

IR1> = 4A;
t1> = 0.35s
IR1>> = 6A;
IR2>> = 7A;
t1>> = 0.1s
t2>> = 0s

IR1> = 4A;
t1> = 0.35s
IR1>> = 6A;
IR2>> = 7A;
t1>> = 0.1s
t2>> = 0s

IR> = 5A;
t> = 0.55s
IR>> = 8A;
t>> = 0.2s

Theory of protections - differential protections

Theory of protections - differential protections

<u>Comparative protections</u> - they work on the principle of comparing measured physical quantities at the input and output of a protected section or object. From the name of the group of protections itself, this is a comparison of two measured quantities from two places, usually measured at the beginning and end of the protected section or object.

For comparators otherwise called differential protections to compare these quantities between input and output, they must be connected by an auxiliary line. This type of connection is a typical feature of given protection. If the protected section or object inside this section is fault-free, the values of the comparison quantities are the same. At different comparison values, the protection evaluates whether the fault is inside the protected area and gives an impulse to switch off in the event of an internal fault. ***Comparative protections only monitor their protected object or section, they do not need to adapt in time to other protections and belong to the basic quick protections.***

The purpose of differential protection is to protect electrical machines sensitively and selectively. The most common are transformers, generators, or large motors.

Differential line protections are now commonly used. Differential protections are quite often used to protect alternators, both rotor and stator protection. Differential protections are connected before and after the winding. For this reason, it is necessary for the generator to have a stator winding a node connected.

The calculation of operating characteristics is based on measurement errors that affect the individual deviations of the unique devices used. Therefore, it is necessary to have information about all used devices i.e., complete information about the operation and parameters of all used devices.

The similar principles apply to each instrument current transformer as to a conventional transformer, with deviations in the linear range being at least depending on the type of CT. The error rate increases significantly mainly in the saturation range when the deviations of the measurement inaccuracy are high. Compensation for such errors is calculated as the sum of all fault factors.

Calculation of the total error current:

$$I_{d2} = CT_{error} + excitation\ current + TR_{error} + safety\ margin + relay\ errors \quad (4)$$

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

Calculation of the first slope setting:

$$SLP_1 = CT_{error} + excitation\ current + TR_{error} + safety\ margin + relay\ errors \quad (5)$$

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

Calculation of the 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 by doubling the first.

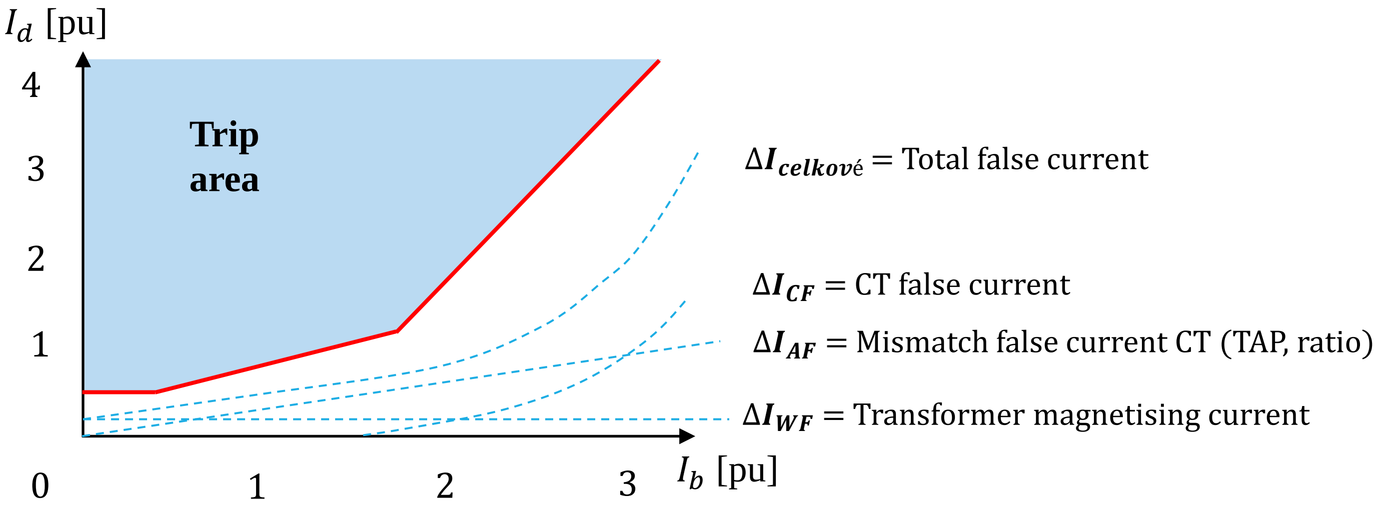


Fig. 4 Characteristics of the effect of differential protection

The remaining missing points are calculated according to the relationship:

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

The CT TAP compensation factor is calculated according to the relationship:

$$TAP = \frac{S * 1000}{\sqrt{3} * U_{L-L}} * CT = \frac{10{,}5 * 1000}{\sqrt{3} * 11} * \frac{5}{600} = 4.592 \qquad (8)$$

Checks for correct CT sizing are calculated according to the relationship:

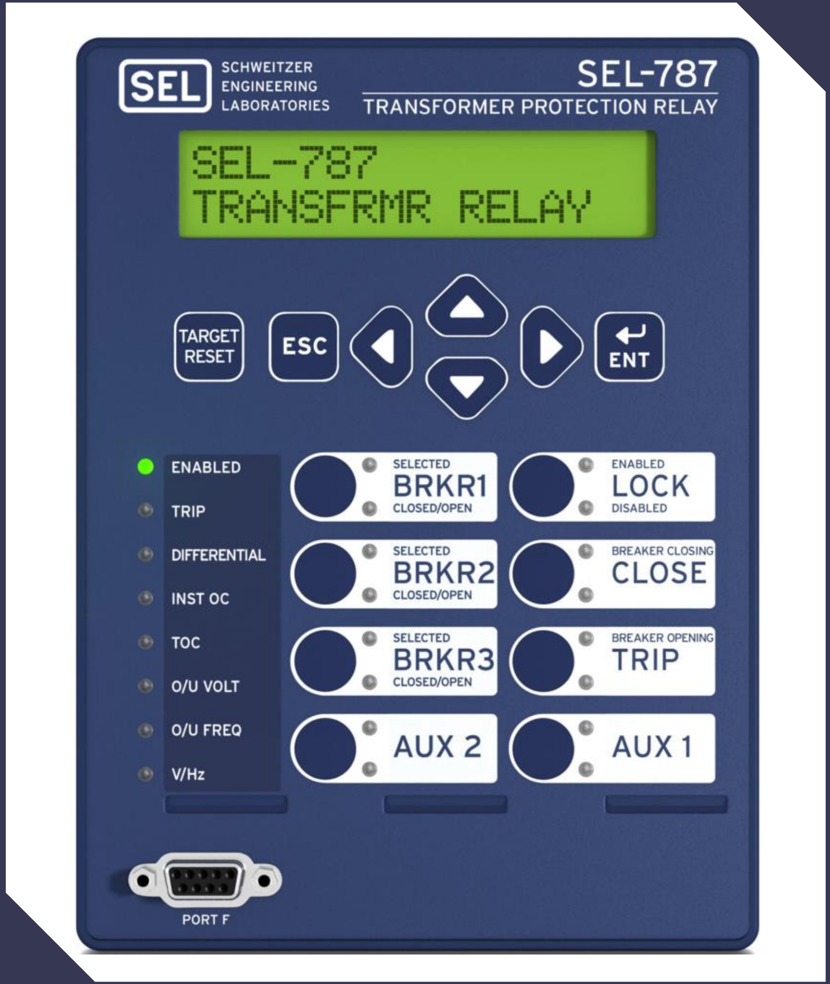
$$\frac{TAP_{max}}{TAP_{min}} \leq 7.5 \qquad (9)$$

Differential protection relays

1 LEDs on the front panel alert the operator to a fault and basic operations.

2 2*16-character LCD display provides navigation, relay control, data, and diagnostics via preset messages or up to 32 customizable messages on the display

3 Differential protection control buttons



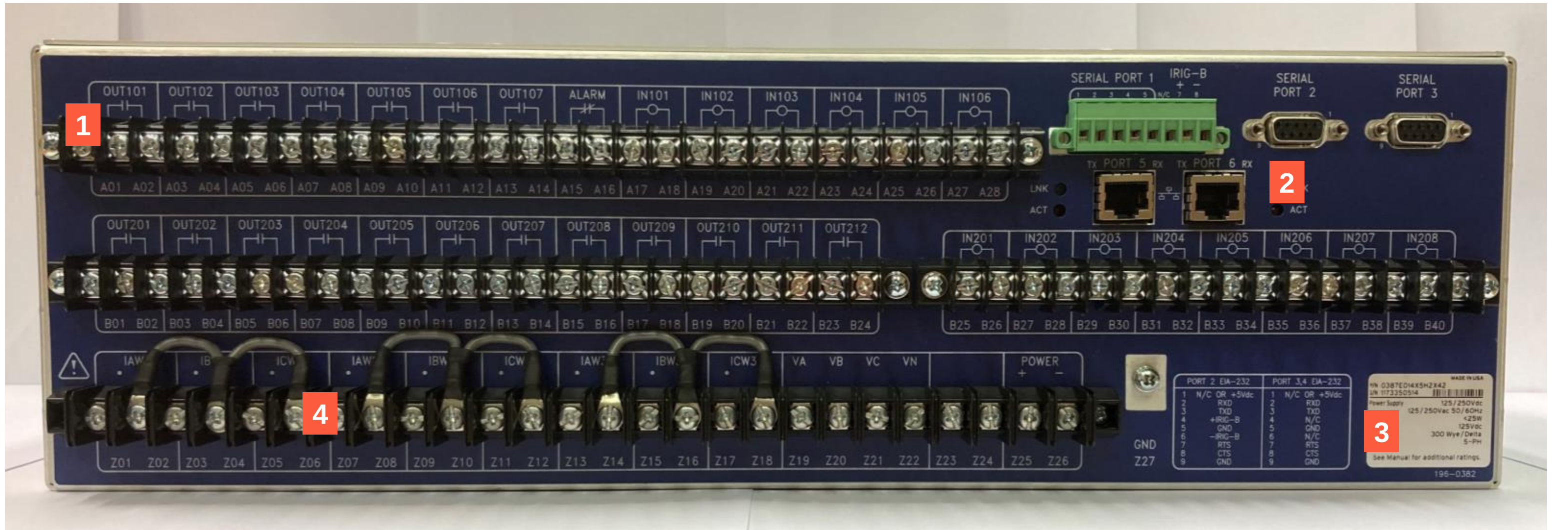
Differential protection relays

1 Card slots contain slots for inputs/outputs

2 Wide range of communication protocols and media provides flexibility in communicating with other devices and control systems.

3 A label indicating the permitted supply voltage for the differential relay

4 Voltage and current input card slots



Theory of protections - differential protections

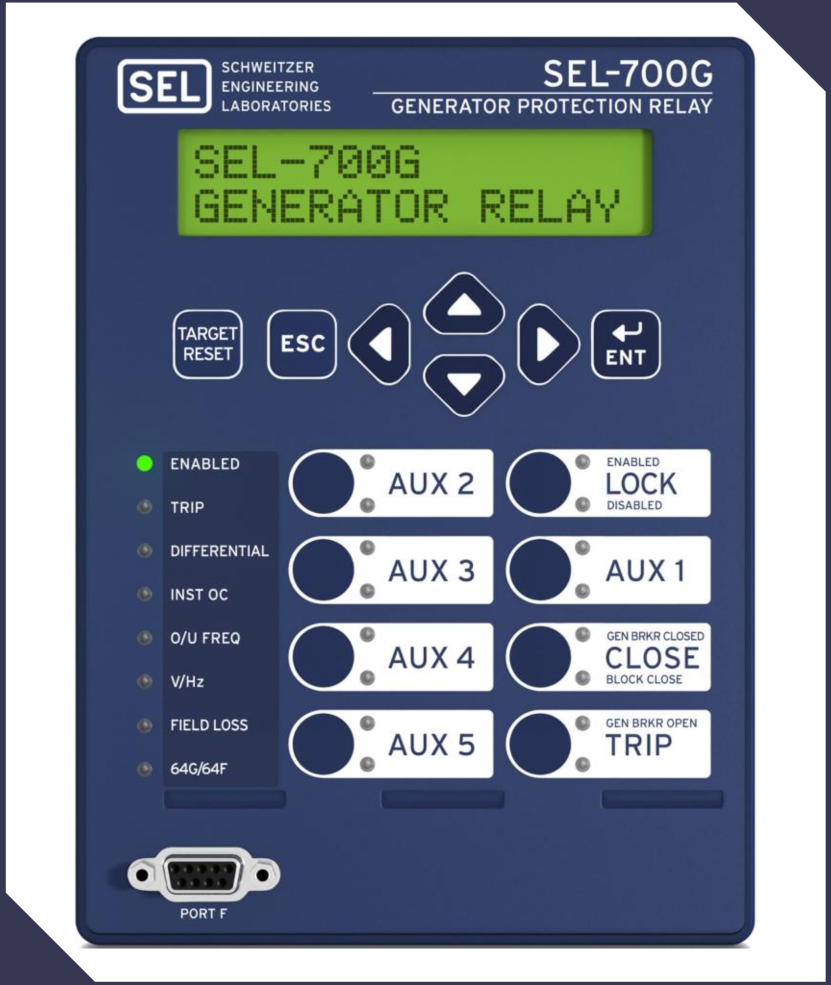
Factors affecting CT saturation:

- ***Residual magnetism in the CT core***
- ***Mismatch of CT characteristics***
- ***CT circuit overload***

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

Specify the end of the first slope and the beginning of the second slope in the operating characteristic.

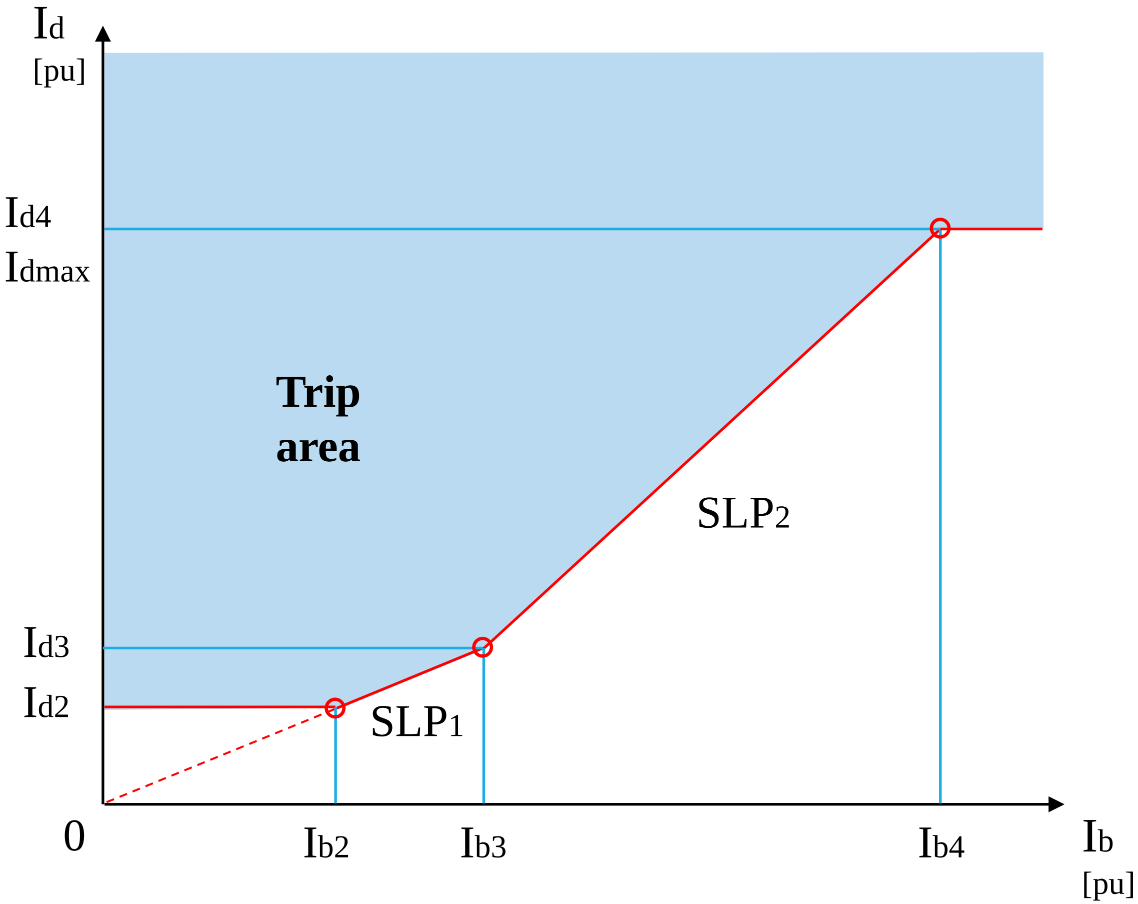
The upper limit of the differential current I_{dmax} is selected in the range of 8 to 10.



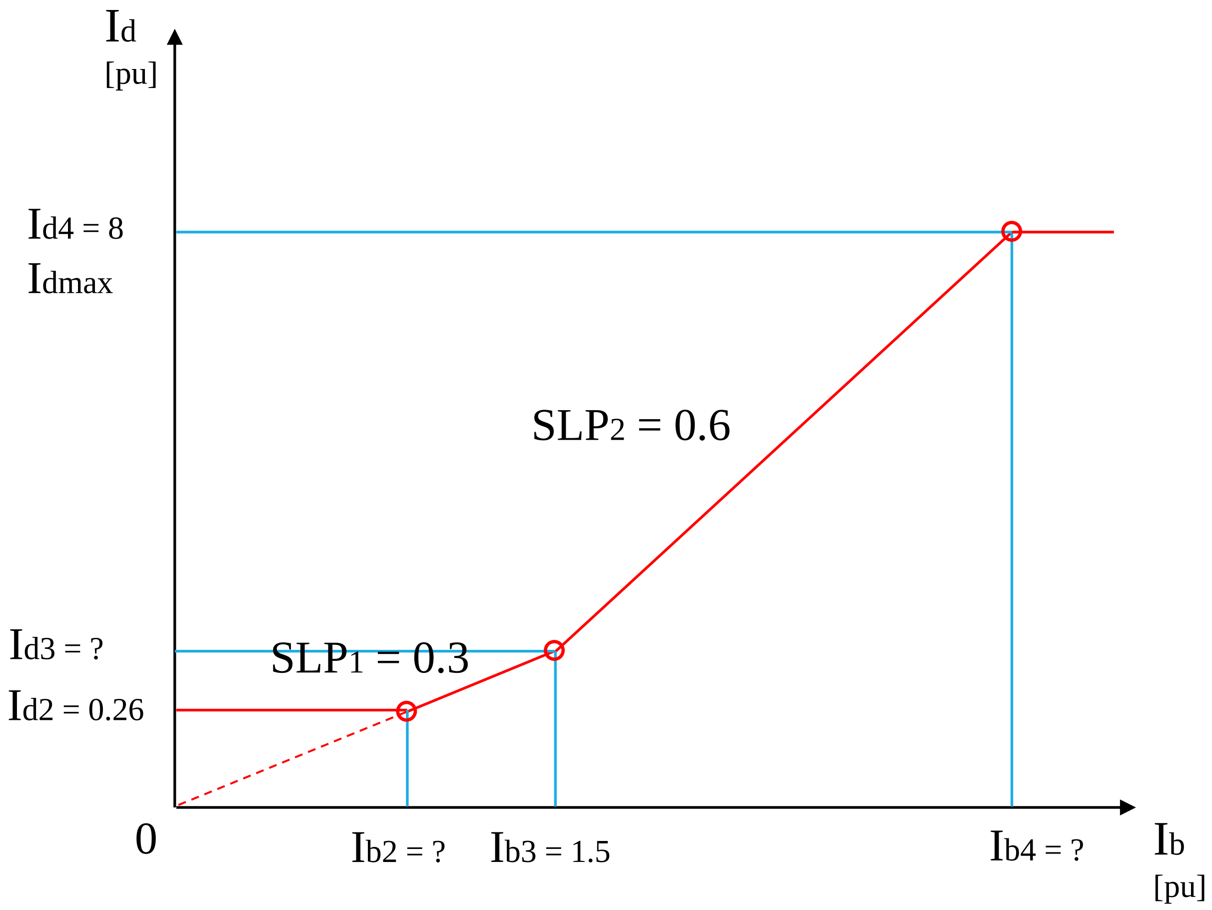
Differential protection characteristics

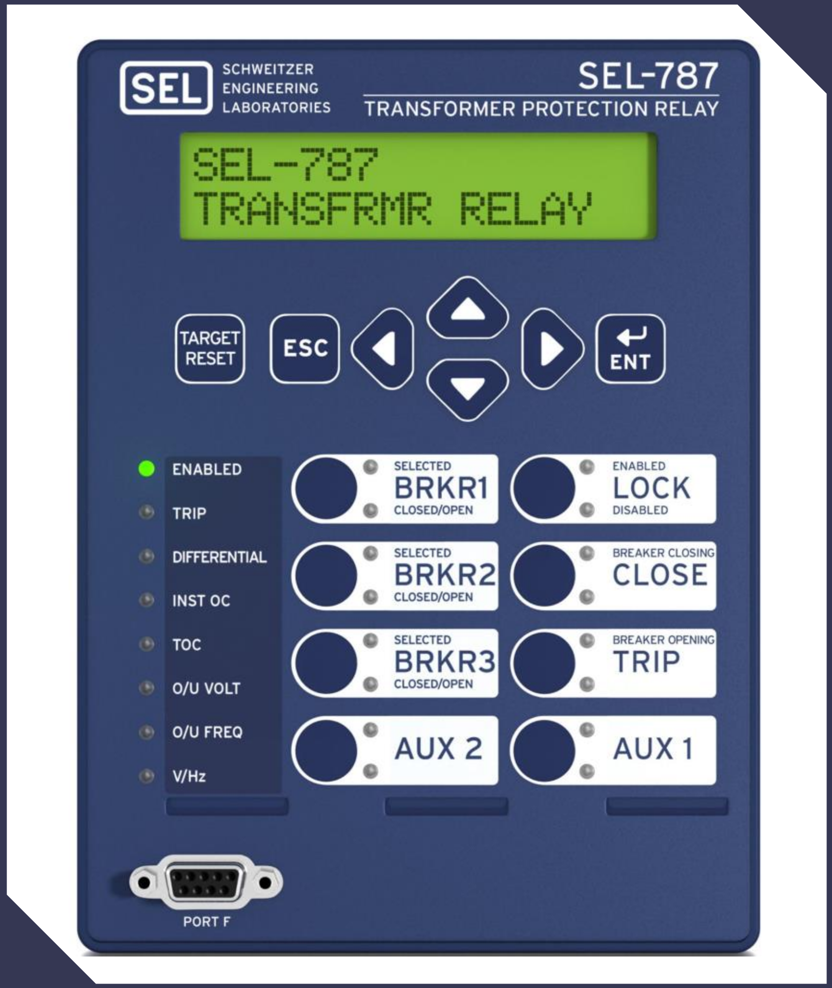
I_{s*} – *CT secondary side current*

$$I_d = |\overline{I_{1s*}} * TAP + \overline{I_{2s*}} * TAP| \quad (9) \qquad I_b = \frac{|\overline{I_{1s*}} * TAP| + |\overline{I_{2s*}} * TAP|}{2} \quad (10)$$



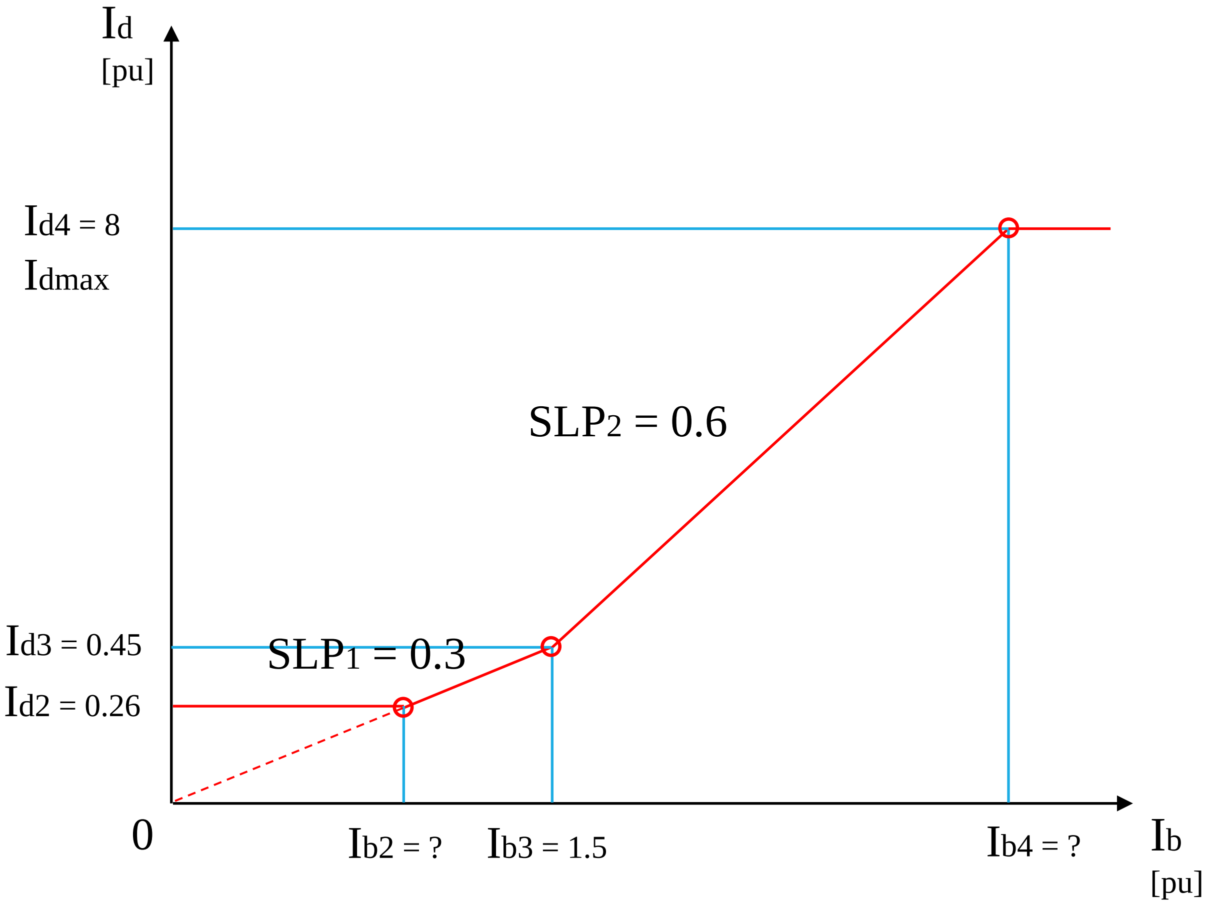
Differential protection characteristics





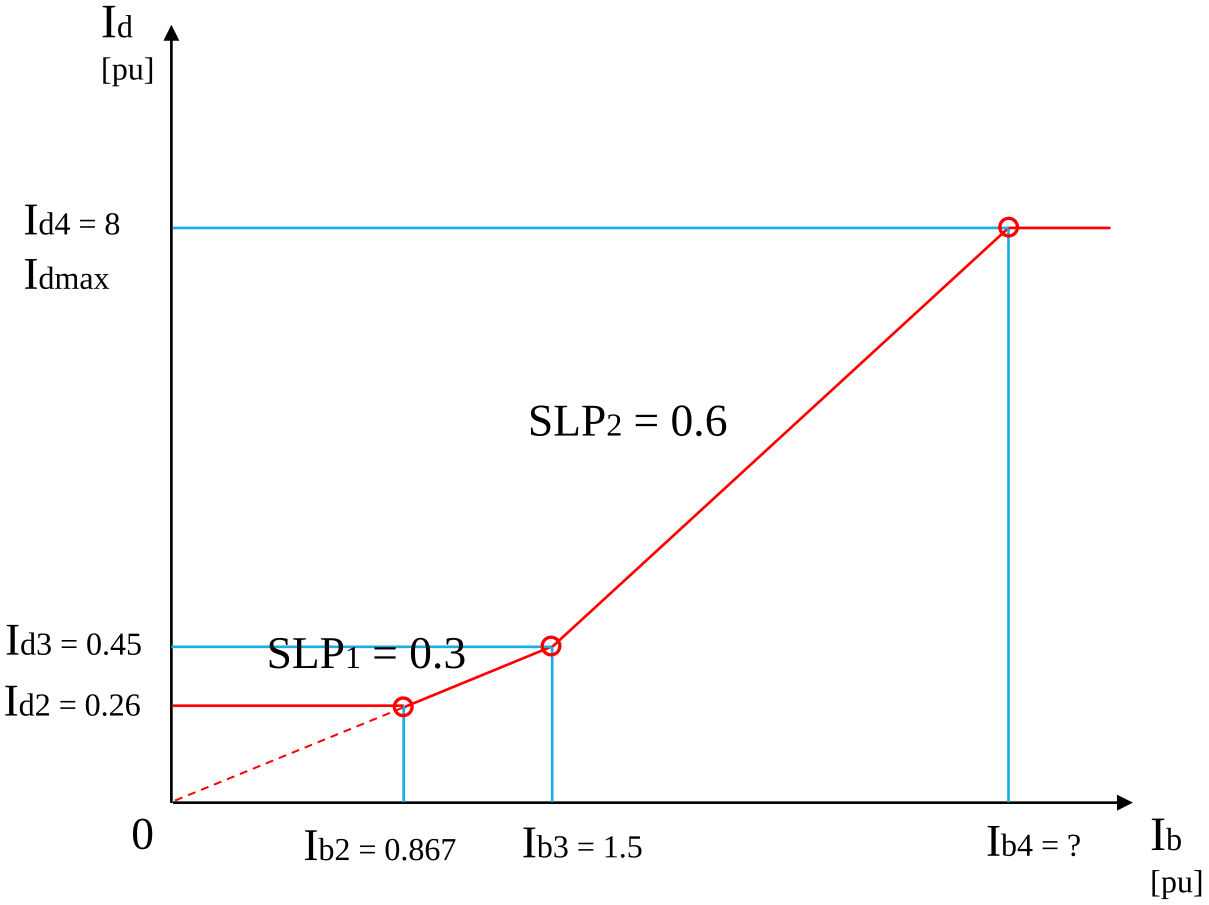
Differential protection characteristics

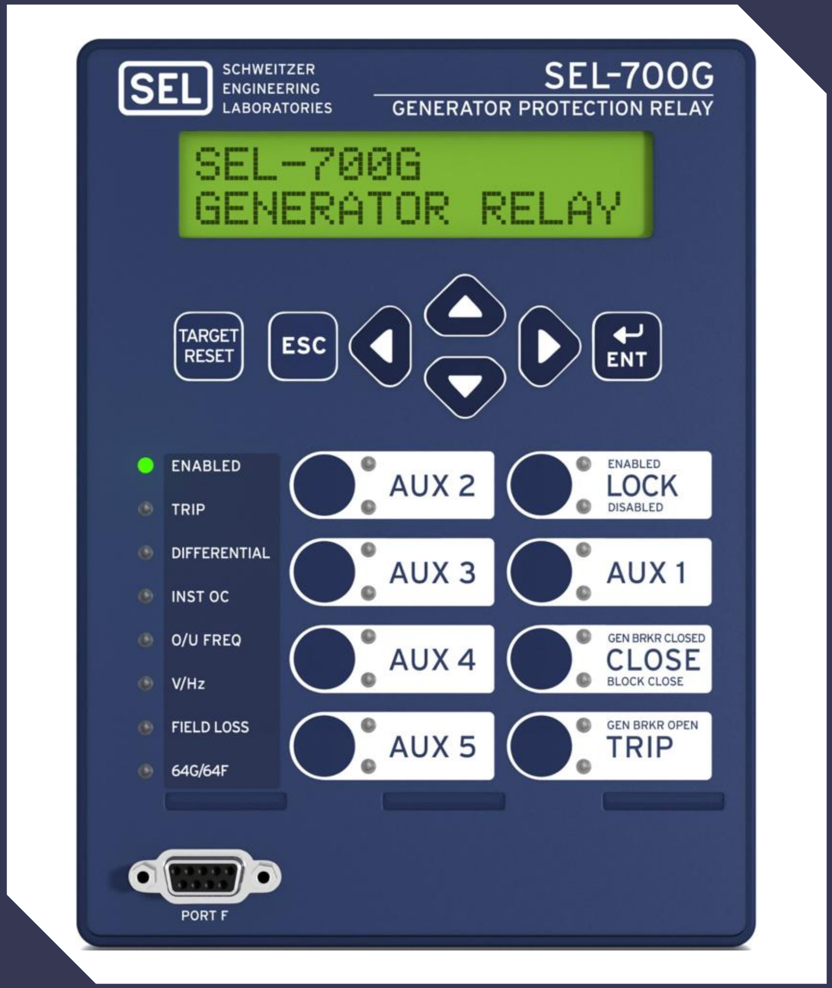
$$0.3 = \frac{I_{d3}-0}{1.5-0} \Rightarrow I_{d3} = 0.3*1.5 = 0.45$$



Differential protection characteristics

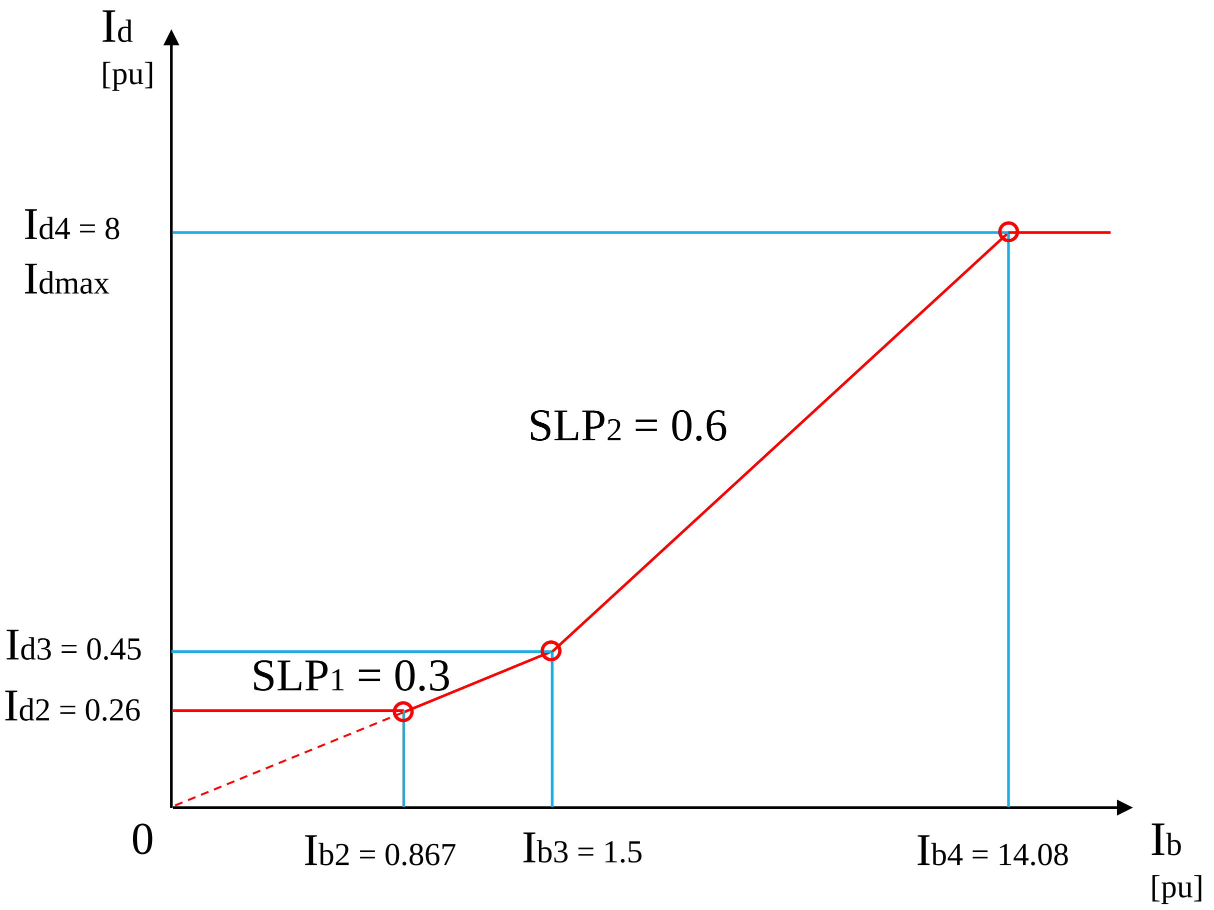
$$0.3 = \frac{0.45-0.26}{1.5-I_{b2}} \Rightarrow I_{d2} = (0.45\text{-}0.19)/0.3 = 0.867$$



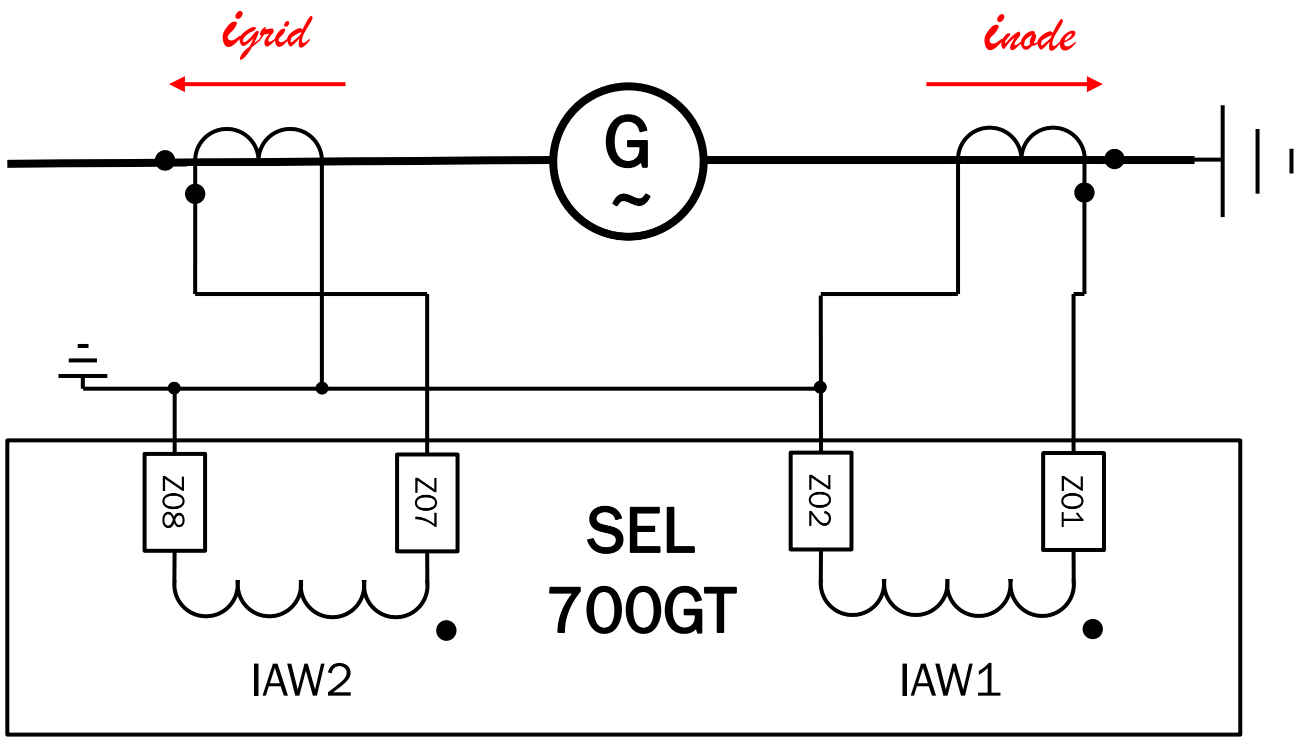


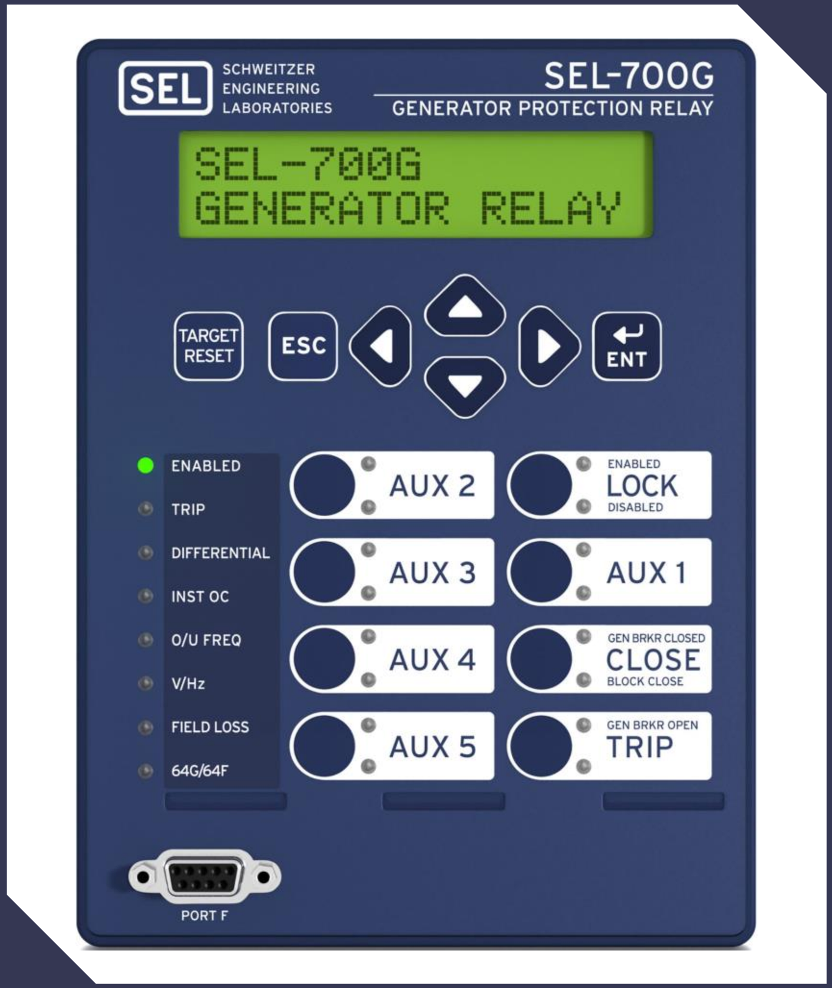
Differential protection characteristics

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



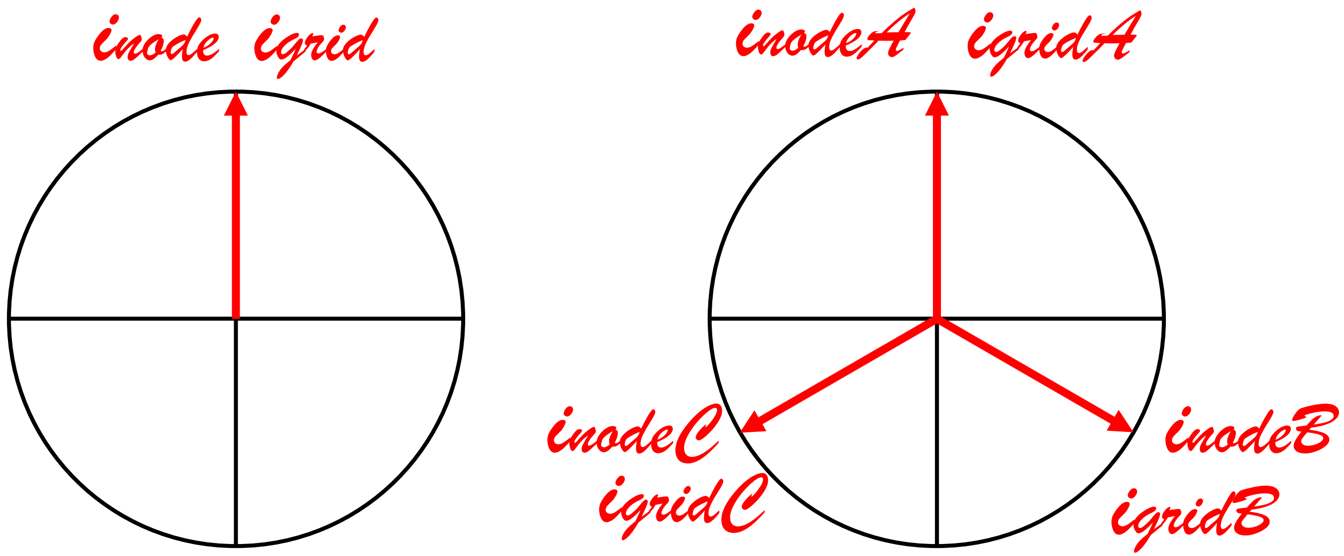
Differential protection of the generator





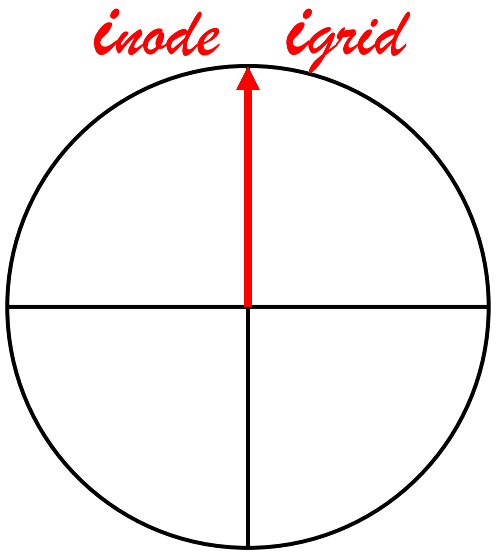
Differential protection of the generator

Vector representation of G currents

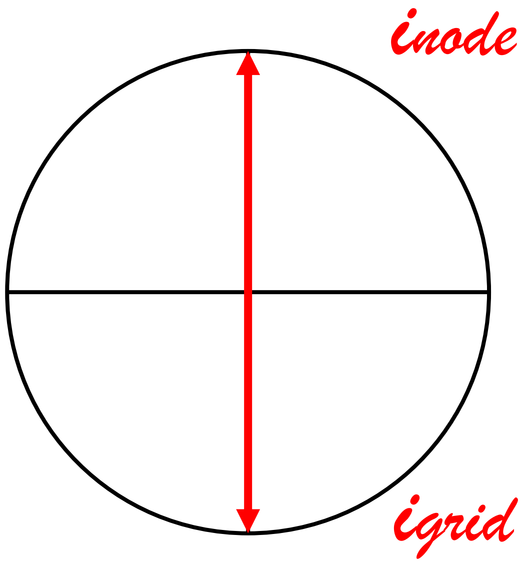


Differential protection of the generator

QuickCMC test

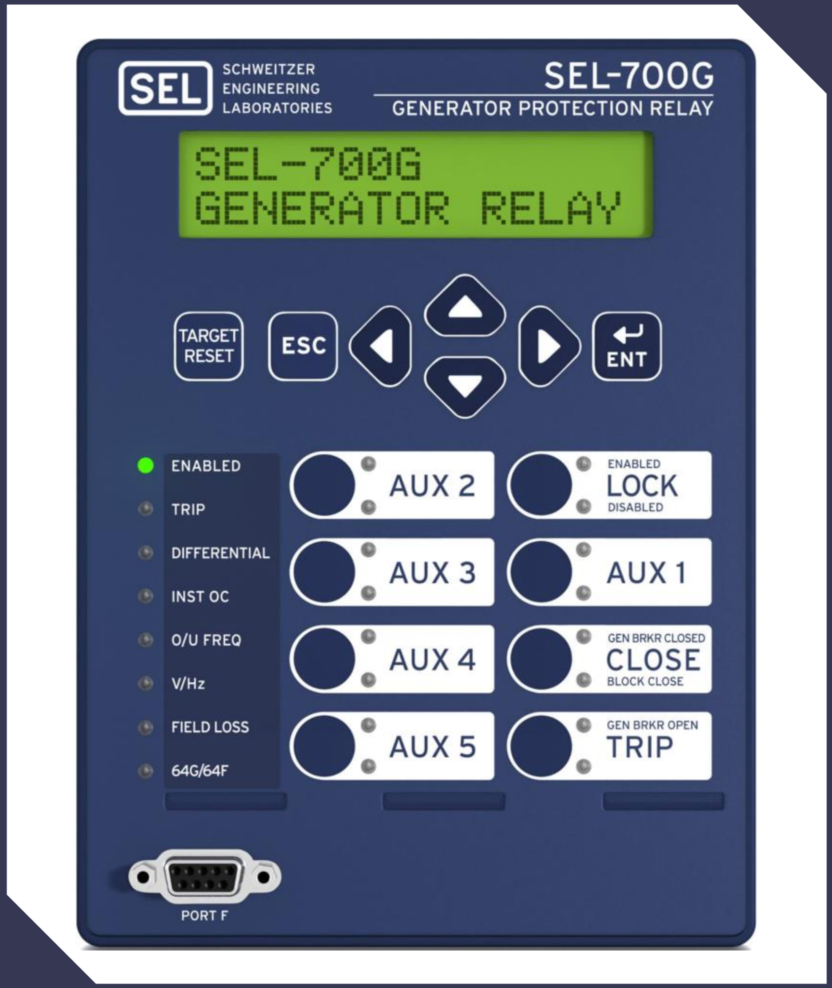


Stability test

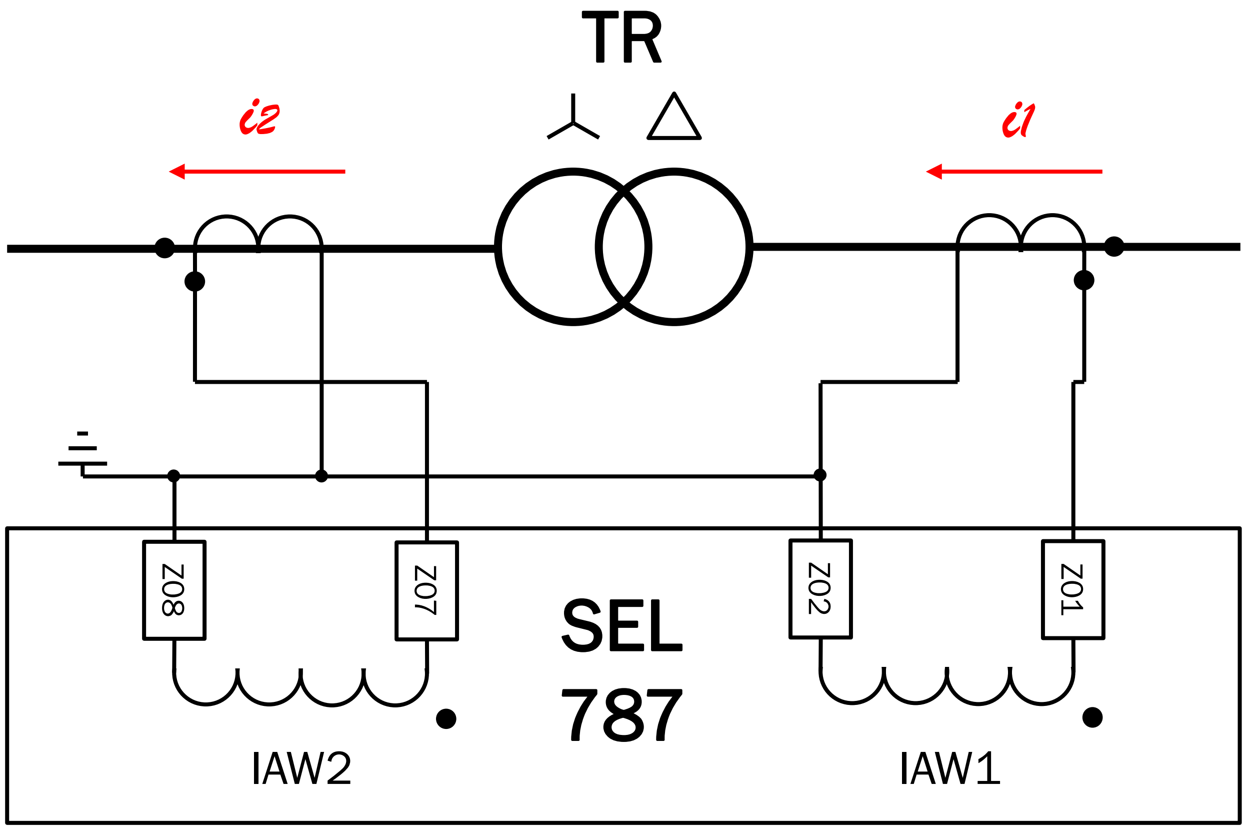


Instability test

The angle of the vector depends on the connection of the test device to the protection and on the device itself.

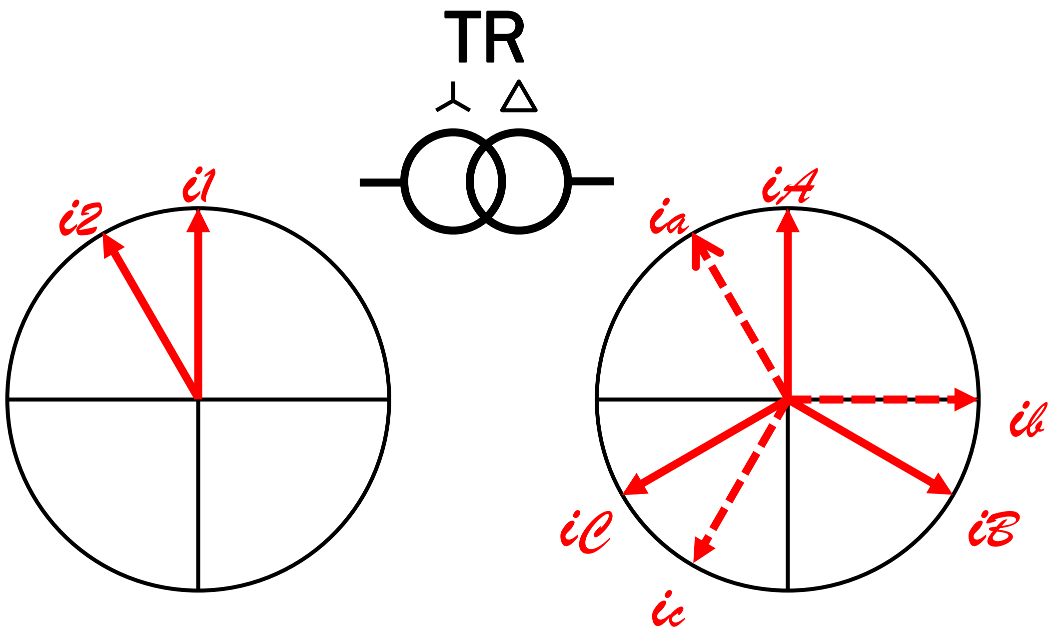


Differential protection of the transformer

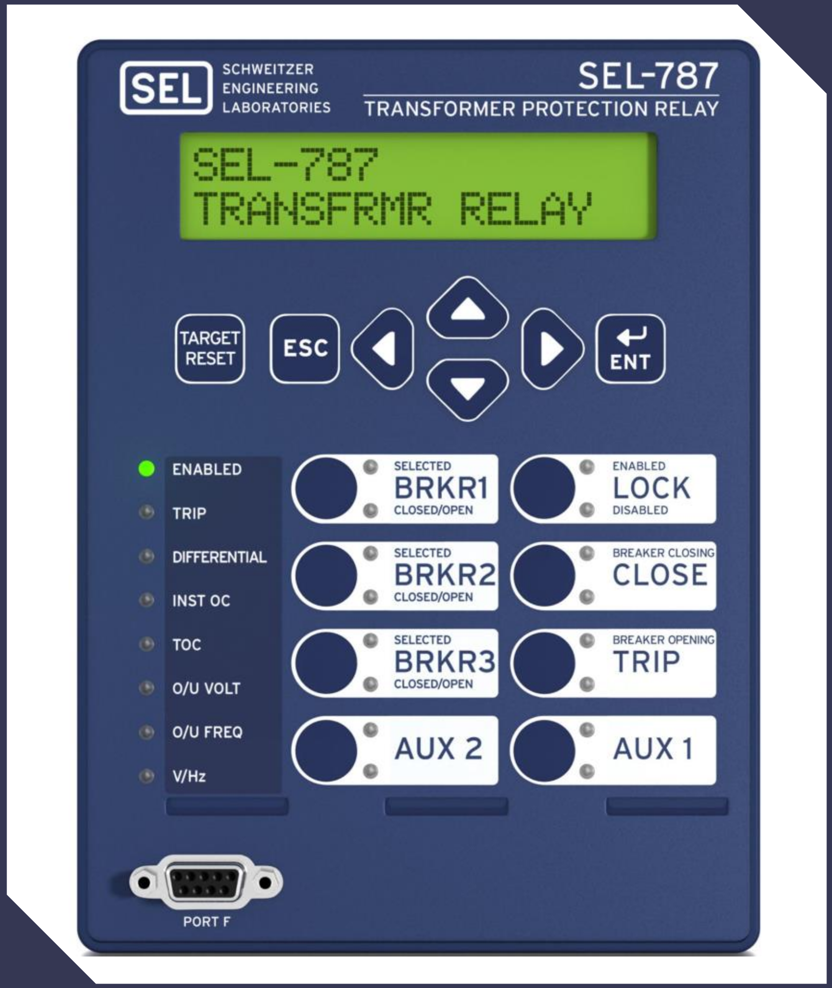


Differential protection of the transformer

Vector representation of TR currents

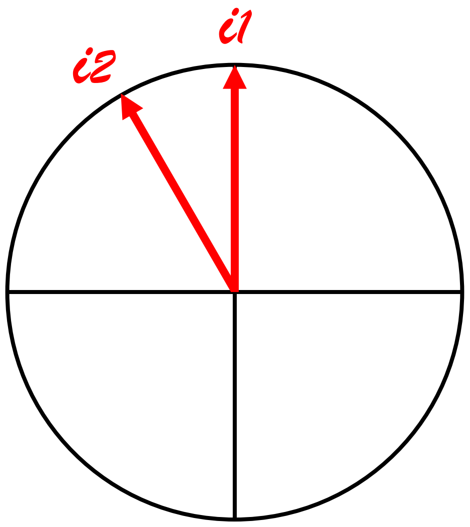


Dyn11 transformer clock angle

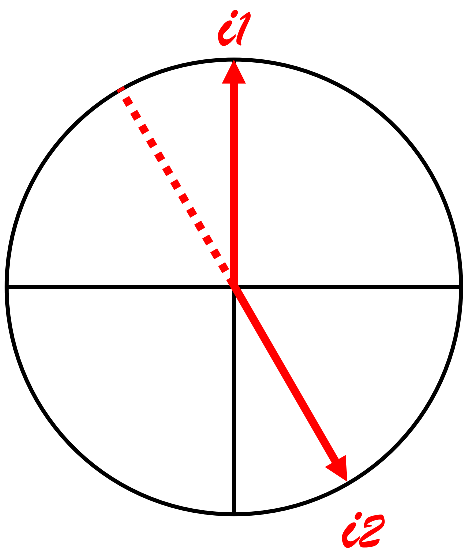


Differential protection of the transformer

QuickCMC test



Instability test

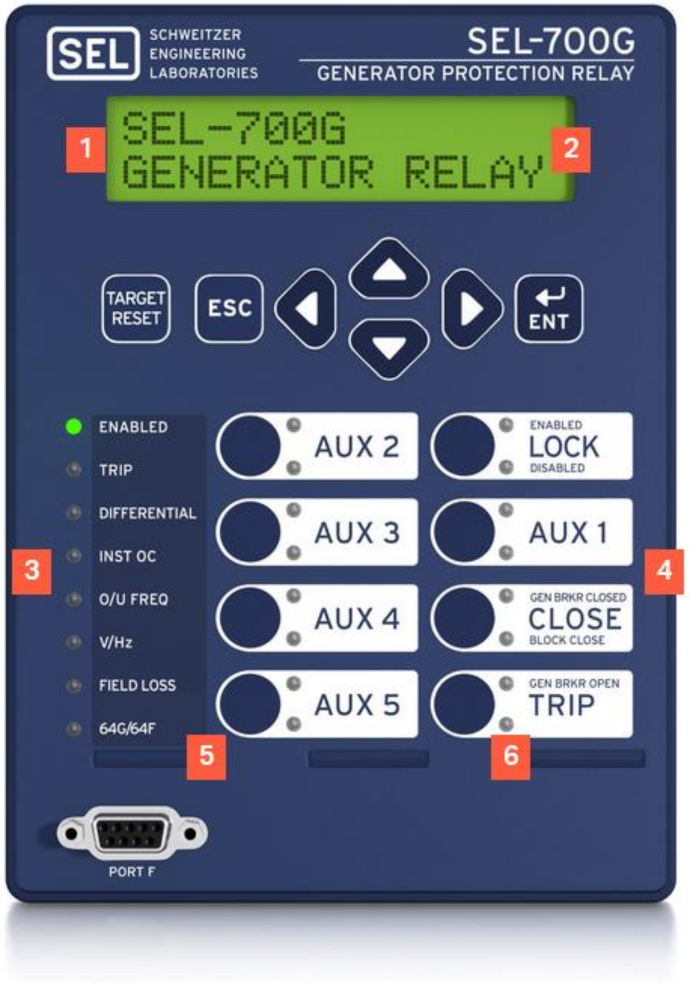


Stability test

The angle of the vector depends on the connection of the test device to the protection and on the device itself.

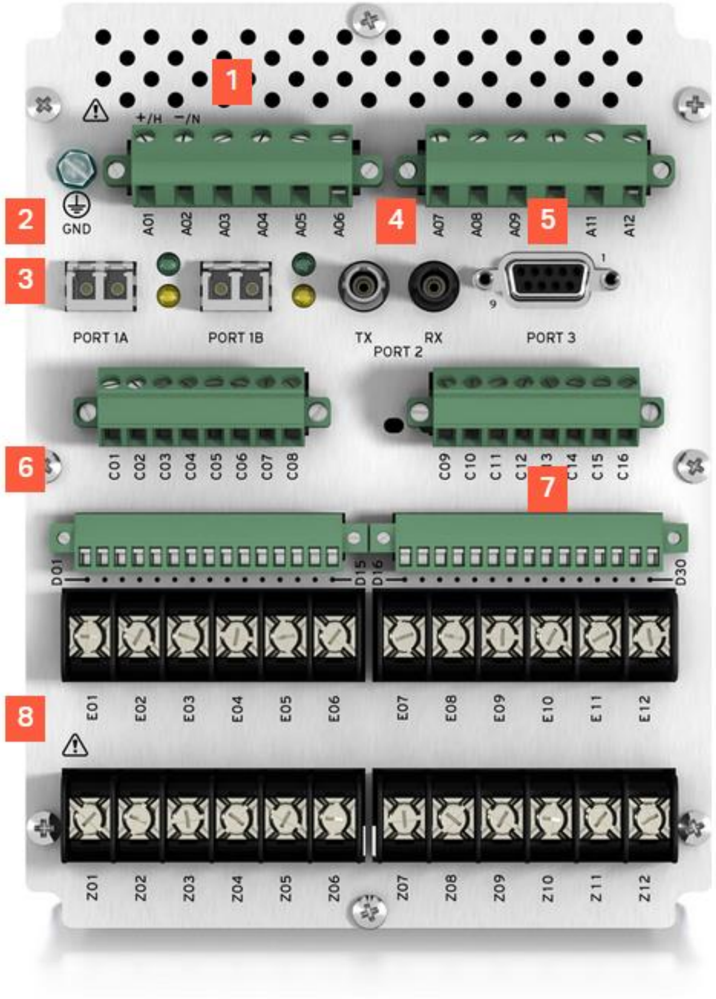
Differential protection of the generator

1. Large 2 × 16 character LCD
2. Default messages or up to 32 customizable display labels notify personnel of power system events or the relay status
3. Programmable front-panel tricolor LEDs
4. Customizable pushbuttons and labels
5. User-configurable label kit
6. Two programmable tricolor LEDs per pushbutton



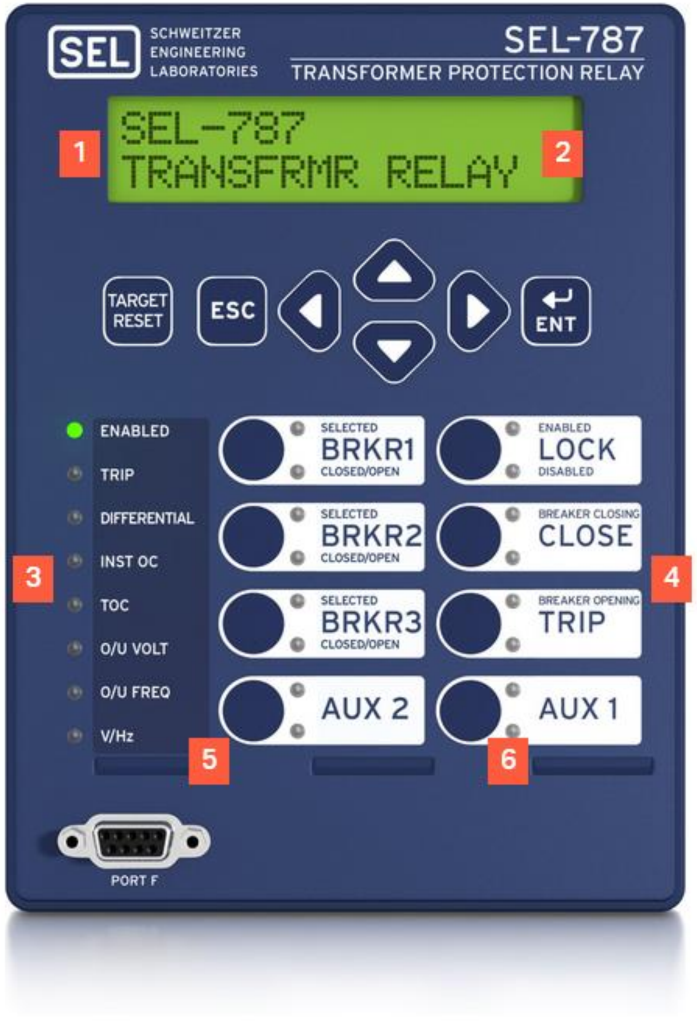
Differential protection of the generator

1. Power supply options include 110–250 Vdc/110–240 Vac or 24–48 Vdc
2. An integrated web server enables direct relay access for metering and monitoring data without the need for external PC software
3. A wide variety of communications protocols and media provide flexibility to communicate with other devices and control systems
4. Fiber-optic serial port
5. MIRRORED BITS communications provides fast and reliable relay-to-relay communication
6. Positions for optional expansion cards
7. Optional RTD inputs
8. CT and PT inputs are located on one card, allowing for more I/O in other slots



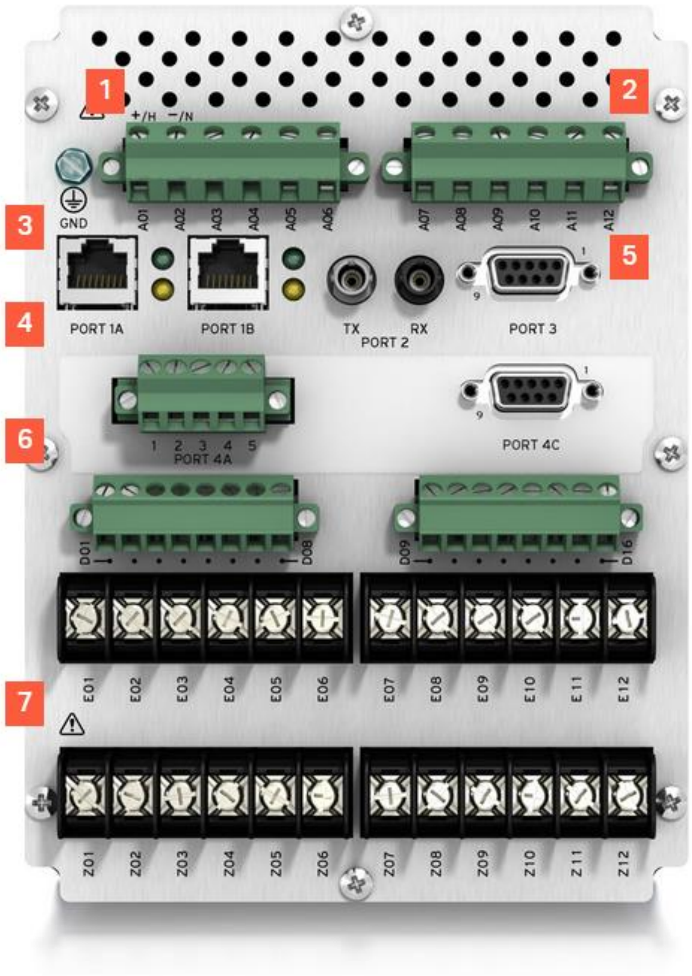
Differential protection of the transformer

1. Large 2 × 16 character LCD
2. Default messages or up to 32 customizable display labels notify personnel of power system events or the relay status
3. Programmable front-panel tricolor LEDs
4. Customizable pushbuttons and labels
5. User-configurable label kit
6. Two programmable tricolor LEDs per pushbutton



Differential protection of the transformer

1. Power supply options include 110–250 Vdc/110–240 Vac or 24–48 Vdc
2. 2 digital inputs (DI) and 3 digital outputs (DO)
3. A wide variety of communications protocols and media for flexibility to communicate with other devices and control systems
4. An integrated web server enables direct relay access for metering and monitoring data
5. EIA-232 serial port (P3) and fiber-optic EIA-232 serial port (P2) with IRIG-B input
6. Positions for optional I/O cards
7. Positions for current and voltage options



Theory of protections– frequency protection

Theory of protections– frequency protection

To protect an important global parameter, such as frequency, it is necessary to use frequency protection when changing frequencies (81).

Under frequency protection (81U):

- *Setting range: 45 – 50 Hz*

Over frequency protection (81O):

- *Setting range: 50 – 55 Hz*

Frequency protection setting (81):

- *Under frequency (81U): $f_< = 48$ Hz; $t_> = 0.1$s*
- *Over frequency (81O): $f_> = 52$ Hz; $t_> = 0.1$s*

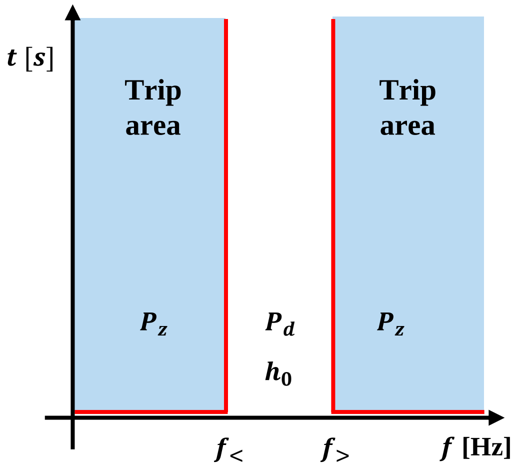


Fig. 5 Characteristics of frequency protection operation

P_d – permitted area
P_z – forbidden area
h_0 – limit of operation
$t_>$ – time delay

Theory of protections – over voltage/under voltage protection

Theory of protections – overvoltage/undervoltage protection

It is always necessary to find out the actual VT conversion before the actual setting. The most common secondary voltage VT is 100V or 110V. To set more levels, we must observe ΔU ≥ 0.1 * Un. Under voltage protection is used in practice with overcurrent protection and interlocking, i.e., as overcurrent protection with under voltage interlock (50/27).

Voltage protection (81U/81O):

- ***Setting range kc: (0.8 – 2) * Un***
- ***Time delay range: (0.1 – 10) s***

Setting calculation:

$$U_r = \frac{kc*Un}{PTN} = \frac{1*15.75e3V}{\frac{15000V}{100V}} = 105V \qquad (11)$$

Time delay t_r = 0.5 s

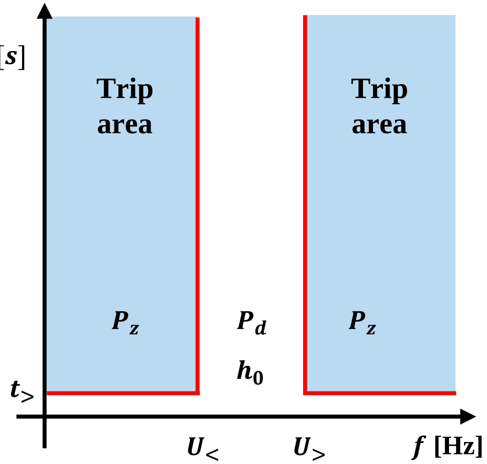


Fig. 6 Characteristics of frequency protection operation

P_d – permitted area; P_z – forbidden area
h_0 – Limit of operation; t_r – Time delay

Theory of protections – distance protection

Distance protection

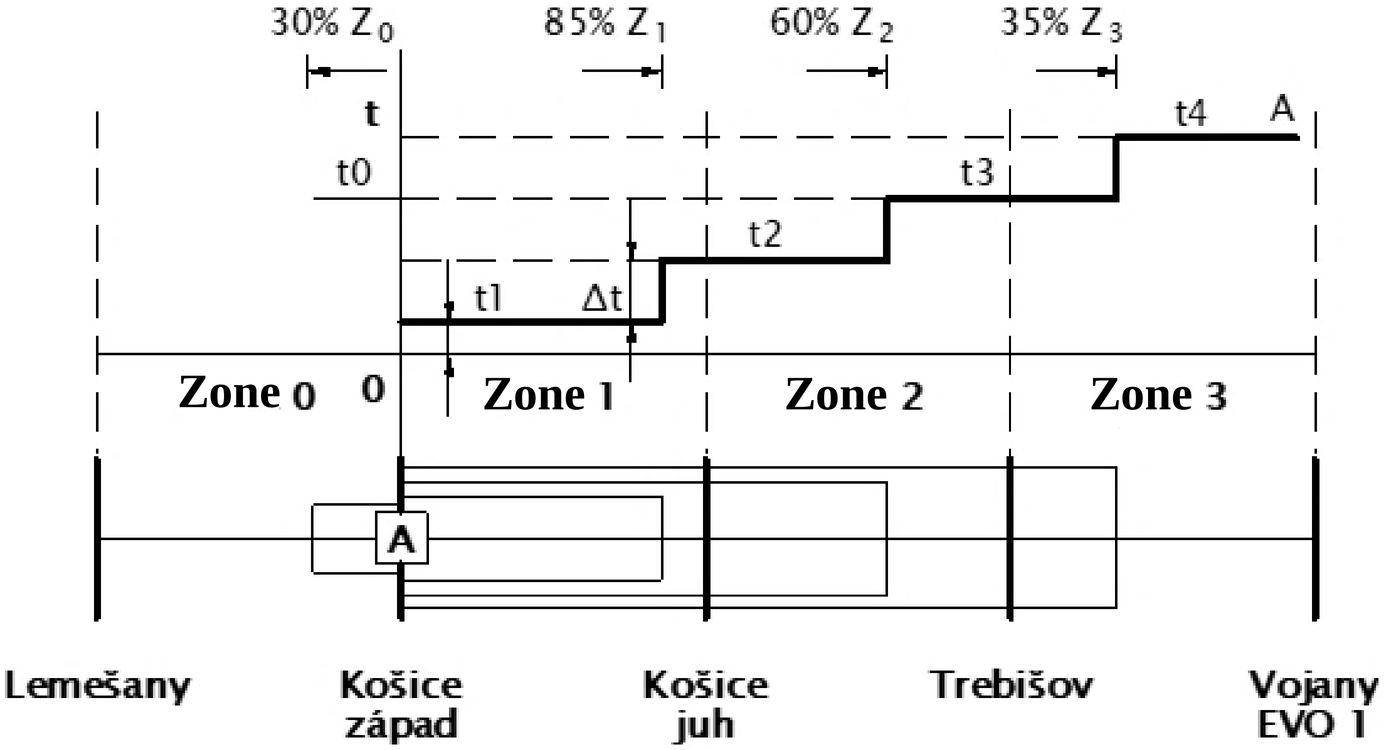


Fig. 7 Schematic designation of distance protection zones

The scheme of designation of distance protection zones shows the action of individual zones, for the forward area they are zones 1, 2 and 3 and for the reverse area zone 0.

Zone 1 shows line protection No. 1 at 85%.

Zone 2 shows line 2 protection at 60% and line 1 protection at 100%.

Zone 3 shows the protection of line No. 3 at 35% and sections No. 1 and No. 2 at 100%.

Zone 0 shows line protection No. 0 at 30%. This zone protects the return area.

The time delay of the individual zones is graded by a constant Δt with a value of 0.4 s, while the time t1 is determined from the range of 20 to 50 ms + the switch-off time of the circuit-breaker.

Distance protection

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

Type	**Rm_1**	**Xm_1**	**Bm_1**	**I_{dov}**	**Rm_0**	**Xm_0**	**Bm_0**	**Voltage**
	[W/km]	**[W/km]**	**[mS/km]**	**[A]**	**[W/km]**	**[W/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

%Line impedance calculation

Zline1 = l1(Rm+jXm)*

%Conversion according to the specified current and voltage transformer

p = CT/VT = (300A/5A)/(22000V/100V)

%Impedance calculation for given zone 1

%Positive sequence vector

*Z1zone1 = p*0.85*Zline1*

%Zero sequace vector

*Z0zone1 = p*0.85*Zline0*

Line Angle = angel(Zline1)

Calculation procedure:

***Zone 1**: is set to 85% of line impedance*

1. Transformer: current transfer in the given station, where the distance protection is located is 300A/5A and the voltage is 22000V/100V.

The instrument current transformer must be able to handle 20x overload with an accuracy of ±10% (saturation limit).

The impedance calculation for zone 1 is performed for the consecutive and non-rotating impedance components according to the parameters of the given line.

Distance protection

%Line impedance calculation

Zline2 = l2*(Rm+jXm)

%Conversion according to the specified current and voltage transformer

p = CT/VT = (300A/5A)/(22000V/100V)

%Impedance calculation for given zone 2

%Positive sequence vector

Z1zone2 = p*(0.6*Zline2+ Zline1)

%Zero sequence vector

Z0zone2 = p*(0.6*Zline2+ Zline1)

A similar calculation is considered for the other zones.

Calculation procedure:

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

Transformer: current transfer in the given station, where the distance protection is located is 300A/5A and the voltage is 22000V/100V.

The instrument current transformer must be able to handle 20x overload with an accuracy of ±10% (saturation limit).

The impedance calculation for zone 2 consists of the impedance of line No. 1 and line No. 2 for the positive and zero sequance component impedance according to the parameters of the given line.

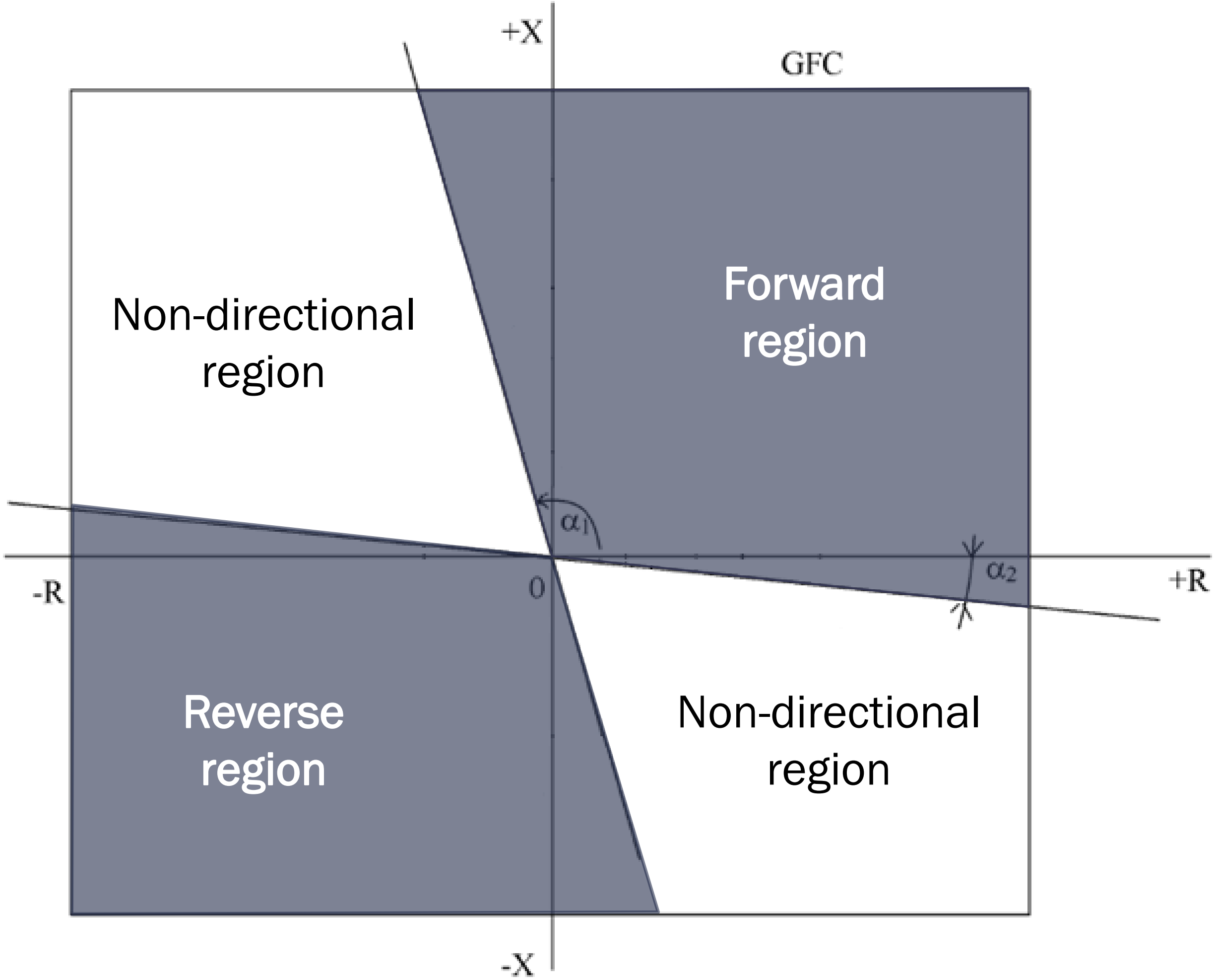


Fig. 8 Directional characteristic of distance protection R-X graph

Distance protection

This type of characteristic was created by a combination of directional, reactance, and resistance characteristics.

Polygonal characteristics consist of two lines. The lines are in most cases passing through the origin of the coordinate system and with the + R axis form angles a1 = 115 to 125 degrees and a2 = -15 to -25 degree.

These lines divide the R-X characteristic into four quadrants, using the forward region in the first quadrant and the reverse region in the third quadrant.

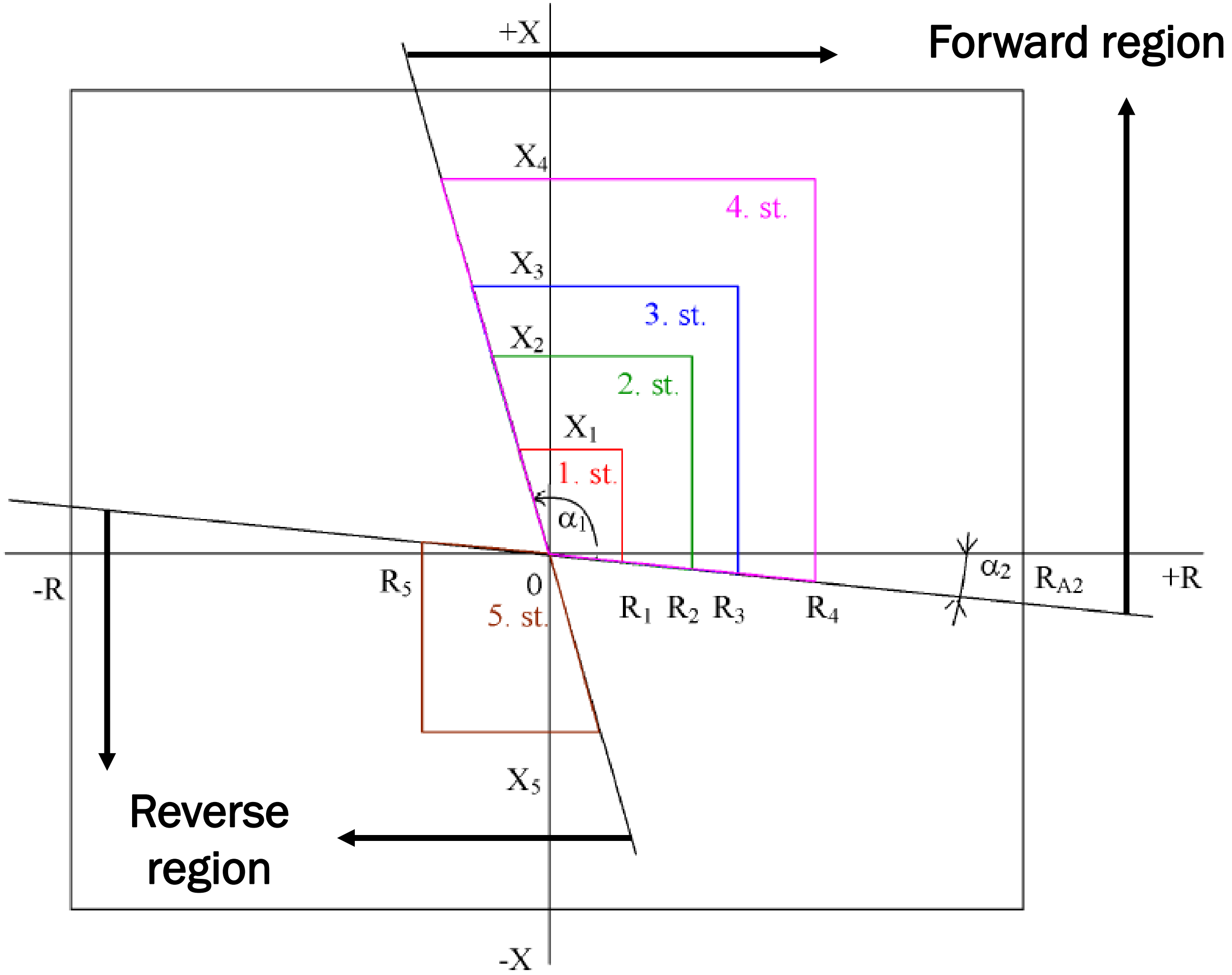


Fig. 9 Impedance polygonal characteristics of distance protection

Distance protection

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

In order to ensure selectivity, the characteristics are arranged in five levels with the possibility of different time settings. Usually, the first 4th characteristic are set in the direction of the line and the fifth characteristic in the direction of the busbar.

Distance protection

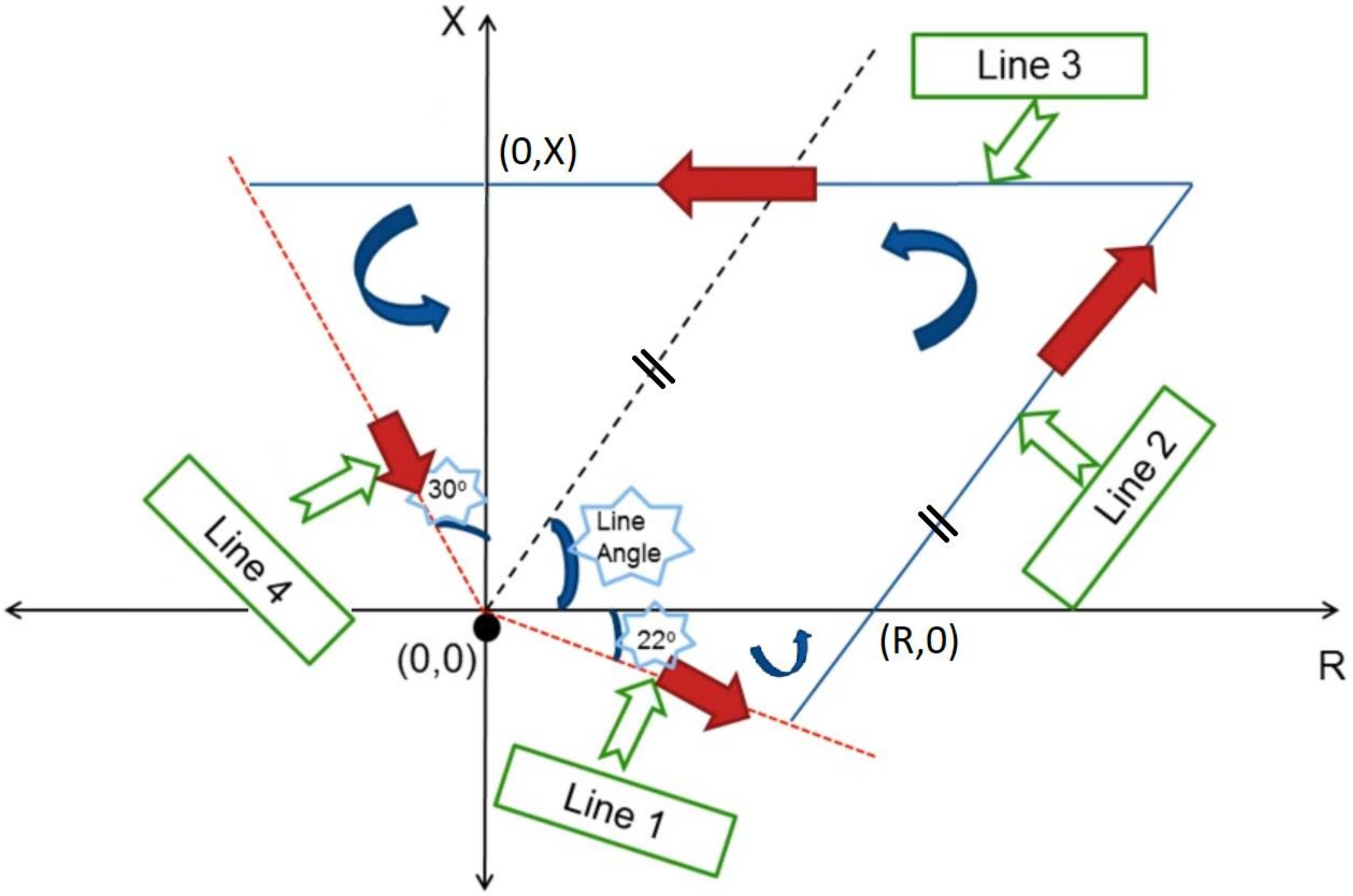


Fig. 10 Polygon characteristics of distance protection

<u>To draw a polygonal characteristic:</u>

<u>Line 1</u>: the size of the line is based on the calculation of the size of the sides of the triangle known angles (Line Angle a a2 = 22°) and coordinates (R, 0).

<u>Line 2</u>: the size of the line is based on the calculation of the size of the sides of a right triangle known angles (Line Angle and 90°) and coordinates (0, X).

<u>Line 3</u>: the size of the line is based on the calculation for Line 2 and coordinates (0, X).

<u>Line 4</u>: the size of the line is based on the calculation of the size of the sides of a right triangle known angles (90°and 30°) and coordinates (0,0).

Sample calculation of protection settings

Calculation of overcurrent protection relay settings

Overcurrent relay

%Grid impedance

*Z1grid = c*Un/(sqrt(3)*Ik3grid) = 1*22e3/sqrt(3)*3.2328e3 = 3.929Ω*

*X1grid = 0.995*Z1grid = 0.995*3.929 = 3.909Ω*

*R1grid = 0.1*X1grid = 0,1*3.909 = 0.391 Ω*

*Z1grid = R1grid+1j*X1grid = 0.391+j3.909Ω*

% Nominal feeder current

*IN = Sn/(sqrt(3)*Un1) = 1000e3/sqrt(3)*22e3 = 26.243 A*

%Cable line impedance

*Rl = p/qn*1000 = 1/54/35*1000 = 0.529Ω/km*

Xl = 0.14Ω/km

Z1line = l(Rl+1j*Xl) = 1*(0.529+j0.14) = 0.529+j0.14Ω*

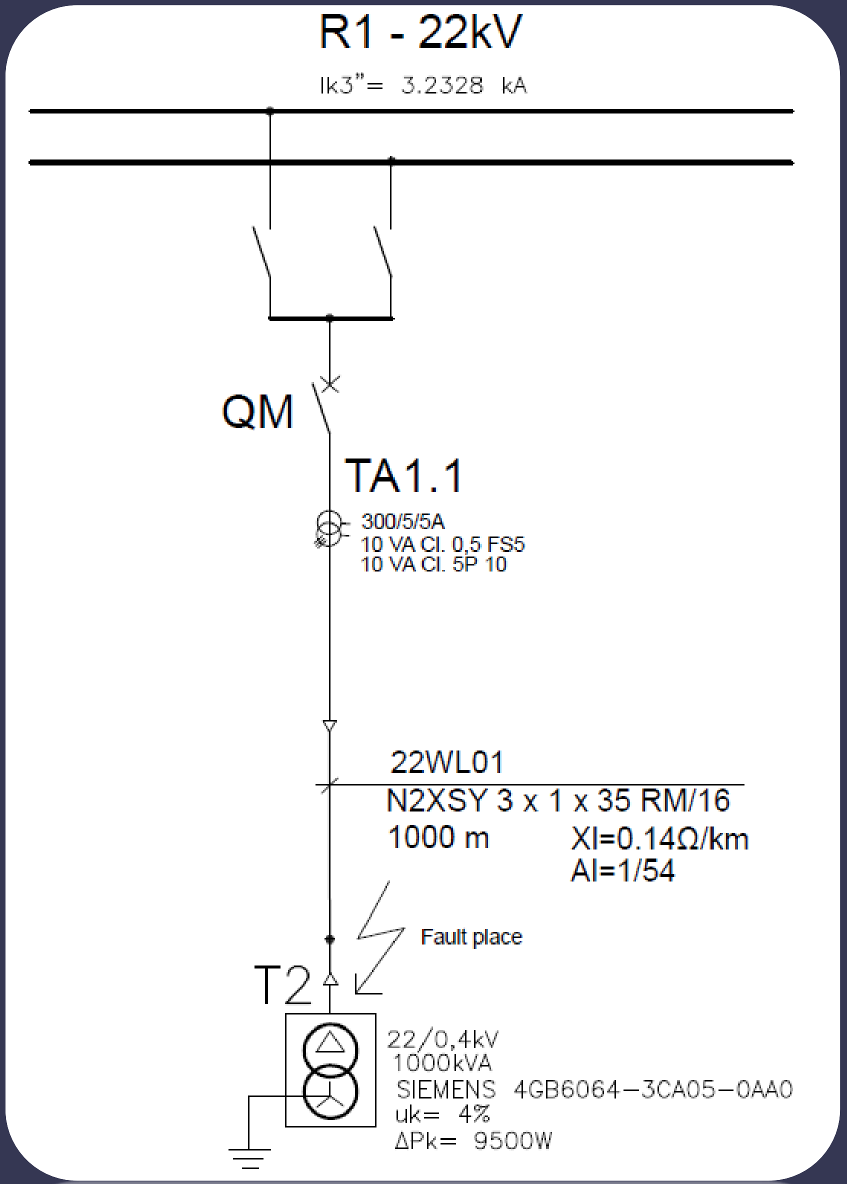


Fig. 11 Sample assignment

Overcurrent relay

%Short-circuit current calculation

Z1fault = Z1grid+Z1line= 0.391+j3.909 + 0.529+j0.14 = 0.92+j4.049Ω

Ik3R1= (c*Un)/(sqrt(3)*abs(Zk1))= 1*22e3/sqrt(3)*abs(Z1fault) = 3.058kA

Ik2R1 = sqrt(3)/2*Ik3R1 = sqrt(3)/2*3.058 = 2.649kA

% Calculation of the inrush overload protection current

I> = (kb*IN)/(kp*pp) = 1.1* 26.243 /0.95*300/5 = 0.506A

% Calculation of the inrush current of short-circuit protection

I>> = (0.8*Ik2R1)/(kc*pp) = 0.8*2.649e3/1.5*300/5 = 23.547A

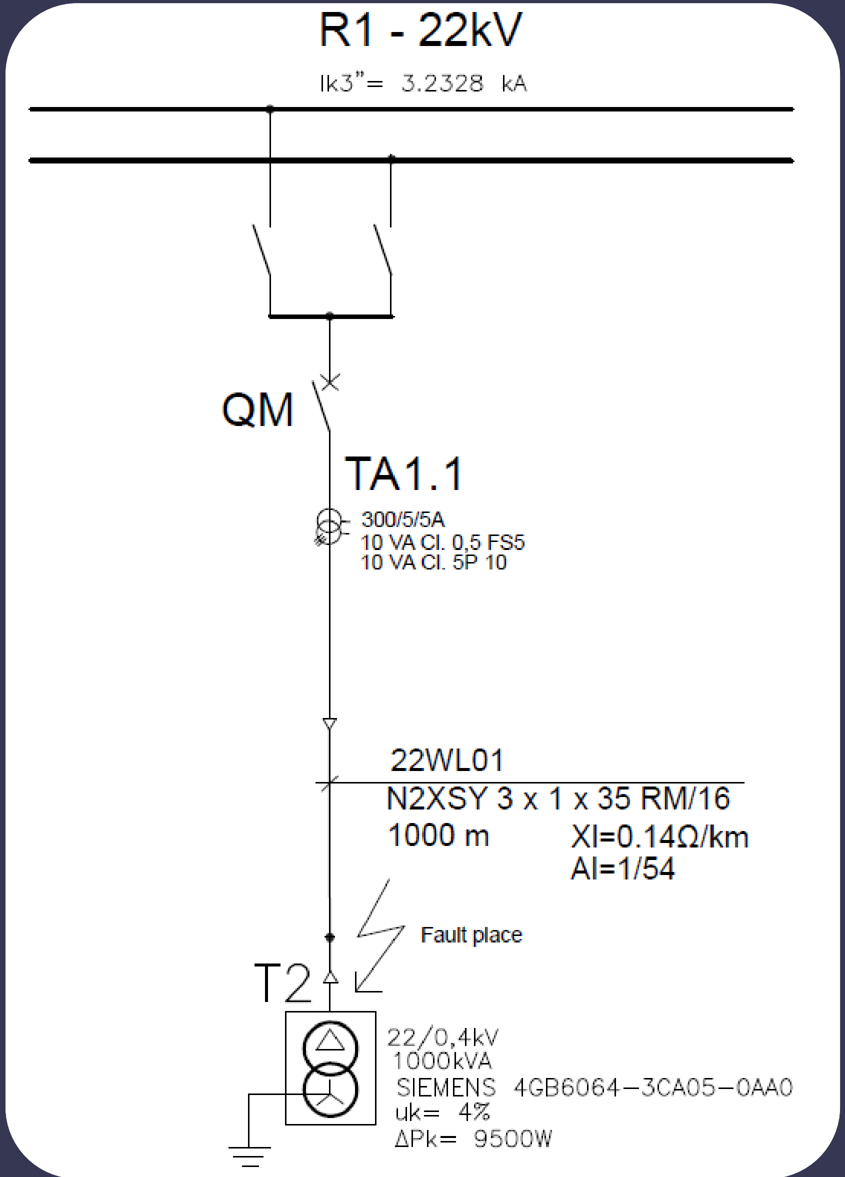


Fig. 11 Sample assignment

Overcurrent relay

%Overload protection inrush current

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

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

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

%Short-circuit protection inrush current

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

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

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

We choose the time delay for overload t> 0.25s and for short-circuits, t>> 0s with consideration for protection of other sections only by using fuses and circuit breakers.

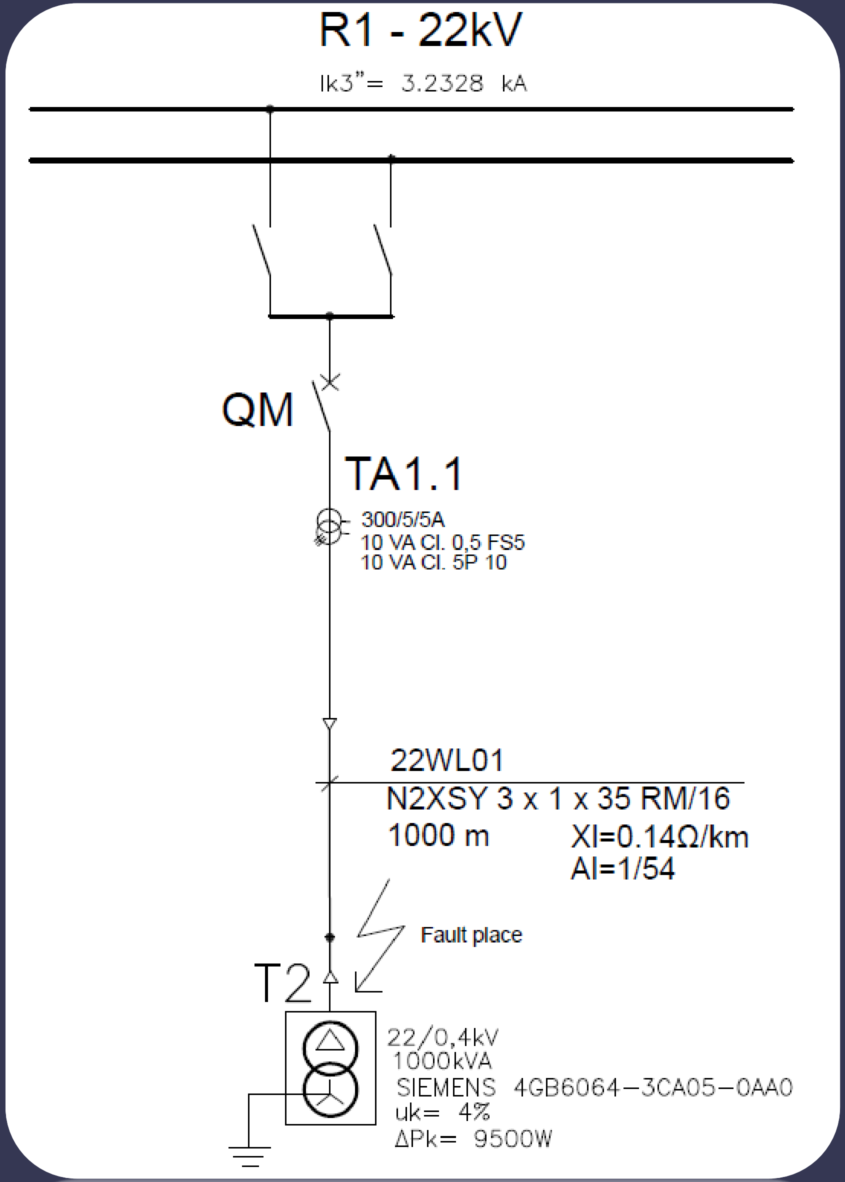


Fig. 11 Sample assignment

Calculation of generator overcurrent protection settings

Generator overcurrent protection

When calculating Rg, we calculate the ratio coefficient, which converts the reactance to an approximate resistance according to the size of the reactance. Thus, it considers the resistance of the conductor used for the winding according to the magnitude of the power reactance and the voltage of the generator.

Rg = 0.05*Xd" for generators with Urg > 1 kV a Sg ≥ 100 MVA.

Rg = 0.07*Xd" for generators with Urg > 1 kV a Sg < 100 MVA.

Rg = 0.15*Xd" for generators with Urg ≤ 1000 V.

%Generator impedance

Xd = xd"*ZrG = 0.165*11.618 = 1.917Ω

Rg = 0.07*Xd" = 0.07*1.917 = 0.134 Ω

Kg = Un/Urg*c/(1+xd"*sin(pf))= 11e3/11e3*1/(1+0.165*sin(acos(0.9))= 0.933

Z1g = Kg*(Rg+1j*Xd") = 0.933 *(0.134 +j1.917) = 0.125+j1.788Ω

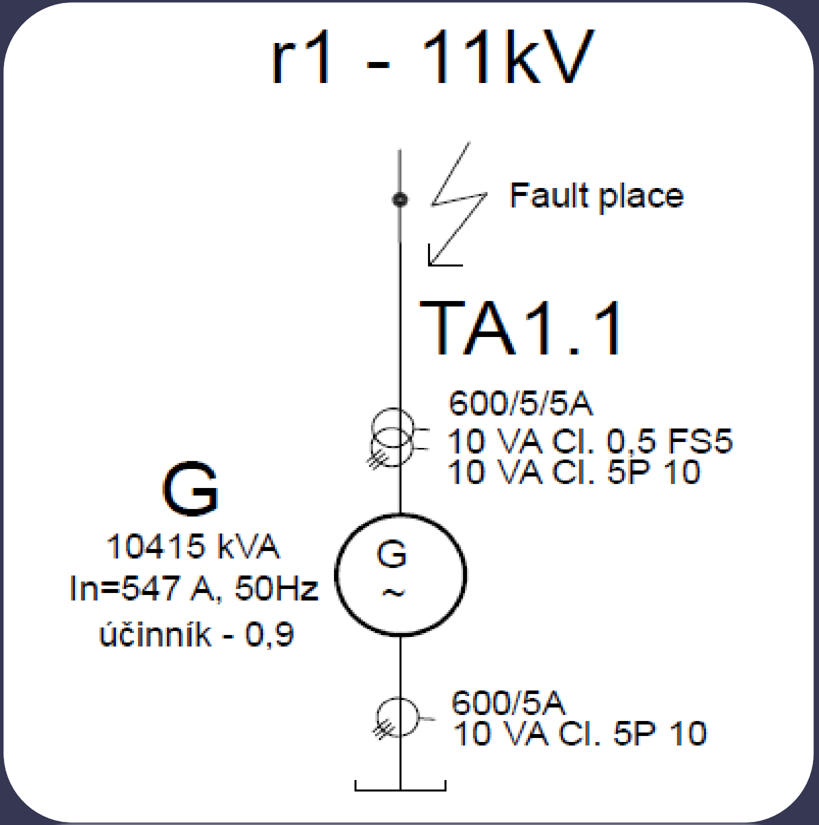


Fig. 12 Sample assignment

Generator overcurrent protection

%Short-circuit current calculation

Ik3g = (c*Un)/(sqrt(3)*abs(Z1g)) = 1*11e3/sqrt(3)*abs(Z1g) = 3542.569A

Ik2g = sqrt(3)/2*Ik3g = sqrt(3)/2*3542.569 = 3067.956A

IN = 547A

%Calculation of the inrush overload protection current

I> = (kb*IN)/(kp*pp) = 1.1*547/0.95*600/5 = 5.28A

%Calculation of the inrush current of short-circuit protection

I>> = (0.8*Ik2g)/(kc*pp) = 0.8*3067.956/1.5*600/5 = 13.635A

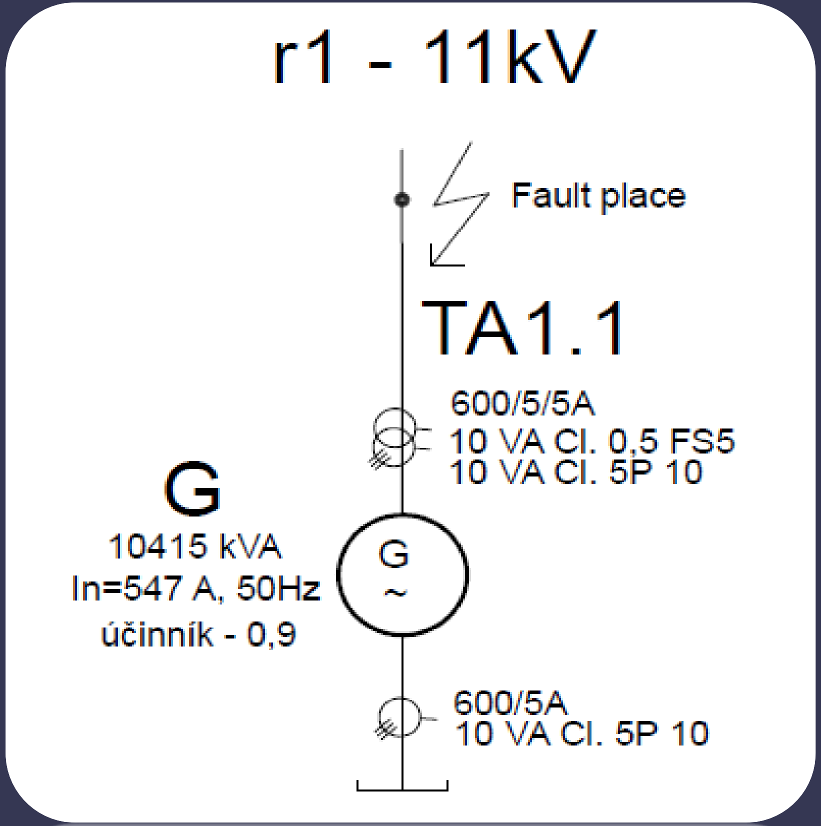


Fig. 12 Sample assignment

Generator overcurrent protection

%Overload protection inrush current

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

$$5{,}28A \leq I_{R>}$$

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

%Short-circuit protection inrush current

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

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

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

We choose the time delay for overload t> 0.25 s and for short circuits, t>> 0s.

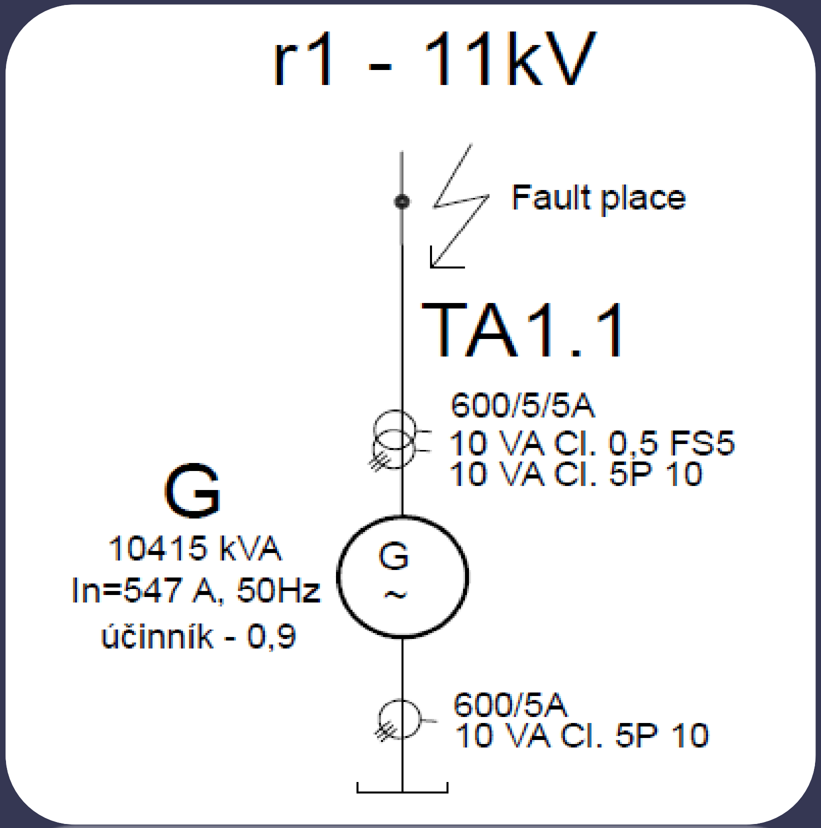


Fig. 12 Sample assignment

Generator overcurrent protection

Overcurrent protection of the generator with respect to the protected device for this example, it is necessary for the generator to switch off this protection last if there are others before this protection. This principle is critically for the correct selective shutdown of a fault section or device, as the generator acts in the network, both the power supply and its time delay for shorts and overloads are ranked among the slowest to maintain the stability of the electrical system and not the worst BLACKOUT state for misconfigured protective devices.

BLACKOUT ***- This term refers to a large-scale power outage in a vast area for tens of hours or days, which will affect many people. Transmission system decay into separate islands => cascade fault propagation => BLACKOUT.***

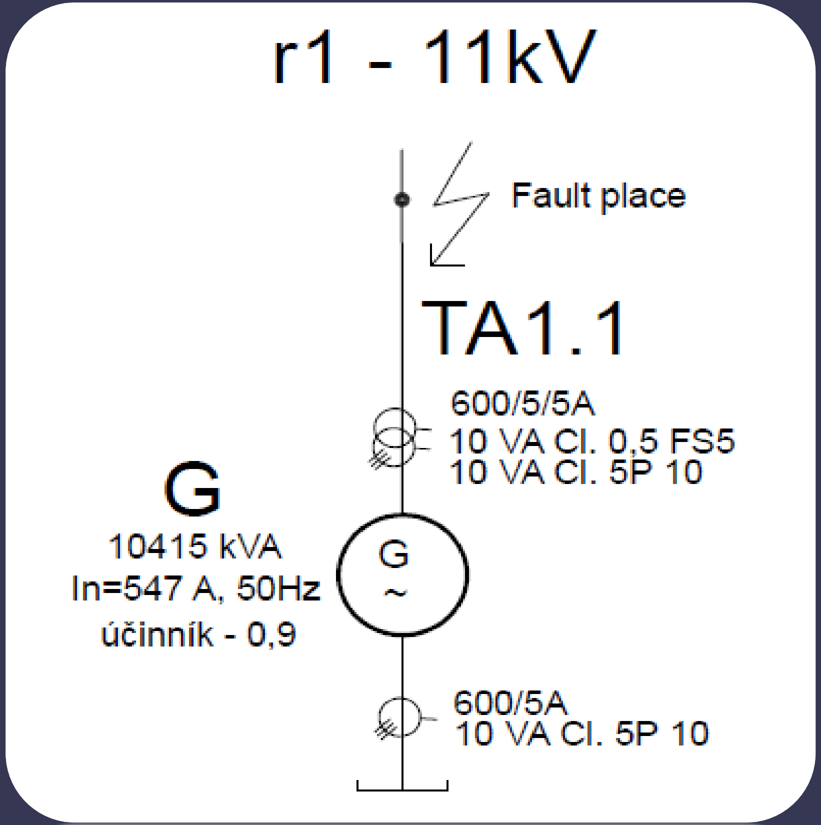


Fig. 12 Sample assignment

Calculation of generator differential protection settings

Differential protection of the generator

<u>*Calculation of the total error current O87P:*</u>

$$I_{d2} = CT_{error} + excitation\ current + TR_{error} + safety\ margin + relay\ errors$$

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

<u>*Calculation of the first slope setting:*</u>

$$SLP_1 = CT_{error} + excitation\ current + TR_{error} + safety\ margin + relay\ errors$$

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

<u>*Calculation of the second slope setting:*</u>

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

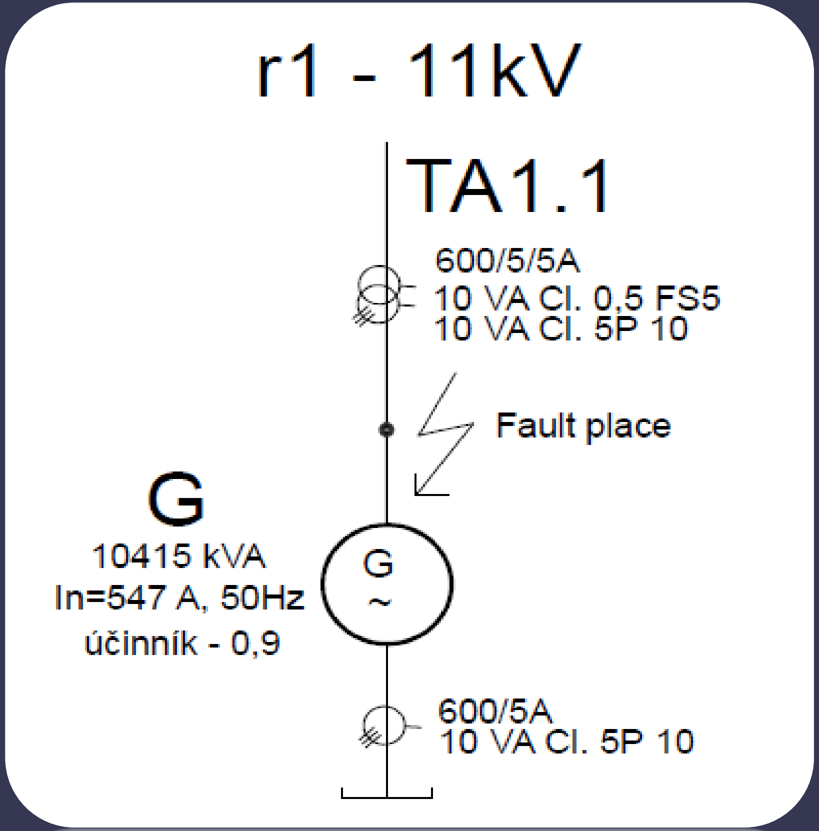


Fig. 13 Sample assignment

Differential protection of the generator

Calculation of current transformer coefficient:

$$CT_1 = \frac{600}{5} = 120 \qquad CT_2 = \frac{600}{5} = 120$$

The breakpoint IRS1 is determined for a stabilization current I_b in the range of 1.5 to 2.5. For example, we choose 1.5. The upper limit U87P of the differential current I_{dmax} is selected in the range 8 to 10. For the example, we choose 8. We set the second harmonic to 20%, and we set the fifth harmonic to 40%.

The CT TAP compensation factor is calculated according to the relationship:

$$TAP = \frac{S*1000}{\sqrt{3}*U_{L-L}} * CT = \frac{10.5*1000}{\sqrt{3}*11} * \frac{5}{600} = 4.593$$

A differential protection start-up test

$$Id_{Prim.} = Id_{Sec.} = TAP * SLP_1 = 4.593 * 0.3 = 1.378A$$

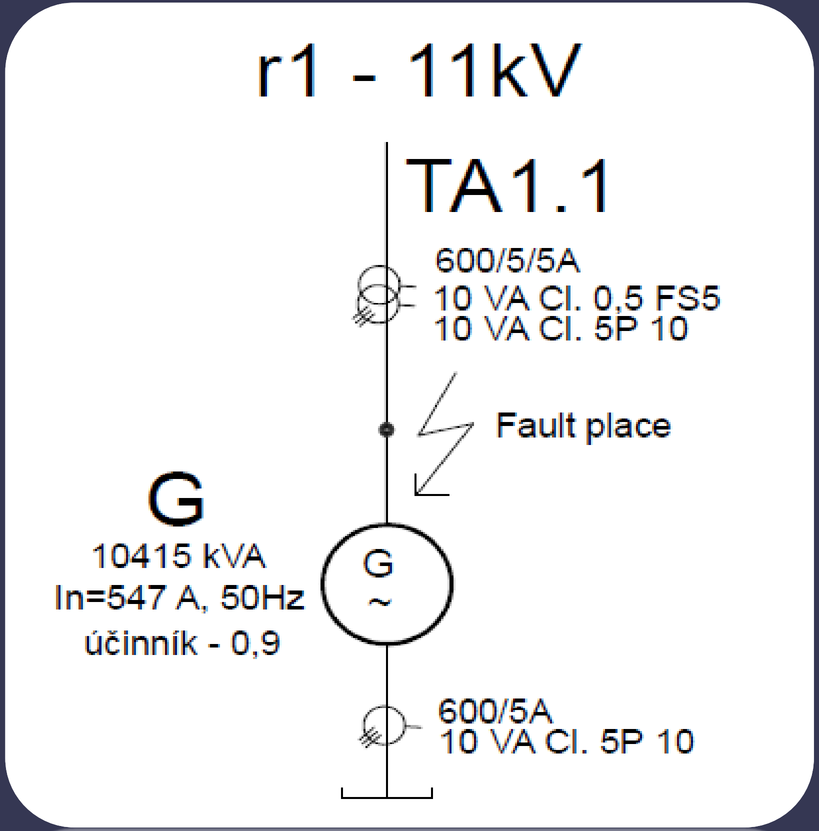


Fig. 13 Sample assignment

Transformer overcurrent protection calculation calculation

Transformer overcurrent protection

The current transformer has a transmission of pp = 300/5A and is connected to the primary winding of the transformer. At the nominal current of the primary winding for a given section I_N = 209.5 A.

The current transformer has a transmission of pp = 600/5A and is connected to the secondary winding of the transformer. At the nominal secondary winding current for the given section I_N = 419 A.

The change is that for setting the overcurrent protection for the primary winding we count on a short circuit on the secondary side of the transformer and for the secondary winding of the transformer on the contrary i.e., a short circuit on the primary side of the transformer.

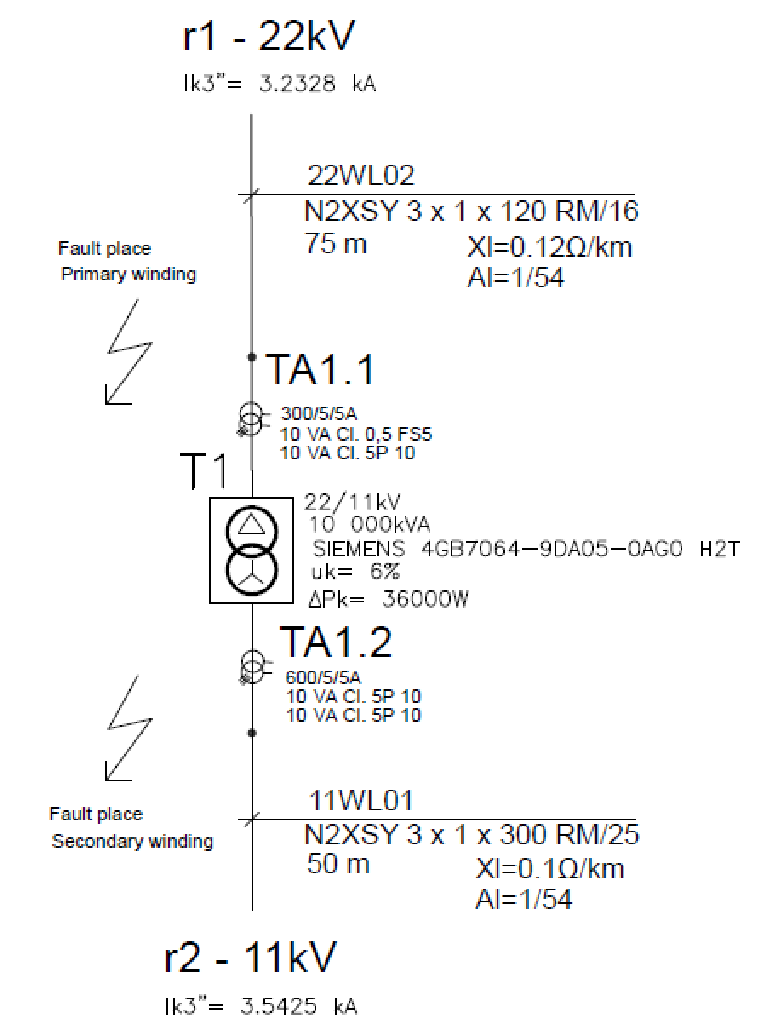


Fig. 14 Sample assignment

Transformer overcurrent protection

%Grid impedance primary winding TR

ZPgrid = c*Un/(sqrt(3)*Ik3grid) = 1*22e3/sqrt(3)*3.2328e3 = 3.929Ω

XPgrid = 0.995*ZPgrid = 0.995*3.929 = 3.909Ω

RPgrid = 0.1*XPgrid = 0.1*3.909 = 0.391 Ω

Zpgrid = RPgrid+1j*XPgrid = 0.391+j3.909Ω

%Grid impedance secondary winding TR

ZSgrid = c*Un/(sqrt(3)*Ik3grid) = 1*11e3/sqrt(3)*3.5425e3 = 1.793Ω

XSgrid = 0.995*Zsgrid = 0.995*1.793 = 1.784Ω

RSgrid = 0.1*XSgrid = 0.1*1.784 = 0.178 Ω

ZSgrid = RSgrid+1j*Xsgrid = 0.178+j1.784Ω

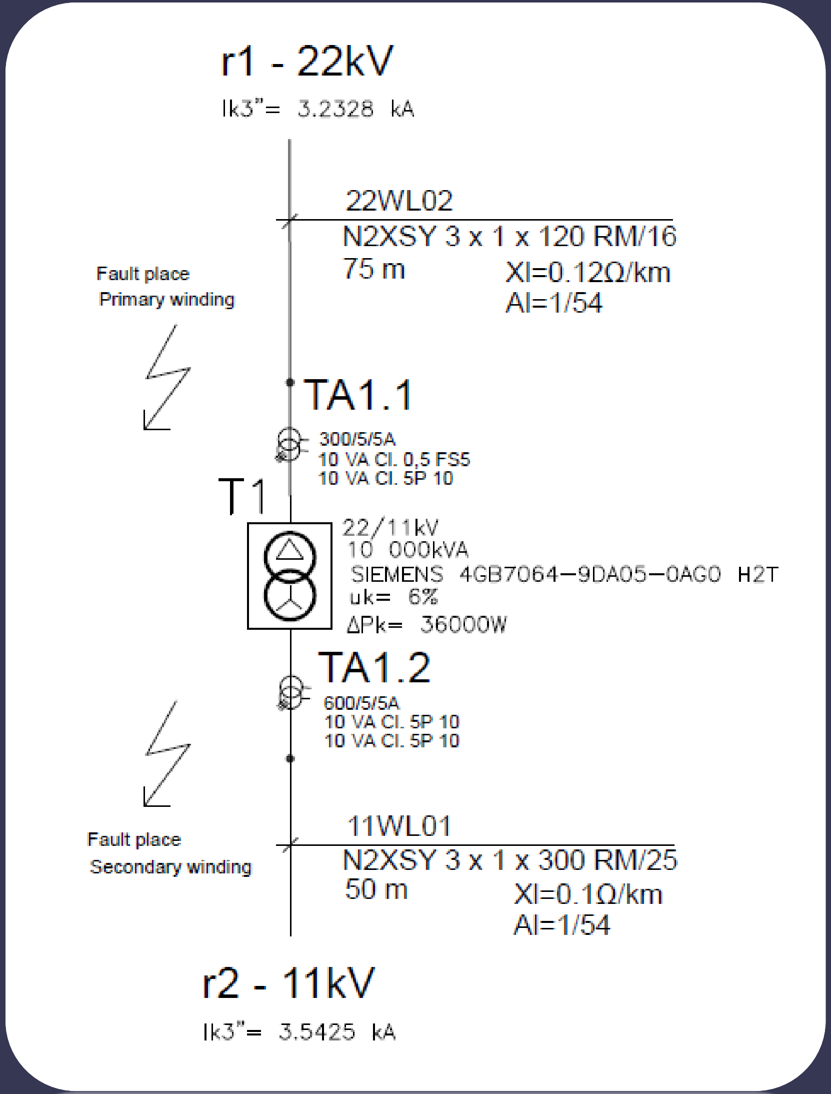


Fig. 14 Sample assignment

Transformer overcurrent protection

% Nominal feeder current TR

$INP = 209.5A$

$INS = 419A$

%Primary winding cable impedance TR

$RlP = p/qn*1000 = 1/54/120*1000 = 0.154\Omega/km$

$XlP = 0.12\Omega/km$

$ZPline = l*(RlP+1j*XlP) = 0.075*(0.154 + j0.12) = 0.012+j0.009\Omega$

%Secondary winding cable impedance TR

$RlS = p/qn*1000 = 1/54/300*1000 = 0.062\Omega/km$

$XlS = 0.1\Omega/km$

$ZSline = l*(RlS+1j*XlS) = 0.05*(0.062 + j0.1) = 0.003+j0.005\Omega$

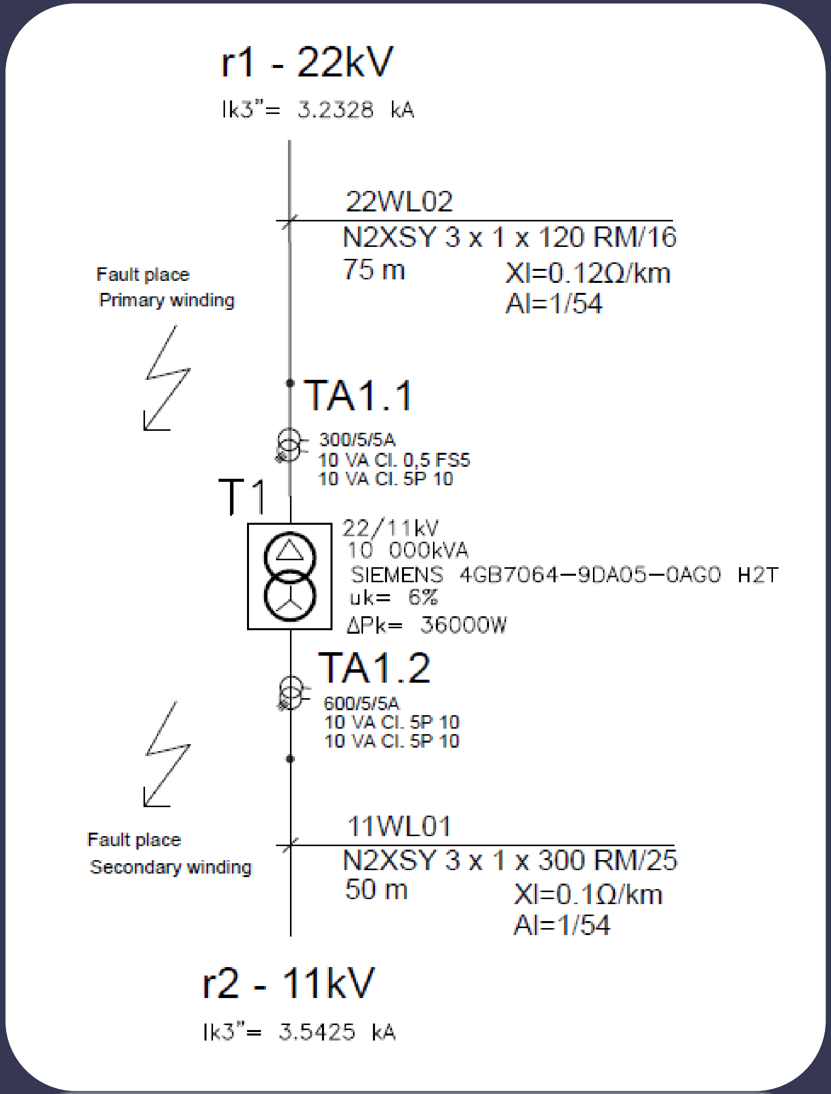


Fig. 14 Sample assignment

Transformer overcurrent protection

%Transformer impedance calculation

ur = dPk/Sn = 0.0036

Rt = (ur*Un1^2)/Sn = (0.0036*22e3^2)/10e6 = 0.174Ω

ux = sqrt(uk^2-ur^2) = sqrt(0.06^2-0.0036^2) = 0.0599

Xt = (ux*Un1^2)/Sn = (0.0599*22e3^2)/10e6 = 2.899Ω

Kt1 = 0.95*c/(1+0.6*(Xt/(Un1^2/Sn)))

= 0.95*1/(1+0.6*(2.899/(22e3^2/10e6))) = 0.917

Z1T1 = Kt1*(Rt+1j*Xt) = 0.917*(0.174+j2.899) = 0.16+j2.658Ω

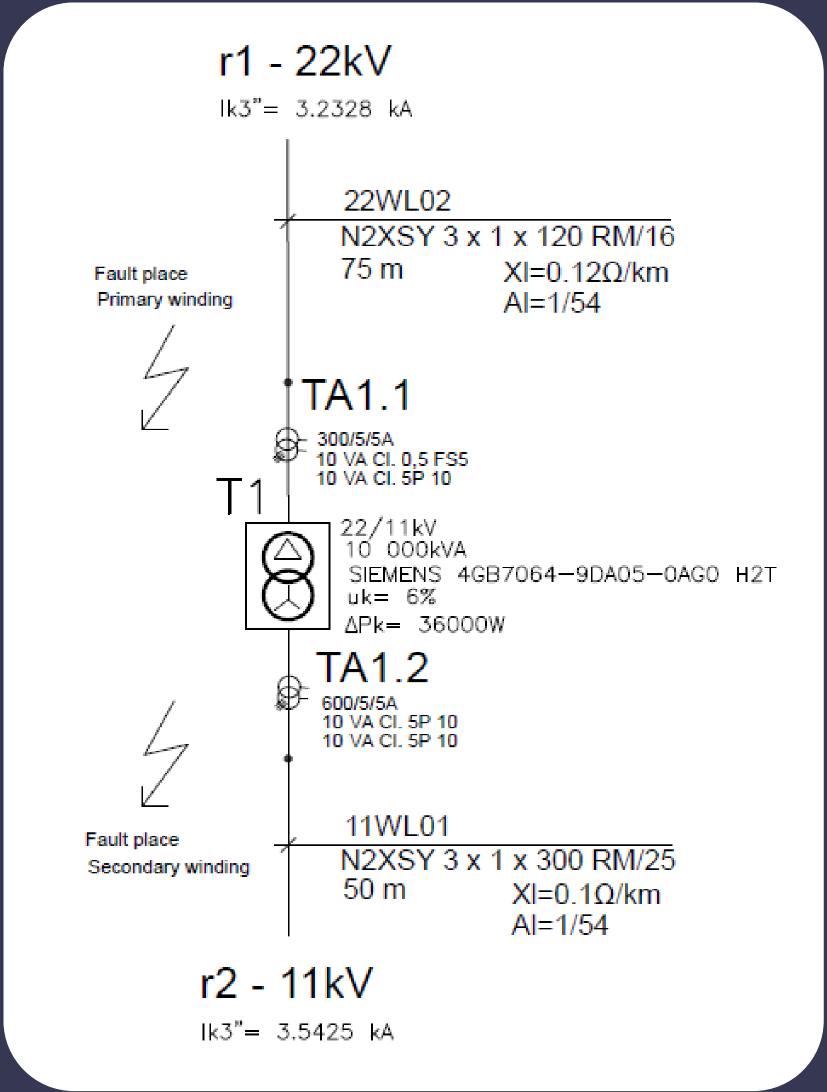


Fig. 14 Sample assignment

Transformer overcurrent protection

%Calculation of short-circuit current of primary winding TR

Z1P = ZSgrid*((22e3/11e3)^2)+ZSline*((22e3/11e3)^2)+Z1T1

=(0.178+j1.784)*((22e3/11e3)^2)+(0.003+j0.005)*((22e3/11e3)^2)+(0.16+j2.658)= 0.886+j9.814Ω

Ik3P= (c*Un)/(sqrt(3)*abs(Zk1))= 1*22e3/sqrt(3)*abs(Z1P) = 1.289kA

Ik2P = sqrt(3)/2*Ik3P = sqrt(3)/2*1.289e3 = 1.116kA

%Calculation of short-circuit current of secondary winding TR

Z1S = ZPgrid*((11e3/22e3)^2)+ZPline*((11e3/22e3)^2)+Z1T1 *((11e3/22e3)^2

=(0.391+j3.909)*((11e3/22e3)^2)+(0.012+j0.009)*((11e3/22e3)^2)+ 0.16+j2.658*((11e3/22e3)^2

= 0.141+j1.644Ω

Ik3S= (c*Un)/(sqrt(3)*abs(Zk1))= 1*11e3/sqrt(3)*abs(Z1P) = 3.849kA

Ik2S = sqrt(3)/2*Ik3S = sqrt(3)/2*3.849e3 = 3.333kA

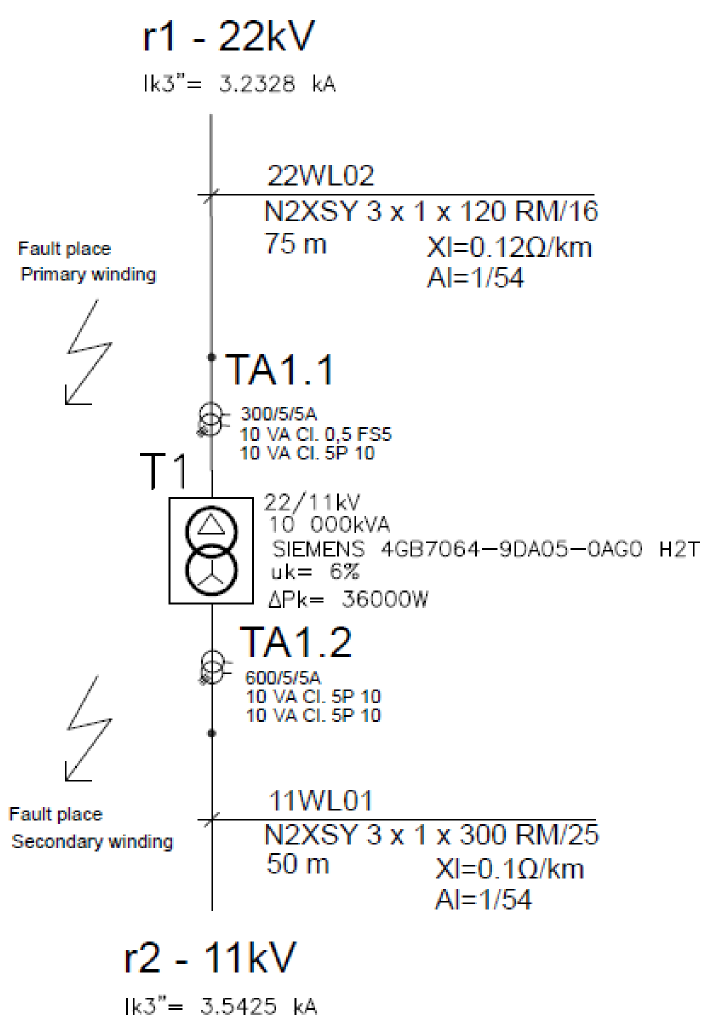


Fig. 14 Sample assignment

Transformer overcurrent protection

%Calculation of the inrush current of the primary winding overload

$I{>}P = (kb*INP)/(kp*pp) = (1.1*209.5)/(0.95*300/5) = 4.043A$

%Calculation of the inrush current of the secondary winding overload

$I{>}S = (kb*INS)/(kp*pp) = (1.1*419)/(0.95*600/5) = 4.043A$

%Calculation of the inrush current of protection for short-circuits of the primary winding

$I{>>}P = (0.8*Ik2S)/(kc*pp) = (0.8*3.333e3)/(1.5*300/5) = 29.627A$

%Calculation of the inrush current of the protection for short-circuits of the secondary winding

$I{>>}S = (0.8*Ik2P)/(kc*pp) = (0.8*1.116e3)/(1.5*600/5) = 4.96A$

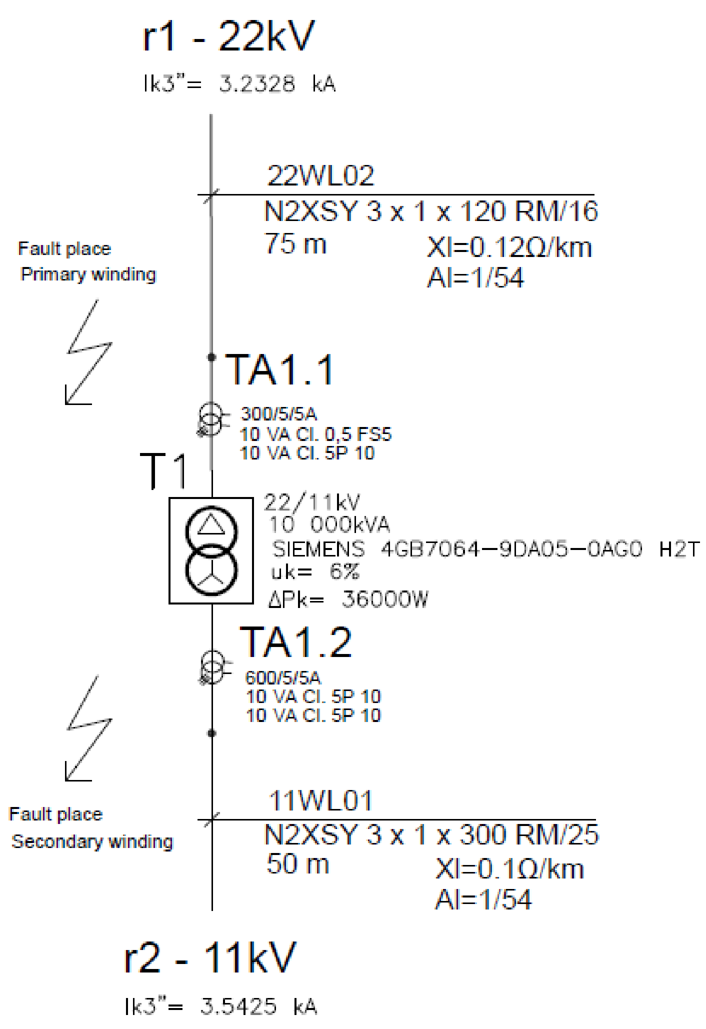


Fig. 14 Sample assignment

Transformer overcurrent protection

% Protection inrush current for primary TR overload

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

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

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

%Protection inrush current value for primary TR short circuit

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

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

$$I_{R\gg} = 7A$$

We choose the time delay for overload t> 0.25s and for short-circuits, t>> 0s.

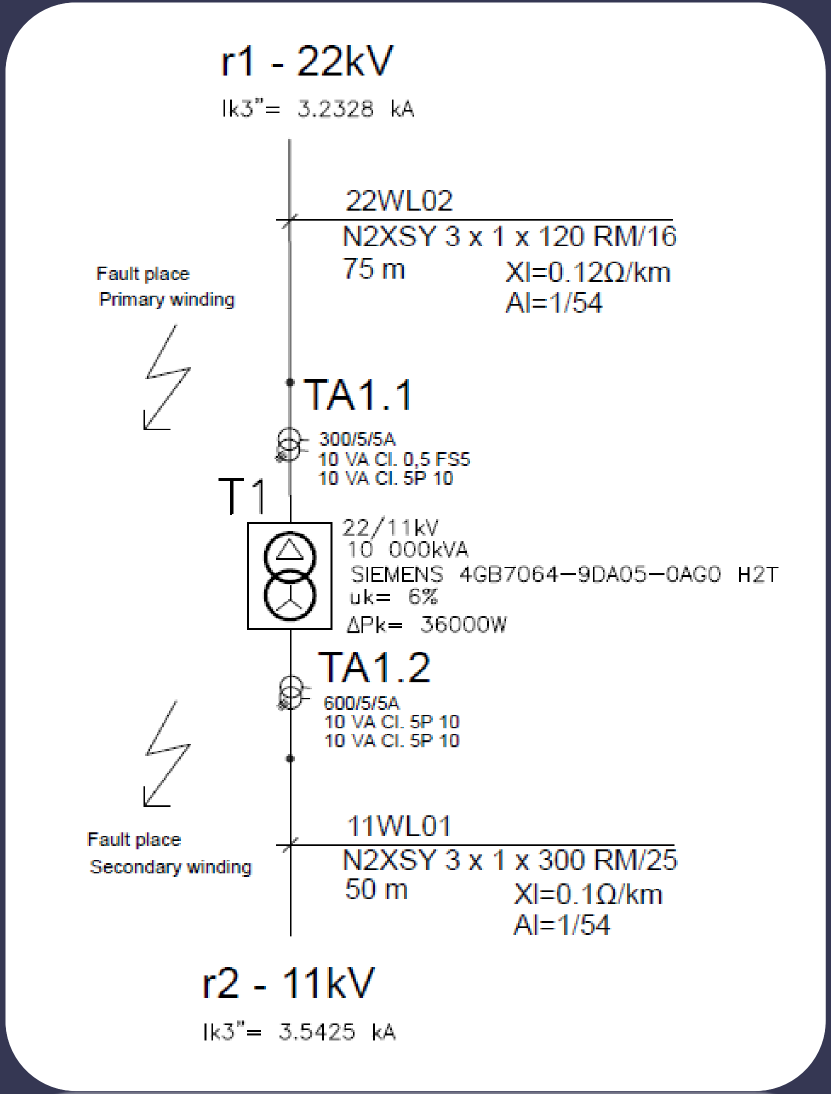


Fig. 14 Sample assignment

Transformer overcurrent protection

%Protection inrush current value for secondary TR overload

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

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

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

%Protection inrush current value for secondary TR short-circuit

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

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

$$I_{R\gg} = 4.8A$$

We choose the time delay for overload t> 0.25s and for short-circuits, t>> 0s with consideration for protection of other sections only by using fuses and circuit breakers.

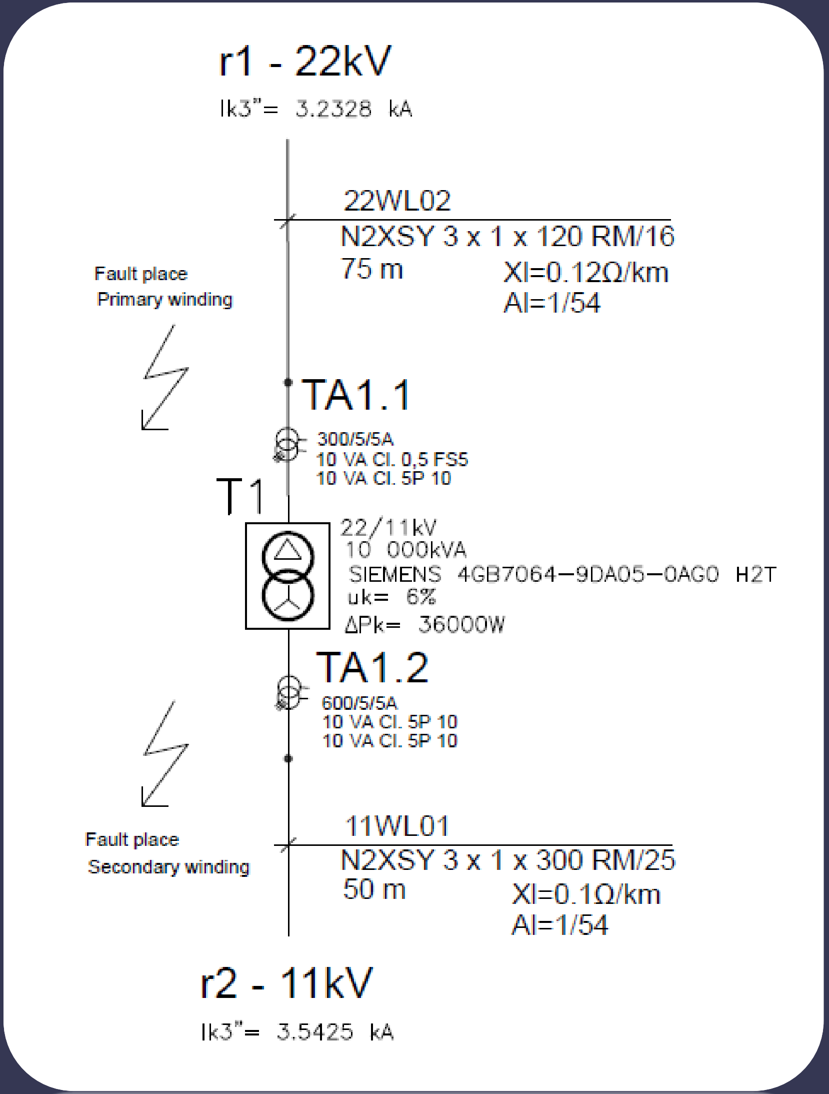


Fig. 14 Sample assignment

Transformer differential protection setting calculation

Transformer differential protection

Calculation of total error current O87P:

$$I_{d2} = CT_{error} + excitation\ current + TR_{error} + safety\ margin + relay\ errors$$

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

Calculation of the first slope setting:

$$SLP_1 = CT_{error} + excitation\ current + TR_{error} + safety\ margin + relay\ errors$$

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

Calculation of the second slope setting:

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

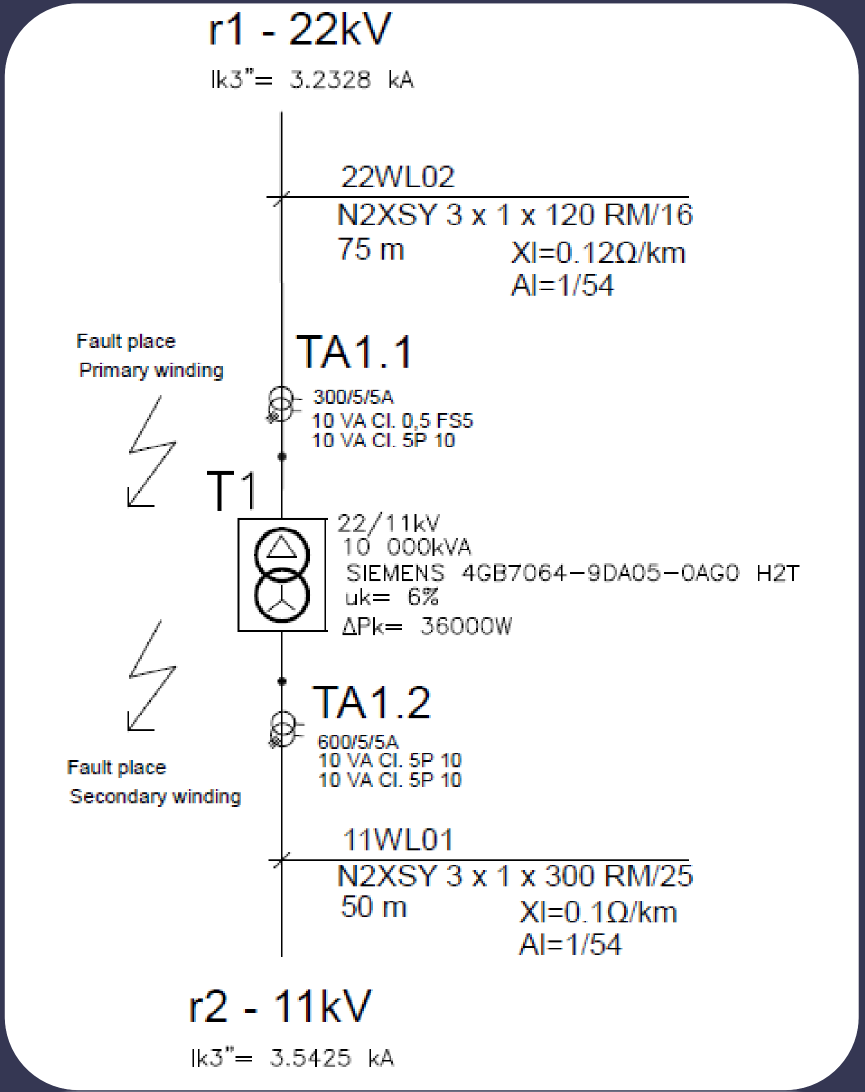


Fig. 15 Sample assignment

Transformer differential protection

Calculation of current transformer coefficient:

$$CTR_1 = \frac{300}{5} = 60 \qquad CTR_2 = \frac{600}{5} = 120$$

***The breakpoint IRS1** is determined for a stabilization current I_b in the range of 1.5 to 2.5. For example, we choose 1.5.*

***The upper limit U87P** of the differential current I_{dmax} is chosen in the range 8 to 10. For example, we choose 8.*

We set the second harmonic to 20%, and we set the fifth harmonic to 40%.

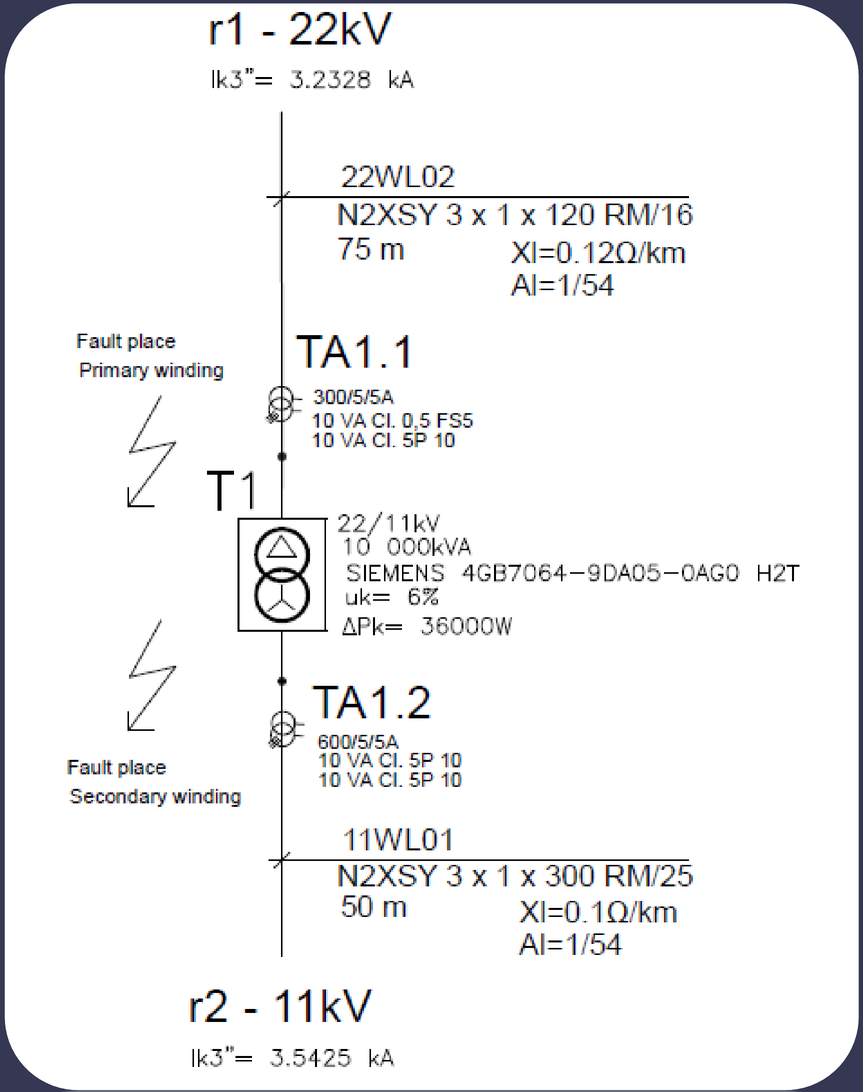


Fig. 15 Sample assignment

Transformer differential protection

The CT TAP compensation factor is calculated according to the relationship:

$$TAP = \frac{S*1000}{\sqrt{3}*U_{L-L}} * CT = \frac{10*1000}{\sqrt{3}*22} * \frac{5}{300} = 4.374$$

The CT TAP compensation factor is calculated according to the relationship:

$$TAP = \frac{S*1000}{\sqrt{3}*U_{L-L}} * CT = \frac{10*1000}{\sqrt{3}*11} * \frac{5}{600} = 4.374$$

Differential protection start-up test

$$Id_{Prim.} = Id_{Sec.} = TAP * SLP_1 = 4.374 * 0.3 = 1.312A$$

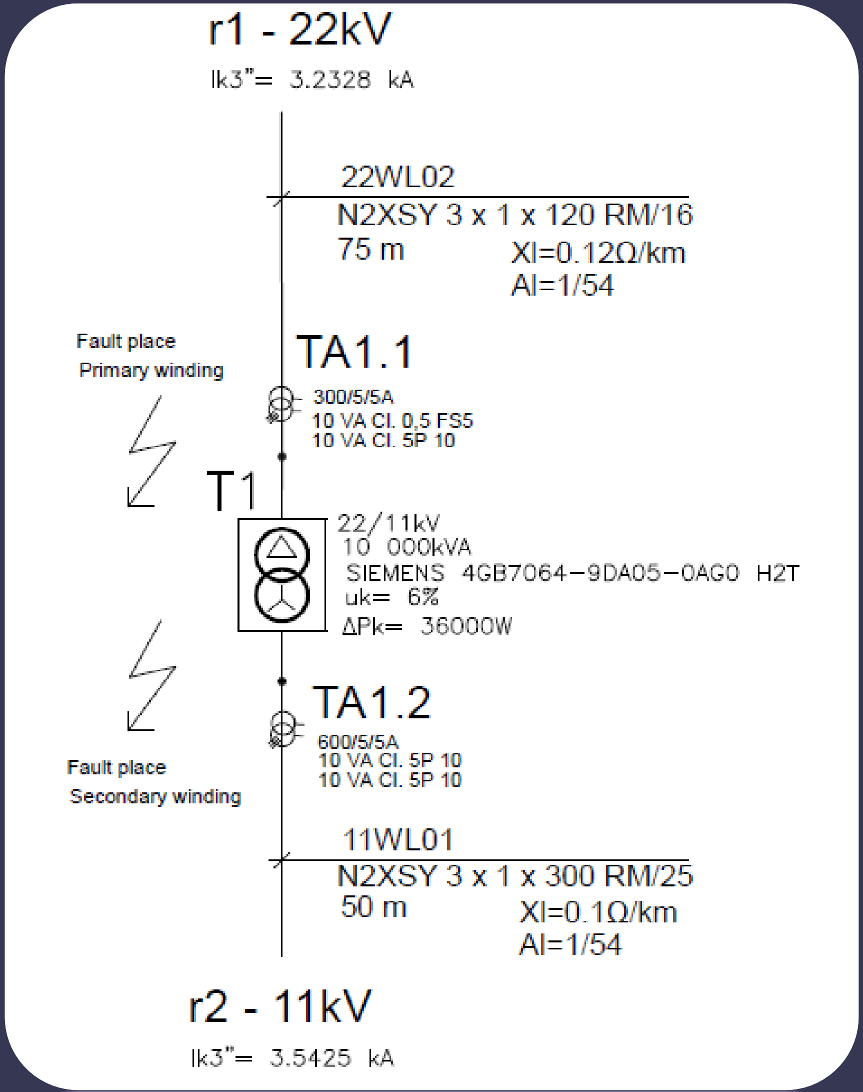
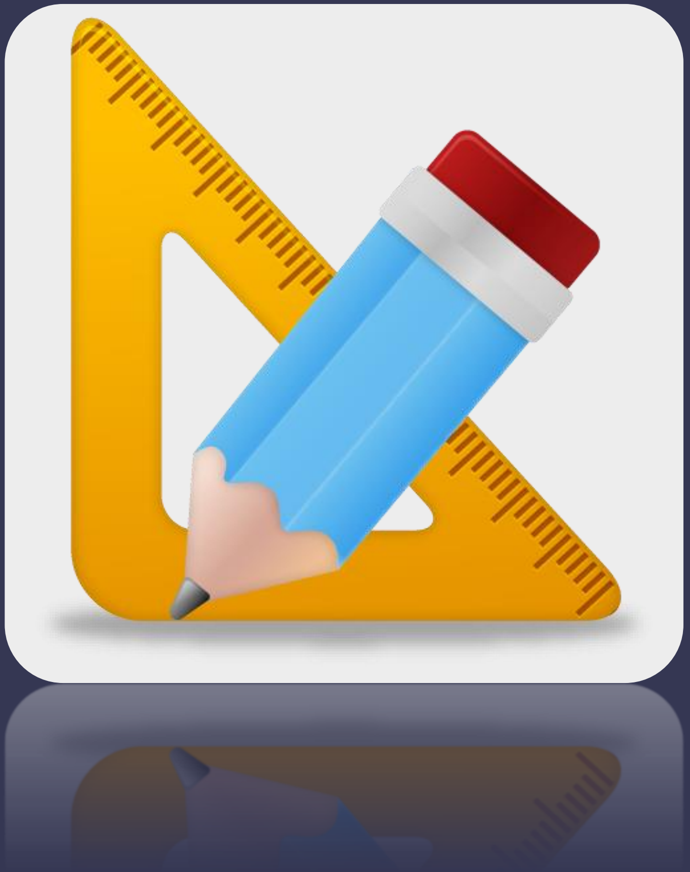


Fig. 15 Sample assignment

Sample connection of set protections and testing



Feeder protection relay SEL-751/751A

Instructional video manual for measuring SEL-751/751A

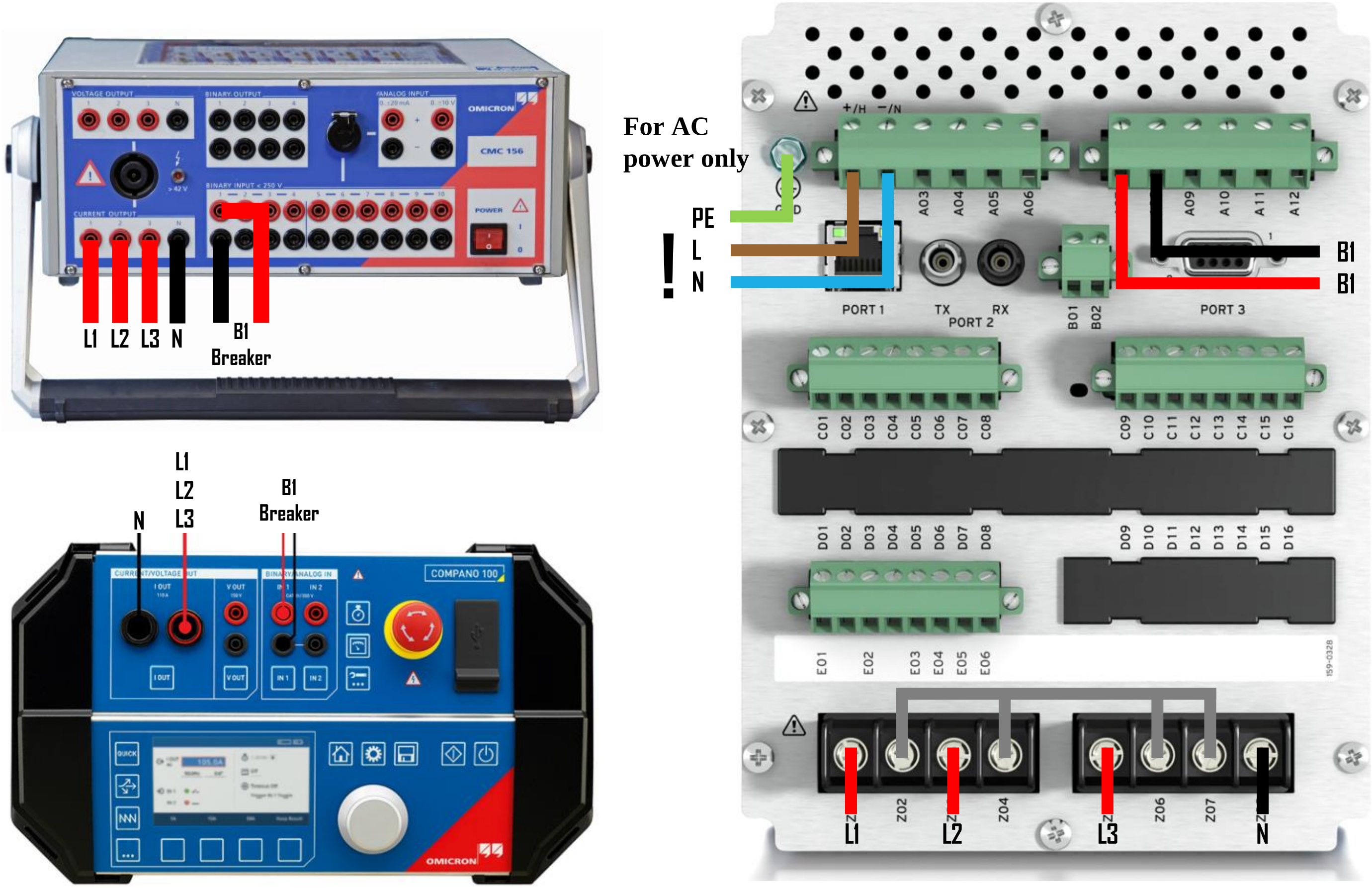
https://selinc.com/products/751/?vidId=117499#tab-video

https://moodle.tuke.sk/moodle/mod/resource/view.php?id=50793

https://www.youtube.com/watch?v=aWA-BxFz1vM&t=1s

Feeder protection relay SEL-751/751A

Wiring diagram from the video measurement manual REF 543



Generator protection relay SEL-700G/700GT

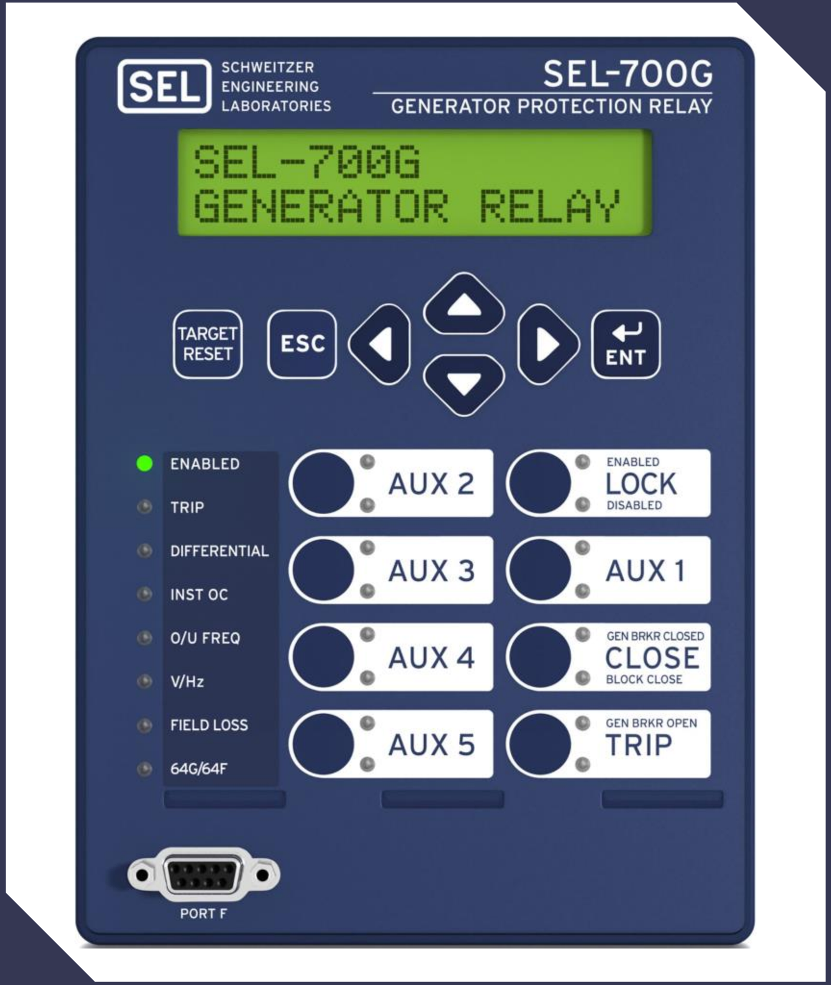
Instructional video manual for measuring SEL-700G/700GT

TUKE moodle

https://moodle.tuke.sk/moodle/mod/resource/view.php?id=50810

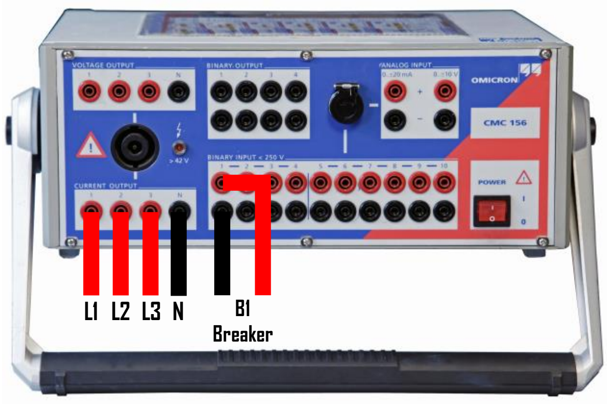
YouTube

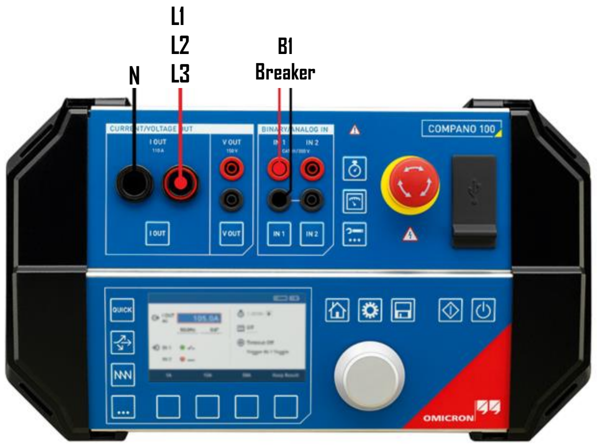
https://www.youtube.com/watch?v=Pk44-tIxNDU

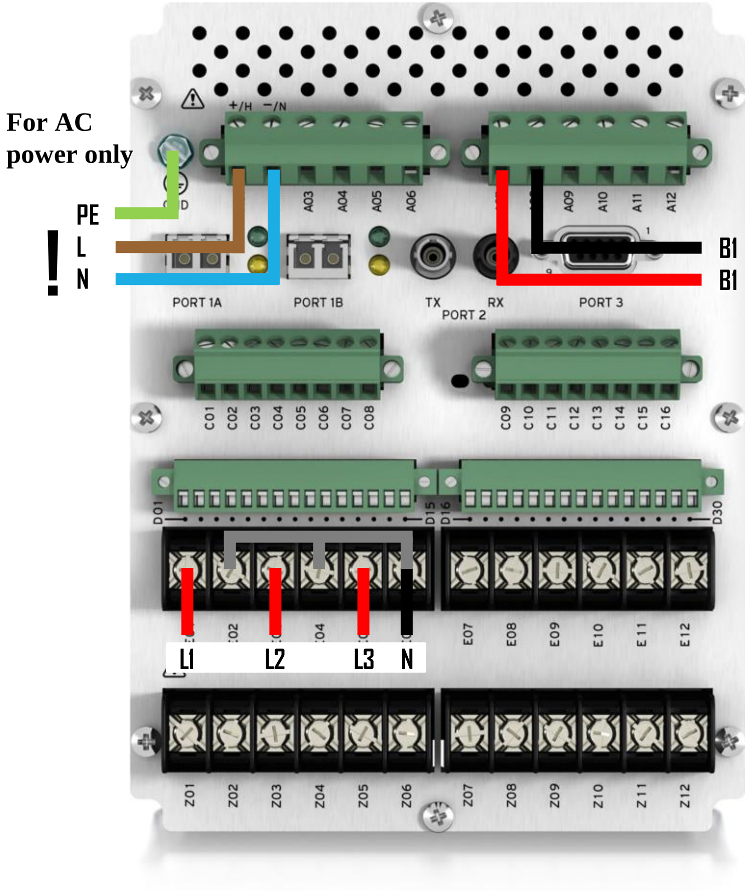


Generator protection relay SEL-700G/700GT

Wiring diagram from the video manual for measuring SEL-700GT







Transformer protection relay SEL-787

Instructional video manual for measuring SEL-787

SEL-787 overcurrent protection

TUKE moodle

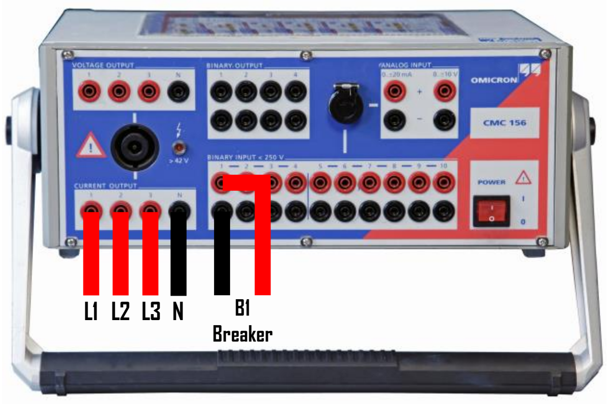
https://moodle.tuke.sk/moodle/mod/resource/view.php?id=50818

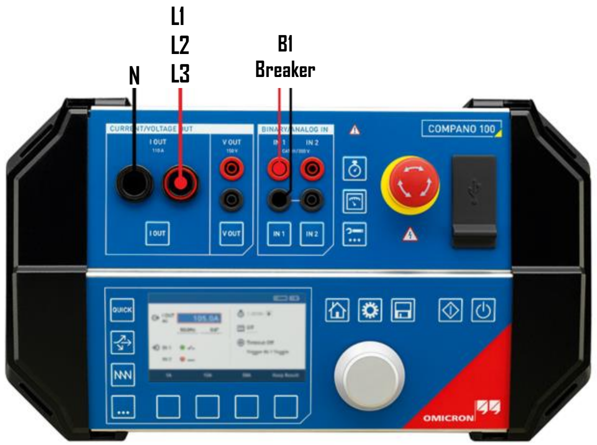
YouTube

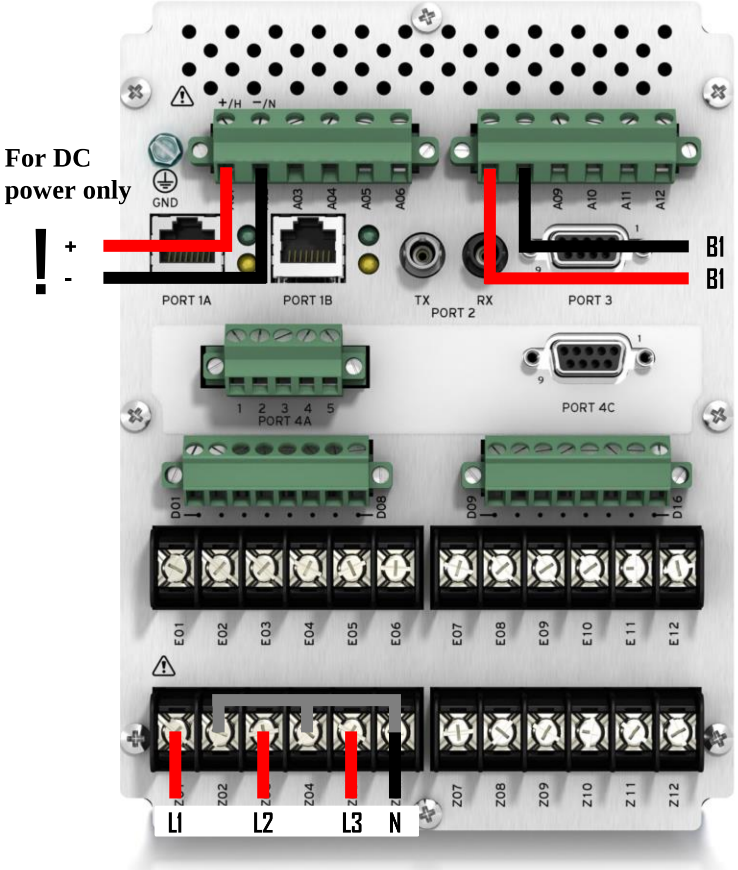
https://www.youtube.com/watch?v=Qm3J9yngE5I

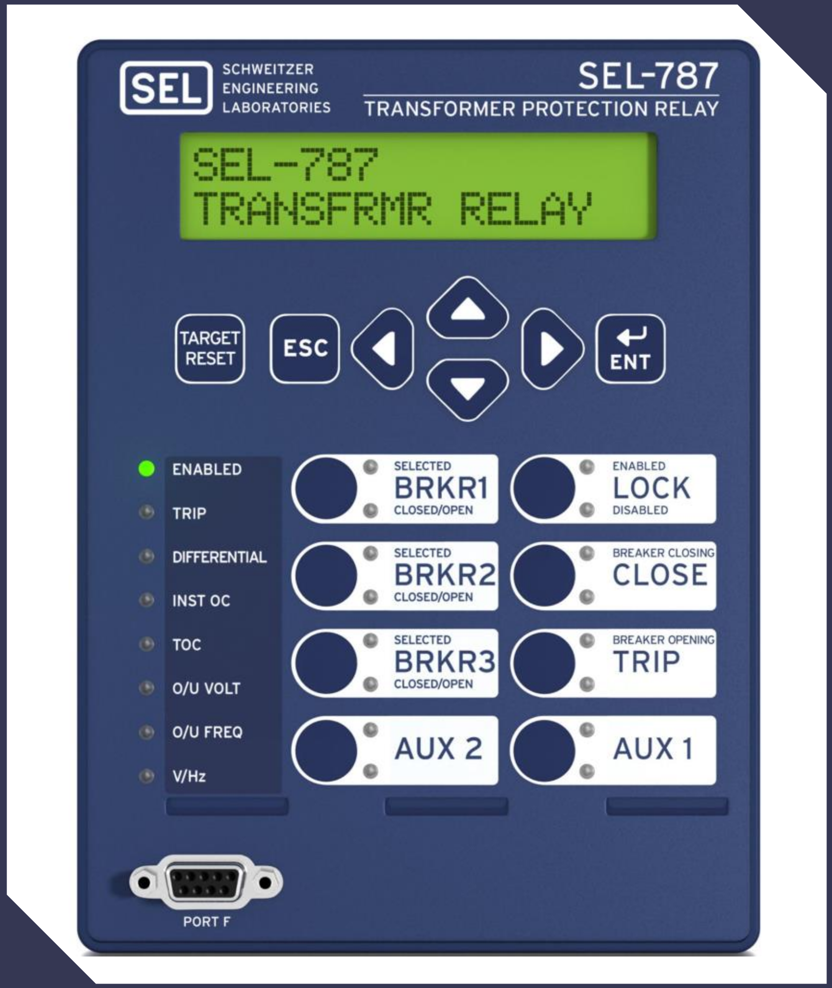
Transformer protection SEL-787 overcurrent primary

Wiring diagram from the video manual for measuring SEL-787



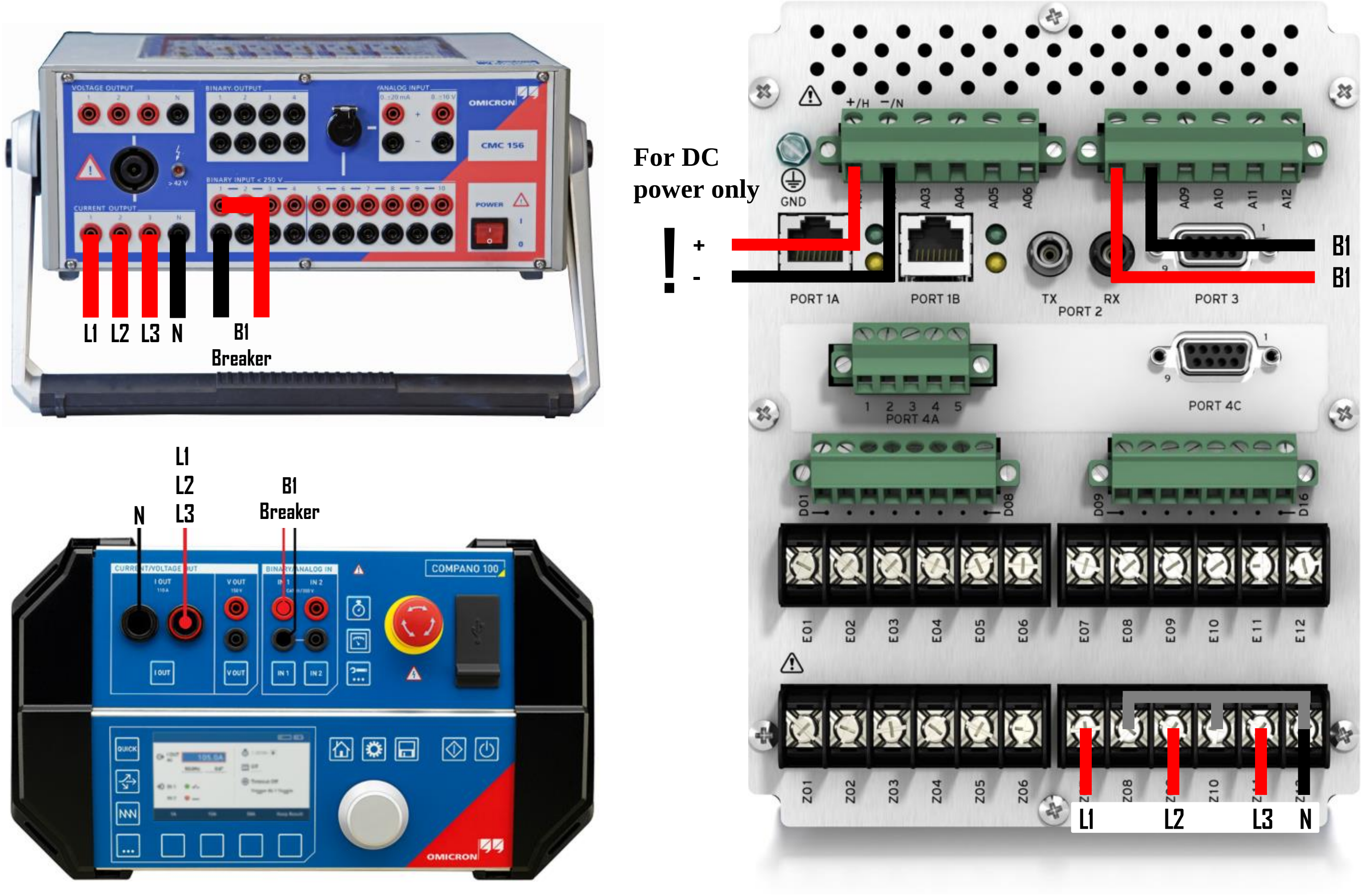






Transformer protection SEL-787 overcurrent secondary

Wiring diagram from the video manual for measuring SEL-787



Transformer protection relay SEL-787

Instructional video manual for measuring SEL-787

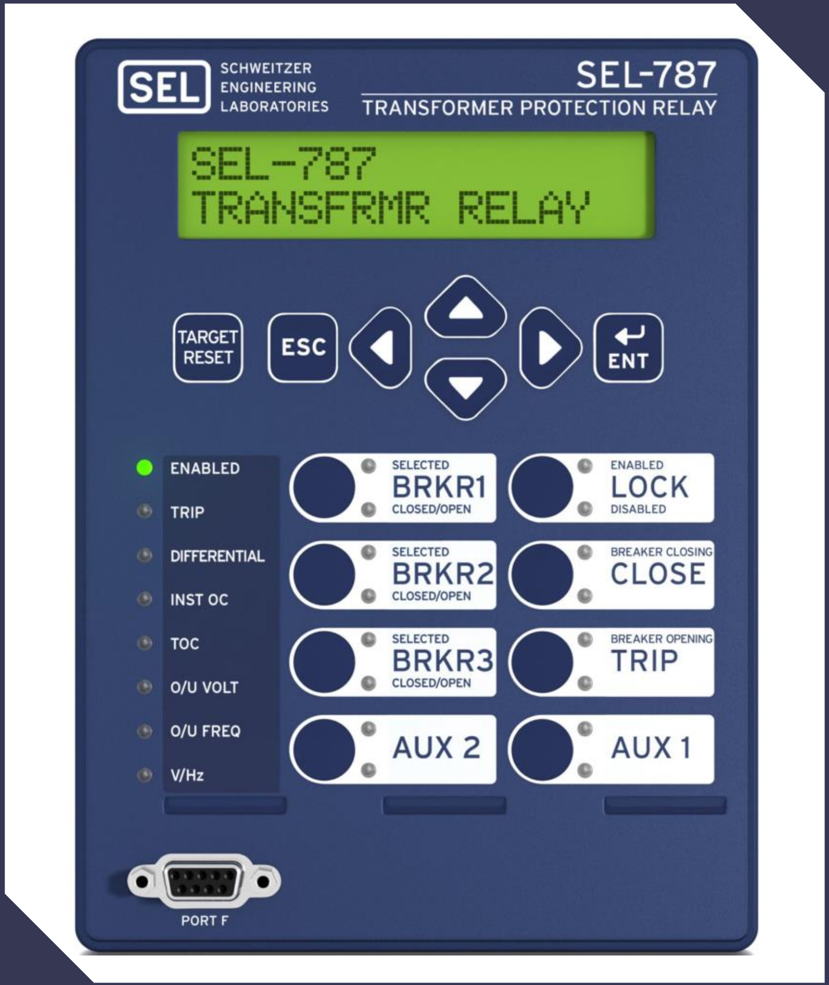
Differential protection SEL-787

TUKE moodle

https://moodle.tuke.sk/moodle/mod/resource/view.php?id=50828

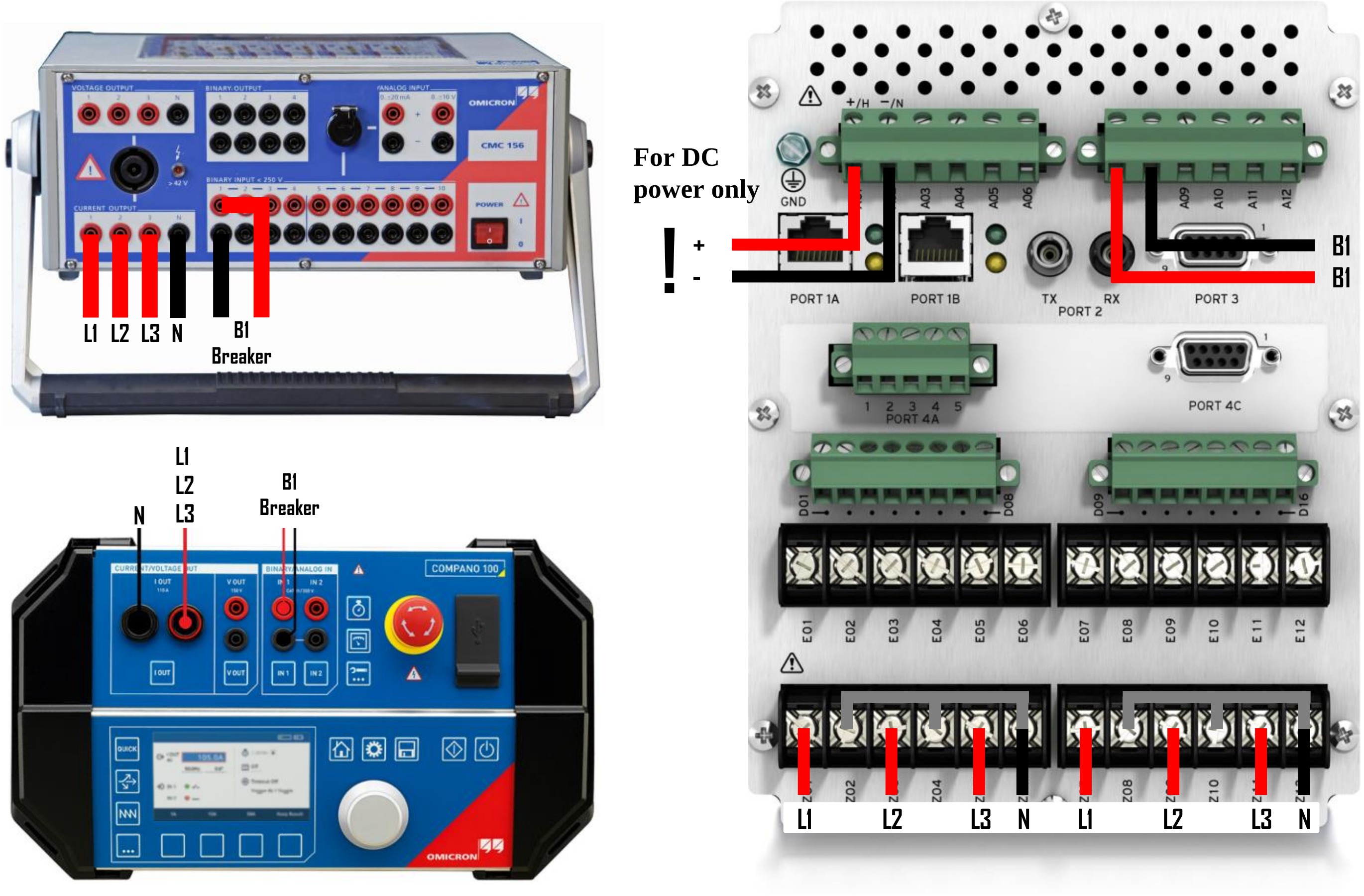
YouTube

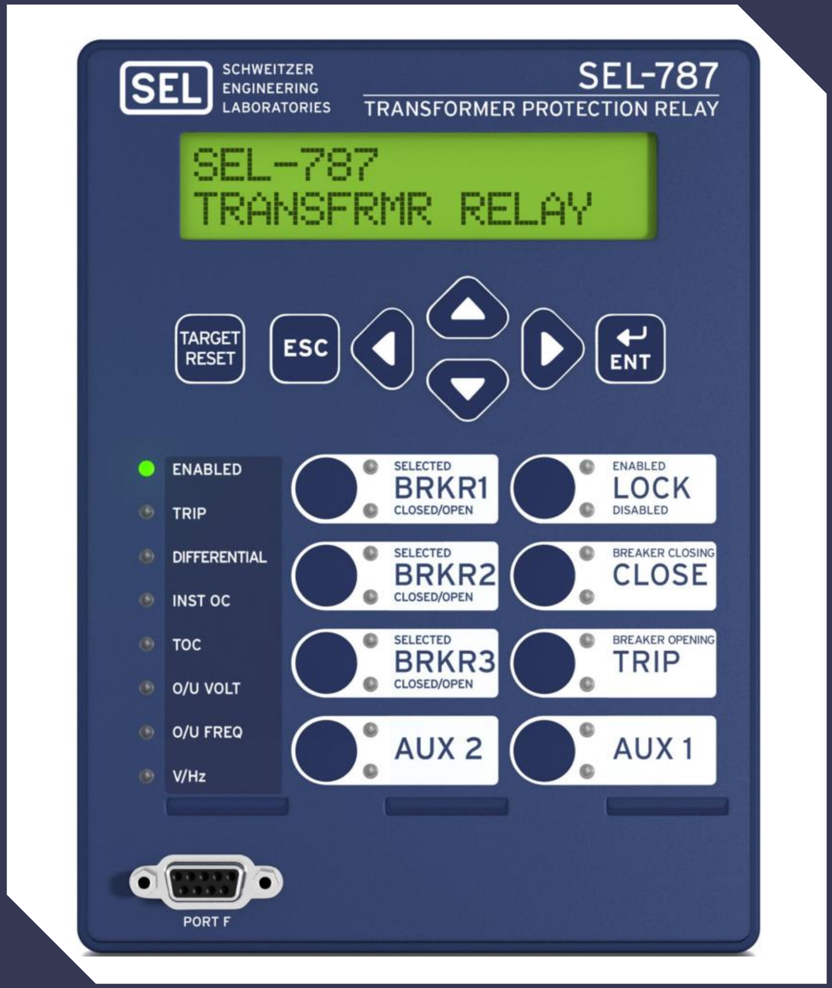
https://www.youtube.com/watch?v=d8hEM48tIh4



Transformer protection relay SEL-787

Wiring diagram from the video manual for measuring SEL-787





Sample connection and testing using SEL-AMS

SEL-AMS relay test system

1. The LEDs on the front panel show the status of the test equipment inputs and outputs
2. Switch for switching on / off the DC power supply 24V and 125V.
3. SEL-AMS (4000) relay test device On / Off Switch

SEL-AMS relay test system

1 Analog outputs for powering current and voltage inputs of the protection relay.

2 Input strip and ground strip

3 DC power supply outputs for 24V and 125V

4 Switching contact output strip

5 SEL-AMS (4000) power connector and ground terminal

SEL-AMS relay test system

SEL-AMS relay test system parameters

Frequency range 10 - 300 Hz

The input signal time must not exceed 255 milliseconds.

The voltage and current range cannot reach 3.535 times the preset output values for each protection relay.

Example for SEL-787

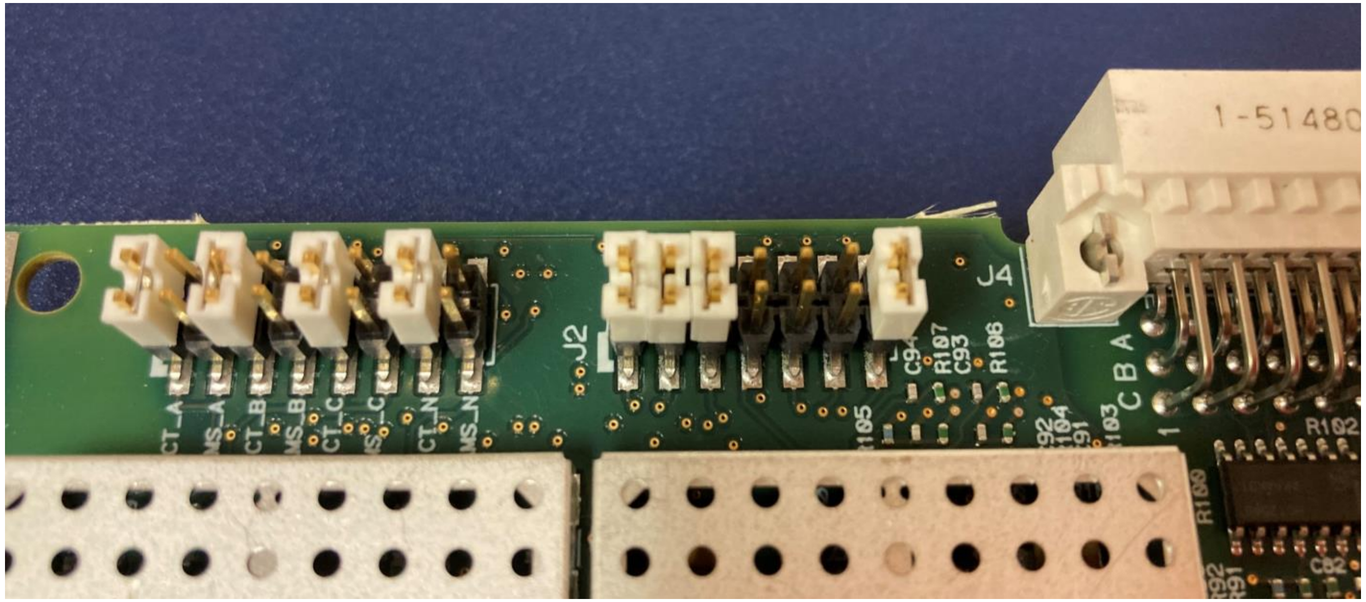
Voltage range 0 - 720 V

Current range 0 - 374.5 A

Software required to control the SEL-5401 tester.

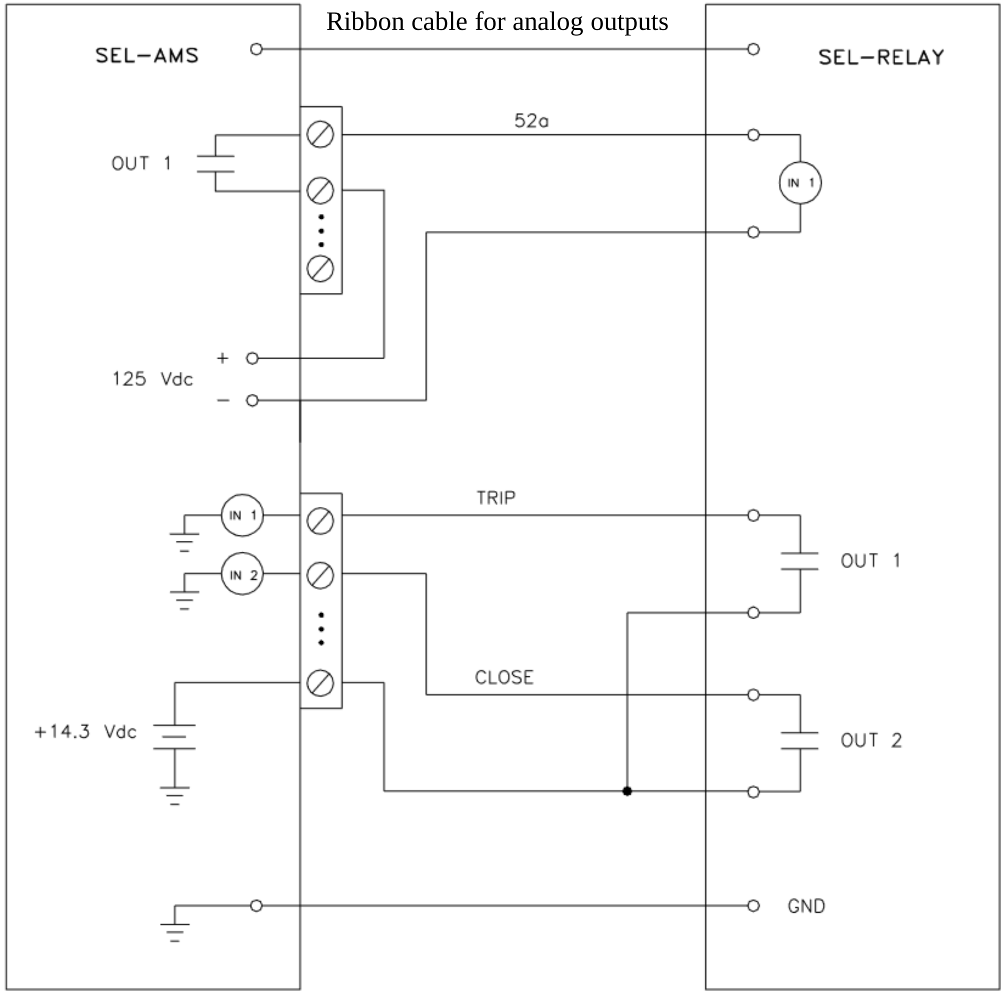
SEL-AMS relay test system

Compatibility with the tested relay is also a condition of using this SEL-AMS relay test system. This can easily be seen by looking at board E (input board for CT and VT), where the inputs for connecting the ribbon cable and the contacts of the AMS must be available.



SEL-AMS relay test system

Wiring diagram of SEL-AMS and tested relay



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Parameterization of protection relays in electrical systems

Published by the Technical University in Košice in 2022
Time New Roman text rate (Microsoft Office)
Cambria Math (Microsoft Office)
115 pages, 15 images, 2 tables
First edition
ISBN 978-80-553-4067-8

The teaching text is intended for students of electrical engineering faculties in study programs focused on electric power engineering, users of electric power equipment, and the professional public.