INTRODUCTION TO THE PARAMETERIZATION OF PROTECTION RELAYS

ELECTRICAL RELAYING IN ELECTRIC POWER SYSTEM

A11
Tk/TK11
AT31/31X
SPAJ 140 C
REF 543

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ABB
ASEA BROWN
BOVERI

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The teaching text describes complex procedures for parameterization of ABB protection relays and mechanical protection relays, a theoretical basis for measuring instrument current transformers, and a description and connection of independent 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.

CONTENTS

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This teaching text enhances the knowledge from lectures and scripts: Electrical protection in the EC (ISBN: 978-80-553-3613-8) and Protection in electrical systems: Exercise instructions (ISBN: 80-7099-133-X) from the subject Electrical protection in the electricity system.

Their understanding and mastery are essential for the follow-up subject Protection systems in electric power systems at the master engineering study.

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Thanks also go to ABB for donating the REF 543 and SPAJ 140C 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 identify 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 with 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.***

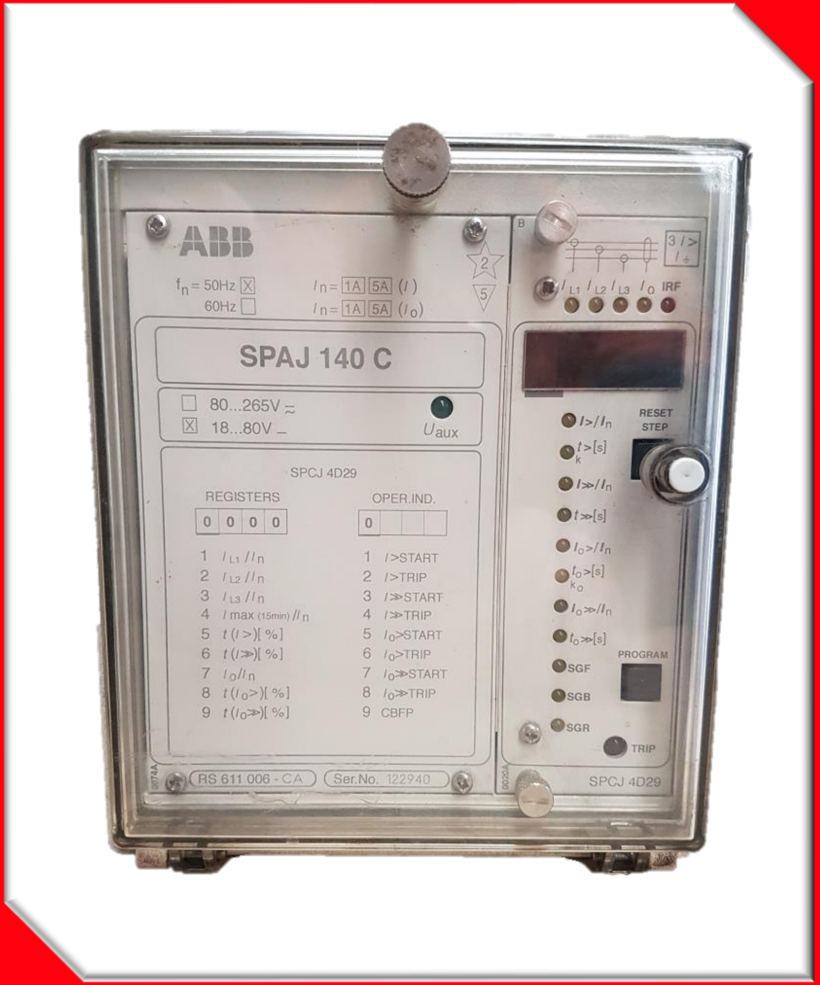
Theory of protections – overcurrent protection

Theory of protections – overcurrent protection

To properly design protections in electrical systems, it is necessary to get acquainted with some key concepts of safety relays. These quantities depend on the design of the relay and are therefore unusual for each relay. ***The nominal values of the relays are indicated on the protection label, especially for the primary and auxiliary circuits.***

<u>The rated consumption</u> of the safety relay Sn is the power consumption in the relay circuits in VA for alternating current or in W for direct current, at the rated value of current (voltage), constant temperature of the relay, and at ambient temperature +20°C. Relay consumption is of great importance for the correct dimensioning of the current and voltage instrument transformers. To start the relay, it is necessary to bring the power input, which must be equal to the minimum consumption of the relay. The consumption of the relay in operation does not have to be equal to the nominal consumption of the Sn relay. ***It is calculated as follows:***

$$S = U_r * I_r \qquad (1)$$



Theory of protections – overcurrent protection

<u>The holding ratio of the protection relay</u> kn is defined as the ratio of the waste value to the starting value. The holding ratio value is always less than one and is given for the unloaded relay contacts. Then the value of the holding ratio is the largest. If the contacts are loaded, then a current will develop through the current passing through the contacts.

<u>The following applies to current relays:</u>

$$k_n = \frac{I_0}{I_r} \qquad (2)$$

<u>Where:</u>

I_0 is the waste value of the relay current [A]

I_r is the inrush current of the relay [A]

<u>The following applies to voltage relays:</u>

$$k_n = \frac{U_0}{U_r} \qquad (3)$$

<u>Where:</u>

U_0 is the waste value of the relay voltage [V]

U_r is the inrush voltage of the relay [V]

Theory of protections – overcurrent protection

<u>Relay time</u> t_{dr} is the time that elapses from the moment of a start to the moment of relay operation (e.g., until the relay contact closes).

<u>The total time of the relay</u> t_{c-dr} is the time that elapses from the moment of start-up to the action of the end relay of the protection. This period consists of several periods of individual articles, which contain protection e.g., start-up cell times, time cell times, end cell times, etc.

<u>The dispersion of the relay</u> $\pm\Delta X_{des}$ is given by the difference between the mean value X determined from 10 measurements and between the extreme value maximum X_{max} and the minimum X_{min}. It is important to know to scatter value, especially for time relays.

It is calculated as follows:

$$+\Delta X_{des} = X_{med} - X_{min} \qquad (4)$$

$$-\Delta X_{des} = X_{med} - X_{max} \qquad (5)$$

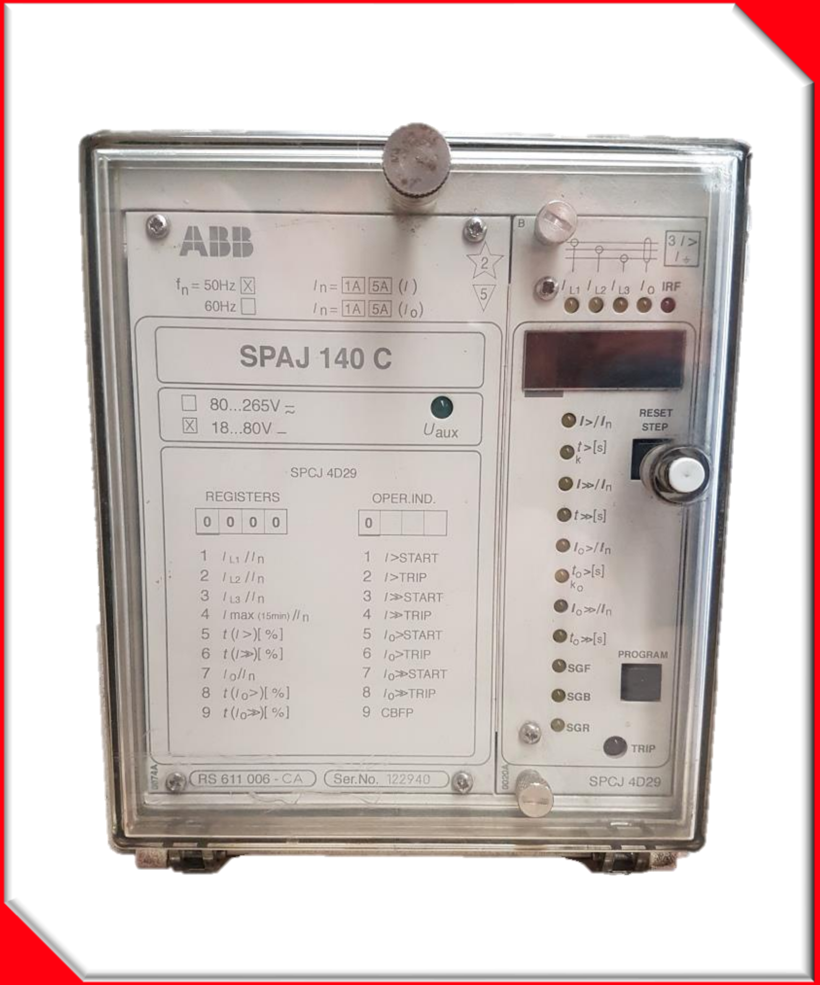
Theory of protections – overcurrent protection

Relay error ΔX is the difference between the detected (measured) start value of relay X_{des} and the set value X_N on the protection or its part. *Calculated according to the relationship:*

$$\Delta X = X_{des} - X_N \qquad (6)$$

The relative error of the relay ΔX_r is given as the ratio of the absolute error of the relay ΔX and the set value of the relay X_N and is given as a percentage. The absolute and relative errors of the relay can have a positive or negative value. *It is calculated as follows:*

$$\Delta X_r = \frac{\Delta X}{X_N} * 100 = \frac{X_{des} - X_N}{X_N} * 100 \qquad (7)$$



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

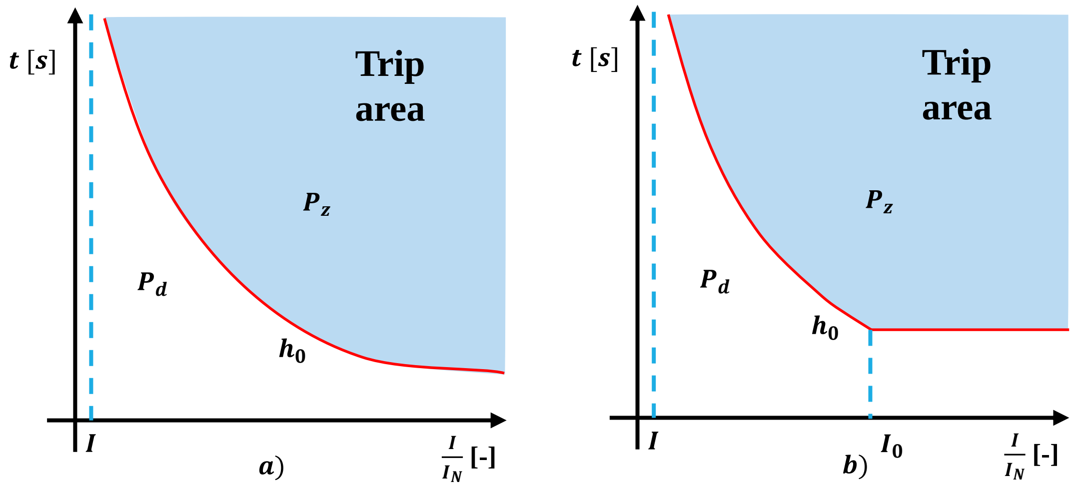


Fig. 1 Speed characteristics a) time-dependent; b) semi-dependent

Theory of protections – overcurrent protection

<u>Definite time</u> - acts according to the set time t> when the current kI> is reached. For larger currents I/IN > kI> already has a constant operating time and does not depend on the current change.

<u>Immediate</u> - acts when the set current kI> 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

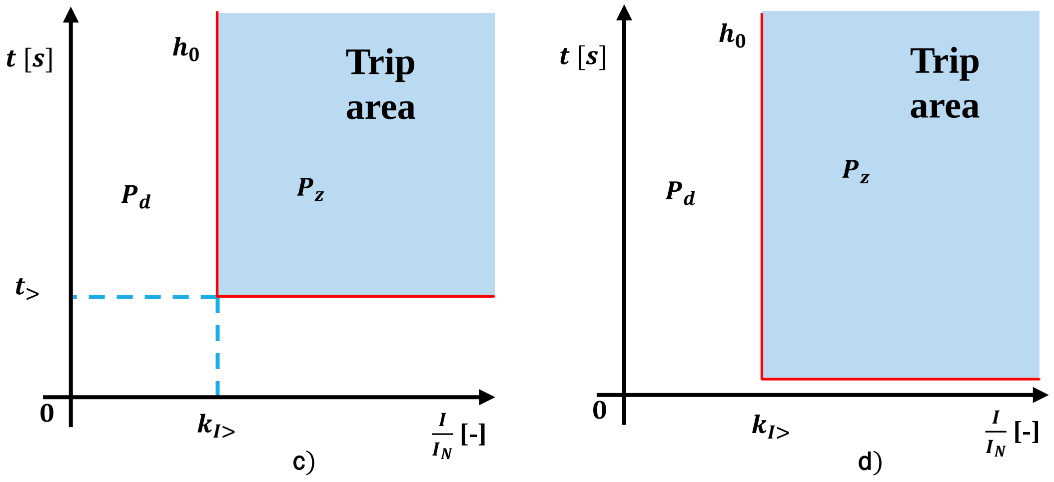
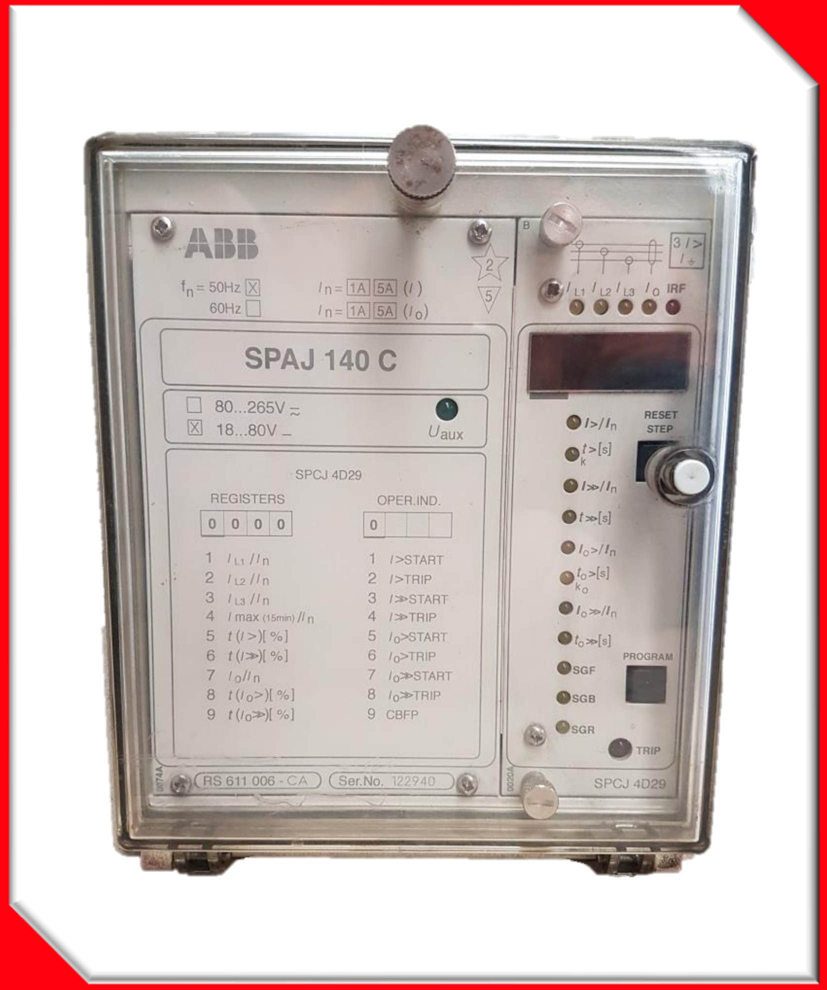


Fig. 2 Speed characteristics c) definite time; (d) immediately acting



Theory of protections – overcurrent protection

The setting of unique 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 grave 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 rare 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

<u>**Determining the size of the time coordination interval Δt:**</u>

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

<u>**Setting the starting current I_r:**</u>

- <u>**the starting current of the relay I_r must be greater than I_n:**</u>

$$I_r \geq I_n * \frac{k_b}{k_p * p_i} \qquad (8)$$

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

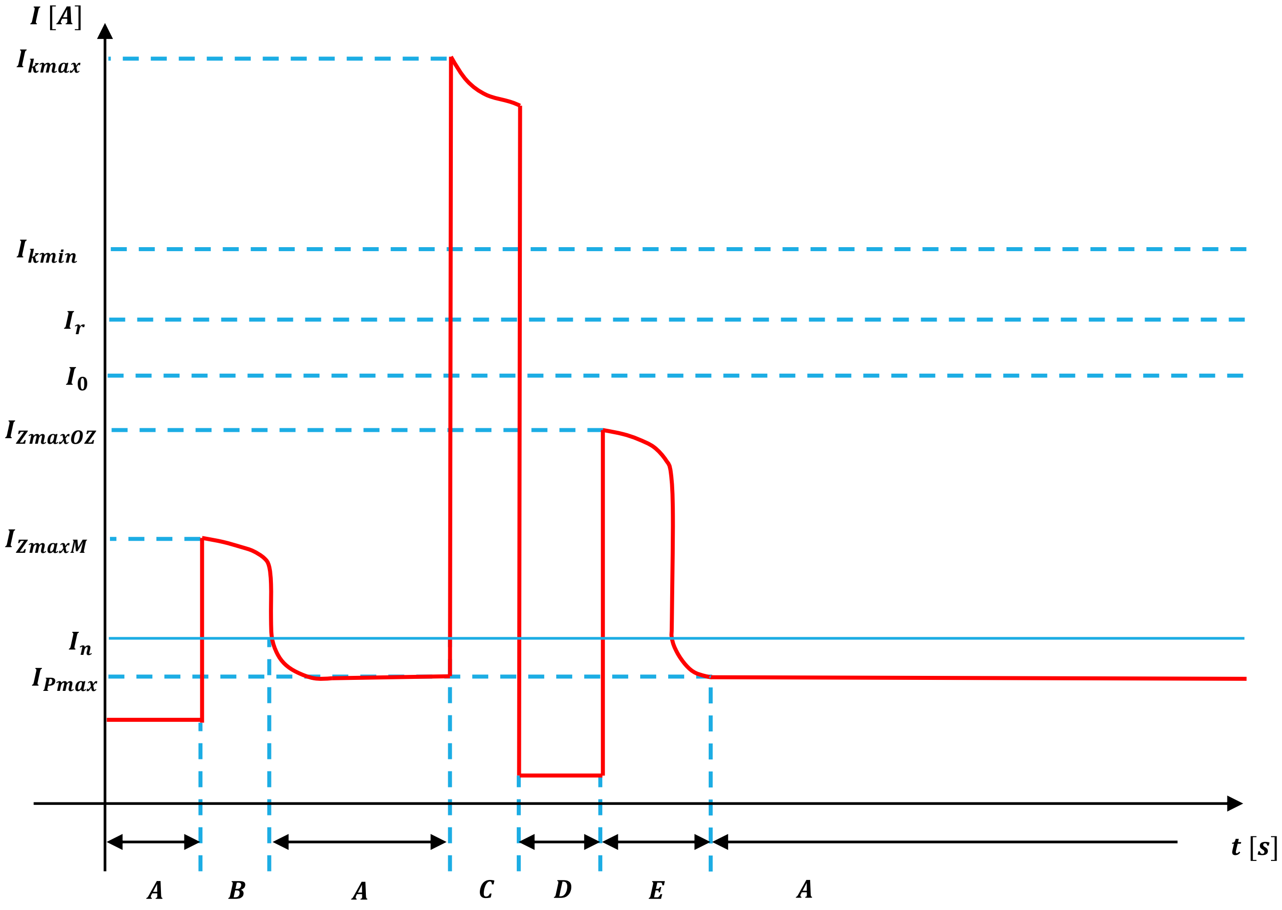
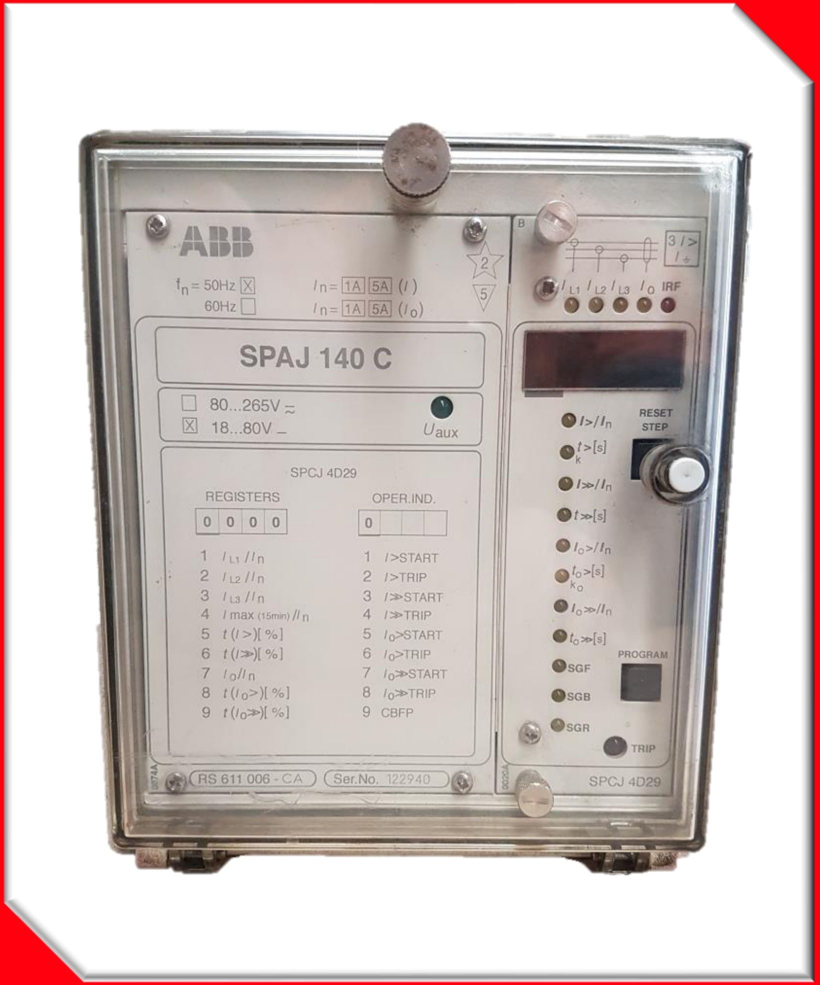


Fig. 3 Current ratios for various operating and fault conditions



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.

$$I_r \leq I_{k2fmin} * \frac{1}{k_c * p_i} \qquad (9) \qquad\qquad k_c = \frac{I_{k2fmin}}{I_r * p_i} \qquad (10)$$

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 k_c 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 I_r. This change in protection will start at lower currents.

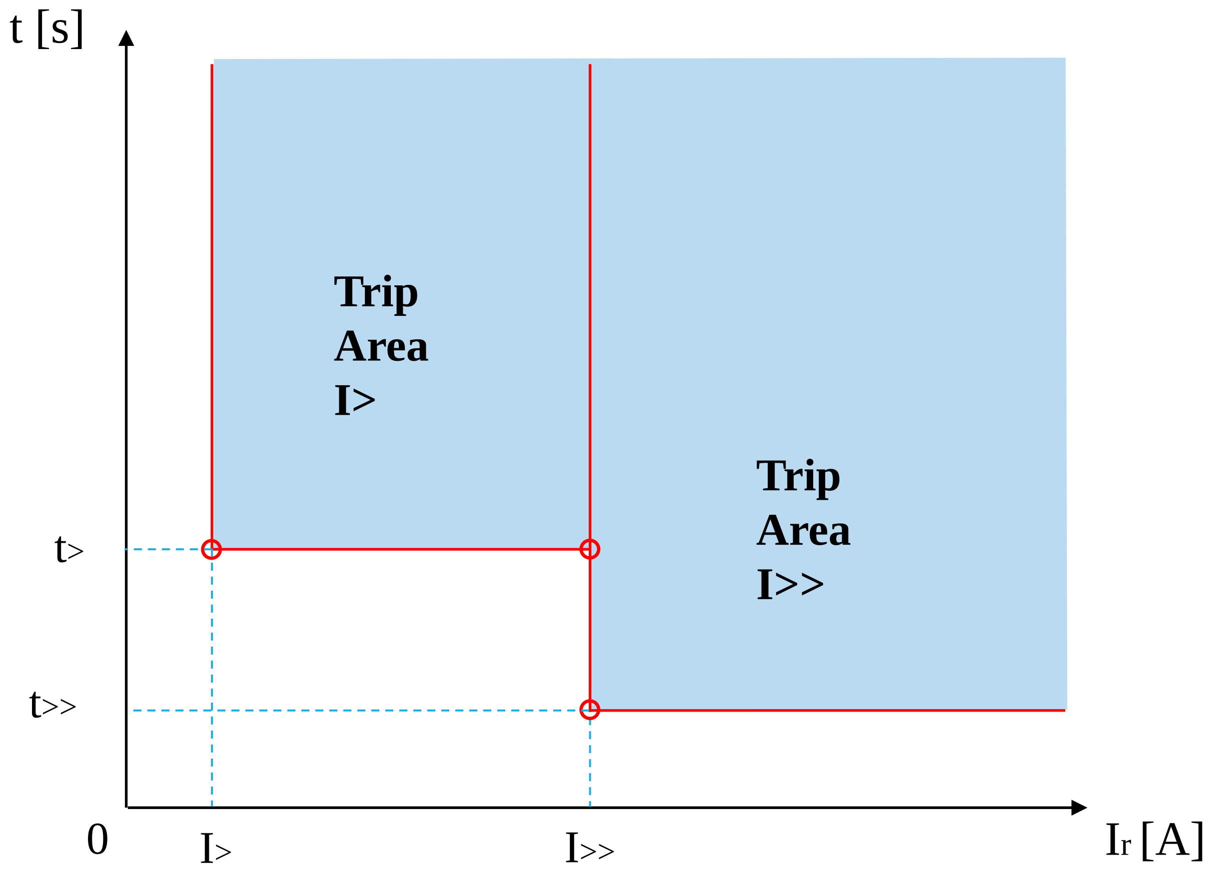
Setting of overcurrent protections

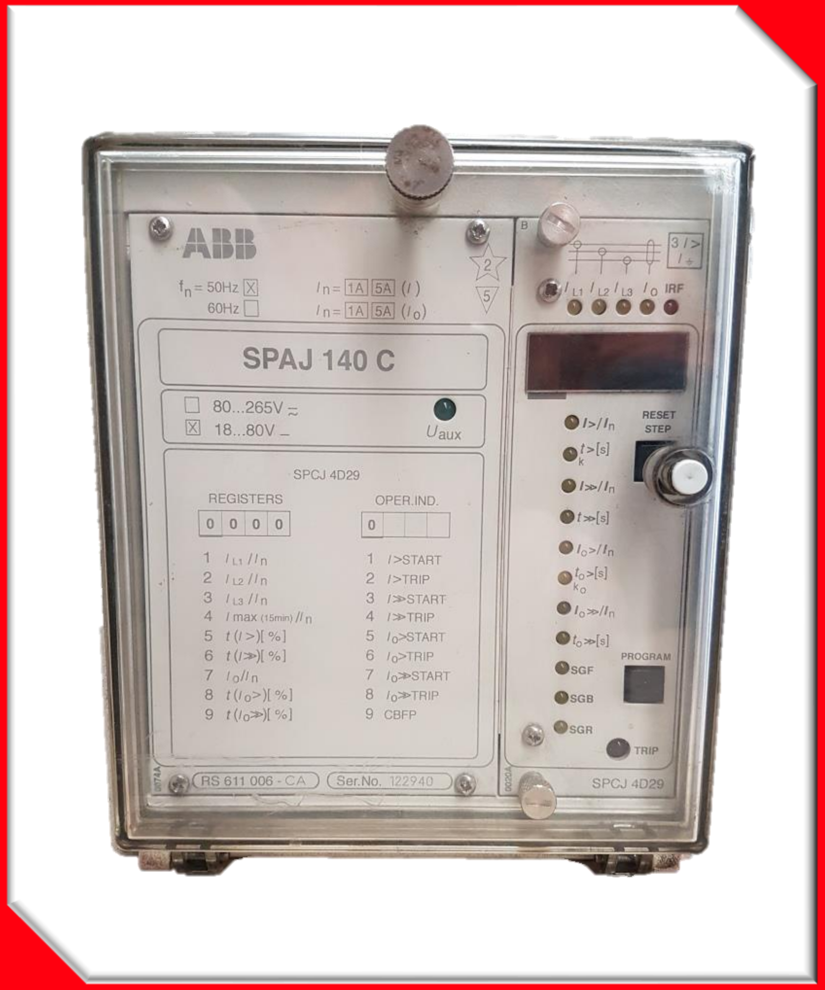
The three-phase short-circuit current is usually the largest. In the event of a short circuit in the vicinity of a transformer with a grounded node or a grounding transformer, the single-phase short-circuit current may be greater than the three-phase. This is especially true for transformers with Yz, 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





Theory of CT

Theory of CT - overcurrent number

<u>The rated conversion</u> k_I of the instrument current transformer is the ratio of the rated primary current I_{1n} to the rated secondary current I_{2n} i.e.:

$$k_I = \frac{I_{1n}}{I_{2n}} \qquad (11)$$

Let ΔI be the projection of the current phasor $\dot{I}_2$ from the current phasor $\dot{I}_1$. This current ΔI represents the <u>absolute current error</u> of CT and is given by:

$$\Delta I = k_I * I_2 - I_1 \qquad (12)$$

<u>The relative current error</u> ε_I is given by:

$$\varepsilon_I = \frac{\Delta I}{I_1} * 100 = \frac{k_I * I_2 - I_1}{I_1} * 100 \qquad (13)$$

Theory of CT - overcurrent number

The actual value of the external load Z_s is given by the sum of the impedances of the devices and leads connected to the secondary terminals of the current transformer. Thus, the load cannot exceed the nominal current I_{2s}.

$$U_{2s} = Z_s * I_{2s} \rightarrow Z_s = \frac{U_{2s}}{I_{2s}} \qquad (14)$$

The rated load Z_n of the current transformer is the impedance that can be connected to the secondary terminals of the CT, while the permissible current error in the measuring range is unexceed.

$$Z_n = \frac{S_n}{{I_{2n}}^2} \qquad (15)$$

The overcurrent factor n of the safety current transformer is defined as n-times the rated primary current I_{1n} at which the total current transformer error gains a specified value of 5% or 10% (accuracy class CT 5P or 10P).

Theory of CT - overcurrent number

<u>**The rated overcurrent number**</u> **n_n of the instrument current transformer is n_n multiple of the rated primary current I_{1n}, at which the relative error of the secondary current I_2 reaches ε_I = -10% of the total secondary current if the CT is loaded with the rated load Z_n, at the rated secondary power factor cosβ 0.8 inductive and at nominal frequency f_n.**

$$n_n \cong n_s * \frac{Z_s}{Z_n} \rightarrow n \cong n_n * \frac{Z_n}{Z} \; alebo \; n_n * \frac{S_n}{S} \qquad (16)$$

<u>The value of the primary current</u> at which the error of the secondary current reaches -10%.

$$I_1' = n_s * I_{1n} \qquad (17)$$

<u>The actual value of the overcurrent number</u> is determined from the relation:

$$n_s = \frac{I_1'}{I_{1n}} \cong n_n * \frac{Z_n}{Z_s} \qquad (18)$$

Theory of CT - overcurrent number

Total load **$\dot{Z}_c$, which is given by the phasor sum of the outer and inner load of the current transformer:**

$$\dot{Z}_t = \dot{Z} + \dot{Z}_i = \sqrt{(Z_n * \cos\beta + R_2)^2 + (Z_n * \sin\beta + R_2 * \tan\beta_i)^2} \quad (19)$$

We construct a line with the directive U_0/I_0 = 9*Z_t, which passes through the origin of the coordinate system. This line intersects the no-load characteristic at point A. The horizontal coordinate of point A is the magnitude of the sought current I_0', which is needed to determine the overcurrent number:

$$n = \frac{I_0'}{0{,}1 * I_{2n}} = 10 * \frac{I_0'}{I_{2n}} \quad (20)$$

However, this method has its limitations, and therefore the overcurrent number is determined according to point B, which is determined as the intersection of the characteristic and the line with the directive U_0/I_0 = 7*Z_t. The vertical coordinate of point B is the sought voltage U_{0n}. The overcurrent number is determined from the relationship:

$$n = \frac{U_{0n}}{0{,}9 * I_{2n} * Z_c} \quad (21)$$

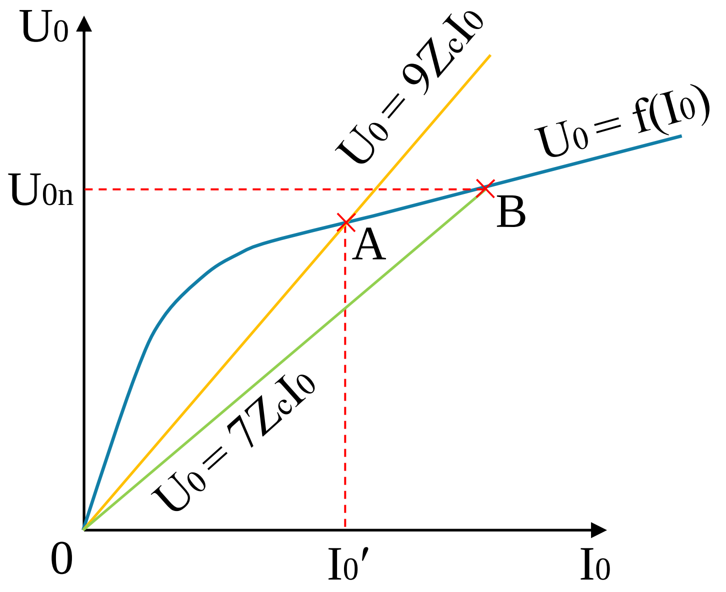


Fig. 4 Magnetization characteristic of CT

Theory of CT - overcurrent number

Determining the values of U_{lim}, I_{lim} from the definition according to the relative current error is difficult. The U_{lim} and I_{lim} values determine how much the current transformer magnetic circuit should be oversized compared to the standard version so that it does not oversaturate the unidirectional component of the AC:

$$U_{lim} > n_n * \left(\frac{S_n}{I_{2n}} + R_2 * I_{2n}\right) \qquad (22)$$

and current limit size:

$$I_{lim} > n_n * I_{2n} * \delta \qquad (23)$$

Let us denote the current component ΔI_q, which represent the projection of the phasor $\dot{I}_0$ perpendicular to the phasor of the primary current $\dot{I}_1$. This component of the current in relative values represents the angular error of CT and is given by:

$$\delta = \frac{\pi}{180} * \delta_{st} = \tan \delta_{st} = \frac{\Delta I_q}{I_1} \qquad (24)$$

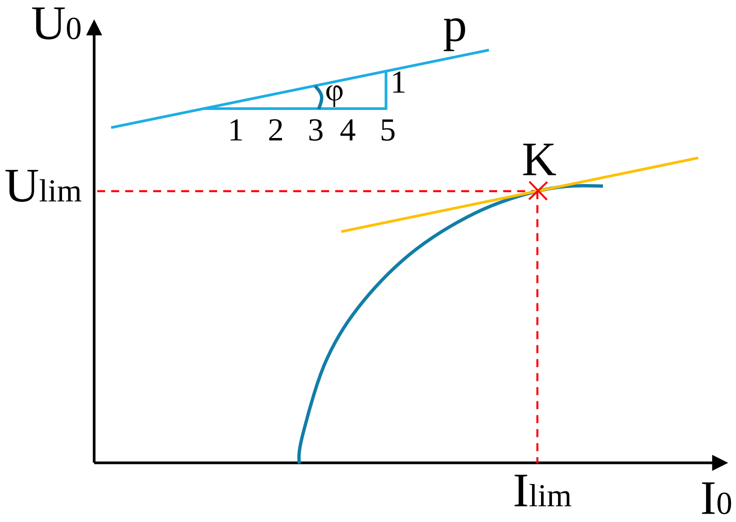
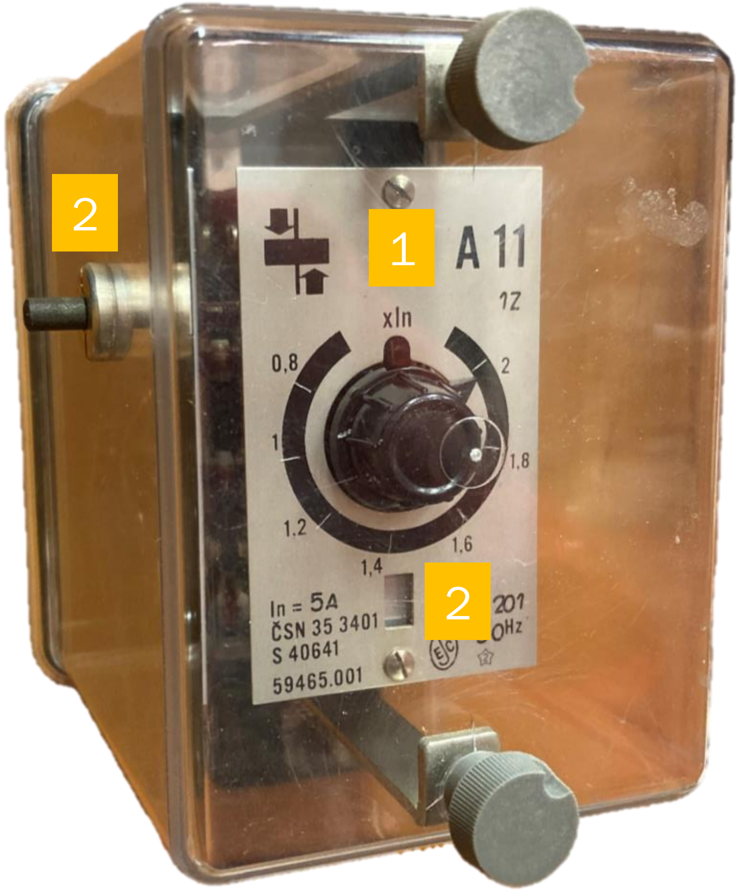


Fig. 5 Magnetization characteristics of CT in logarithmic scale

Description of protection relays

Overcurrent relay A11



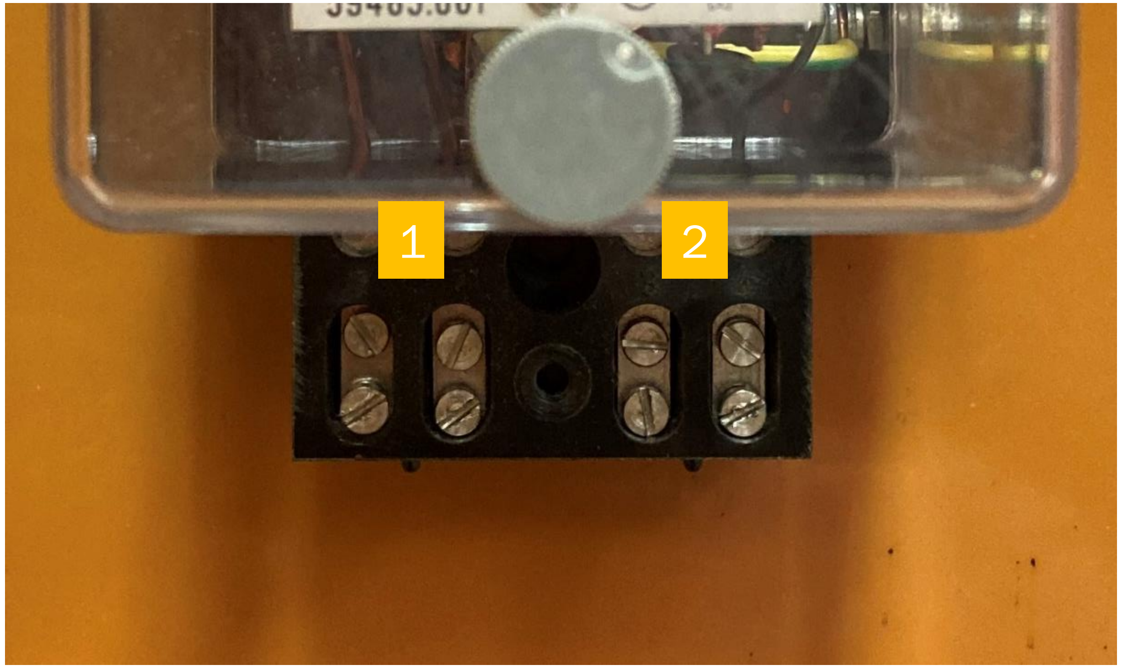
1 Scale with rotary switch 4-10 A

2 Status signaling reset button

Overcurrent relay A11

1 Power inputs (1; 2)

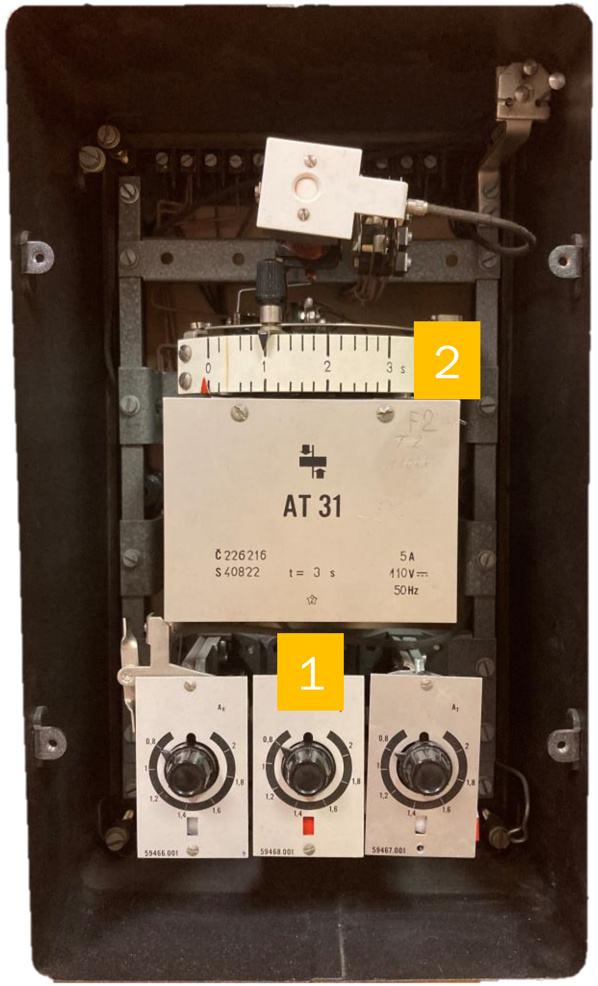
2 Relay outputs (3; 4)



Overcurrent time-independent relay AT 31

1 Scale with rotary switch 4-10 A, for three overcurrent starting cells AR (L1), AS (L2), and AT (L3).

2 Scale with 0-3 s rotary switch, which consists of a mechanical time element.



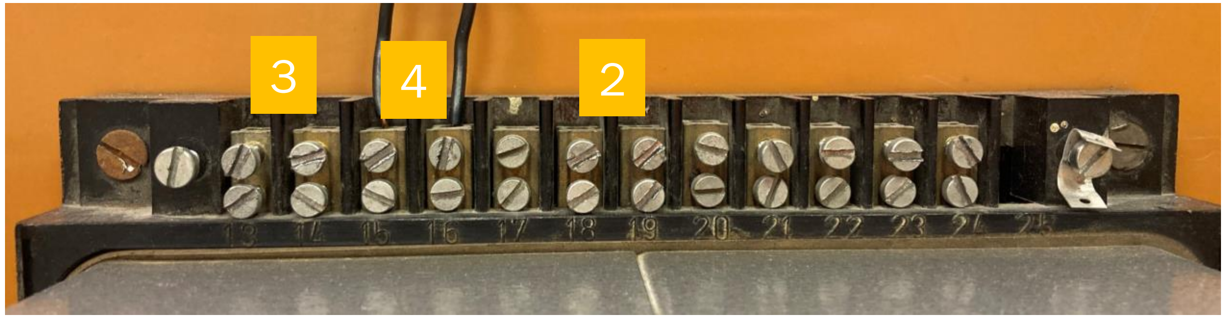
Overcurrent time-independent relay AT 31

1 AC power inputs (7; 10), (8;11), (9;12)

2 Relay output (18; 19)

3 DC power inputs 110 V (13; 15)

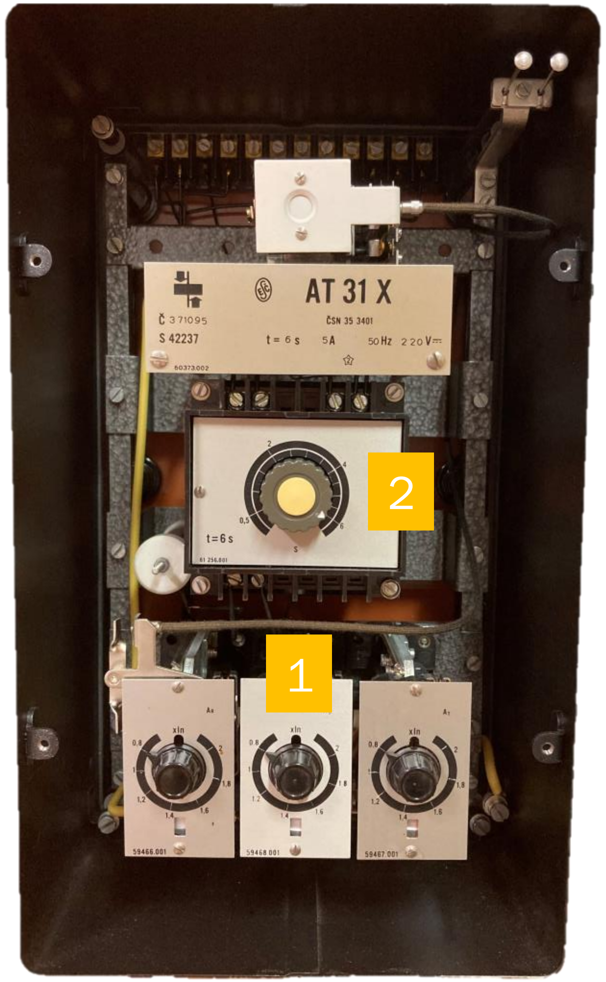
4 Time member power input (14; 16)



Overcurrent time-independent relay AT 31X

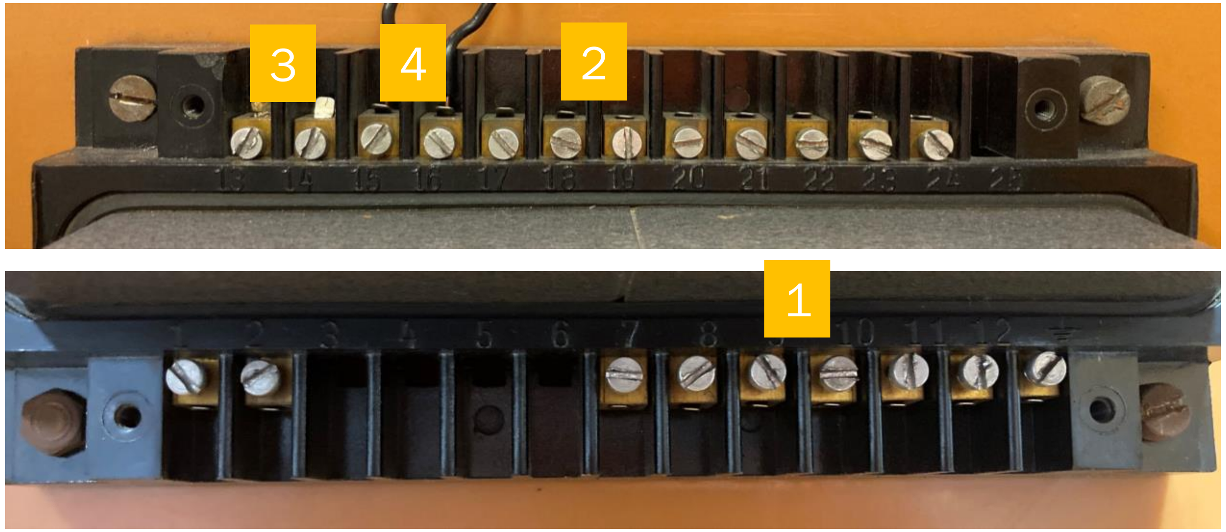
1. Scale with rotary switch 4-10 A, for three overcurrent starting cells AR (L1), AS (L2), and AT (L3).

2. Scale with a 0.5-6 s rotary switch, which consists of an electronic time cell.



Overcurrent time-independent relay AT 31X

1	AC power inputs (7; 10), (8;11), (9;12)	2	Relay output (18; 19)
3	DC power inputs 220 V (13; 15)	4	Time member power input (14; 16)



Overcurrent time-independent relay AT 31/31X

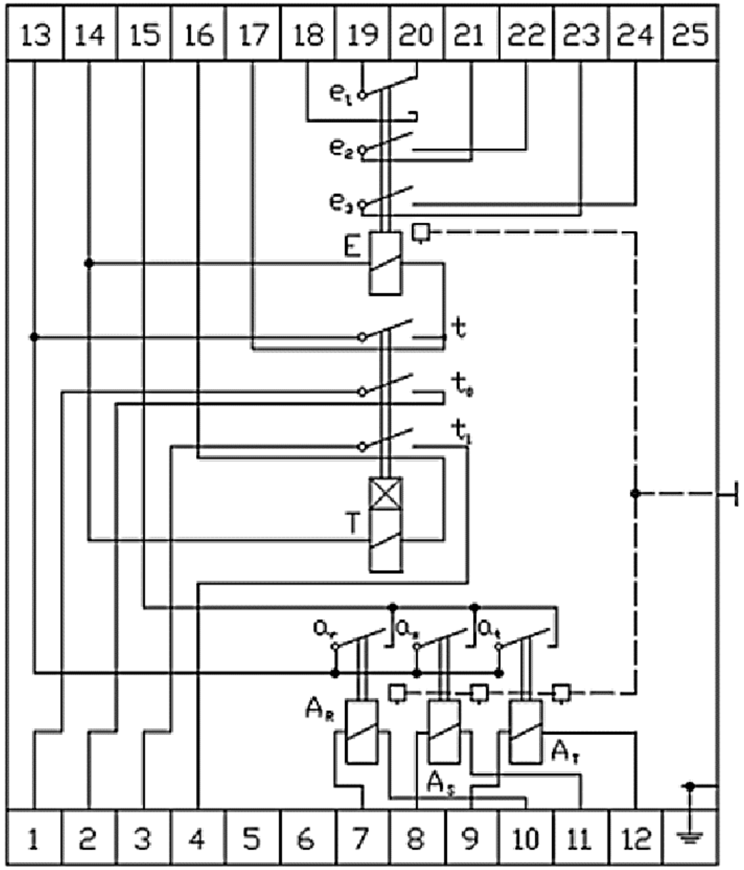
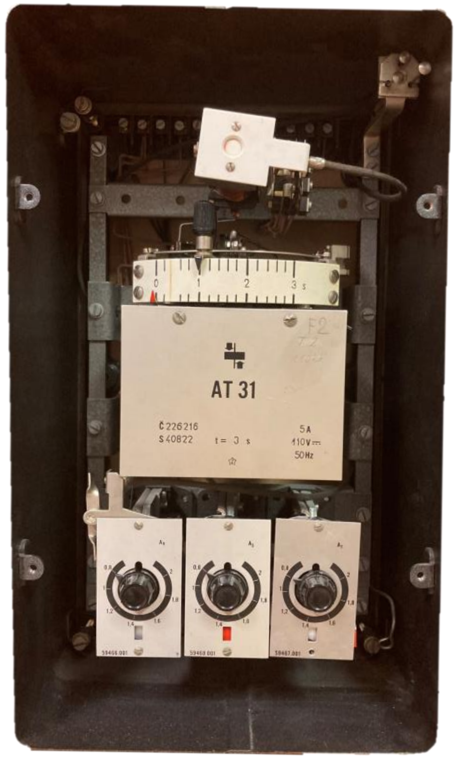


Fig. 6 Internal connection of AT31 / AT31X protection



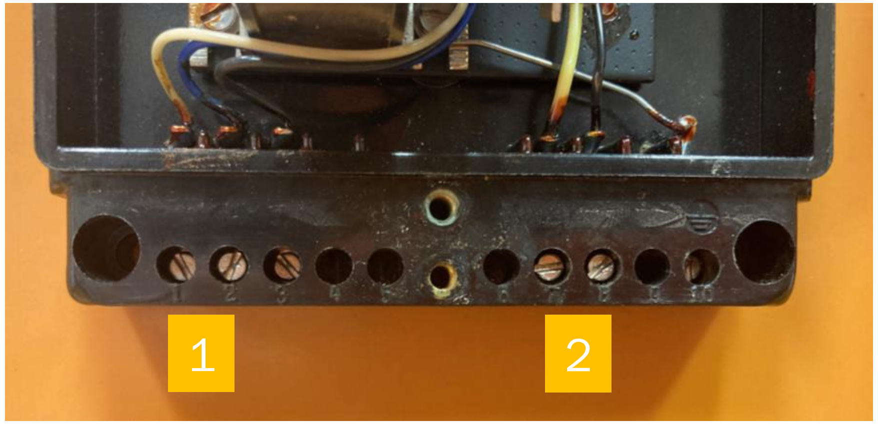
Time relay Tk/TK11

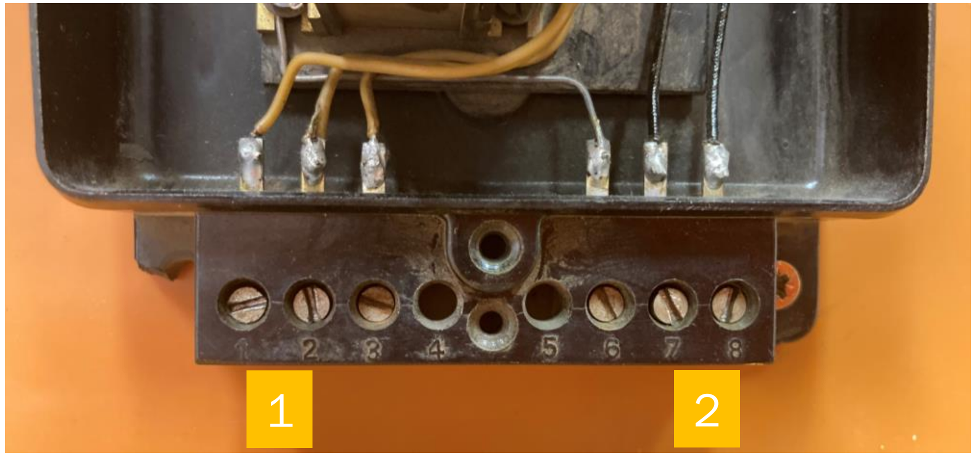
1 Scale with slide switch 5-20 s, which consists of a mechanical time element.

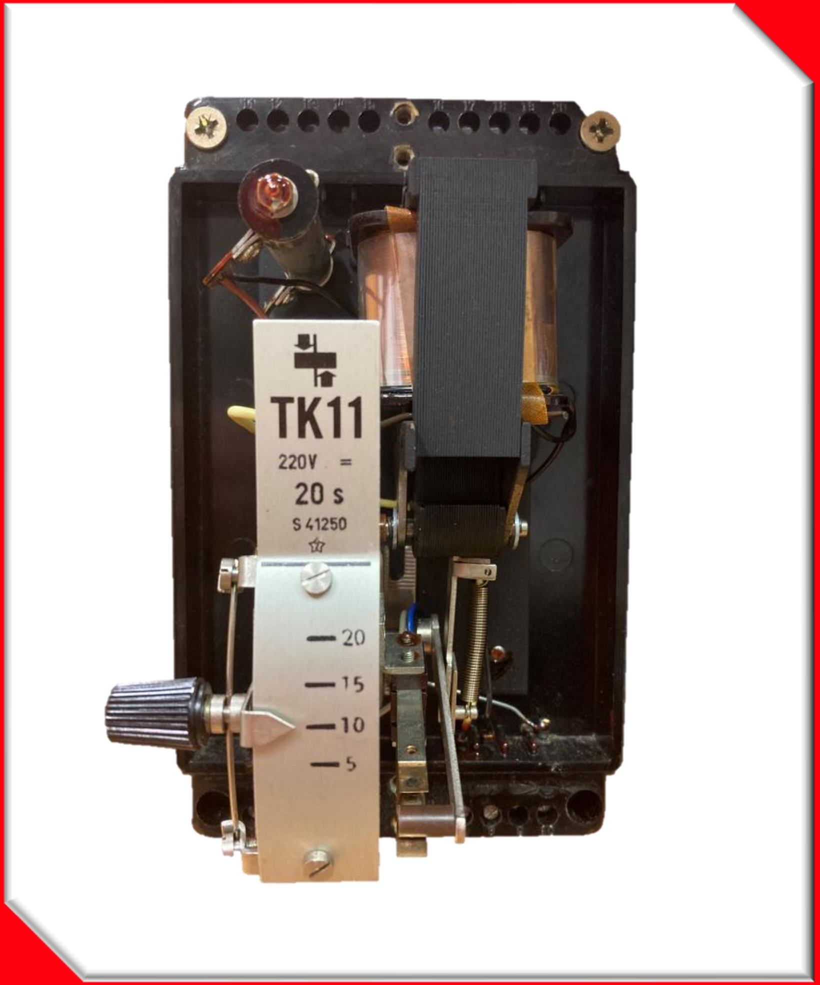
Time relay Tk/TK11

1 Power inputs (1; 2)

2 Relay output (7; 8)







Feeder terminal REF 543

1 LCD display with graphical interface

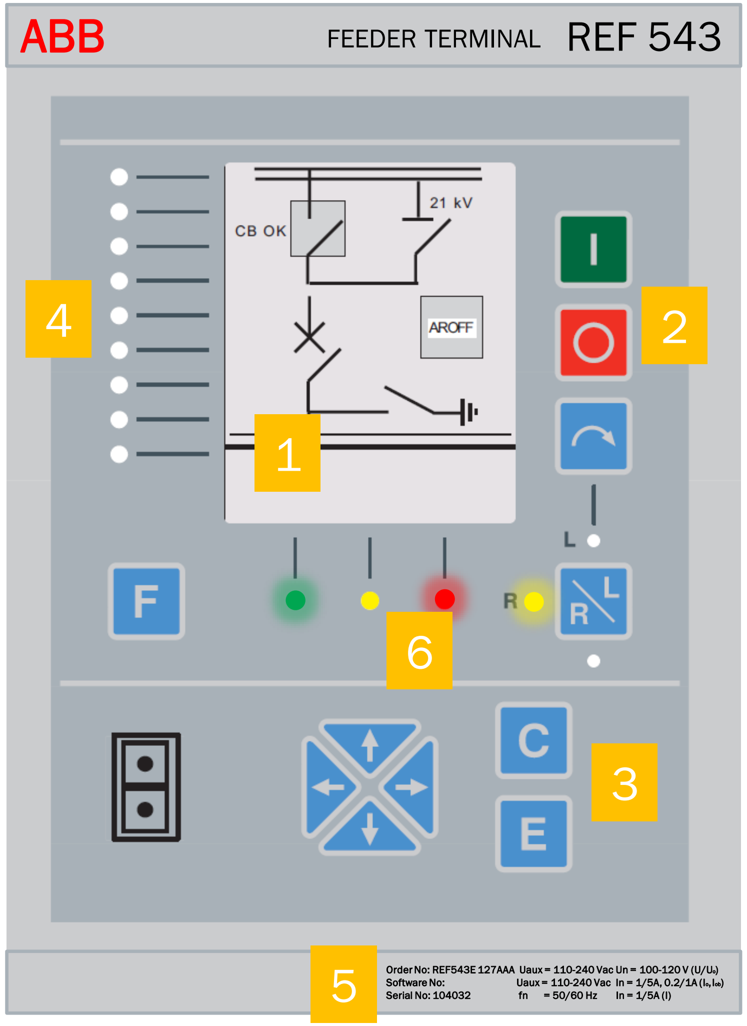
2 Controls for manipulation in the diagram

3 Buttons to move in the menu

4 Programmable LEDs for signalling and alarms

5 Description of protection, supply voltage, etc.

6 Status warning signal



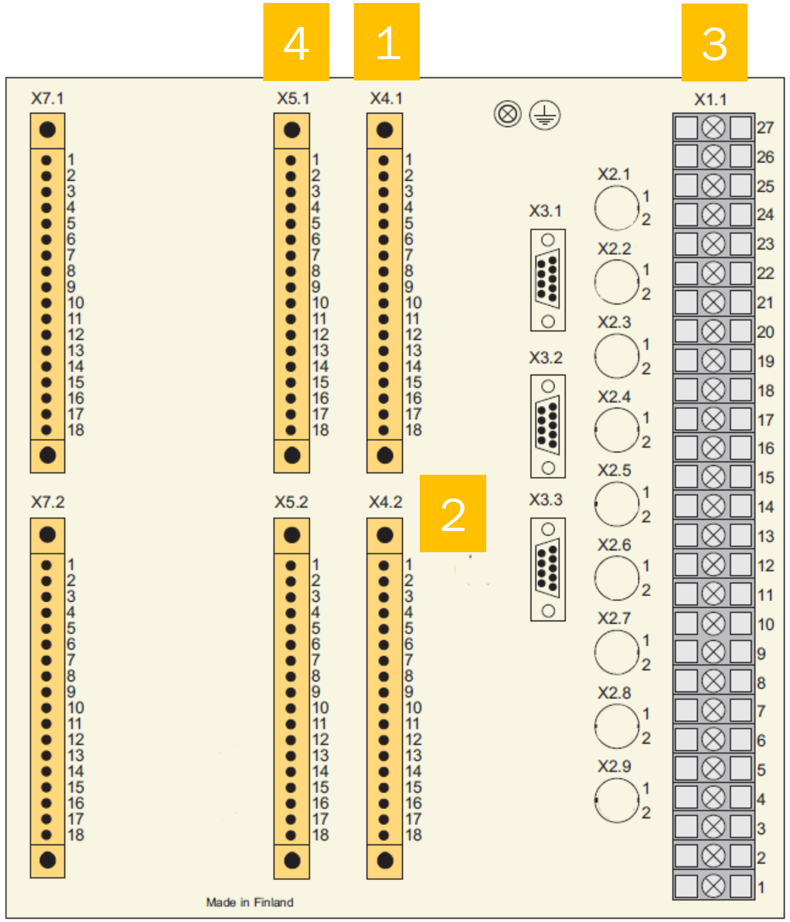
Feeder terminal REF 543

1 Power and switch bar

2 Switching elements bar

3 Current and voltage input bar

4 Logic input bar



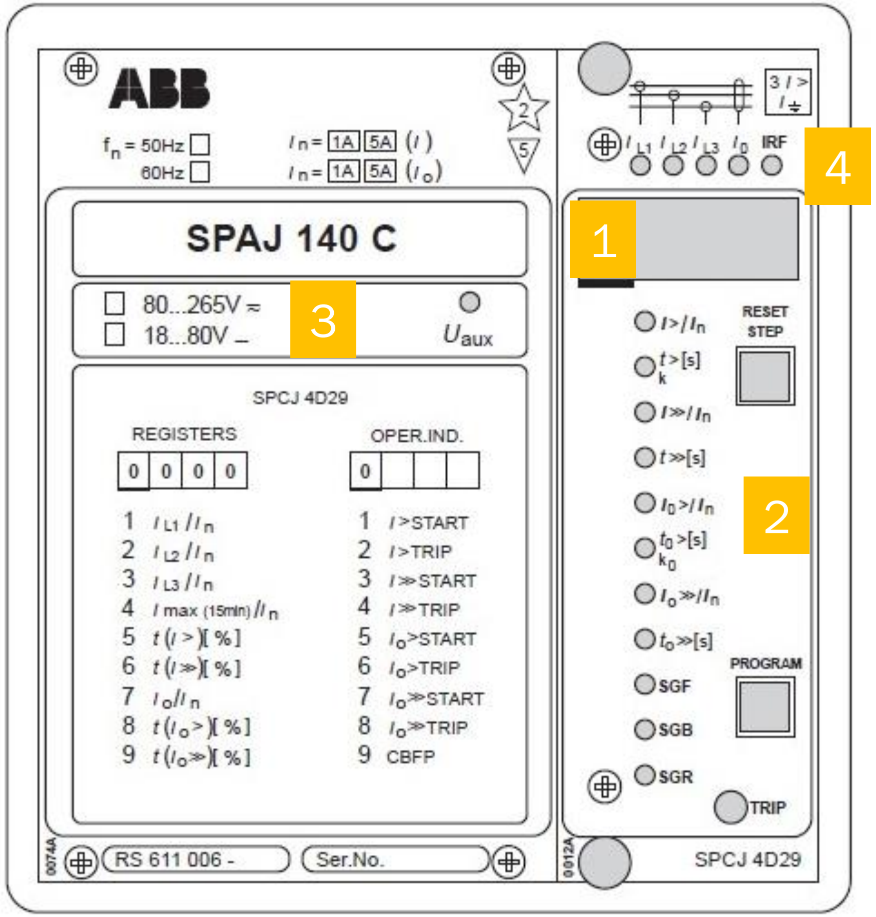
Overcurrent relay SPAJ 140C

1 Seven-segment display

2 Control buttons

3 Supply voltage

4 LED status signalling

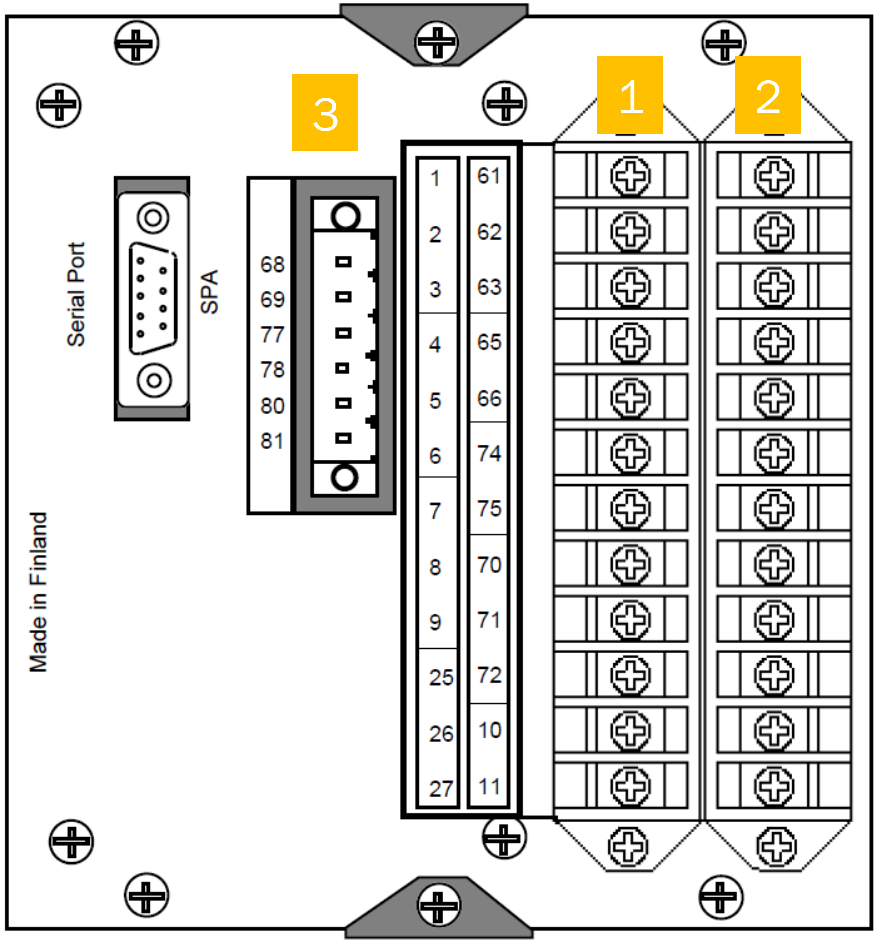


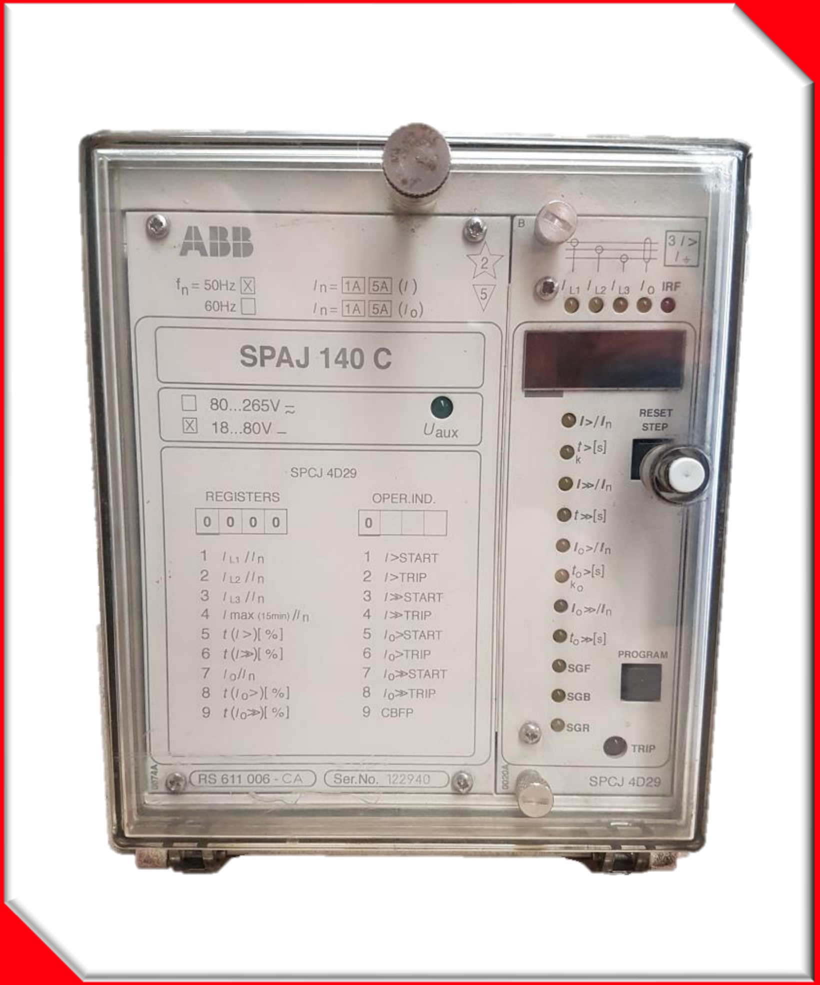
Overcurrent relay SPAJ 140C

1 Current and voltage input bar

2 Power and switch bar

3 Logic output bar





Sample calculation of overcurrent protection

Overcurrent protection

%Grid impedance

$Z1grid = Un/(sqrt(3)*Ik3grid) = 22e3/(sqrt(3)*3.2328e3) = 3.929\Omega$

%Nominal line current

$IN = Sn/(sqrt(3)*Un1) = 1000e3/(sqrt(3)*22e3) = 26.2432\ A$

%Cable line impedance

$Xl = 0.14\Omega/km$

$Z1line = l*Xl = 1*0.14 = 0.14\Omega$

%Transformer impedance

$ur = dPk/Sn = 9500/1000000 = 0.0095$

$Rt = (ur*Un2\text{^}2)/Sn = (0.0095*400\text{^}2)/1000000 = 0.0015\Omega$

$ux = sqrt(uk\text{^}2-ur\text{^}2)= sqrt(0.04\text{^}2 – 0.0095\text{^}2) = 0.0389$

$Xt = (ux*Un2\text{^}2)/Sn = (0.0389 *400\text{^}2)/1000000 = 0.0062\Omega$

$Kt2 = 0.95/(1+0.6*(Xt/(Un2\text{^}2/Sn))) = 0.95/(1+0.6*(0.0062 /(400\text{^}2/1000000)))$

$= 0.9284$

$Z1T1 = Kt2*(Rt+1j*Xt) = 0.9284*(0.0015 +1j* 0.0062) = 0.0014+j0.0058\Omega$

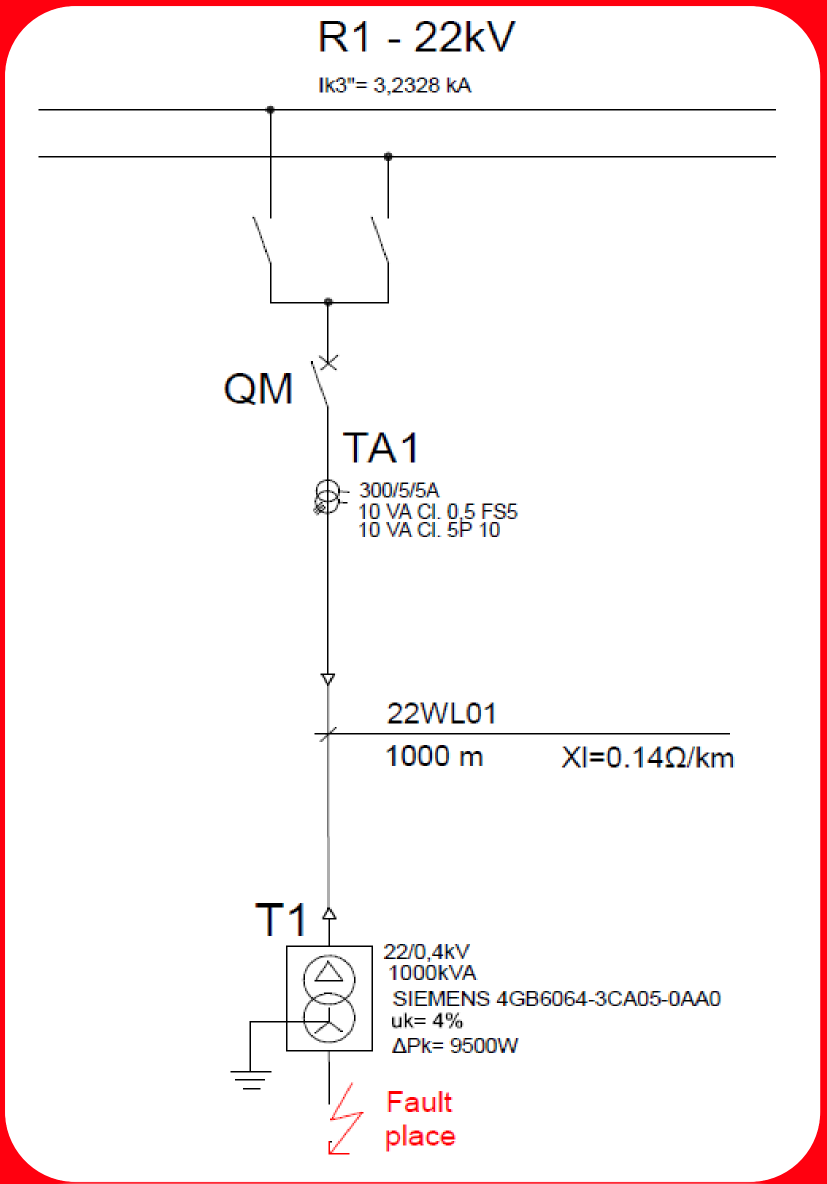


Fig. 7 Sample assignment

Overcurrent protection

%Short-circuit current calculation

Z1fault = Z1grid+Z1line+abs(Z1T1) =

= 3.929(0.4/22)^2 + 0.14*(0.4/22)^2 + 0.006 = 0.0073Ω*

*Ik3R1= Un/(sqrt(3)*abs(Zk1))= 400/(sqrt(3)*abs(Z1fault)) = 31.694kA*

*Ik2R1 = sqrt(3)/2*Ik3R1 = sqrt(3)/2*31.694 = 27.448kA*

%Conversion of short-circuit current to 22 kV side of the transformer

Ik2R122 = Ik2R1(0.4/22) = 499.0473A*

%Calculation of overload protection current

*I> = (kb*IN)/(kp*pp) = (1.1* 26.2432) / (0.95*300/5) = 0.5064A*

%Calculation of the starting current of short-circuit protection

*I>> = (0.8*Ik2R122)/(kc*pp) = (0.8*499.0473) / (1.5*300/5) = 4.436A*

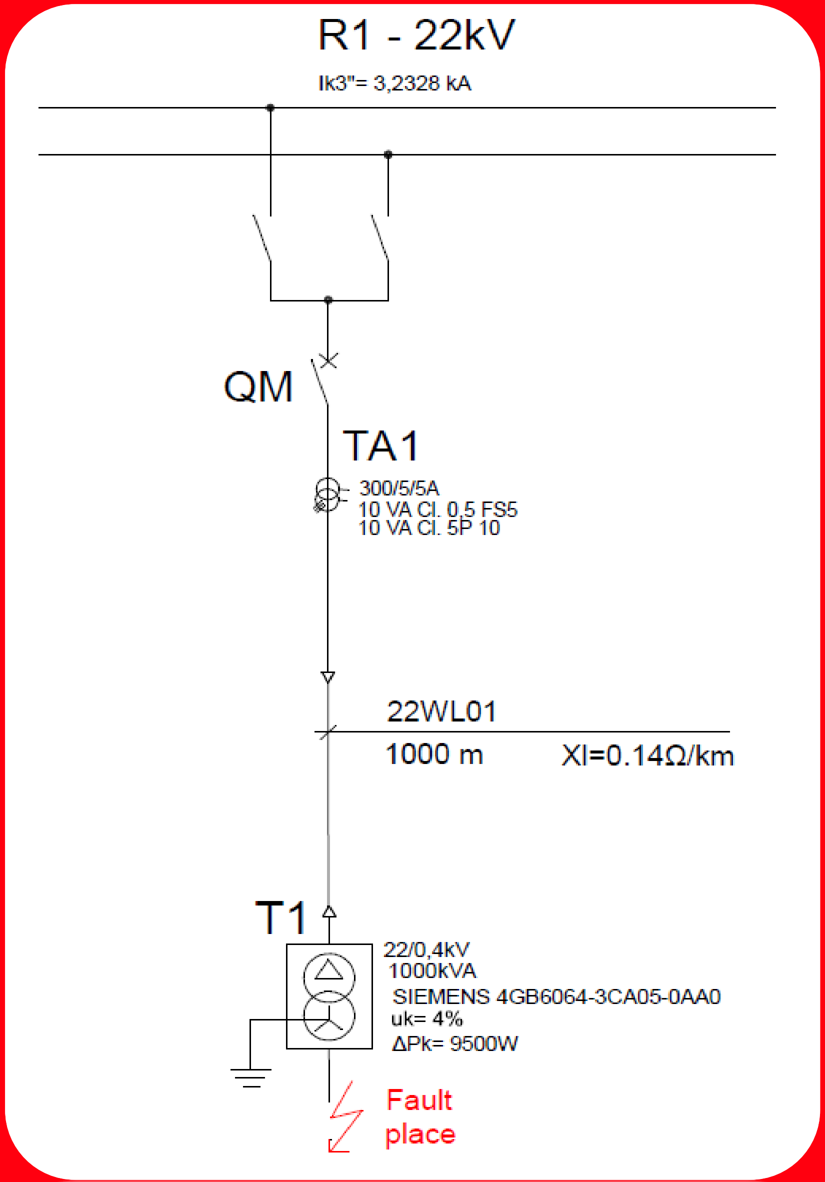


Fig. 7 Sample assignment

Overcurrent protection

%Overload protection inrush current

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

$$0.5064A \leq I_{R>}$$

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

%Short-circuit protection inrush current

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

$$4.436A \geq I_{R\gg} > 1A$$

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

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.

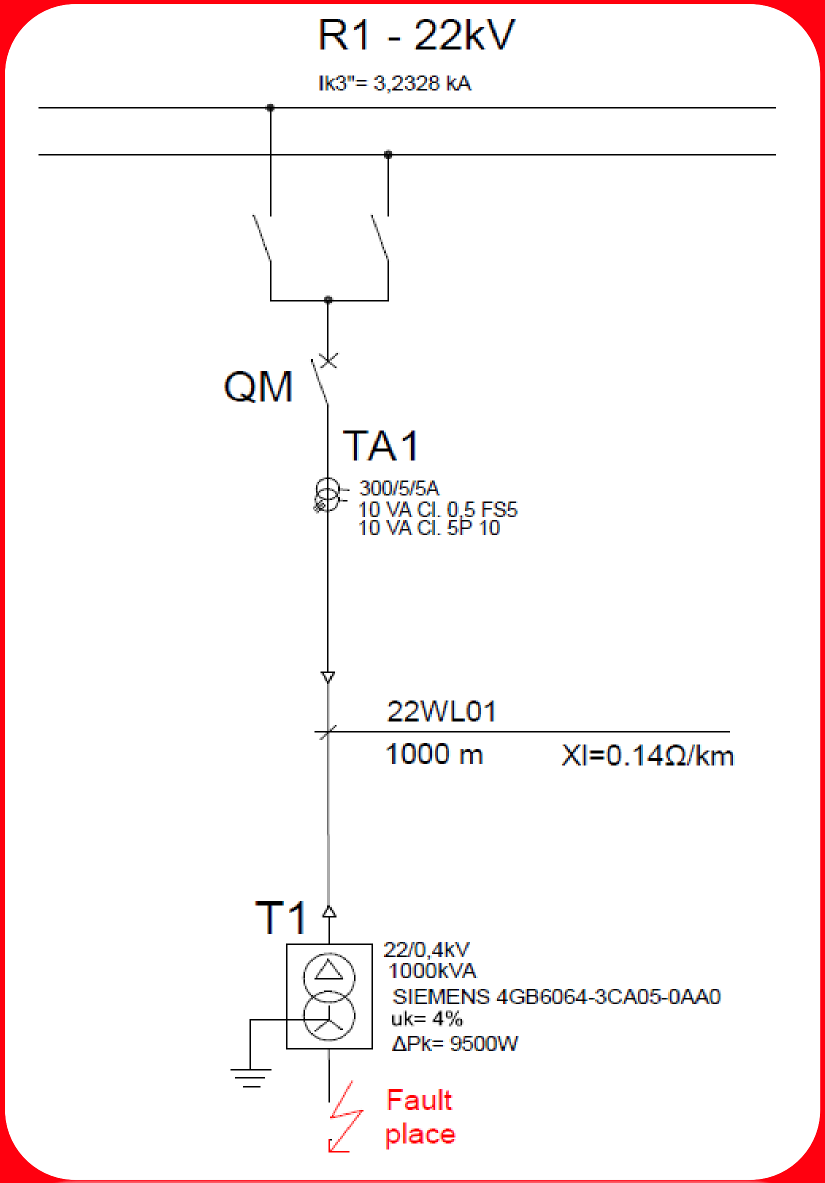


Fig. 7 Sample assignment

Sample connection of set protections and testing

Overcurrent protection relay SPAJ 140 C

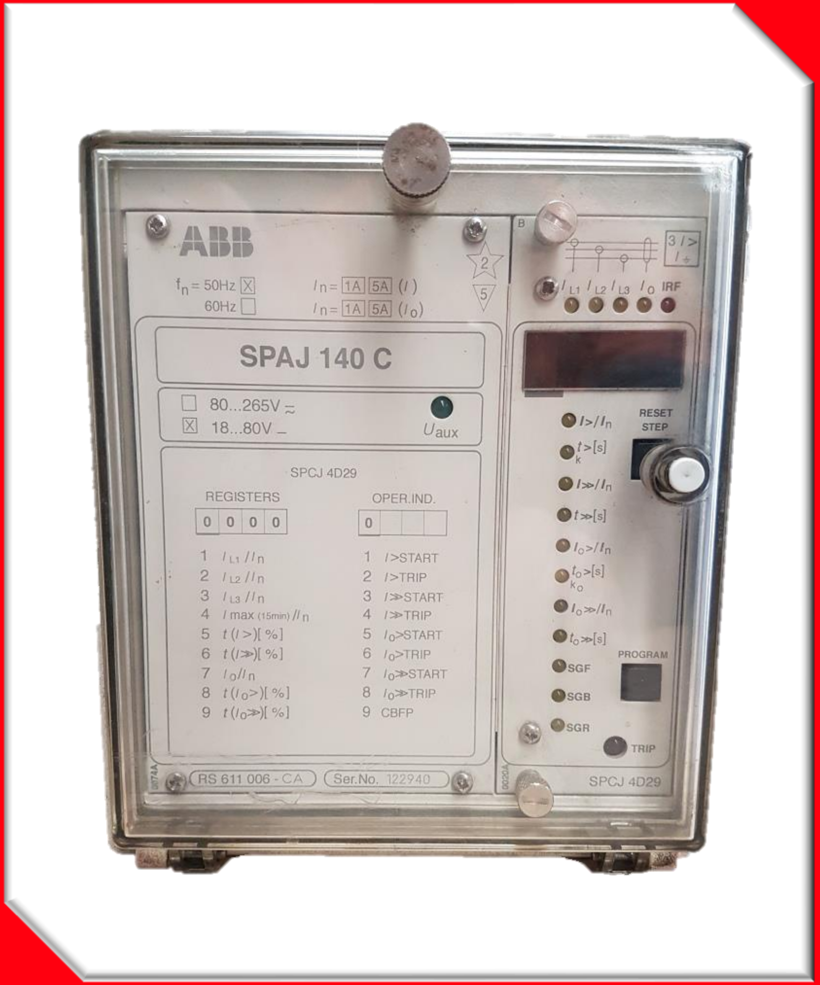
Instructional video manual for measuring SPAJ 140 C

TUKE moodle

https://moodle.tuke.sk/moodle/mod/resource/view.php?id=54590

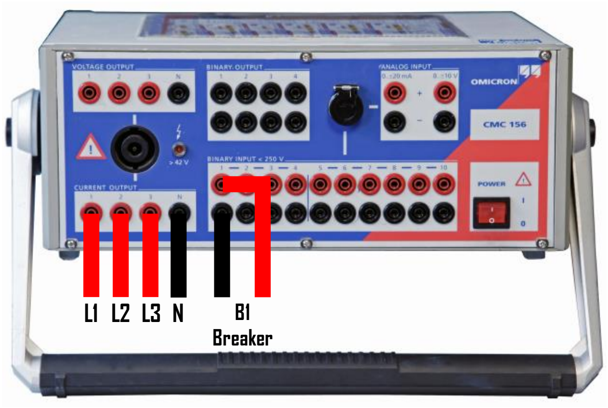
YouTube

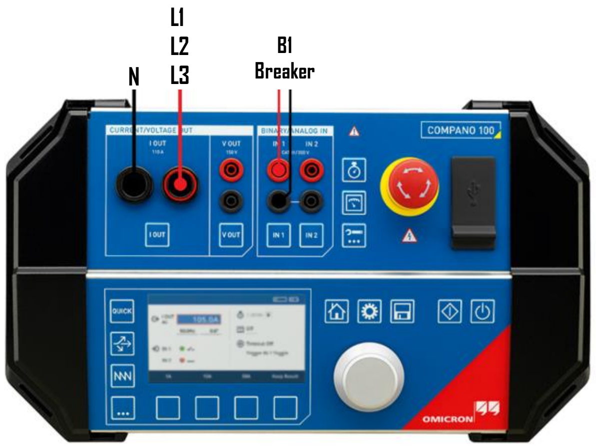
https://www.youtube.com/watch?v=OVTCl_9jMBU&t=1s

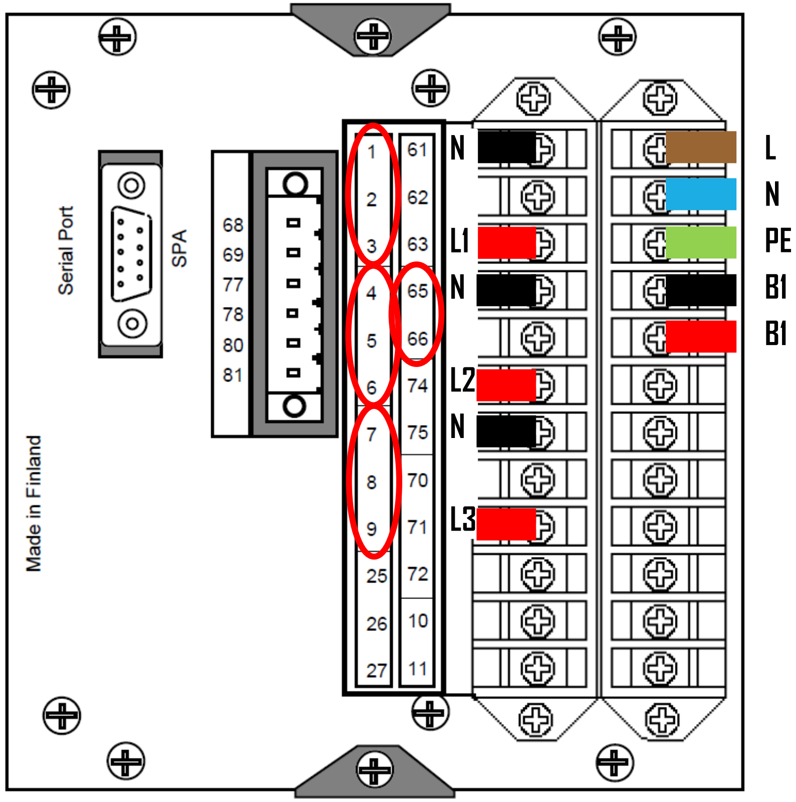


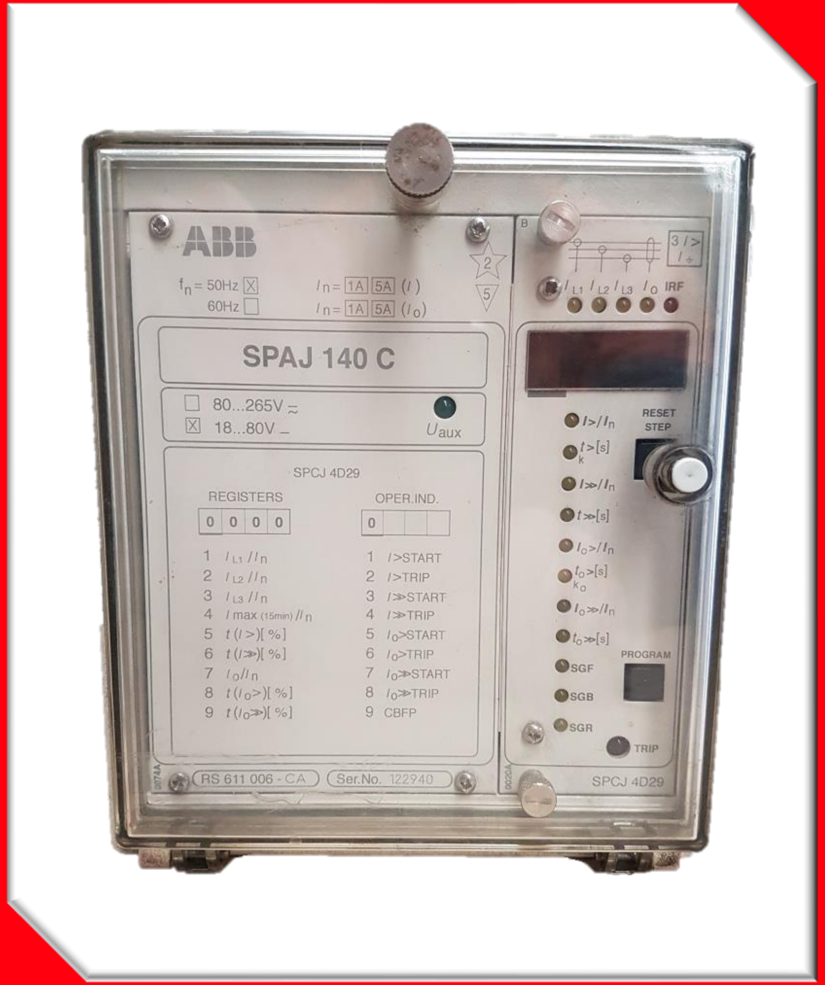
Overcurrent protection relay SPAJ 140 C

Wiring diagram from the video measurement manual SPAJ 140C









Feeder terimal relay REF 543 overcurrent

Instructional video manual for measuring REF 543

Overcurrent protection REF 543

TUKE moodle

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YouTube

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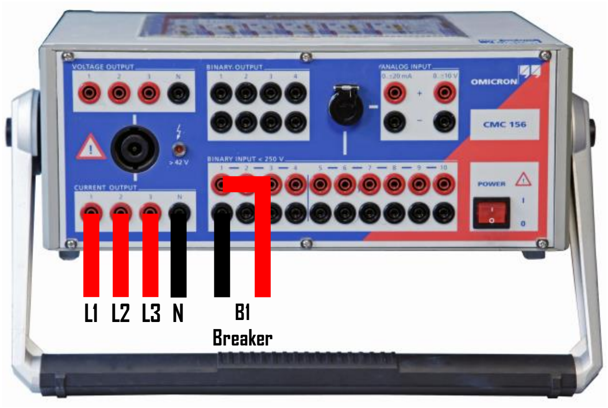
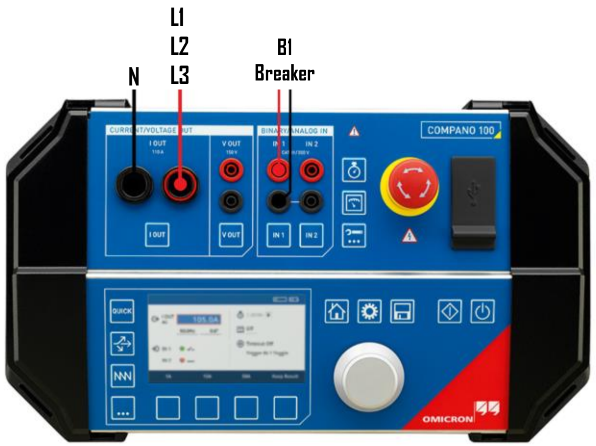
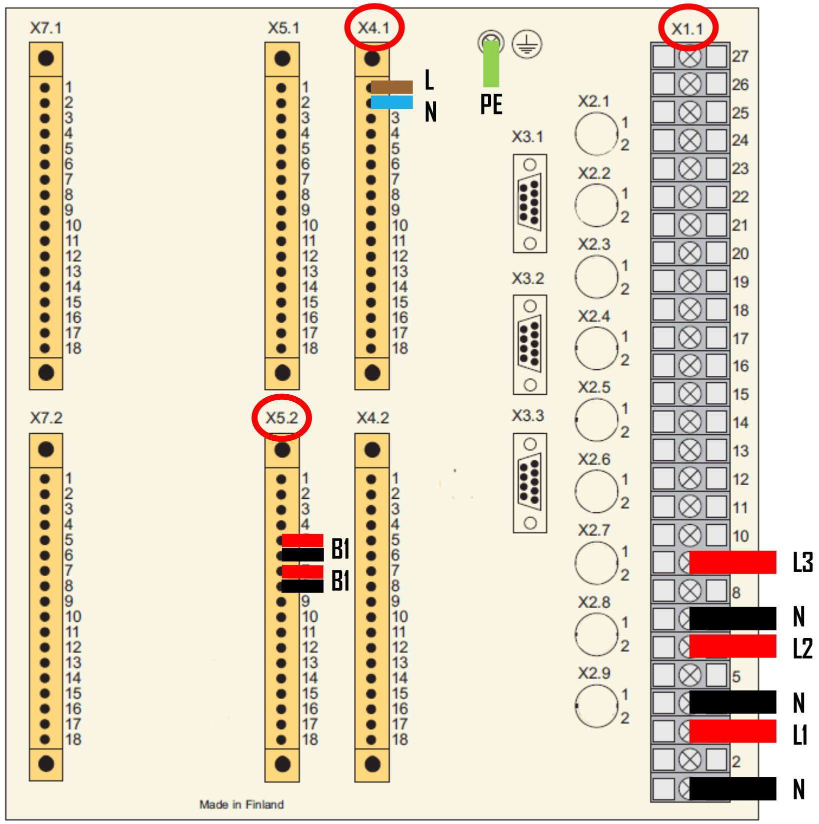
Feeder terimal relay REF 543 overcurrent

Wiring diagram from the video measurement manual REF 543







Feeder terimal relay REF 543 voltage

Instructional video manual for measuring REF 543

Voltage protection REF 543

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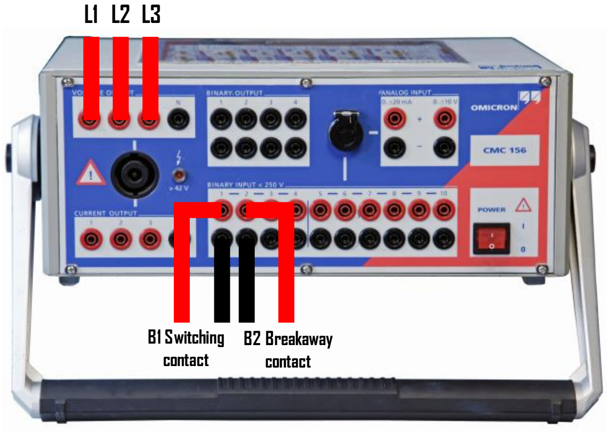
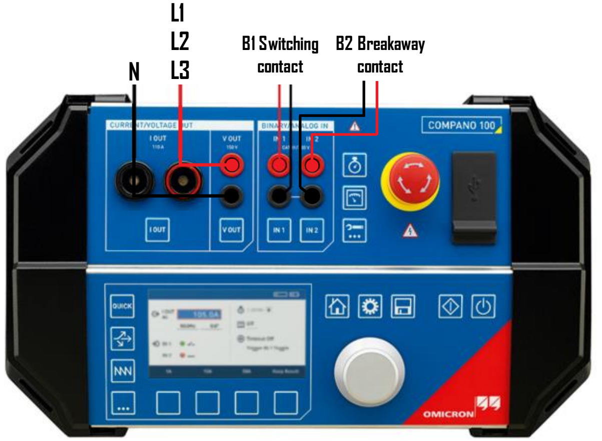
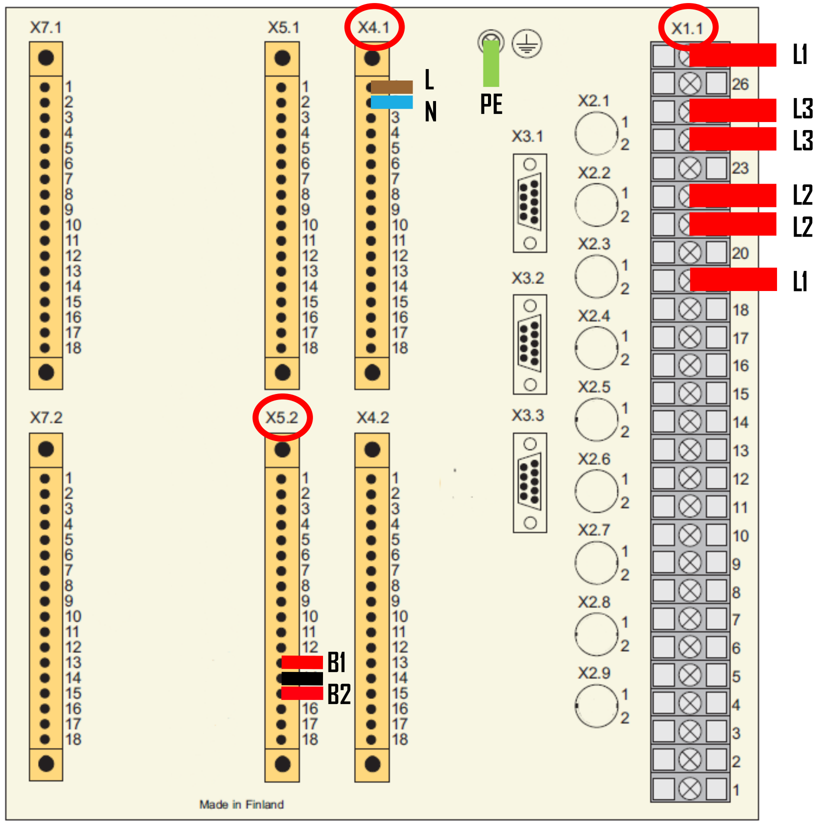
Feeder terimal relay REF 543 voltage

Wiring diagram from the video measurement manual REF 543







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