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USER DOCUMENTATION
for FRA

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CHANGE SHEET

Version	Date	Description	Author
1.0	15.01.2025	First Edition	Ing. Hajdušek René., doc. Ing. David Topolánek Ph.D.
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AUTHORIZATION

Version	Quality Manager / Date	Project Manager / Date
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In1.1	

Content

Definition of the scope of the FRA system

The FRA **system** is used to monitor, analyze and manage fault events in electrical networks. It allows you to view a list of all recorded failures, which are clearly arranged in a table with the possibility of filtering and sorting by various parameters. Detailed information about each event includes the data needed to locate and describe it, making it easier to identify the causes and consequences of failures. The system thus provides users with tools for effective analysis and troubleshooting of network issues.

In addition to managing individual events, the system also offers statistical reports that help identify patterns of failures and their geographical distribution. These statistics include, for example, the frequency of failures, the effectiveness of automatic re-on, and the visualization of the occurrence of failures on the map. Thanks to these functions, the system contributes to improving reliability, optimizing maintenance and increasing the operational resilience of electrical networks.

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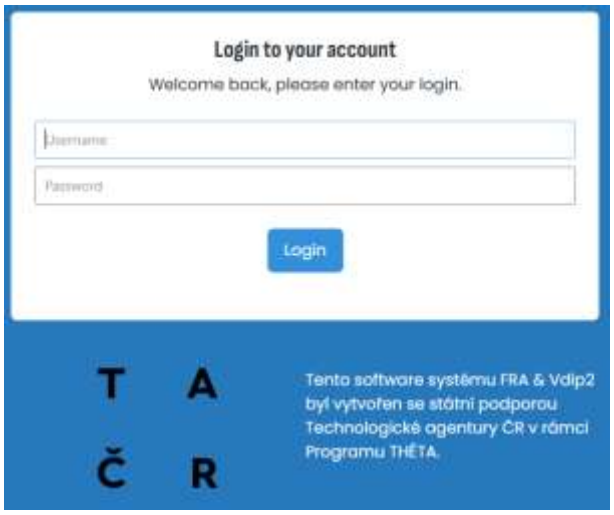
FRA User Interface

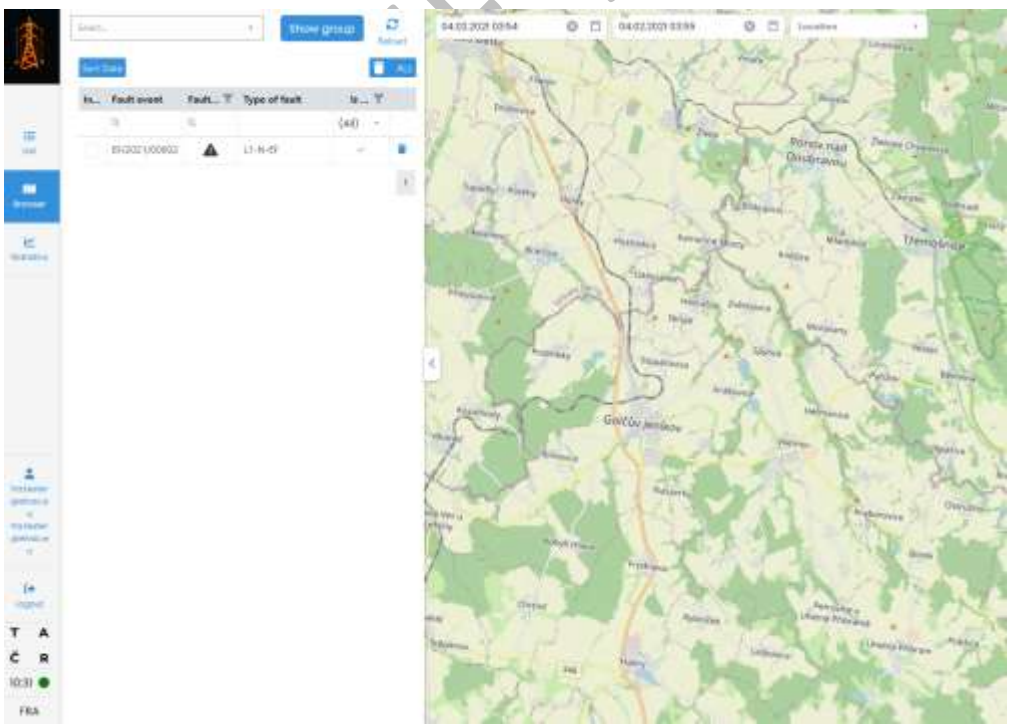
The user logs in to the application using the assigned login and password. Based on the assigned login, the user is also assigned the following permissions:



After logging in to the user interface, the main navigation bar is on the left. On this panel, you can switch between three basic tabs:

- List (Fault event list) – a list of events with parameters
- Browser (Event Browser) – viewing events with localization on the map
- Statistics – statistical evaluation of failures

The tabs allow you to click through to individual UI modules for different views of recorded and evaluated fault events. A description of the individual tabs and how to navigate them is presented below.



Fault event list

The *Fault event list* (*List*) tab allows you to display a list of all fault events with assigned parameters. Individual events are introduced as table rows, and the selected parameters represent table columns. In the table, individual events can be filtered and sorted by the selected column.

The displayed parameter fields in the table are:

- **Is authorized**

  Identification of the Fault Event Authorisation Status *Is Authorized* – The Fault Group to which the Fault Event belongs has been authorised by an authorised employee (such closed events/groups contain a completed fault location and can no longer be modified)

- **Name**

  Name of the fault, name is composed according to the key

  TP/yyyy/nnnnn,

  where *TP* is the type of fault: EF = ground fault/ SC = short circuit
  yyyy is the year in which the failure occurred
  nnnnn is the event identification number

- **Start date**

  Date and time of occurrence of the event – corresponds to the start time of the Data Segment (DS) in which the given failure is located, the data segment represents the semi-steady state of the given failure record (see Figure 4)

- **End date**

  Date and time of the end of the event – corresponds to the end time of the Data Segment (DS) in which the given failure is located, the data segment represents the semi-steady state of the given failure record (see Figure 4)

- **Fault group**

  The event group to which the event was assigned. Each fault event is assigned one default Fault Group (FG). In the event that there are multiple fault events in the fault record, these events are automatically assigned to one FG. A group of events is subject to the following markings:

  FG/yyyy/nnnnn,

  where *yyyy* is the year in which the failure occurred
  nnnnn is the identification number of the group

- **Fault type**

  The type of disorder has two values:

  EarthFault Ground Connection
  ShortCircuit – Short Circuit

- **Type of fault**

Type of disorder with respect to the phases affected. The marking captures which phases (L1, L2, L3) were affected by the failure, or whether there was also a connection with the ground (N). An overview of the options is given in the table:

Table 1: Type of fault options

Type of fault	Description
L1-N-EF, L2-N-EF, L3-N-EF	Ground connection in phase L1, L2, L3
L2-N-L3-N, L1-N-L3-N, L1-N-L2-N	Double earth connection (two non-congruent earth connections) on one HV outlet
L1-N-Lx-N, L2-N-Lx-N , L3-N-Lx-N	Double earth connection (two non-concurrent earth connections) one ground connection is located on the given outlet in the L1, L2, L3 phase and the other on another HV outlet (Lx)
L1-N, L2-N, L3-N	Single-phase short circuit in phase L1, L2, L3
L1-L2, L2-L3, L1-L3	Two-phase short circuit between phases L1-L2, L2-L3, L1-L3
L1-L2-N, L2-L3-N, L1-L3-N	Two-phase ground fault between conductors L1-L2-N, L2-L3-N, L1-L3-N
L1-L2-L3	Three-phase short circuit
L1-L2-L3-N	Three-phase ground fault

- **State**

  The evaluation status of the FRA processing event, the possible statuses that can be displayed in the user interface, are listed in the following table:

State	Description
SuccessfulyCalculated	Successful evaluation of the event
SuccessfullyCalculatedWithAlert	A successful evaluation of an alert event
SuccessfulyCalculatedEmpty	A successful evaluation of the event took place, but the location of the fault location was not determined.
AnalysisFailed	The calculation ended in error.
AnalysisTimeOut	The calculation took too long.
FaultAnalysisInProgress	Analysis of the received fault signal is in progress
FaultEventTimeOut	The calculation took too long, Comtrade was not delivered.
ComtradeGetFile	Request Comtrade file, waiting for delivery.
AnalysisInProgressVDIPSmelc	A calculation is in progress.

- **Description** – additional information from the calculation process
- **Start date** – numeric identifier of the derivation from the start time of the event
- **… (more options)**
  - **Show event detail**

    Clicking on the event detail (more description below Fault *event detail info*)
  - **Show group (map)**

    Clicking on the Browser tab with a pre-selected given group of events – displaying the group in the map and its parameters.
  - **Show event (map)**

Clicking on the Browser tab with a pre-selected event – displaying the event in the map and its parameters.

- **Delete**
  Option to delete event.

Fault event browser

At the top of the module there is a drop-down menu with the choice of a group of events that the user wants to browse and display on the map. After selecting and pressing the *Show group button*, the map will display the designated location of the fault – event groups and at the same time display a group table including the listed events.

Reload button updates the list of events

The *Sort date button* sorts events by date and time of occurrence

The Delete all *button* allows you to delete all events from the list loaded into the UI

The icon allows you to delete one fault record from the event list.

The generated table of events assigned to a group allows you to view the details of individual events, delete events from the group (delete event records). The table allows filtering or sorting according to individual parameters. The event parameters in each column are:

- **Included**

  Indicate whether an event belongs to a selected group

- **Fault event**

  Event identifier

- **Fault type**

  Fault type: ground fault/short circuit – distinguished by an icon

  Ground Connection

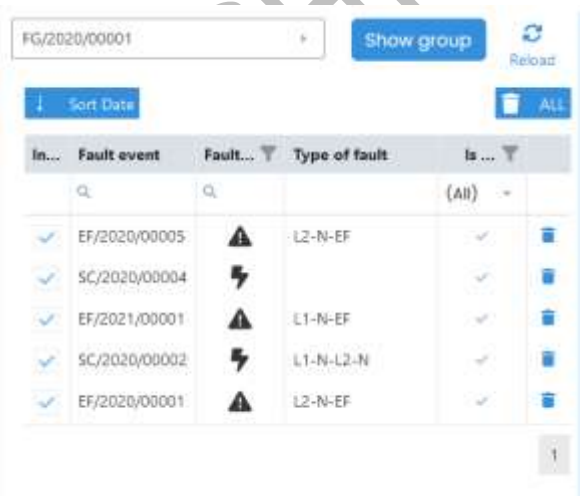
  short circuit

- **Type of fault**

  Event type relative to affected phases (see Table 1)

- **Is authorized**

  Identification of the Fault Event Authorisation Status *Is Authorized* – The Fault Group to which the Fault Event belongs has been authorised by an authorised worker (events/groups closed in this way contain a completed fault location and can no longer be modified).



Basic and detailed information about a fault event

By selecting a fault event in the **Browser tab**, a panel with its description will be displayed. The panel header lists its numeric code and the event type flag – SC short circuit or EF ground fault. The numeric code

of the fault event represents the year in which the event was recorded and the forward slash of the order of the event in that year. There is also a Detail button in the header to display detailed information about each event.

The description of the failure event is made by means of basic data (items) on the initial page of the event and in more detail in the**Detail** disorders. The meaning of the information in each item is given inTable 2.

Table 2 Basic and detailed information about a fault event

Název položky		Popis - význam informace		Pozn.
anglicky	česky	pro události typu zkrat (SC)	pro události typu zemní spojení (EF)	
Type of fault	Typ poruchy	udává typ zkratu - jednofázový (L1-N, L2-N, L3-N), dvoufázový (L1-L2, L2-L3, L1-L3), dvoufázový zemní (L1-L2-N, L2-L3-N, L1-L3-N), třífázový (L1-L2-L3), nebo třífázový zemní (L1-L2-L3-N), dvojité ZS na stejném vývodu (L2-N-L3-N, L1-N-L3-N, L1-N-L2-N), dvojité ZS na různých vývodech (L1-N-Lx-N, L2-N-Lx-N, L3-N-Lx-N)	udává typ jednochuhého zemního spojení (ZS) - L1-N-EF, L2-N-EF, L3-N-EF	
Start time of fault	Začátek poruchy	odpovídá času začátku Data Segmentu (DS), ve kterém se nachází daná porucha		
End time of fault	Konec poruchy	odpovídá času konce Data Segmentu (DS) v kterém se nachází daná porucha - zpravidla odpovídá i době přerušení zkratového proudu (vypnutí)	odpovídá času konce Data Segmentu (DS) v kterém se nachází daná porucha - zpravidla odpovídá času konce poruchového záznamu, nemusí tedy odpovídat době vypnutí zemního spojení	viz položka DS name
Fault duration	Doba trvání poruchy	celková doba trvání zkratu určená jako časový interval mezi počátkem (Start time of fault) a koncem poruchy (End time of fault)		
Faulty Feeder	Postižený vývod	identifikace vývodu, ve kterém byla porucha detekována vývodovou ochranou		
Current to earth	Proud zemí	efektivní hodnota proudu tekoucího místem poruchy do země - hodnota se zobrazuje jen u zemních poruch - jednofázový, dvoufázový zemní, a třífázový zemní zkrat, nebo dvojité zemní spojení	efektivní hodnota proudu tekoucího místem poruchy do země	
Maximal earth fault current	Maximální proud zemí	tato položka se u poruch typu zkrat nezobrazuje	efektivní hodnota proudu tekoucího místem poruchy do země za předpokladu kovového zemního spojení	
Network nominal voltage	Nominální napětí sítě	nominální napětí sítě, ve které porucha nastala, uvedené v kV		
Neutral point earthing	Způsob uzemnění uzlu	způsob uzemnění uzlu napájecího transformátoru - účinně uzemněný (Solidly Earthed), kompenzovaný (Compensated), izolovaný (Isolated), uzemněný přes resistor (Resistor Earthed), kombinovaný (Combinated), nespecifikováno (Unspecified)		
Weather info	Informace o počasí	uvádí oblačnost, teplotu, vlhkost, tlak, rychosti větru v místě a době poruchy		
Fault location GPS	Místo poruchy	geografické souřadnice místa poruchy v geopodkladu - podbarvení okna signalizuje úroveň věrohodnosti údaje (zelená=důvěryhodný výsledek lokalizace, červená= nedůvěryhodný výsledek lokalizace), odpovídají černě zobrazenému bodu v úseku vedení v poruše v mapovém podkladu		
Distance from start node	Vzdálenost poruchy od	délka vedení mezi počátečním uzlem úseku vedení v poruše a místem poruchy		Tyto položky jsou pouze v detailním popisu poruchové události, v úvodním panelu jsou dostupné přímo z mapového podkladu - viz Obrázek 1
Faulted element	Úsek vedení v poruše	identifikátor úseku vedení, na kterém byla porucha lokalizována - odpovídá červeně zobrazenému úseku v mapovém podkladu		
Faulted element node	Počáteční uzel prvku v poruše	identifikátor počátečního uzlu (podpěrného bodu) úseku vedení, na kterém byla porucha lokalizována - odpovídá červeně zobrazenému bodu v mapovém podkladu		
Reactance to the fault	Reaktance do poruchy	podélná reaktance vedení mezi napájecí rozvodnou a místem poruchy v ohmech		
Distance to the fault location	Vzdálenost do poruchy	délka vedení mezi napájecí rozvodnou a místem poruchy		
Fault location distance error	Chyba lokalizace	zobrazení hodnoty vyžaduje autorizaci poruchové události a zadání souřadnic skutečného místa poruchy (předpokladem je tedy dohledání poruchy)		
Date code	Časový kód	časový kód poruchy je čas začátku poruchy zapsaný bez oddělovacích znaků		
DS name	Označení datasegmentu	uvádí datasegment (část poruchového záznamu), ve kterém se nachází porucha a který byl podkladem pro její lokalizaci		
State	Stav	uvádí výsledek výpočetního algoritmu pro lokalizaci - SuccessfulyCalculated (úspěšně vypočteno), SuccessfullyCalculatedWithAlert (úspěšně vypočteno s výstrahou), AnalysisFailed (analýza selhala)		

Information about the failure event is further supplemented on the home page by displaying it in an interactive map base, where it is possible to identify individual elements of the distribution network in the vicinity of the failure – see Figure 1.

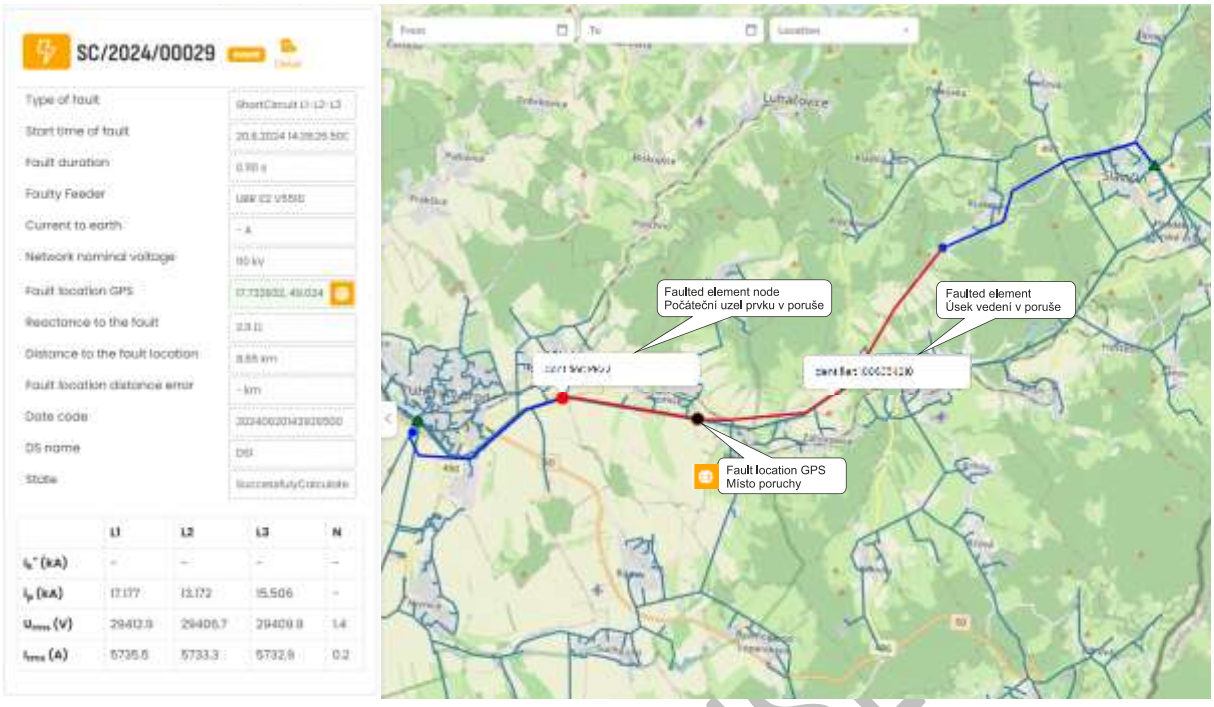


Figure 1 Description of the failure in the map

Furthermore, each fault event is described by the characteristic values of currents and voltages from the data segment (DS) that was used to locate the fault and is given in the description. The table of values is located at the bottom of the start panel, see the image above (bottom left corner):

- Effective value of the AC component of the short-circuit current – initial symmetrical surge short-circuit current – *IK"* (kA) – only for short-circuit fault (SC)
- Maximum instantaneous short-circuit current value – surge short-circuit current – *ip* (kA) – for short-circuit fault (SC) only
- Effective value of fundamental harmonic stress of the fault – *Urms* (V)
- Effective value of fundamental harmonic current disturbance – *Irms* (V)

In the **Fault Event Detail,** other characteristic values are then listed in detail, including the display of the course of the instantaneous value of the fault current from the corresponding data segment. Also in the Detail tab, the values are identical for both types of fault – short circuit (SC) and ground fault (EF)

The **Zero Sequence Harmonic table** shows the results of the harmonic analysis of the non-rotating component of current and voltage:

Zero Sequence Harmonic

	1st	2nd	3rd	4th	5th	6th	7th
$I_{fault\ FFT}$ (A)	-	-	-	-	-	-	-
I_{E_FFT} (A)	16.3	15.9	13.4	6.8	15.9	1.7	3.5
$U^{(0)}$ (V)	776.8	15.7	65.9	4.1	289.9	7.3	15.2

- Effective value of the current due to *Ifault* FFT (A) 1st to 7th harmonics – valid value is displayed only for fault type earth fault (EF)
- Effective value of ground current (three times the non-rotating component of the current) *IE* FFT (A) 1st to 7th harmonics – a valid value is displayed for both short circuit (SC) and ground fault (EF)
- Effective value of the non-rotating voltage component $U^{(0)}$ (A) 1st to 7th harmonic – valid value is displayed for both short circuit (SC) and ground fault (EF)

The **Short-circuit current levels table** lists the characteristic values of short-circuit current in individual phases and ground current (N) and valid values are displayed only for short-circuit (SC) faults in the columns that correspond to the short-circuit type:

Short-circuit current levels

	L1	L2	L3	N
I_k'' (kA)	2.327	2.115	2.218	-
i_p (kA)	3.437	3.036	3.302	-
I_k (kA)	2.195	2.029	2.022	-
I_b (kA)	2.195	2.029	2.022	-
I_{th} (kA)	2.135	1.989	1.900	-

- Effective value of the alternating component of the short-circuit current – initial symmetrical surge short-circuit current – IK" (kA)
- Maximum instantaneous value of short-circuit current – surge short-circuit current – *ip* (kA)
- Effective value of short-circuit after DC component wear-up – steady-state short-circuit current – *IK* (kA)
- Effective value of short-circuit current at the time of shutdown – tripping short-circuit current – *Ib* (kA)
- Effective value of short-circuit current over the duration of the fault – equivalent warming current – *Ith* (kA)

The **U/I conditions of masted feeder protection** table includes:

U/I conditions of master feeder protection

	L1	L2	L3
U_{rms} (V)	9459.2	10136.3	9880.8
I_{rms} (A)	2194.5	2029.2	2022.4
U_{ph} (°)	-152.9	90.9	-29.6
I_{ph} (°)	158.1	34.9	-79.7
	(1)	(2)	(0)
U_{rms} (V)	9764.6	194.3	348.7
I_{rms} (A)	2080.5	112.9	5.1
U_{ph} (°)	-150.5	49.5	99.3
I_{ph} (°)	157.8	162.1	-127.9

- effective values of the basic harmonics of **the phase currents Irms** and the voltage **Urms** (L1, L2, L3) and the symmetrical components - (1) consecutive, (2) reverse and (0) non-rotational subtracted for the given DataSegment fault event of the outlet protection Master,

- angles of fundamental harmonics of phase currents **Iph** and voltage **Uph** (L1, L2, L3) and symmetrical components - (1) consecutive, (2) reverse and (0) non-rotational subtracted for a given DataSegment of the fault event of the outlet protection Master.

For a graphical display of the course of fault currents in individual phases, the**Detail** Fault Events Designated Panel **Current estimation of phase.** By selecting the buttons **L1, L2, L3, N** You can display the course of individual short-circuit currents from the data segment specified in the item **DS name**. InFigure 2 you can see an example of the displayed course of the fault current in the L1 phase and a legend according to which selected values from the tables are marked **Short-circuit current levels** and **U/I conditions of master feeder protection**.

Figure 2 Display of the fault current in the Fault Event Detail

Fault record and information on the operation of outlet protections

All data and information on the basis of which the fault event is located and described are available in **Detail** Events in the tab **Master.** This designation is used to designate the outlet protection that was the first to detect the fault and recorded it in its fault recorder. Each such fault record has its own unique ID, which is also displayed on the tab - e.g. Master C(1086) – see Figure 3. The Download Documents and InfoDMU items allow you to download files for a more detailed analysis of the fault event and the implemented functions.

Figure 3 Master tab in Failure Event Detail

The **Master panel** provides detailed information about the fault record (including the possibility of downloading it) and identification of the outlet protection and information about its operation.

The basic information about outlet protection is:

- Fault record ID – identification of the fault record
- Feeder protection ID – identification of the outlet protection
- Feeder name – designation of the outlet with protection
- Start date – start time of the fault record
- Result of 1st AR cycle (Successful, Unsuccessful)
- Duration of 1st AR cycle – doba trvání 1. OZ
- Result of 2nd AR cycle (Successful, Unsuccessful)
- Duration of 2nd AR cycle – doba trvání 1. OZ
- Record sampling frequency
- Actual system frequency
- Pick-up of overcurrent protection
- Start of overcurrent protection
- Pick-up of earth fault protection
- Start of earth fault protection

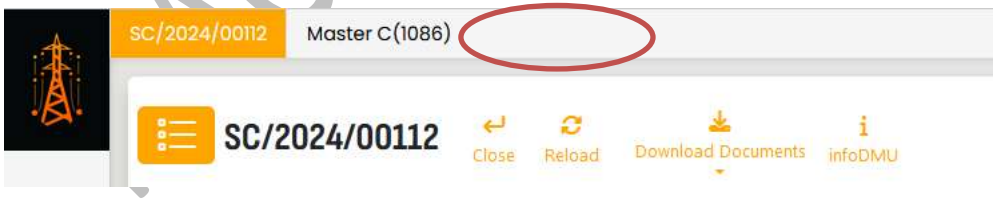
The rest of the panel **Master** (see Figure 4) is used to display and describe the fault record in a graphical form in the **Current oscillogram** and **Voltage oscillogram**, in which the division of the entire record into individual data segments (DS) is visible, and on the other hand by a table of values **Data segments**where each data segment is described by the following values:

- Type of event – the type of the data segment indicates what part of the fault record the given data segment displays, the following types are defined:
  Fault – this is a DS containing a fault event (ground fault, short circuit)
  Prefault – pre-fault normal operating condition
  Disconnected outlet
  Disconnected_ReverseVoltage – disconnected outlet with reverse voltage
  FaultFreeState – Restore normal operating state after failure
  OZ1L1, OZ1L2, OZ1L3 – single-phase OZ first cycle
  OZ1L123 – three-phase OZ first cycle
  OZ1L1_ReverseVoltage – single-phase OZ with counter-voltage, first cycle
  *OZ1L3OZ1L3*_ReverseVoltage – three-phase OZ with countervoltage, first cycle
  OZ2L1, OZ2L2, OZ2L3 – single-phase OZ second cycle
  OZ2L123 – three-phase OZ second cycle
  OZ2L1_ReverseVoltage – single-phase OZ with counter-voltage, second cycle
  OZ1L123_ReverseVoltage – three-phase OZ with counter-voltage, second cycle
- Type of fault – type of fault according to the classification inTable 1, only appears for Fault data segments

- Fault duration – the duration of the data segment is given by the difference between the beginning of the datatsegment (Start time of fault) and its end (End time of fault)
- Start time of fault – the start time of the datatsegment
- End time of fault – End time of the datatsegment
- Breaker disconnected fault – the circuit breaker interrupted the passage of short-circuit current in phases indicated as L1/L2/L3 (only for data segments containing a short circuit – type Fault, SC)
- Breaker closed to fault – the switch switched the outlet to a short circuit in phases indicated as L1/L2/L3 (only for data segments containing a short circuit – type Fault, SC)
- Breaker opened – status of the switch in phases indicated as L1/L2/L3 (1 – open, 0 – on)
- $UL1_{Rms}$, $UL2_{Rms}$, $UL3_{Rms}$ – average effective value of phase voltages in the data segment in V
- $UL1_{ph}$, $UL2_{ph}$, $UL3_{ph}$ – average value of the angle of phase voltages in the data segment in °
- $IL1_{Rms}$, $IL2_{Rms}$, $IL3_{Rms}$ – average effective value of phase currents in the data segment in A
- $IL1_{ph}$, $IL2_{ph}$, $IL3_{ph}$ – average value of the angle of phase currents in the data segment in °
- IE_{Rms} – average effective value of the country flow in the data segment in A
- IE_{pH} – average value of the flow angle of the countries in the data segment in °
- IE_{TERMS} – the actual RMS value of the earth current (3 x non-rotating current component at the outlet) – also contains the harmonic distortion of the *IE current*
- $U^{(0)}_{rms}$, $U^{(1)}_{rms}$, $U^{(2)}_{rms}$ – average RMS value of the symmetrical voltage components in the data segment in V
- $At^{(0)}_{pH}At^{(1)}_{pH}At^{(2)}_{pH}$ – average value of the angle of the symmetrical components of the voltage in the data segment in °
- $And^{(0)}_{Rms}And^{(1)}_{Rms}And^{(2)}_{Rms}$ – average effective value of the symmetrical components of the current in the data segment in A
- $And^{(0)}_{pH}And^{(1)}_{pH}And^{(2)}_{pH}$ - average value of the angle of the symmetrical components of the current in the data segment in °

Figure 4 Description of the fault record

If there is another tab in the **Fault Detail** in addition to the **Master** tab , it is a fault that was powered on both sides, and in addition to the outlet protection marked **Master,** it was also recorded by another "Slave" outlet protection in the opposite direction of the power supply. Since the fault record of the Slave PTO protection is also used for localization, it is processed and stored in the same way. On this tab, the fault record of this "Slave" PTO protection is described in an absolutely identical way.



Fault Event – Fault location

The localization of faults of the short circuit (SC) type by the FRA system can be divided into two specific tasks, which differ in the way the reactance of the fault loop is calculated and the subsequent determination of the fault location based on this value:

a) Single-sided power line

In the case of solving a fault event that occurred in a radial network and was identified and recorded by one outlet protection, the fault is supplied by a single source of fault current and the reactance of the fault can thus be determined from the currents and voltages recorded by this outlet protection. However, the radial arrangement of the affected outlet complicates the unambiguous assignment of the fault site to the calculated reactance value, and localization is successful only if the calculated reactance value corresponds to a single site on the affected outlet.

If the calculated reactance value corresponds to several places on the affected outlet, the fault cannot be considered localizable – its description does not display the GPS coordinates in the Fault location GPS item, nor other coordinates determining its position in the**Detail** failure or map (*Distance from start node, Faulted element, Faulted element node*). The failure event status is marked as *SuccessfullyCalculatedWithAlert* and the warning is further specified by the note: *Can't determine location location*. An example of such unsuccessful localization is given at Figure 5.

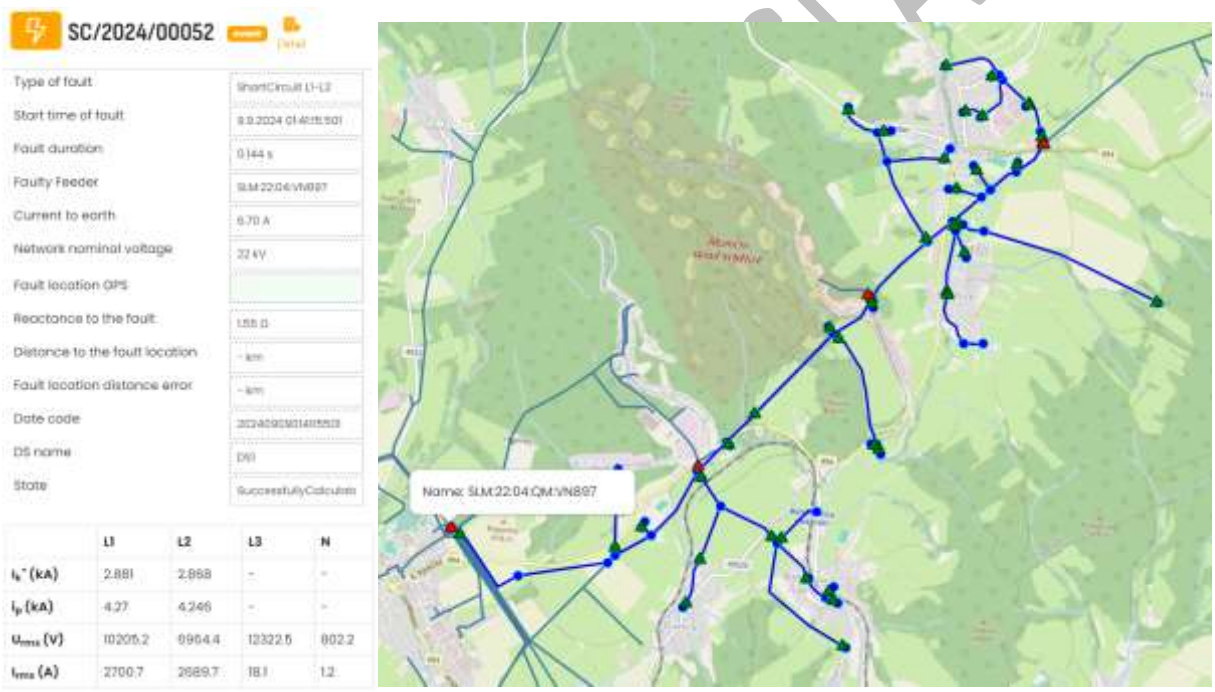


Figure 5 Example of unsuccessful localization of a single-sided power fault

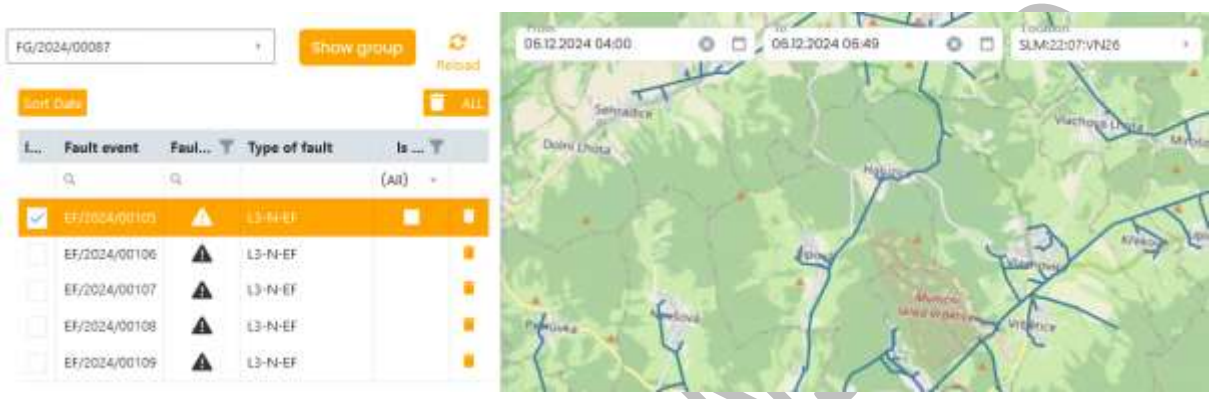
b) Double-sided power line

In the case of solving a fault event that occurred in the circular or continuous network and was identified and recorded by the outlet protections at both ends of the affected line, it is a fault supplied from two sources of fault current. To determine the reactance of the fault, the currents and voltages recorded by both outlet protections are used, and the calculation principle used based on the solution of two fault loops allows to eliminate the localization error caused by the fault resistance in a two-way power supply. In this way, the fault is localized unambiguously and the result of the localization corresponds to a single point in the map base.

Grouping of fault events – Fault Group

In addition to unique identifiers, each failure event is also assigned the designation of the FG (Fault Group). If we change the assigned designation of the fault group to one common fault group for selected faults, we can merge fault events that are locally and temporally identical and for which we assume that they have arisen from the same cause – faults on the same element of the system. By evaluating a group of faults, it is possible to increase the accuracy of localization and get closer to the actual cause of the fault. Also, the grouping of failures can be used for a detailed description of the given failure events and a detailed analysis of their cause and manifestations.

To search for fault events suitable for grouping, you can use the filters of the map base with the display of fault events and filter out faults in the selected outlet (Location) and time interval (From – To).



This step selects fault events that occurred on the selected outlet within the defined time range – they can have the same cause and can be analyzed with possible grouping.

If the above events have the same cause, those that are similar in place and time can be added to the selected (yellow, see the figure above) failure events by marking the Included box in the first column of the table. The procedure is illustrated in Figure 6, where the fault event EF/2024/00105 of the FG/2024/00087 group EF/2024/00106 is added.

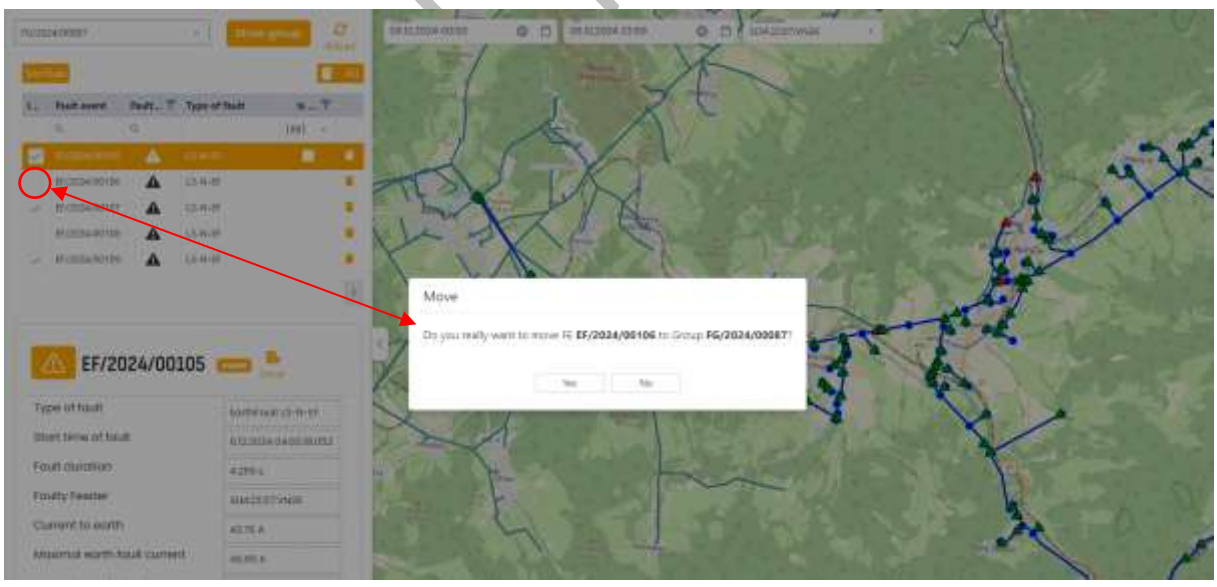


Figure 6 Add a fault event to a group

The created group of failure events can now be displayed using the Show group button (displays the detail of the selected group) in the map and with basic information in its description – see Figure 7. The map base displays all localized failure events included in the group and listed in the list of failure events. By applying the Show group button, the filters are automatically set so that the table contains all events in the group. The filters of the map base correspond to the location (affected outlet) and the time range from the beginning of the first failure event in the group to the end of the last one in the group. By extending the time of the filter set in this way, it is possible

to supplement the table of events with other possible relevant failures (e.g. in a situation where the fault search has not yet been completed).

Note: Since each failure event has a unique failure group number (FG) preset, the group can also consist of a single failure event. It can then be worked with in the same way as with a group of multiple failure events!

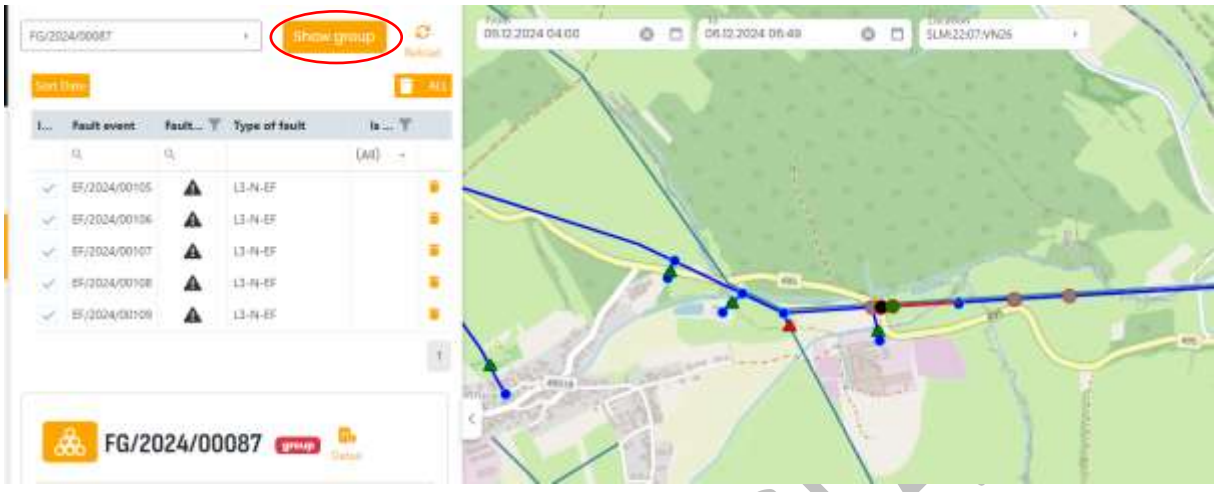


Figure 7 Group view

Fault Group basic information

The description of a group of fault events is based on the same items (Table 2), as a description of one failure event and also its display in the map base, corresponds to the display of individual failure events. However, when describing and displaying a group, the meaning of some items or the color marking of position indicators in the map background changes:

1. Type of fault – is determined as the intersection of types of failures in a group, based on what types of failures each failure event is. If the fault type matches all events, the type is filled in. If there is a match to at least the fault character of the Earth Fault/Short Circuit, EarthFault/ShortCircuit is filled in here. If the fault events are of different types, the result is the description CombinedFault.
2. The start time of fault is the beginning of the first failure in the group
3. The end time of fault is the end of the last failure in the group
4. The location of the failure (Fault location GPS) is the place of the so-called priority localization, i.e. the result of the localization of the fault event in the group that has been evaluated as trustworthy (unambiguous) – this failure event is marked in the list of fault events included in the group with a red symbol of the type of failure – see Figure 8. The results of localization in the remaining failure events are colored gray in the map and their coordinates are not stated in the group description.

   Note: A failure event of a given group is marked as a priority localization, The parameters of this priority event of the group are copied into the detailed information of the given FG. The event (FE) with the greatest distance from the power substation that has a valid localization (GPS field is colored green) is marked as priority, if none of the events has a valid localization, then the white coloration is preferred (it is not possible to decide on the plausibility) and the last red coloration (untrusted localization) – information about the plausibility of the localization is also copied into the FG field:

5. The basic description of the group contains the Exact Location item, in which there is a button for adding the actual location of the failure to the map base Select Location. With this button, a moving point is inserted into the map, which can be placed according to the known position of the actual fault. After its placement, it is colored green and its position determines the value in the Fault location distance error item – see Figure 8.
6. Button **Detail** located in the header of the Failure Group Basic Information Panel (Figure 8) will also display a panel of detailed information, where it is possible to add other facts found at the actual location of the failure – see the next chapter.

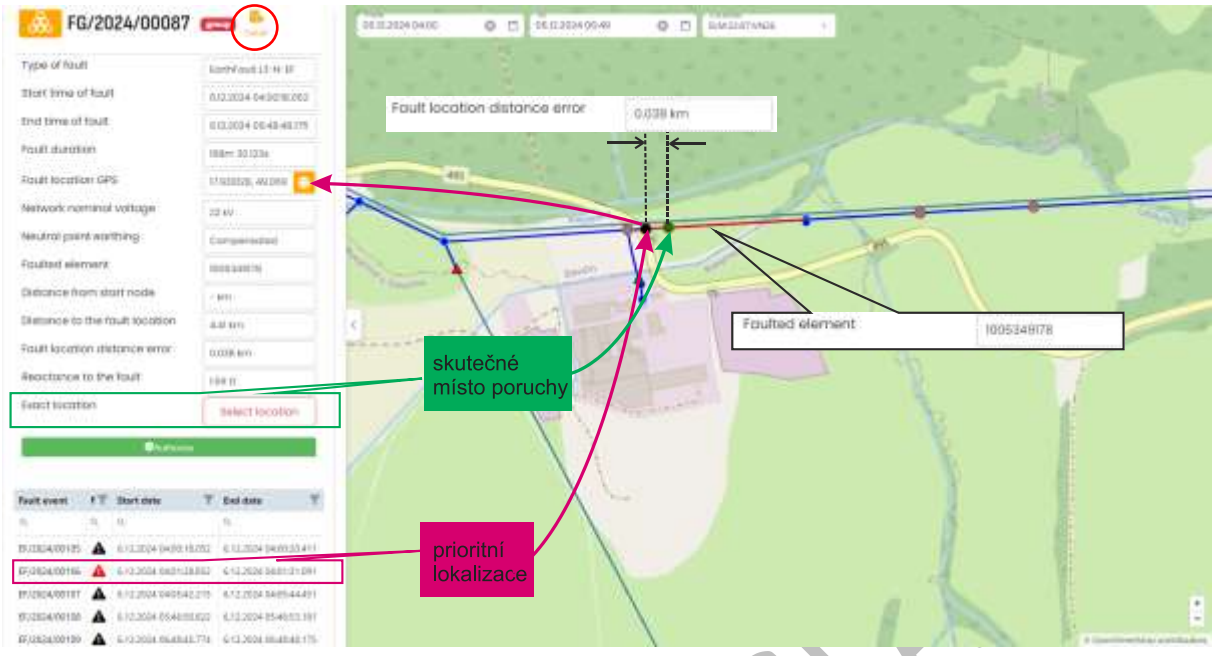


Figure 8 Display and basic description of the group of disorders

Fault Group detail information

The FG Detail Information Panel is divided into two sections. In the first one, there is a detailed description of the group of failures through items that are identical to the detailed description of the failure event and their meaning is given in Table 2 with the exceptions listed in the previous chapter.

The second part of the panel is intended to describe the actual fault based on the information found by the fault crew at the location where it was found. This panel consists of a set of editable windows, into which it is possible to enter the details of the actual fault in the form of a description (Enter text) or by selecting an item from the menu displayed by clicking in the window (Select). The importance of individual items is Figure 9 and by entering the specified information about the fault, a fault message is created.

The last step is to save it (Save) and authorisation (Save and Authorize) using the buttons at the bottom right (see Figure 9), where by authorizing a failure, the error message created in this way is locked for further editing, as well as the entire group of failure events. After authorization, all information about the failure and group of failures is taken as verified, e.g. for the purposes of statistics in other modules of the FRA system.

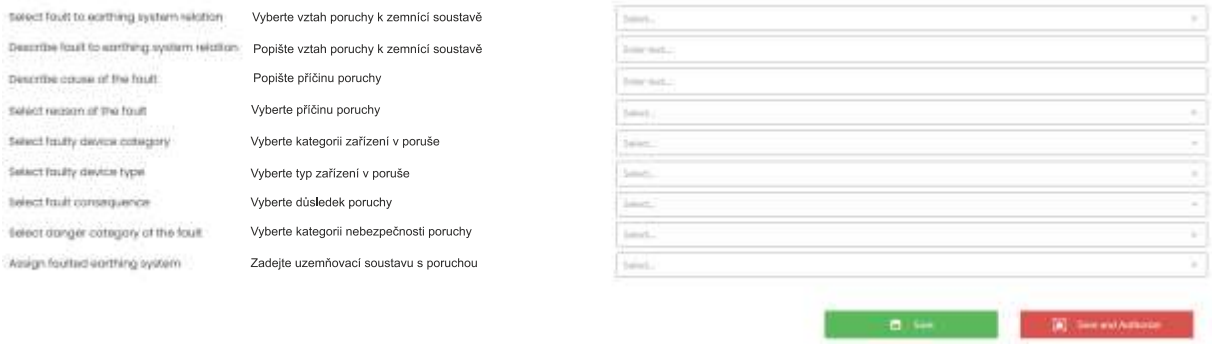


Figure 9 Part of the panel of detailed information about the group of failures – fault message

Network map icon description

The map base for displaying fault events is equipped with a filter for filtering, located in the upper left corner - Figure 10. Failure events can be selected using this filter according to the location – by selecting the line outlet in the power substation – or by the time interval (From –To) in which the fault event was recorded. Type text in the Location field to find the name you need.

The display of the fault event is the place marked with a black dot where the fault was located and a red colour of the network element in which the fault is located – see Figure 10. The fault event is displayed in the state (configuration) of the fault terminal, which corresponds to the time of its occurrence and is given by the state of the individual switching elements (breakdown points) in the outlet at the beginning of the fault event (the outlet separation is deep blue). Switching elements are represented in the map by triangular markers and their current state is given by its coloring – green = on, red = off. Hovering over a marker displays the identifier of a specific switching element. Example of a switching element identifier in Figure 10 is the identifier of the power switch in the outlet of the VN26 power substation.

The entire outlet in the current connection is highlighted in a rich blue color in the network map (available system model) and is divided into individual sections defined by blue dots of the same color. These points also have their identification markings, which are displayed by hovering. Example in Figure 10 shows the endpoint identifier of the network element with the TS designation that corresponds to the distribution transformer station (DTS).

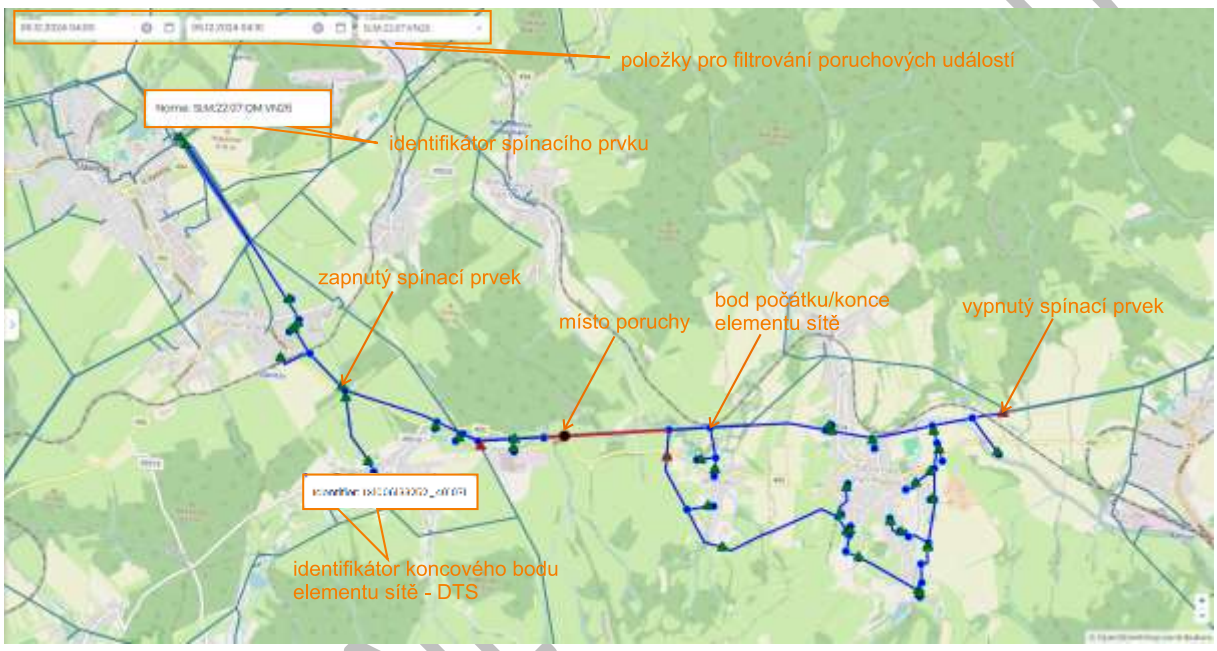
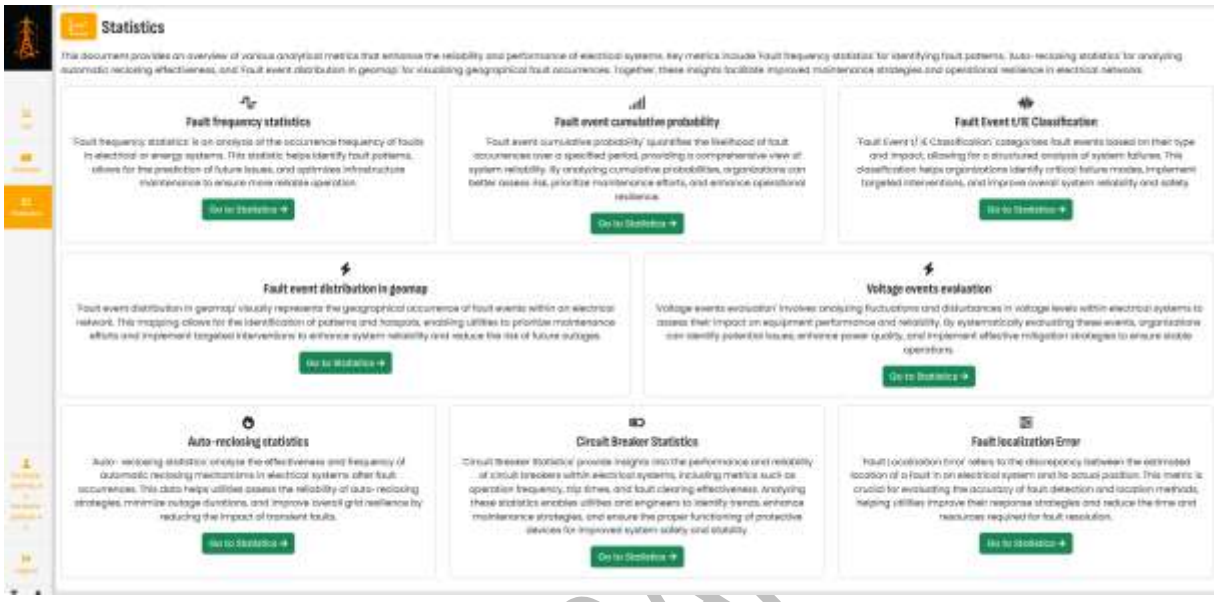


Figure 10 – Legend of the map base

Fault event statistics

The *Statistics tab* provides the user with an overview of various indicators evaluated from the analyzed records. Key metrics include *Fault frequency statistics* to identify fault patterns, *Auto-reclosing statistics* to analyse the effectiveness of automatic re-engagement, and *Fault event distribution in* geomap to geographically visualise fault occurrences on the map. The analysis of these indicators and insights contributes to improving the reliability, maintenance strategies and operational resilience of power grids.



There are a total of 8 modules in the statistics tab, allowing a detailed view of the selected indicator using various variants of graphs and histograms. You can go to the details of each statistical module by clicking on the *Go to Statistics button*. Individual modules allow filtering of the displayed data – by place and date of occurrence, or by types of individual events. The individual modules are described in more detail below:

Fault frequency statistics

Fault frequency statistics is an analysis of the frequency of failures in a selected period in a selected area of the distribution system. These statistics help identify patterns of failures, predict future problems, and optimize infrastructure maintenance to ensure more reliable operations.

The module displays a graph of the frequency of occurrence of failures in individual years, where the types of included failures are color-coded. Data can be filtered based on:

- type of failure (*Type of fault*) (see Table 1),
- the time range of flights from-to (*From-To*),
- outlet from the HV substation, or outlet protection, which signaled the occurrence of a fault (*Location*),
- Indicates whether the fault is *authorized*.

Fault event cumulative probability

Fault event cumulative probability quantifies the probability of fault events occurring over a period of time and provides a comprehensive view of the reliability of the system. By analyzing cumulative probabilities, you can better assess risks, prioritize maintenance, and increase operational resilience.

In the General section, the drop-down menu selects between the characteristic values of the currents in the analyzed events. The characteristic values of the short-circuit current are described in the table below. Some values include only certain types of short/ground faults. The characteristic values of the short-circuit current are in accordance with the ČSN EN 60909-0 standard. The values related to the earth current (*Current to earth, Maximal earth fault current*) are already described in Table 2. In addition, in the case of short-circuit currents, it is possible to distinguish values according to individual phases (L1), (L2), (L3) or to include all phases together (L123), the earth current (three times the non-rotating component of the current) is marked (N).

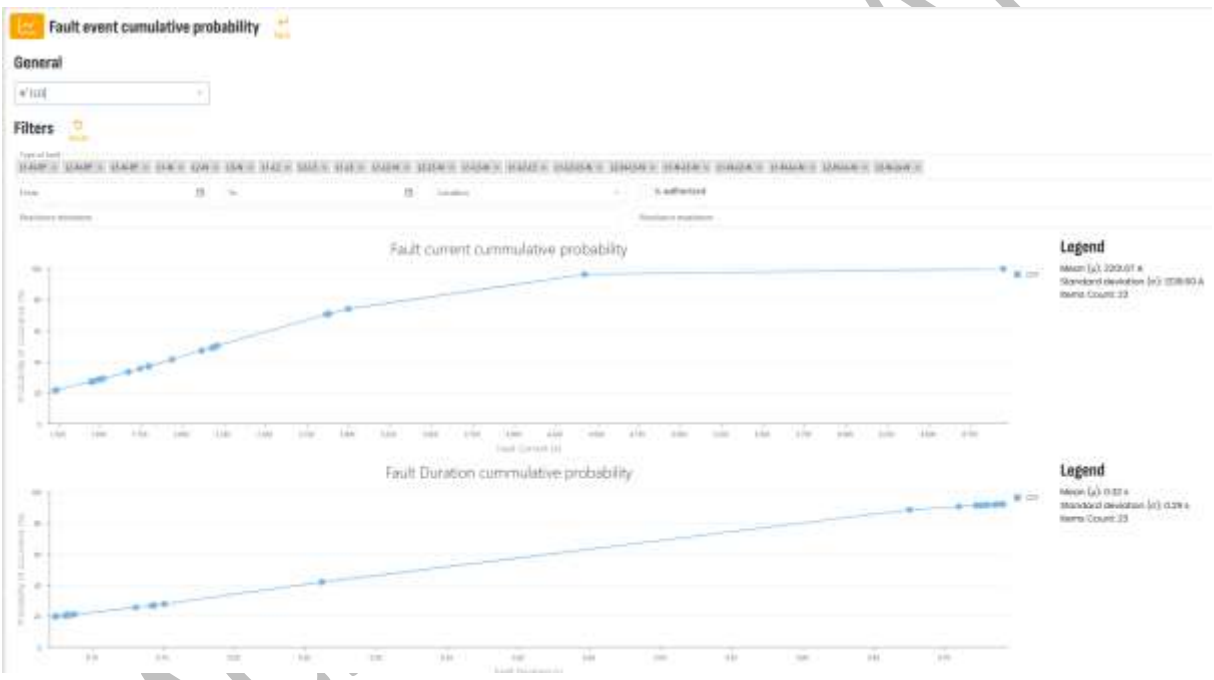
Table 3: Characteristic values of short-circuit current

Only for short circuits	Ik''	Initial Symmetrical Surge Short-Circuit Current
	Ip	Surge Short-Circuit Current
	Ib	Shut-off short-circuit current
	Ik	Steady Current Short-Circuit
	Ith	Equivalent Warming Short-Circuit Current
	Idc	Direct Current Component of Short Circuit Current
For short circuits and ground connections	Current to earth	Fault current closing with earth (for more detailed description in Table 2)
Only for ground connections	Maximal earth fault current	Maximum fault current closing the ground (for more detailed description in Table 2) – is calculated only for the earth connection where it corresponds to the metal earth connection

The accumulated probability is plotted in the graphs using the curve of the distribution function. The upper graph shows the distribution of the magnitude of the selected fault current, the lower graph shows the distribution of the fault duration. The legend on the right side adds information about the displayed statistical file – arithmetic mean (*Mean*), standard deviation (*Standard deviation*) and the number of included samples – events (*Items Count*).

The displayed statistical file can be filtered according to several parameters:

- type of failure (*Type of fault*) (see Table 1),
- the time range of flights from-to (*From-To*),
- outlet from the HV substation, or outlet protection, which signaled the occurrence of a fault (*Location*),
- Indicates whether the fault is *authorized*.
- short-circuit reactance range (line between the supply substation and the fault site) (*Reactance minimum – Reactance maximum*),
- the range of the fault current (*ikMinimum-ikMaximum*).



Fault event time/earth fault classification

This module – Classification of fault events by time and ground current – categorises fault events based on their type and impact, allowing for a structured analysis of system faults. This classification helps to identify critical failure pathways, perform targeted interventions, and improve overall system reliability and safety.

The module displays two histograms – a distribution of events according to duration and a division according to the size of the earth current. The individual types of displayed defects are color-coded. Clicking on the button ≡ offers the possibility of exporting the chart to PNG, JPEG, PDF and SVG formats. The displayed statistical file in the graphs can be filtered according to several parameters:

- type of failure (*Type of fault*) (see Table 1),
- From To months,
- outlet from the HV substation, or outlet protection, which signaled the occurrence of a fault (*Location*),

- Indicates whether the fault is *authorized*.
- short-circuit reactance range (line between the power substation and the fault site) (*Reactance minimum – Reactance maximum*).

Fault event distribution in geomap

The statistical module *Fault event distribution in geomap* – Distribution of fault events in the map – visually illustrates the geographical occurrence of fault events in the power grid. This mapping makes it possible to identify problematic localities and reveal patterns of failures.

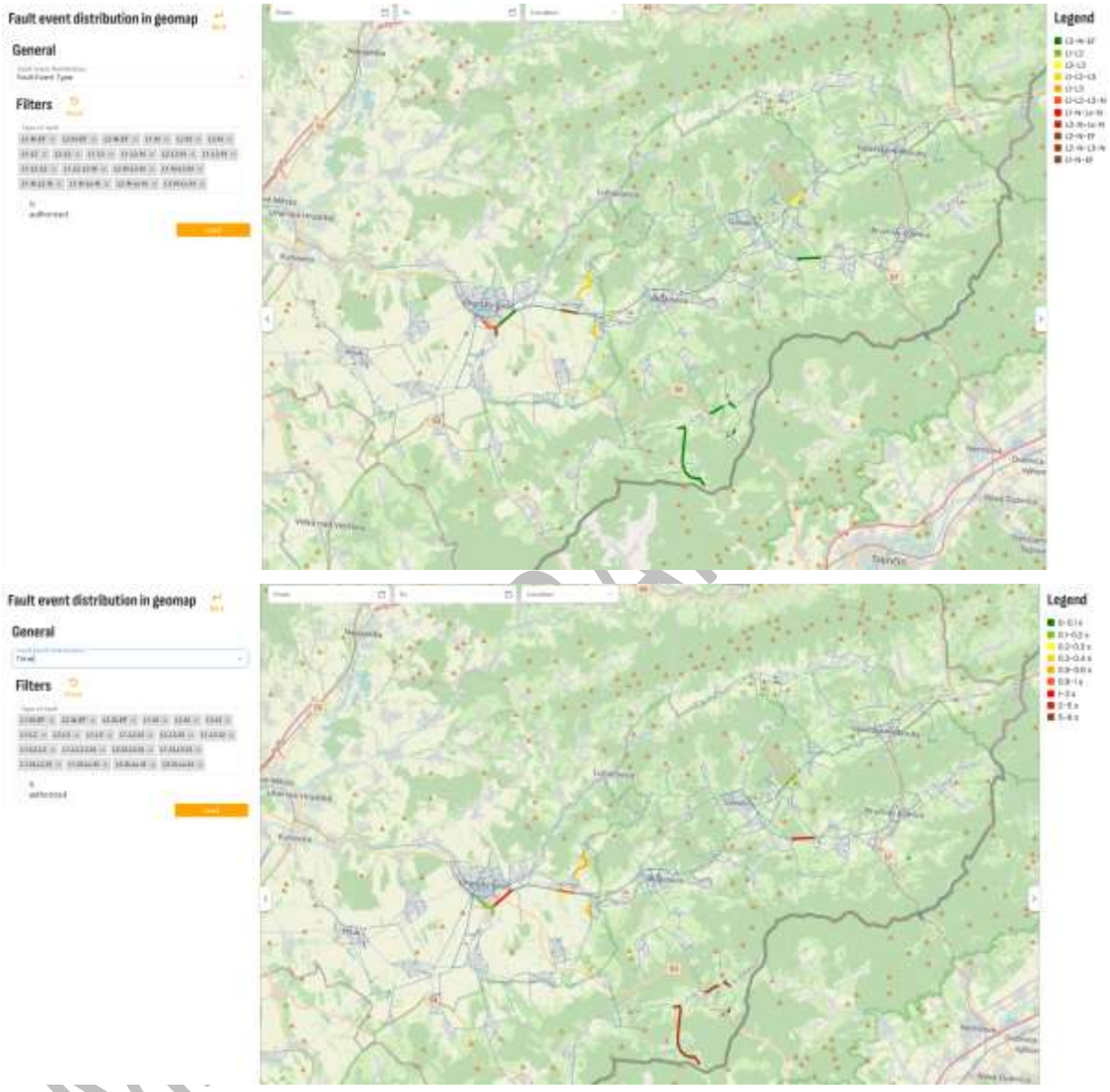
The map view shows the topology of the distribution network with highlighting the lines on which the fault was located. The criterion for distinguishing events is selected in the drop-down menu in *the General* section under *Fault Event Distribution.* The categories according to which events can be evaluated are:

- *Fault Event Type*,
- Event duration (*Time*)
- Current *to Earth*,
- *Fault Location Distance Error*.

In the *Filters section*, you can then limit the static file by

- type of failure (*Type of fault*) (see Table 1),
- Indicates whether the fault is *authorized*.

On the right side of the screen there is a legend (*Legend*), where the displayed events are distinguished in a color scale.



Voltage events evaluation

The *Voltage events evaluation module* includes the analysis of voltage drops, increases and interruptions, i.e. continuous voltage events.

There are two sets of graphs to display in the module – the first type plots the distribution function, the second type then the distribution of events according to the residual voltage and duration according to the relevant ČSN EN 50160 standard.

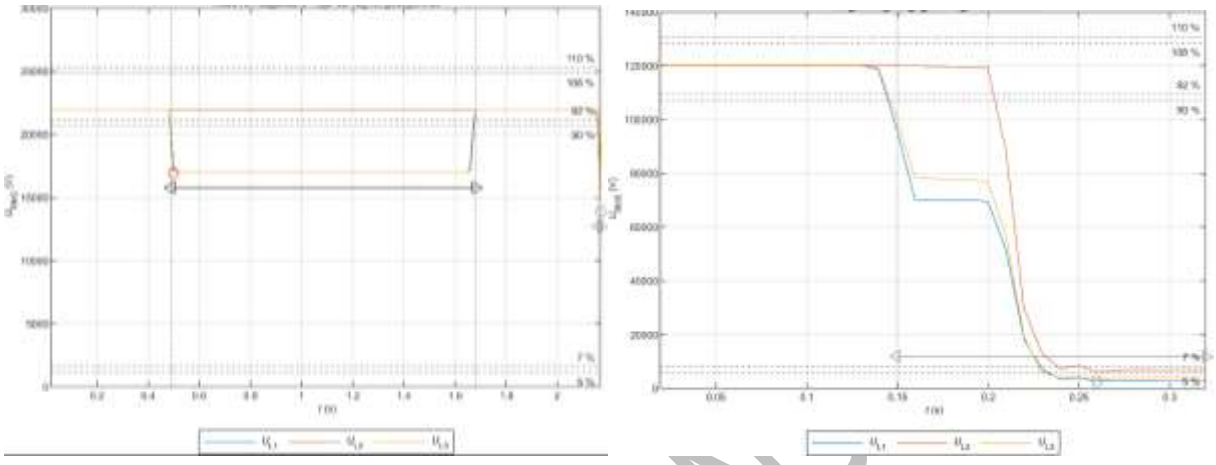
By default, the statistical set of displayed events can be filtered by

- type of failure (*Type of fault*) (see Table 1),
- the time range of flights from-to (*From-To*),

- outlet from the HV substation, or outlet protection, which signaled the occurrence of a fault (*Location*),
- Indicates whether the fault is *authorized*.

The following filters are also added:

- If only those events that ended within the analyzed COMTRADE record (*Only completed voltage events*) should be included.
  The figure shows an example of a properly completed event within a record (left) and an event not completed within a record (right).

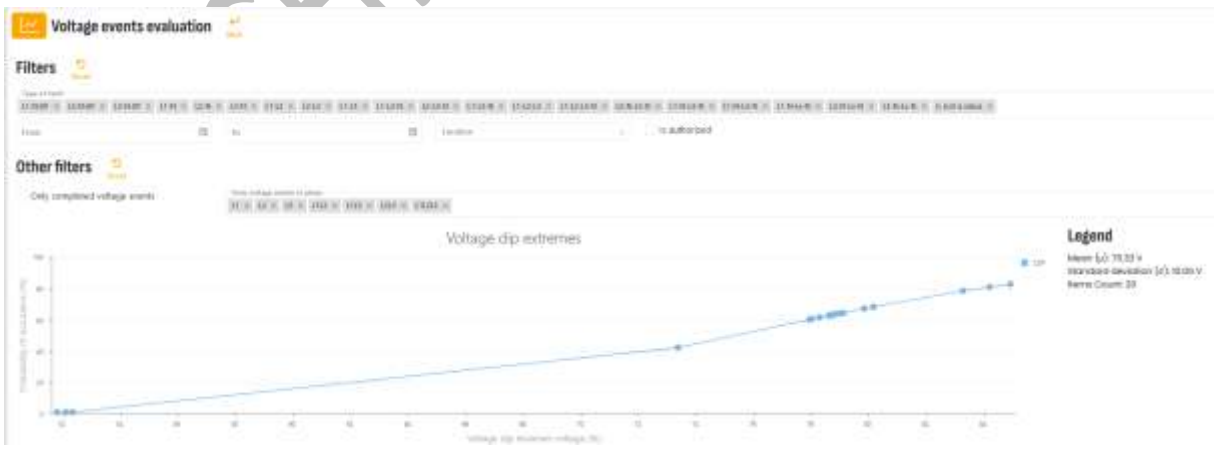


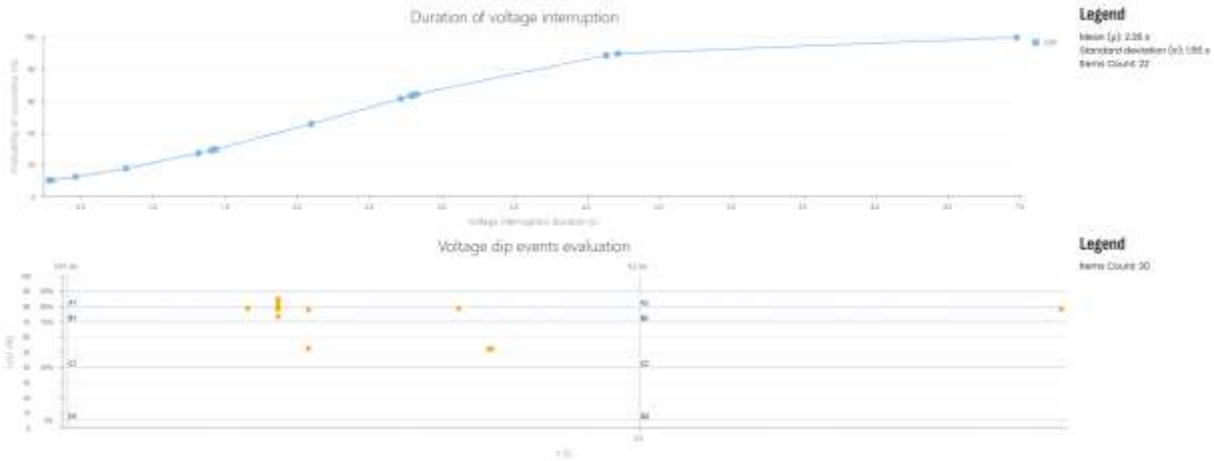
- Include only *voltage events in phase*. Using the previous figure, this voltage increase can be (and filtered) by the L2 phase.

The first two graphs show the distribution of extremes of characteristic values of dips or increases in voltage. In the case of *dips*, it is the residual stress *Ures* expressed in proportion to the nominal stress. This voltage is defined as the lowest measured voltage at a drop on any channel. Voltage increase (*swell*) is the maximum voltage at increase, which is defined as the highest measured voltage at increase on any channel.

The x-axis corresponds to these values of voltage, the y-axis corresponds to the accumulated probability, the legend on the right side adds information about the displayed statistical file – *Mean*, *Standard deviation* and number of included samples – events (*Items Count*).

Similarly, the accumulated probability for interruption is plotted using the distribution function. However, the y-axis plots the duration of the interruption in seconds.





The second part concerns the evaluation of voltage events – classification into categories described in ČSN EN 50160. These categories are divided according to the duration of the event and the magnitude of the relative residual voltage *u*, or the maximum voltage at increase. In the graph, individual events are represented by points in the plane with the indicated and defined categories A1 to D5. The table then shows the number of events in each category. The same overview is done to increase the voltage.

Auto-reclosing statistics

The *Auto-reclosing statistics module* analyses the effectiveness and frequency of automatic re-switching mechanisms in the distribution network after a fault has occurred. Clicking on the button ≡ offers the possibility of exporting the chart to PNG, JPEG, PDF and SVG formats.

There are two graphs to display in the module – the first type is a bar graph showing the number of OZ cycles with a distinction between whether it is successful (*Succesful*) or not (*No*).

By default, the statistical set of displayed events can be filtered by

- type of failure (*Type of fault*) (see Table 1),
- the time range of flights from-to (*From-To*),
- outlet from the HV substation, or outlet protection, which signaled the occurrence of a fault (*Location*),
- Indicates whether the fault is *authorized*.

Circuit Breaker Statistics

The *Circuit Breaker Statistics module* provides an overview of the ability and reliability of circuit breakers in the distribution system, including indicators such as switching frequency, tripping time and fault disconnection efficiency.

By default, the displayed events can be filtered by

- type of failure (*Type of fault*) (see Table 1),
- the time range of flights from-to (*From-To*),
- outlet from the HV substation, or outlet protection, which signaled the occurrence of a fault (*Location*),
- Indicates whether the fault is *authorized*.

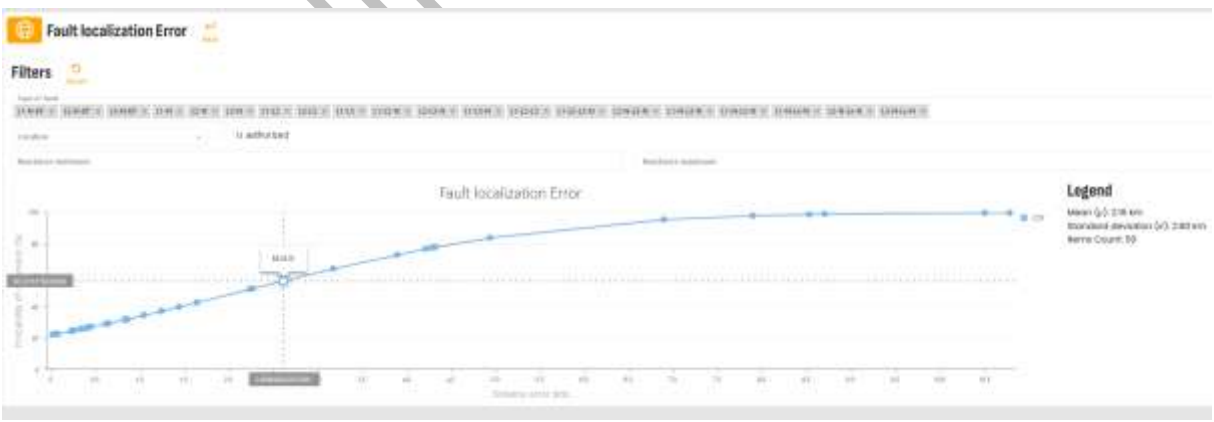
Clicking on the button ≡ offers the possibility of exporting the chart to PNG, JPEG, PDF and SVG formats.

Fault localization Error

The *Fault localization Error* module evaluates the difference between the estimated fault location (determined by the fault location calculation algorithm based on fault records) and its actual location (specified by the DS operator's employee).

Localization error data is plotted using a distribution function, where the x-axis is the localization deviation in kilometers; the y-axis is the accumulated probability. The legend on the right side adds information about the displayed statistical file – arithmetic mean (*Mean*), standard deviation (*Standard deviation*) and the number of included samples – events (*Items Count*).

- type of failure (*Type of fault*) (see Table 1),
- From To months,
- outlet from the HV substation, or outlet protection, which signaled the occurrence of a fault (*Location*),
- Indicates whether the fault is *authorized*.
- short-circuit reactance range (line between the supply substation and the fault site) *Reactance minimum – Reactance maximum*).



Requirements for parameterization of the IED fault record

To ensure compatibility of fault logs and the FRA system, below is a recommendation for setting up fault pinpoint protection recorders (IEDs).

Analog signals:

The fault record must contain information about three phase currents on the monitored outlet and three phase voltages, which can be supplemented by a ground current IE and a non-rotating voltage component of 3xU0. Alternatively, three combined voltages and a non-rotating voltage component or 3xU0 can be used (phase voltage is preferred).

Digital signals:

At least information about the status of the outlet switch (OFF) – three-pole (HV) or individual poles of the single-pole circuit breaker (HV) must be stored in the fault record.

	Channel name = Channel ID	CCBM	Channel Type	Name on the input to the FRA module
L1 current	'iL1','Ia','MMI3f1:I L1'	1	Analog	iL1
L2 current	'iL2','Ib','MMI3f1:I L2'	2	Analog	iL2
L3 current	'iL3','Ic','MMI3f1:I L3'	3	Analog	iL3
Current E	'iE','','MMI3f1:IN'	4	Analog	And
Phase voltage L1	'uL1','Va-g','MMU3f1:U L1'	5	Analog	uL1
Phase voltage L2	'uL2','Vb-g','MMU3f1:U L2'	6	Analog	uL2
Phase voltage L3	'uL3','Vc-g','MMU3f1:U L3'	7	Analog	uL3
Voltage consecutive component	'uN','',''	8	Analog	*Unused*
Switch Status (Off=1) L123	'1pole open L1', *'QM OFF'*	591	Digital	L1open, L2open, L3open
On/off switch status (Off=1) L1	'1pole open L1', 'CB1', 'L1open'	591	Digital	L1open
Switch status (Off=1) L2	'1pole open L2', 'CB2', 'L2open'	592	Digital	L2open
Switch status (Off=1) L3	'1pole open L3', 'CB3', 'L3open'	593	Digital	L3open

Note.:

Switch commands can be used when the Switch Status channel is not known/stored to recalculate the switch status (approximately). If there was no command to the switch during the entire comtrade (i.e. both commands are 0 all the time), then the state of the switch cannot be reconstructed – by default it is assumed that it was on, i.e. the state of the switch is set for the entire time comtrade = 0.

If there is no Current E channel in Comtrade, it can be calculated by simply adding all three channels of the current (see function fce_Vdip2_ReconstructIEfromPh). Its sample rate is also taken from comtrade, which is marked as VZcomCFG (in the Vdip structure) and VZcom (as an input variable to FRAsmelcovacSequence)

Recommended Fault Recorder Settings for SIprotect Protections:

Sip 4 – 800 Hz, 5s Save with Trip, prior/after time 0.2s

Sip 5 – 4 kHz, 5s Save with Trip, prior/after time 0.2s

Note.:

The Siprotec 4 7SJ63 protection has a sampling frequency of 800Hz, max. recording length 5s, trip log records max. 8 records (the recording length is always according to the duration of the failure - in the case of longer failures, a maximum of 5s is recorded -+ prior/after time 0.2s). New records overwrite the old ones => max. 5s records can be stored in total. The possibility of a maximum length of one recording of 5s has its pros and cons, see. experimental recordings. We still have to agree on the final max. length.

The record type is Power System Fault (individual Fault events related to each other are in one record).

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