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## **EXPERIMENTAL MEASUREMENTS OF GROUND FAULTS IN THE COMPENSATED UBR/SLM SYSTEM**

**Summary report from the experimental measurement**

Project number: TK04020230

Project title: Development of a system for autonomous analysis of fault records in distribution systems

**Brno**

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**Summary report of the 2024 experimental measurement**

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## 1 Introduction

The aim of the experimental measurements carried out on 22 and 23 October 2024 was to verify the pilot operation of the Vdip2 and FRA system installed at the location of the Uherský Brod and Slavičín substations at the outlet of HV 75 and HV26.

## 2 Description of the experiment

Experimental measurements of the ground fault (ZS) were carried out in the 22 kV distribution system supplied from the TR 110/22kV transformer station Uherský Brod and Slavičín (alternatively). A VN75 outlet was set aside for the measurement of the WS, on which it was possible to reconfigure both the power supply from Slavičín and Uherský Brod during the WS.



*Giant. 2-1 Ground connection at DTS Vlčí 400953*

The actual failure was realized by connecting the selected phase L3 with the grounding system via an auxiliary remotely controlled single-pole disconnector (see Giant. 2-1) either

directly (metal ground connection) or through electrolytic resistance (resistive ZS) or a damaged cable (arc ZS), depending on the type of simulated failure. The earth resistance of the earth system with the connected phase was about 30  $\Omega$  (measured at a soil resistivity of 50  $\Omega\text{m}$ ). The tests were carried out throughout the entire period without interruption in the supply of electricity with the help of the PPN platoon.

During the tests, two series of measurements were carried out, differing in the power supply substation UBR and SLM and the connection of the affected outlet, which was always considered in two modifications UBR1/SLM1 and UBR2/SLM2. A list of all tests and their parameters is given below.

*Tab. 2-1: Configure the tested network during experimental measurements powered by UBR*

<b>Test number</b>	<b>Time: 22.10.2024</b>	<b>Involvement</b>	<b>Type ZS</b>	<b>Tune-up</b>
1a	09:47:58.202	UBR 1	Metal	Fine-tuned
1b	10:04:44.747	UBR 1	Metal	Fine-tuned
1c	10:19:35.701	UBR 1	Metal	Fine-tuned
2	10:51:06.661	UBR 1	Metal	tuned -7.2A
3	11:03:06.925	UBR 1	Metal	tuned -10A
4	11:24:22.122	UBR 1	Metal	retuned +5A
5	11:33:44.237	UBR 1	Metal	retuned +12A
6	11:44:03.805	UBR 2	Metal	Fine-tuned
7	12:14:58.781	UBR 2	Arc	Fine-tuned
8a	12:33:23.391	UBR 2	Arc	tuned -5A
8b	12:46:43.731	UBR 2	Arc	tuned -5A
9	12:56:03.765	UBR 1	Arc	Fine-tuned
10	13:28:38.765	UBR 1	resistance 1200 $\Omega$	Fine-tuned
11	13:43:03.911	UBR 2	resistance 1200 $\Omega$	Fine-tuned
12	14:15:01.854	UBR 2	resistive 400 $\Omega$	Fine-tuned
13	14:27:38.621	UBR 1	resistive 400 $\Omega$	Fine-tuned
14	14:47:45.972	UBR 1	resistive 200 $\Omega$	Fine-tuned
15	14:56:21.395	UBR 2	resistive 200 $\Omega$	Fine-tuned
16	15:13:09.621	UBR 2	resistive 100 $\Omega$	Fine-tuned
17	15:23:02.321	UBR 1	resistive 100 $\Omega$	Fine-tuned

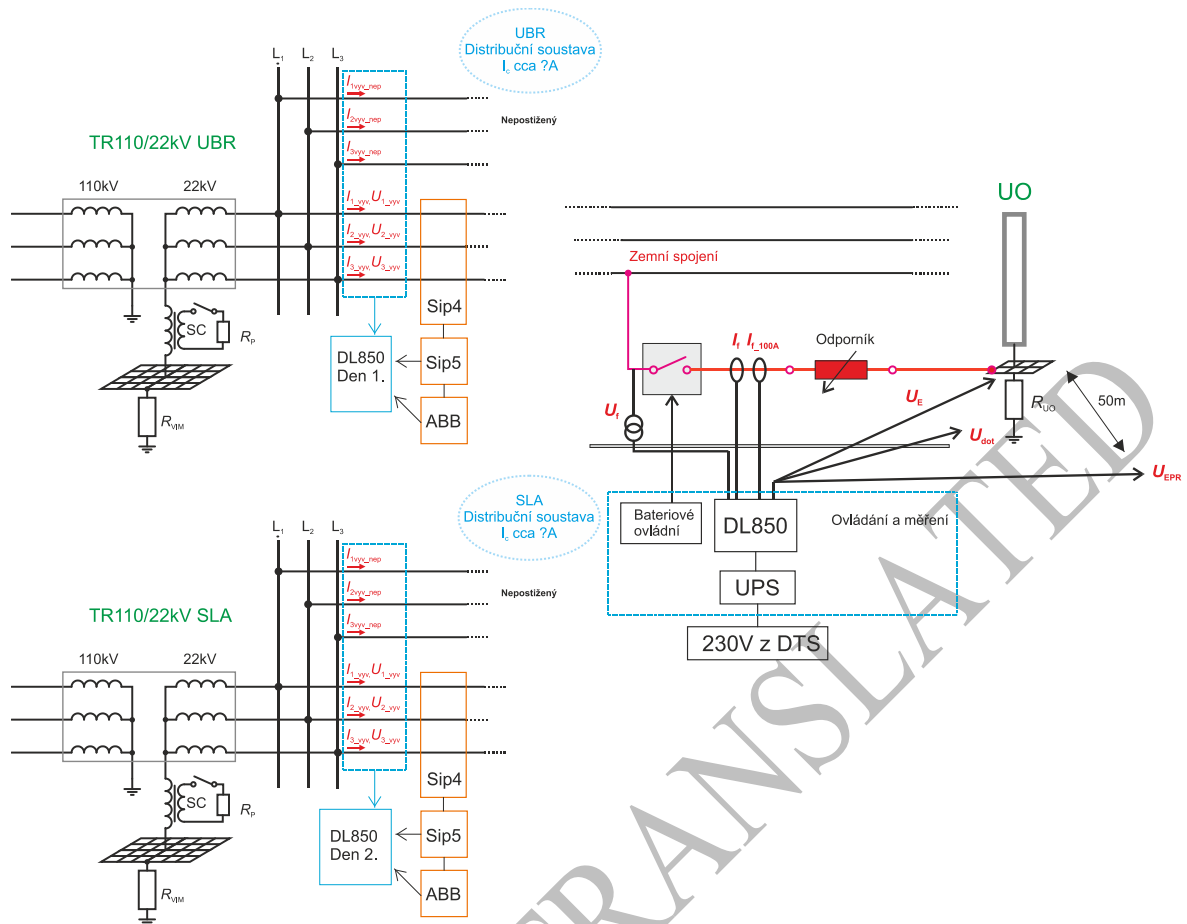
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Tab. 2-2: Configure the tested network during experimental measurements powered by SLM

Test number	Time: 23.10.2024	Involvement	Type ZS	Tune-up
1	10:23:39.203	SLM 1	Metal	Fine-tuned
2	10:36:10.674	SLM 1	Metal	tuned -5A
3a	10:42	SLM 1	Metal	tuned -12A
3b	11:05:25.472	SLM 1	Metal	tuned -12A
4	11:13:39.310	SLM 1	Metal	retuned +5A
5	11:24:21.790	SLM 1	Metal	retuned +12A
6	11:33:15.033	SLM 2	Metal	Fine-tuned
7	12:13:07.662	SLM 2	Arc	Fine-tuned
8	12:20:45.904	SLM 2	Arc	tuned -10A
9	12:28:48.580	SLM 1	Arc	Fine-tuned
10a	12:58	SLM 1	resistance 1400 $\Omega$	Fine-tuned
10b		SLM 1	resistance 1400 $\Omega$	tuned -10A
10c	13:14	SLM 1	resistance 1400 $\Omega$	tuned -10A
11	13:24	SLM 2	resistance 1400 $\Omega$	tuned -5A
12	13:44:36.492	SLM 2	resistive 400 $\Omega$	Fine-tuned
13	13:51:43.533	SLM 1	resistive 400 $\Omega$	Fine-tuned
14	14:07:46.010	SLM 1	resistive 200 $\Omega$	Fine-tuned
15	14:14:52.213	SLM 2	resistive 200 $\Omega$	Fine-tuned
16	14:26:23.084	SLM 2	resistive 100 $\Omega$	Fine-tuned
17	14:32:34.933	SLM 1	resistive 100 $\Omega$	Fine-tuned

## 2.1 Measured quantities

A simplified scheme of experimental measurements and recorded quantities is shown in Giant. 2-2.



*Giant. 2-2 Simplified Configuration Scheme of the System and Measured Quantities During Experimental Ground Fault Measurement*

For the purpose of recording all these variables, a total of two fault recorders were used located in the HV power substation and at the fault site.

The first of the Yokogawa DL850 recorders installed in the power substation monitored the voltage and current conditions on the affected VN75 outlet and on the unaffected outlet. A second Yokogawa DL850 logger was installed at the fault point, where it monitored the fault current (two fault current ranges), the voltage drop at the fault resistance, the voltage of the affected phase, the contact voltages (loaded plate electrode and unloaded rod) and the potential increase voltage of the affected ground system.

## 2.2 Experiments summary table

To compare the individual levels of monitored signals across all tests, all monitored parameters are summarized in the tables below, for the ground fault condition without the auxiliary resistor attached and after the auxiliary resistor is attached.

Note: Tests 1a, 8a, 10b and 14 were not recorded during the tests or are not complete. IN most cases, these tests were repeated.

Tab. 2-3 Summary table of characteristic values of all experiments

Zapojení	Test	Stav Typ (rozladění)	ZS			ZS + R			$R_{zs}$ [ $\Omega$ ]
			$I_f$ [A]	$3xI_{0,po}$ [A]	$U_0$ [kV]	$I_f$ [A]	$3xI_{0,po}$ [A]	$U_0$ [kV]	
UBR 1	1a	kovové	n/a	35,5	12,2	n/a	41,7	11,8	
UBR 1	1b	kovové	2,9	35,7	12,3	11,3	41,9	11,9	
UBR 1	1c	kovové	2,8	35,6	12,3	19,0	41,8	11,9	n/a
UBR 1	2	kovové (-7,2A)	8,5	27,9	11,9	23,9	35,7	11,7	n/a
UBR 1	3	kovové (-10A)	8,9	27,5	12,0	24,0	35,5	11,8	n/a
UBR 1	4	kovové (+5A)	4,2	38,3	11,7	23,0	43,7	11,5	n/a
UBR 1	5	kovové (+12A)	7,9	42,5	11,6	23,9	47,1	11,5	n/a
UBR 2	6	kovové	3,0	34,4	11,7	22,5	40,4	11,5	n/a
UBR 2	7	obloukové	4,7	32,4	10,9	22,5	40,3	11,3	n/a
UBR 2	8a	obloukové (-5A)	n/a	30,8	11,7	n/a	37,0	11,4	n/a
UBR 2	8b	obloukové (-5A)	8,0	29,6	11,7	22,3	35,5	11,2	n/a
UBR 1	9	obloukové	4,0	33,8	11,5	22,3	39,8	11,3	n/a
UBR 1	10	odporové 1200 $\Omega$	2,3	27,8	9,5	7,1	13,3	3,6	1185,5
UBR 2	11	odporové 1200 $\Omega$	2,1	28,1	9,5	7,2	13,6	3,6	1124,1
UBR 2	12	odporové 400 $\Omega$	2,4	31,4	10,7	11,5	21,0	5,7	505,6
UBR 1	13	odporové 400 $\Omega$	2,5	31,6	10,8	11,9	21,5	5,9	481,8
UBR 1	14	odporové 200 $\Omega$	2,6	33,4	11,4	16,2	29,2	8,3	208,4
UBR 2	15	odporové 200 $\Omega$	3,1	32,2	11,4	16,2	28,6	8,4	201,8
UBR 2	16	odporové 100 $\Omega$	2,7	34,3	11,6	19,0	34,3	9,7	97,1
UBR 1	17	odporové 100 $\Omega$	2,9	33,9	11,8	19,1	34,1	9,9	94,8
SLM 1	1	kovové	6,9	42,2	12,0	44,4	58,8	10,3	60,6
SLM 1	2	kovové (-5A)	5,1	38,2	12,0	43,2	55,9	10,4	48,3
SLM 1	3a	kovové (-12A)	7,4	32,5	12,2	42,7	52,6	10,6	79,7
SLM 1	3b	kovové (-12A)	7,6	32,6	12,3	43,6	53,3	10,6	45,1
SLM 1	4	kovové (+5A)	11,1	47,3	12,0	43,5	60,5	10,4	44,1
SLM 1	5	kovové (+12A)	15,1	51,4	11,9	44,4	63,2	10,4	42,6
SLM 2	6	kovové	8,5	44,3	12,3	44,1	59,6	10,7	41,2
SLM 2	7	obloukové	6,4	42,3	12,0	44,7	59,3	10,5	39,2
SLM 2	8	obloukové (-10A)	6,4	33,5	12,3	43,4	53,5	10,6	39,9
SLM 1	9	obloukové	7,1	42,8	11,9	42,3	57,5	10,3	39,7
SLM 1	10a	odporové 1400 $\Omega$	1,9	28,1	9,0	6,7	8,3	1,5	1551,3
SLM 1	10b	odporové 1400 $\Omega$ (-10A)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SLM 1	10c	odporové 1400 $\Omega$ (-10A)	5,9	18,5	7,8	8,3	9,7	1,9	1189,9
SLM 2	11	odporové 1400 $\Omega$ (-5A)	3,6	27,0	9,7	9,6	11,6	2,2	1001,0
SLM 2	12	odporové 400 $\Omega$	3,6	37,7	11,3	19,2	24,4	4,4	363,3
SLM 1	13	odporové 400 $\Omega$	4,4	38,2	11,1	20,0	25,9	4,6	326,1
SLM 1	14	odporové 200 $\Omega$	n/a	40,4	11,7	n/a	38,4	6,9	n/a
SLM 2	15	odporové 200 $\Omega$	6,0	42,4	11,9	30,6	39,9	7,2	122,5
SLM 2	16	odporové 100 $\Omega$	6,1	42,9	12,1	36,1	47,3	8,6	101,4
SLM 1	17	odporové 100 $\Omega$	6,3	42,7	12,0	35,1	46,8	8,5	99,6

Tab. 2-4 Summary Table of Touch Voltages and Potential Increases of Earthing Systems

Stav			ZS				ZS+R			
Zapojení	Test	Typ (rozladění)	$U_{E\_UO}$ [V]	$U_{E\_DTS}$ [V]	$U_{d\_load}$ [V]	$U_{d\_rod}$ [V]	$U_{E\_UO}$ [V]	$U_{E\_DTS}$ [V]	$U_{d\_load}$ [V]	$U_{d\_rod}$ [V]
UBR 1	1a	kovové	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
UBR 1	1b	kovové	90,7	1,1	72,1	81,9	480,4	3,7	243,2	246,6
UBR 1	1c	kovové	89,2	1,6	71,3	80,9	480,8	2,7	379,7	431,7
UBR 1	2	kovové (-7,2A)	265,8	0,7	211,4	240,0	489,4	3,0	385,8	438,5
UBR 1	3	kovové (-10A)	278,7	0,9	221,4	251,5	490,3	3,0	386,2	439,1
UBR 1	4	kovové (+5A)	133,1	0,9	105,8	120,1	477,9	3,2	376,9	428,3
UBR 1	5	kovové (+12A)	250,3	1,0	198,8	225,7	481,1	3,4	378,9	430,7
UBR 2	6	kovové	94,5	0,9	75,1	85,2	480,5	3,0	378,9	430,6
UBR 2	7	obloukové	125,8	1,2	99,8	113,4	468,9	2,9	370,3	420,8
UBR 2	8a	obloukové (-5A)	209,6	1,3	166,3	188,9	466,7	3,3	368,3	418,5
UBR 2	8b	obloukové (-5A)	n/a	1,0	200,8	228,6	n/a	1,4	516,5	587,0
UBR 1	9	obloukové	n/a	0,7	102,3	116,2	n/a	1,9	437,4	537,7
UBR 1	10	odporové 1200 Ω	73,9	1,7	n/a	67,2	223,8	1,8	n/a	202,5
UBR 2	11	odporové 1200 Ω	66,8	n/a	53,4	60,5	227,4	n/a	181,2	205,5
UBR 2	12	odporové 400 Ω	75,7	n/a	60,7	69,0	353,3	n/a	282,1	321,1
UBR 1	13	odporové 400 Ω	78,4	n/a	63,0	71,6	363,1	n/a	290,1	330,2
UBR 1	14	odporové 200 Ω	82,8	n/a	66,6	75,7	444,4	n/a	354,3	403,4
UBR 2	15	odporové 200 Ω	100,4	n/a	80,4	91,4	446,2	n/a	355,4	404,6
UBR 2	16	odporové 100 Ω	87,7	n/a	70,5	79,9	474,3	n/a	378,4	430,1
UBR 1	17	odporové 100 Ω	93,0	n/a	74,8	84,9	475,6	n/a	475,6	431,0

### 3 Description of the FRA system

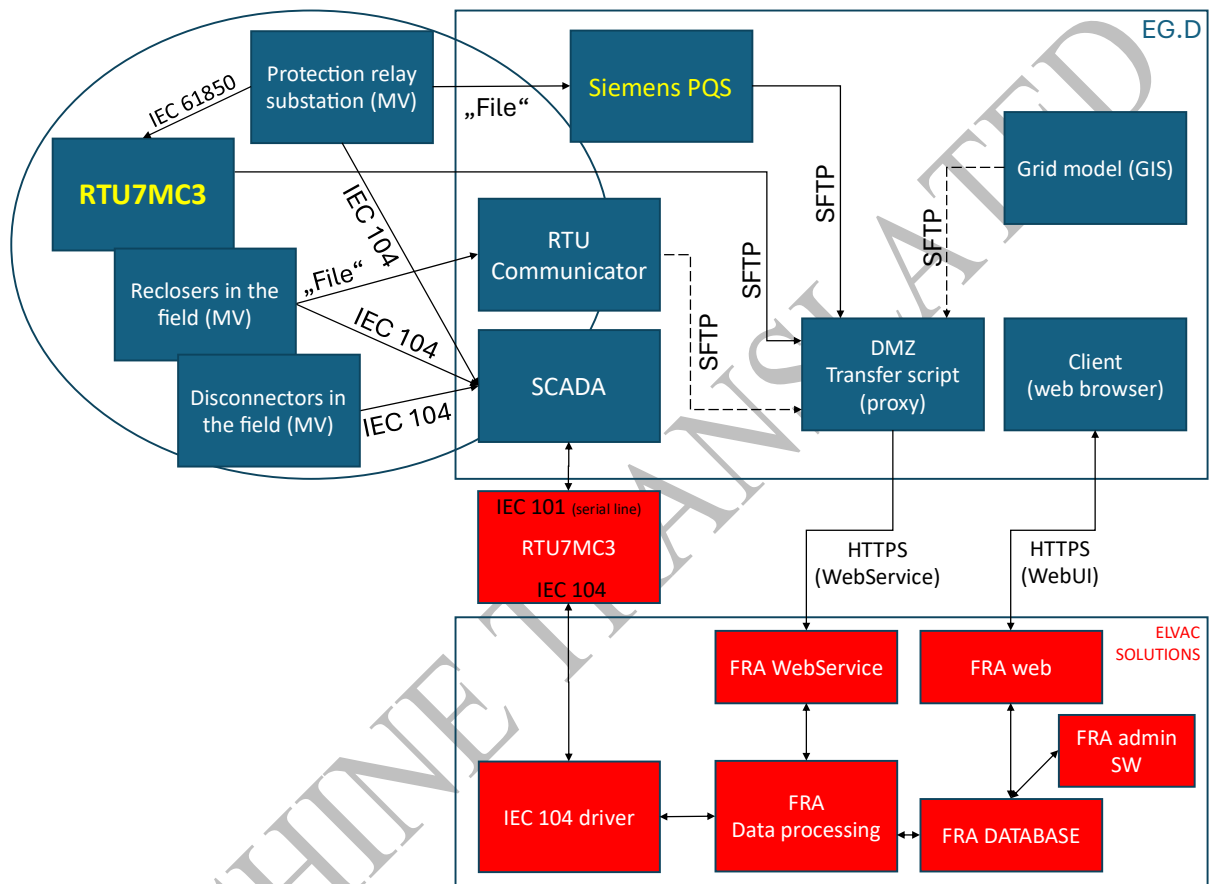
In order to run algorithms for the analysis of fault records and possible fault localisation by the FRA system, it is necessary to provide the necessary set of input data in a relatively short time after the occurrence of the fault event. Input data is of several types:

- Fault events (time-stamped signals)
- Fault records from outlet protections (COMTRADE)
- Topology of the affected network area at the time of the fault (combination of static data from GIS and current states of expansion elements)

The task of the designed infrastructure is to provide all the necessary data in real time. For the needs of pilot operation within the research project, it was necessary to take into account the availability of existing equipment and communication channels in the network of the distribution system operator (EG. D) and to ensure the transfer of the necessary data to a development server located in ELVAC's data network. An essential aspect of the solution design was compliance with the principles of cyber security and the operation of the FRA system without negatively affecting the operation of the distribution network operator.

### 3.1 Basic block communication scheme

The scheme is colour-coded into two groups of devices, systems or functional blocks according to their owner – the elements marked in blue are integrated into the data network of the distribution system operator (EG. D), the elements marked in red belong to ELVAC's data network.



Description of individual blocks in the scheme and their links:

#### Blocks in the EG network. D (blue)

1. Protection relay substation (MV) ... Digital protection of HV/HV outlets at substations – source of fault information and fault records
2. Reclosers in the field (MV) ... reclosers located in the MV network – a source of information about the status of the switching element with the possibility of using an additional fault record
3. Disconnectors in the field (MV) ... section disconnectors in the MV network – source of information on the status of the switching element

4. RTU7MC3 ... Communication unit for downloading records from IEC 61850 protections and forwarding them for further processing via SFTP protocol (or IEC 60870-5-104)
5. Siemens PQS... A tool of the protection manufacturer to download fault records and save them to disk
6. RTU Communicator ... Communication concentrator ensuring the download of fault records from the recloser controllers
7. SCADA ... the distribution system operator's dispatching control system, for FRA purposes, concentrates and transmits fault signals and status information from switching elements in the HV/HV network
8. Grid Model (GIS) ... data describing the physical parameters of the HV/HV network (lengths of individual line sections, cross-sections and types of wires, parameters of transformers, etc.)
9. DMZ Transfer Script (Proxy) ... on a server located in the "demilitarized zone" within the EG infrastructure. D scripts are run at regular intervals to ensure secure data transfer from sources within EG. D towards the FRA server operated on ELVAC's infrastructure, the use of an internet connection
10. Client (web browser) ... the results of the analysis of fault records, including fault localisation and additional and statistical information, are available to users in EG. D available via a common web browser (access security by name and password), use of an Internet connection

#### **Blocks in the ELVAC network (red)**

1. RTU7MC3 (IEC 101 serial line) ... communication unit for transmitting signals from the EG SCADA system. D, connected to the ELVAC data network (via mobile data connection), connection to SCADA via serial line (separation of network communication for cyber security reasons)
2. IEC 104 driver... communication controller integrated into the FRA SW package
3. FRA WebService ... a web service designed to receive data provided via the "Transfer script", especially fault records from protections at outlets from HV/HV substation
4. FRA Data Processing ... algorithms for fault record analysis and fault localisation
5. FRA Database ... a data repository containing both all configuration, topological and fault data entering the calculations, as well as the results of the analysis of these data, including the results of localization

6. FRA Web ... web interface used for visualization and sorting of processed records or localization results, including statistical and analytical data

7. FRA Admin SW... configuration and diagnostic tool for system settings, import of underlying data, checking of internal records and maintenance of data structures

### **Main data streams**

The states of disconnectors in the network, reclosers and switches on the pins are transmitted in a standard way to the SCADA system, from there via the serial line via the IEC101 protocol to the RTU7MC3 and further via the mobile data connection (SIM ELVAC) via the IEC104 protocol to the FRA server. The same data path in the opposite direction can be used to transmit localization results or other analytical outputs available on the server side.

COMTRADE records from the protections on the outlets in the HV/HV substation are downloaded via RTU7MC3 located at the substation and further transmitted via the "DMZ Transfer script" (communication via the Internet) to the FRA server. Scripts on the DMZ workstation in conjunction with the web service on the FRA server side can also be used to transfer records downloaded via "Siemens PQS" or "RTU Communicator". The same method of transmission is also available for data transfer from the GIS system, but this option is not used during pilot operation.

To display the results of the analysis of records and localization of failures using a web browser on the side of the distribution system operator, the "FRA web" is used on the Vdip2 server, from where the transmission takes place via the HTTPS protocol using an Internet connection.

Note: Compression (ZIP) is used to transfer records in COMTRADE format and other data sets in order to reduce the volume of data transferred.

## **3.2 Evaluation of FRA function**

During the tests of the ground connections, it was proved that the created infrastructure of the FRA system described in the chapter 3.1 was fully functional. During the artificially created failures, only one error occurred, when the signaling of the action of the outlet protection was not transmitted, but this error occurred due to the restart of the data source at the PDS level. Since the remaining components of the FRA system have already been continuously tested, the evaluation will also focus on the assessment of the accuracy of the earth current estimation during earth connections, for which there was not enough input data.

The deviation of the result of the estimated earth current by the FRA system from the actual value measured at the fault site is shown in the table Tab. 3-1 for the first day of tests powered by the UBR substation, and Tab. 3-2 for the second day of tests powered by the SLM

substation. These tables contain basic information about each test, residual current deviation evaluation, where:

- a)  $I_{f\ est} (A)$  – is the ground current estimated by the FRA system
- b)  $I_{f\ max} (A)$  – is the maximum value of the ground current estimated by the FRA system (corresponds to the metal earth connection)
- c)  $I_{f\ meas} (A)$  – is the ground current measured at the fault point during earth fault tests
- d)  $\Delta I_f (A)$  – deviation of the estimated and actual value of the ground current (residual current)
- e)  $\Delta I_{f\ max} (A)$  – deviation of the maximum value of the earth current (residual current) from the measured current during the metal earth connection

Furthermore, the information about the attached auxiliary resistor at the moment of estimation of the residual (ground current) *yes* (auxiliary resistor attached) *no* (auxiliary resistor not pinned).

As can be seen from the tables Tab. 3-1 and Tab. 3-2, so the deviations of the estimated and actual fault earth current range from 10A to – 8.7A (the estimated value is less than the actual value). These deviations are caused both by the influence of the charging capacities at the affected outlet and by the measurement uncertainty, as the residual current in this case is extremely low – it forms about 1A difference in the phase current with a nominal current of 300A (i.e. about 0.33%), which is significantly below the level of uncertainty of the instrument current transformers. Residual current estimation allows you to get an idea of the residual current level, despite the average deviations of the estimated current of 3.2 A.

*Tab. 3-1 Estimation of ground current by the FRA system supplied from the UBR substation*

Test číslo	Čas 22.10.2024	Zapojení	Typ ZS	Naladění	$I_f$ est (A)	$I_f$ max (A)	$I_f$ meas (A)	$\Delta I_f$ (A)	$\Delta I_f$ max (A)	Odporník pro $I_f$
15	14:56:21.395	UBR 2	odporové 200 $\Omega$	vyladěno	13,0	20,6	16,2	-3,2	-1,9	ano
9	12:56:03.765	UBR 1	obloukové	Vyladěno	19,7	22,9	22,1	-2,5		ano
6	11:44:03.805	UBR 2	kovové	vyladěno	21,0	24,2	22,5	-1,5		ano
4	11:24:22.122	UBR 1	kovové	přeladěno +5A	25,9	29,8	23,0	2,9		ano
2	10:51:06.661	UBR 1	kovové	podladěno -7,2A	33,1	37,8	23,9	9,2		ano
8a	12:33:23.391	UBR 2	obloukové	podladěno -5A	22,7	26,4	x	x		ano
8b	12:46:43.731	UBR 2	obloukové	podladěno -5A	3,0	3,3	6,6	-3,5		ne
3	11:03:06.925	UBR 1	kovové	podladěno -10A	5,8	6,1	8,8	-3,1		ne
13	14:27:38.621	UBR 1	odporové 400 $\Omega$	vyladěno	0,8	0,9	2,3	-1,5	-2,5	ne
14	14:47:45.972	UBR 1	odporové 200 $\Omega$	vyladěno	1,1	1,2	2,4	-1,3	-2,7	ne
16	15:13:09.621	UBR 2	odporové 100 $\Omega$	vyladěno	2,3	2,6	2,4	-0,1	-7,7	ne
1c	10:19:35.701	UBR 1	kovové	vyladěno	3,1	3,4	2,6	0,5		ne
1b	10:04:44.747	UBR 1	kovové	vyladěno	3,7	3,9	2,8	0,9		ne
5	11:33:44.237	UBR 1	kovové	přeladěno +12A	9,1	10,3	7,8	1,2		ne
12	14:15:01.854	UBR 2	odporové 400 $\Omega$	vyladěno	3,5	4,1	2,2	1,3	0,3	ne
17	15:23:02.321	UBR 1	odporové 100 $\Omega$	vyladěno	4,2	4,8	2,7	1,5	0,9	ne
7	12:14:58.781	UBR 2	obloukové	vyladěno	10,2	13,0	6,0	4,1		ne
11	13:43:03.911	UBR 2	odporové 1200 $\Omega$	vyladěno	9,9	12,8	2,0	7,9	10,0	ne
1a	09:47:58.202	UBR 1	kovové	vyladěno	3,1	3,3		x		ne
10	13:28:38.765	UBR 1	odporové 1200 $\Omega$	vyladěno			2,3	x		

Tab. 3-2 Estimation of the ground current by the FRA system of the system supplied from the SLM substation

Test číslo	Čas 22.10.2024	Zapojení	Typ ZS	Naladění	$I_f$ est (A)	$I_f$ max (A)	$I_f$ meas (A)	$\Delta I_f$ (A)	$\Delta I_f$ max (A)	Odporník pro $I_f$
6	11:33:15.033	SLM 2	kovové	vyladěno	35,2	43,4	43,9	-8,7		ano
8	12:20:45.904	SLM 2	obloukové	podladěno -10A	38,2	47,7	43,4	-5,2		ano
2	10:36:10.674	SLM 1	kovové	podladěno -5A	38,8	49,3	43,3	-4,6		ano
7	12:13:07.662	SLM 2	obloukové	vyladěno	41,1	51,9	44,5	-3,5		ano
16	14:26:23.084	SLM 2	odporové 100 $\Omega$	vyladěno	34,9	53,6	36,1	-1,2	9,8	ano
3b	11:05:25.472	SLM 1	kovové	podladěno -12A	5,1	5,4	7,7	-2,6		ne
4	11:13:39.310	SLM 1	kovové	přeladěno +5A	10,3	11,4	11,3	-1,0		ne
1	10:23:39.203	SLM 1	kovové	vyladěno	7,2	7,9	7,1	0,1		ne
5	11:24:21.790	SLM 1	kovové	přeladěno +12A	18,2	20,4	15,1	3,1		ne
15	14:14:52.213	SLM 2	odporové 200 $\Omega$	vyladěno	9,7	10,7	6,2	3,5	3,6	ne
9	12:28:48.580	SLM 1	obloukové	Vyladěno	10,3	11,4	6,6	3,7		ne
17	14:32:34.933	SLM 1	odporové 100 $\Omega$	vyladěno	12,1	13,4	6,4	5,7	6,3	ne
13	13:51:43.533	SLM 1	odporové 400 $\Omega$	vyladěno	10,3	12,1	4,6	5,8	5,0	ne
12	13:44:36.492	SLM 2	odporové 400 $\Omega$	vyladěno	10,8	12,6	3,8	7,0	5,5	ne
14	14:07:46.010	SLM 1	odporové 200 $\Omega$	vyladěno	14,7	16,6	x	x		ne

## CONCLUSION

### Evaluation of the FRA system

The WS tests proved the full functionality of the deployed FRA system (centralization of fault records, communication infrastructure, SW module functions and their integration on the FRA server). The deviations of the estimated and actual fault earth current range from 10 A to – 8.7 A, where the estimated value is less than the actual value. These deviations are caused both by the influence of the charging capacities at the affected outlet and by the measurement uncertainty, as the residual current in this case is extremely low, i.e. about 0.33% of the rated current, which is significantly below the measurement uncertainty of the instrumented current transformers. Residual current estimation allows to get an idea of the residual current level, despite the stated average deviations of the estimated current of 3.2 A. In the case of higher residual currents, which also have a higher impact on the assessment of the fault hazard, significantly lower deviations of the estimated values can be expected.

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