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

Summary report from the experimental measurement

Project number: TK04020187

Project name: Development of a system for locating faults Vdip of the 2nd generation

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Summary report of the 2024 experimental measurement

Content

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 Ω (measured at a soil resistivity of 50 Ωm). 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

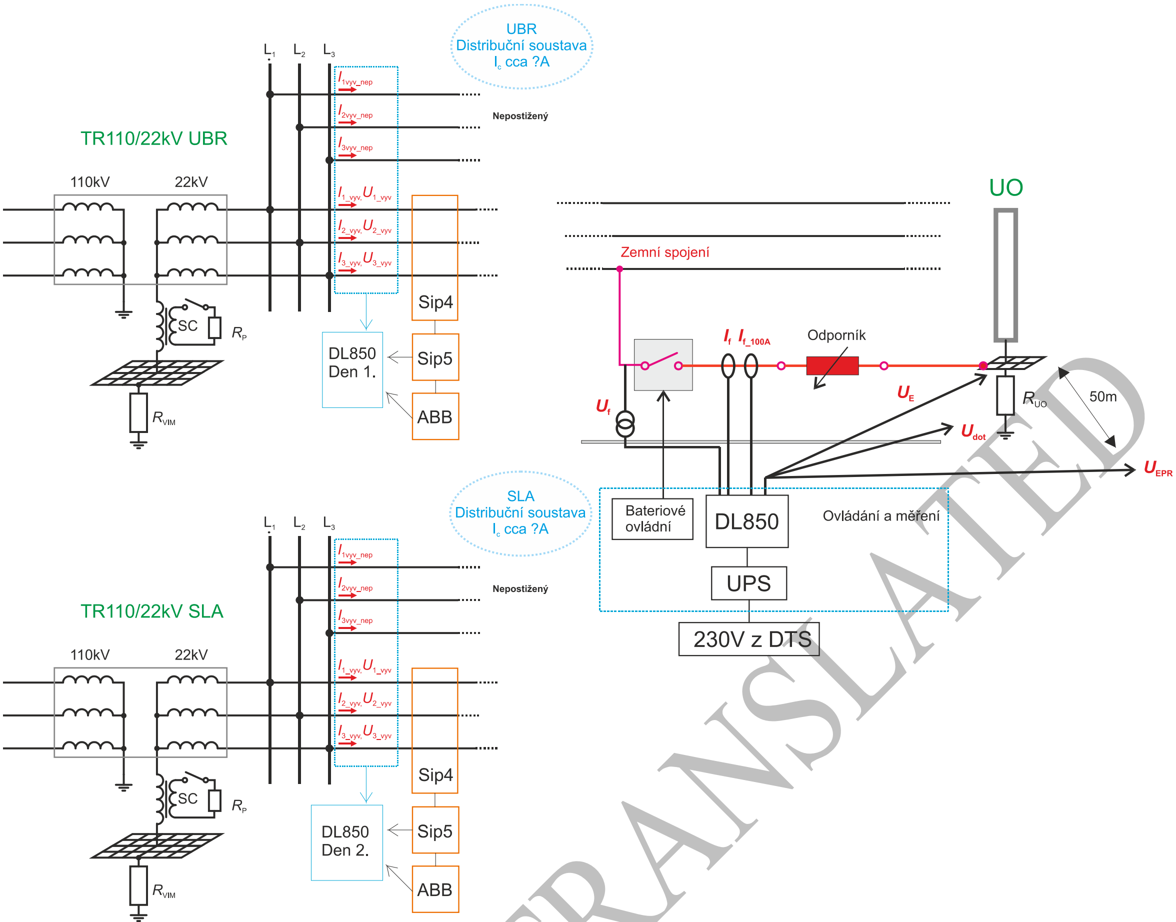
Test number	***Time: 22.10.2024***	***Involvement***	***Type ZS***	***Tune-up***
1a	09:47:58.202	UBR 1	Metal	Fine-tuned
1b	10:04:44.747	UBR 1	Metal	Fine-tuned
1c	10:19:35.701	UBR 1	Metal	Fine-tuned
2	10:51:06.661	UBR 1	Metal	tuned -7.2A
3	11:03:06.925	UBR 1	Metal	tuned -10A
4	11:24:22.122	UBR 1	Metal	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 Ω	Fine-tuned
11	13:43:03.911	UBR 2	resistance 1200 Ω	Fine-tuned
12	14:15:01.854	UBR 2	resistive 400 Ω	Fine-tuned
13	14:27:38.621	UBR 1	resistive 400 Ω	Fine-tuned
14	14:47:45.972	UBR 1	resistive 200 Ω	Fine-tuned
15	14:56:21.395	UBR 2	resistive 200 Ω	Fine-tuned
16	15:13:09.621	UBR 2	resistive 100 Ω	Fine-tuned
17	15:23:02.321	UBR 1	resistive 100 Ω	Fine-tuned

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 Ω	Fine-tuned
10b		SLM 1	resistance 1400 Ω	tuned -10A
10c	13:14	SLM 1	resistance 1400 Ω	tuned -10A
11	13:24	SLM 2	resistance 1400 Ω	tuned -5A
12	13:44:36.492	SLM 2	resistive 400 Ω	Fine-tuned
13	13:51:43.533	SLM 1	resistive 400 Ω	Fine-tuned
14	14:07:46.010	SLM 1	resistive 200 Ω	Fine-tuned
15	14:14:52.213	SLM 2	resistive 200 Ω	Fine-tuned
16	14:26:23.084	SLM 2	resistive 100 Ω	Fine-tuned
17	14:32:34.933	SLM 1	resistive 100 Ω	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

Stav			ZS			ZS + R			R_{ZS}
Zapojení	*Test*	*Typ (rozladění)*	I_f	$3xI_{0\_po}$	U_0	I_f	$3xI_{0\_po}$	U_0	
			[A]	[A]	[kV]	[A]	[A]	[kV]	[Ω]
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 Ω	2,3	27,8	9,5	7,1	13,3	3,6	1185,5
UBR 2	11	odporové 1200 Ω	2,1	28,1	9,5	7,2	13,6	3,6	1124,1
UBR 2	12	odporové 400 Ω	2,4	31,4	10,7	11,5	21,0	5,7	505,6
UBR 1	13	odporové 400 Ω	2,5	31,6	10,8	11,9	21,5	5,9	481,8
UBR 1	14	odporové 200 Ω	2,6	33,4	11,4	16,2	29,2	8,3	208,4
UBR 2	15	odporové 200 Ω	3,1	32,2	11,4	16,2	28,6	8,4	201,8
UBR 2	16	odporové 100 Ω	2,7	34,3	11,6	19,0	34,3	9,7	97,1
UBR 1	17	odporové 100 Ω	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 Ω	1,9	28,1	9,0	6,7	8,3	1,5	1551,3
SLM 1	10b	odporové 1400 Ω (-10A)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SLM 1	10c	odporové 1400 Ω (-10A)	5,9	18,5	7,8	8,3	9,7	1,9	1189,9
SLM 2	11	odporové 1400 Ω (-5A)	3,6	27,0	9,7	9,6	11,6	2,2	1001,0
SLM 2	12	odporové 400 Ω	3,6	37,7	11,3	19,2	24,4	4,4	363,3
SLM 1	13	odporové 400 Ω	4,4	38,2	11,1	20,0	25,9	4,6	326,1
SLM 1	14	odporové 200 Ω	n/a	40,4	11,7	n/a	38,4	6,9	n/a
SLM 2	15	odporové 200 Ω	6,0	42,4	11,9	30,6	39,9	7,2	122,5
SLM 2	16	odporové 100 Ω	6,1	42,9	12,1	36,1	47,3	8,6	101,4
SLM 1	17	odporové 100 Ω	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 Evaluation of the Vdip2 system

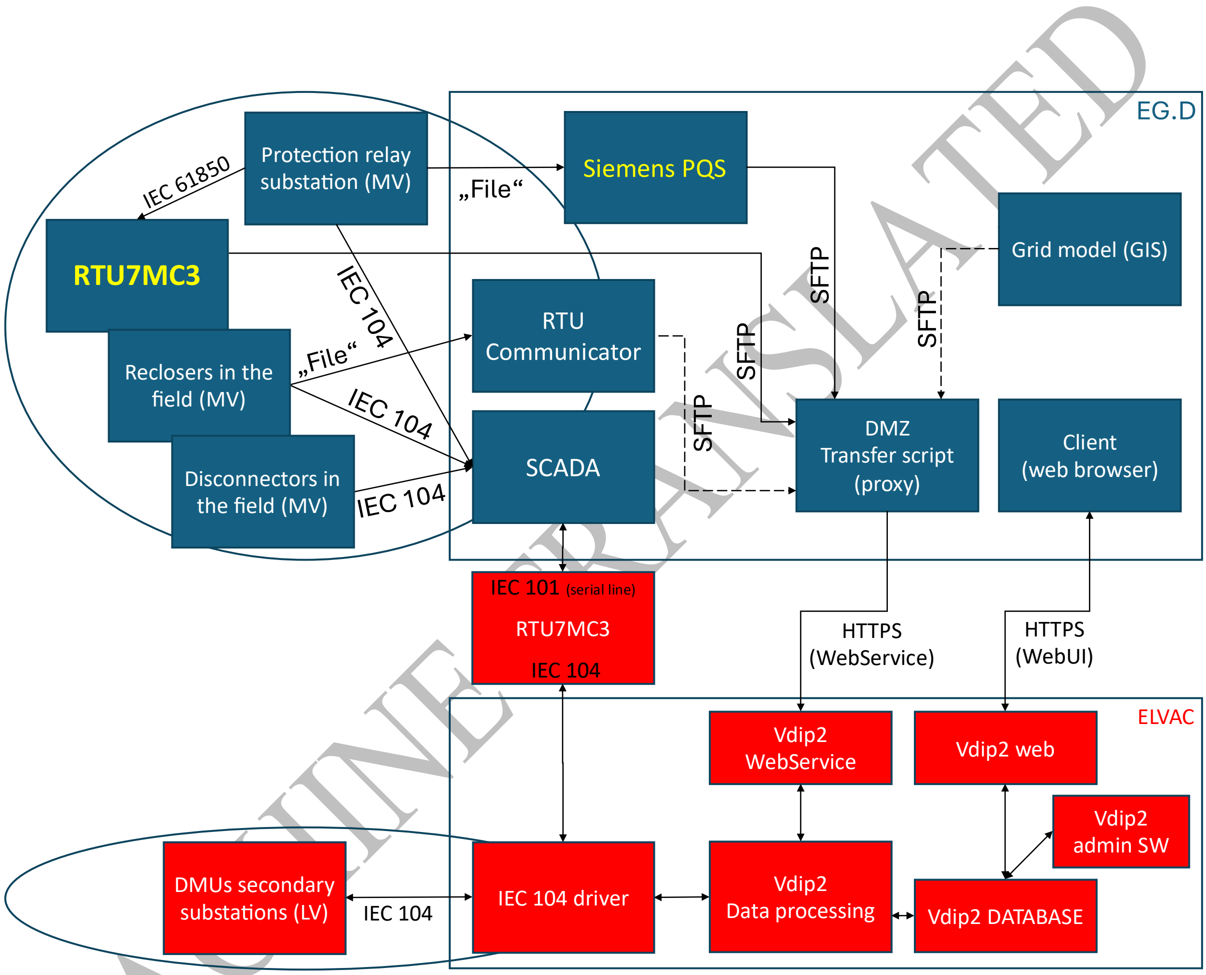
To run algorithms for fault localisation using the Vdip2 method, it is necessary to provide the necessary set of input data in a relatively short time after the occurrence of the fault event. Input data is of several types:

- 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)
- Records from DMUs installed on DTS in the affected area of the distribution network (COMTRADE, acquisition and transmission based on command from the center)

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, where data from DMUs equipped with data SIM cards connected to the same network are also merged. An essential aspect of the solution design was compliance with the principles of cyber security and the operation of the Vdip2 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.



Giant. 3-1: Vdip2 System Communication Diagram

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 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 the purposes of Vdip2, concentrates and transmits fault signals and status information from switching elements in the MV network

8. Grid Model (GIS) ... data describing the physical parameters of the 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 a Vdip2 server operated on ELVAC's infrastructure, using an internet connection

10. Client (web browser) ... the results of fault localization, including supplementary 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. DMUs secondary substations (LV) ... DMU Vdip2 deployed in DTS on selected terminals, these stations create a COMTRADE record with voltage waveforms on the LV side of the transformer at the time of the fault occurring, as well as provide online measurements and data records from the Class S quality meter (use for VQI) and also in connection with the second signal from the GPS phasor values for PMU functionality, Data transmission via mobile data connection

3. IEC 104 driver ... communication driver integrated into the Vdip2 SW package

4. Vdip2 WebService ... a web service designed to receive data provided via the "Transfer script", in particular fault records from protections at outlets from HV substation

5. Vdip2 Data Processing ... algorithms for processing fault records and fault localization using the Vdip2 method

6. Vdip2 Database ... a data repository containing both all configuration, topological and fault data entering the calculations, as well as the results of the processing of these data, including the results of localization

7. Vdip2 Web ... web interface used for visualization and sorting of localization results, including statistical and analytical data

8. Vdip2 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) using the IEC104 protocol to the Vdip2 server. The same data path in the opposite direction can be used to transmit localization results or other measurements and outputs available on the server side.

COMTRADE records from the protections on the outlets in the MV substation are downloaded via RTU7MC3 located at the substation and further transmitted via the "DMZ Transfer script" (communication via the Internet) to the Vdip2 server. Scripts on the DMZ workstation in conjunction with the web service on the Vdip2 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.

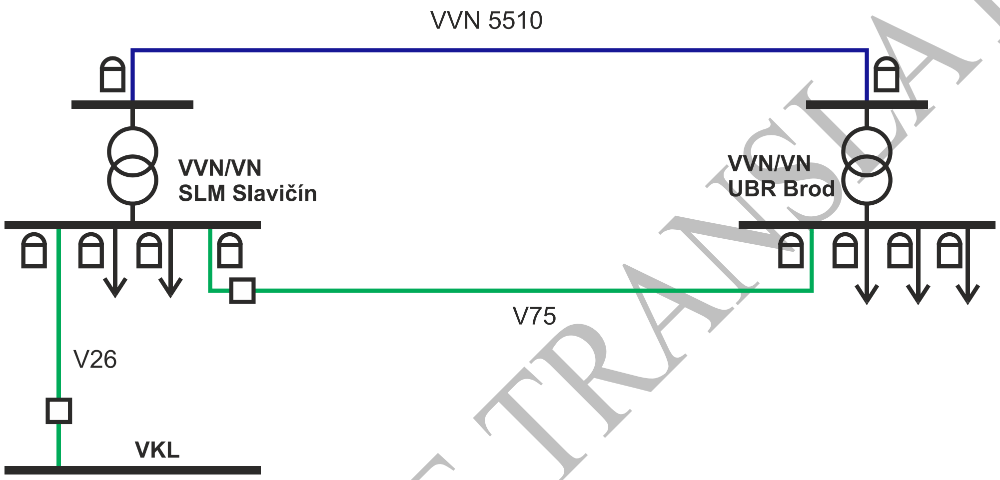
Data from DMUs (measurements, recordings) are transmitted via a mobile data connection (SIM ELVAC) to the communication component "IEC 104 driver" on the Vdip2 server as part of pilot operation. Commands with a timestamp pass the same path in the opposite direction, which is used to create a record in the COMTRADE format using the data in the circular buffer on the DMU side, which is then downloaded to the server.

To display the localization results using a web browser on the side of the distribution system operator, the "Vdip2 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 for the transfer of records in COMTRADE format and other data sets in order to reduce the volume of data transmitted (especially via mobile data connection).

3.2 Real location of parts of the Vdip2 system within the pilot plant

For the purposes of pilot operation, two HV lines (HV 26 and HV75) supplied from the Slavičín (SLM) and Uherský Brod (UBR) substations were selected. The HV26 line is supplied from the Slavičín substation as standard, the VN75 line is supplied from the Uherský Brod substation as standard, but it is also possible to power it from the Uherský Brod substation, which allows the topology to be changed for testing purposes and when two HV lines are equipped with DMU assemblies, the system can be tested on a total of three HV outlets.



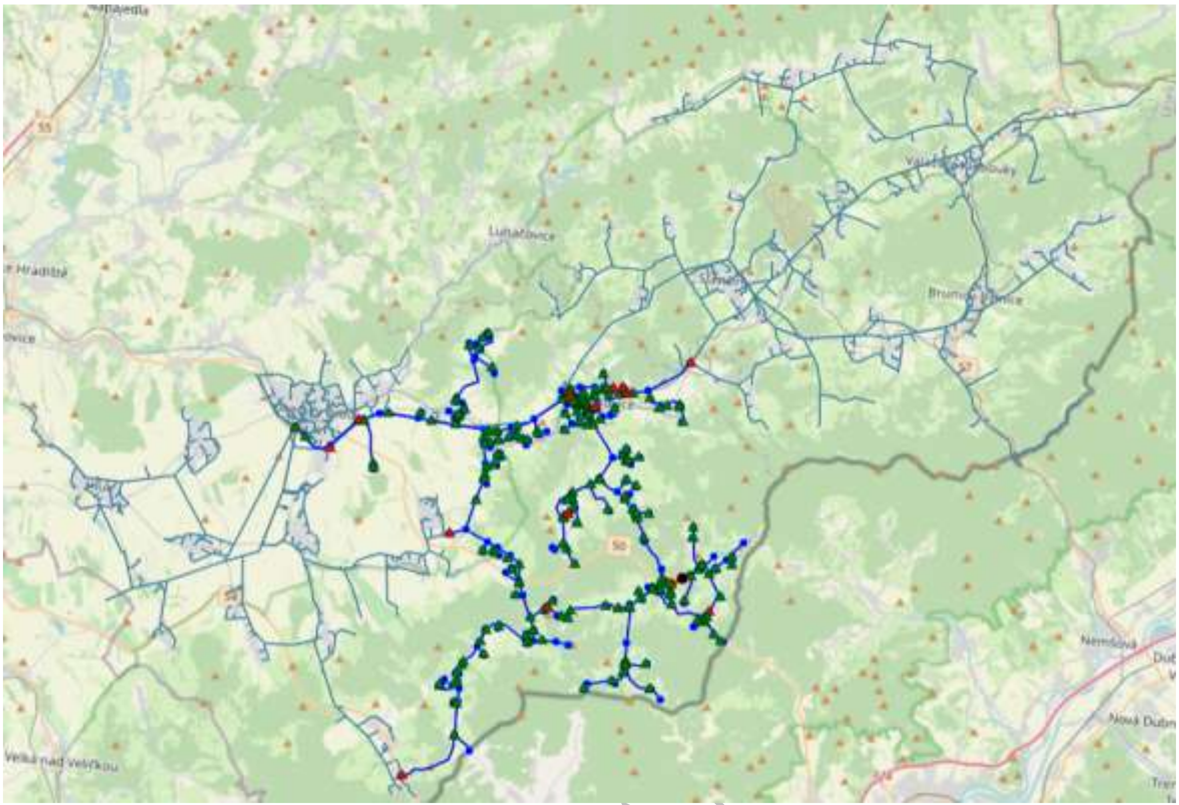
Giant. 3-2: Simplified scheme of the MV system – pilot plant Vdip2

DMU assemblies are installed on a total of 16 DTS, 8 on VN26 and 10 on VN75 - the list is not public.

<u>RTU7MC3 for connection to the SCADA system is installed at the EG headquarters. D in Brno.</u>

<u>The Vdip2 server is located at ELVAC's headquarters in Ostrava.</u>

With regard to the possibilities of development of the Vdip2 system within the area of Uherský Brod + Slavičín, a larger area of the network model has been imported into the Vdip2 system, this area is evident from the figure below, where the richly colored part shows the VN75 outlet powered by UBR, the light-colored area is the available network model.



3.3 Evaluation of the function of the Vdip2 system

During the tests of the ground connections, it was proved that the created infrastructure of the Vdip2 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 Vdip system have already been continuously tested, the evaluation will further focus on assessing the accuracy of the localization of the created earth connections.

The deviation of the result of the localization of the Vdip2 system from the actual location of the fault 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 individual tests, evaluation of localization deviation from the actual fault site:

a) ΔLoc (km) – Tests: Are the original deviations received during the WS tests performed
b) ΔLoc (km) – Fix: Are the deviations received after the error correction identified during the earth fault tests (corresponds to the resulting behavior of the Vdip2 system after the end of development)

c) ΔLoc (km) – Set 2: There are deviations obtained when adjusting the localization method settings with regard to the detected interference (flicker) – the effort was to suppress the influence of flicker on localization by the Vdip system.

Furthermore, the information about the validation of the resulting location of the Loc ERR fault *is yes* (GPS coordinates in the GUI were displayed in red – the localization result is untrustworthy) *no* (GPS coordinates in the GUI were displayed in green – the localization result is trustworthy).

The table also provides information on the magnitude of the reactance to the *fault site Xfault* and Distances to fault *Distance* (km).

Tab. 3-1 Evaluation of Ground Fault Localization with Vdip2 for UBR-Powered Tests

Test číslo	***Čas 22.10.2024***	***Zapojení***	***Typ ZS***	***Naladění***	***ΔLoc (km) Testy***	***ΔLoc (km) Oprava***	***ΔLoc (km) Set 2***	***Loc ERR***	***Vzdálenost (km)***	***X_{faul} (Ω)***	***Pila rušení***
1a	09:47:58.202	UBR 1	kovové	vyladěno	0,84	**0,84**	0,84	ne	26,45	11,84	ne
1b	10:04:44.747	UBR 1	kovové	vyladěno		**0,84**		ne	26,45	11,84	ne
1c	10:19:35.701	UBR 1	kovové	vyladěno	1,24	**1,24**	1,24	ne	26,05	11,44	ano
2	10:51:06.661	UBR 1	kovové	podladěno -7,2A	3,17	**3,17**	3,17	ano	24,12	9,84	ano
3	11:03:06.925	UBR 1	kovové	podladěno -10A	1,24	**1,24**	1,24	ne	26,05	11,44	ne
4	11:24:22.122	UBR 1	kovové	přeladěno +5A	0,84	**0,84**	0,84	ne	26,45	11,84	ne
5	11:33:44.237	UBR 1	kovové	přeladěno +12A	1,63	**1,63**	1,63	ne	25,66	11,05	ne
6	11:44:03.805	UBR 2	kovové	vyladěno	0,83	**0,83**	0,83	ne	28,01	13,59	ne
7	12:14:58.781	UBR 2	obloukové	vyladěno	0,83	**0,83**	0,83	ne	28,01	13,59	ne
8a	12:33:23.391	UBR 2	obloukové	podladěno -5A	10,50	**10,50**	2,45	ne	29,50	10,37	ano
8b	12:46:43.731	UBR 2	obloukové	podladěno -5A	6,89	**6,89**	6,89	ne	25,90	9,91	ano
9	12:56:03.765	UBR 1	obloukové	Vyladěno	0,84	**0,84**	0,84	ne	26,45	11,84	ne
10	13:28:38.765	UBR 1	odporové 1200 Ω	vyladěno		**4,28**	4,28	ano	23,01	4,28	ne
11	13:43:03.911	UBR 2	odporové 1200 Ω	vyladěno	8,70	**8,70**	4,10	ne	27,70	11,10	ano
12	14:15:01.854	UBR 2	odporové 400 Ω	vyladěno	10,78	**10,78**	10,78	ne	29,79	10,26	ne
13	14:27:38.621	UBR 1	odporové 400 Ω	vyladěno	0,83	**0,83**	0,83	ne	28,01	12,73	ne
14	14:47:45.972	UBR 1	odporové 200 Ω	vyladěno	1,43	**1,43**	1,43	ne	25,85	11,25	ne
15	14:56:21.395	UBR 2	odporové 200 Ω	vyladěno	0,84	**0,84**	0,65	ne	26,45	12,69	ne
16	15:13:09.621	UBR 2	odporové 100 Ω	vyladěno	0,64	**0,64**	0,64	ne	27,82	13,56	ne
17	15:23:02.321	UBR 1	odporové 100 Ω	vyladěno	0,84	**0,84**	0,84	ne	26,45	11,84	ne

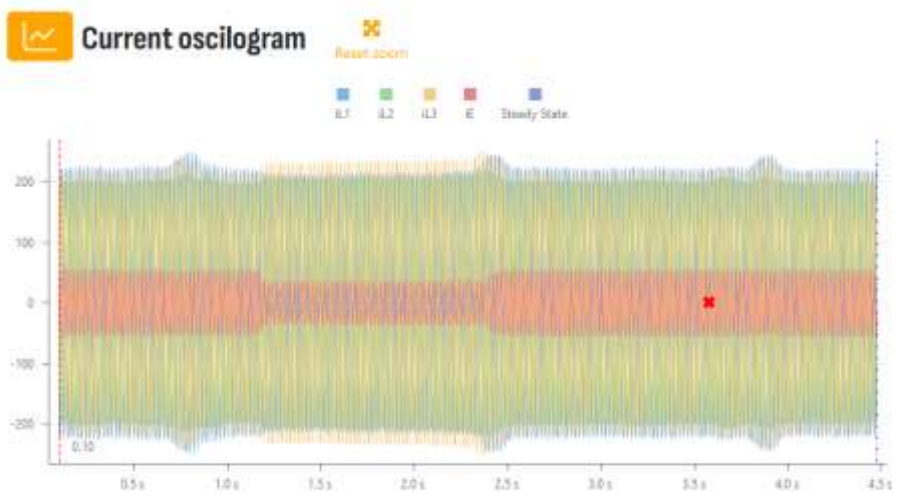
Tab. 3-2 Evaluation of Ground Fault Localization with Vdip2 for SLM-Powered Tests

Test číslo	Čas 22.10.2024	Zapojení	Typ ZS	Naladění	ΔLoc (km) Testy	ΔLoc (km) Oprava	ΔLoc (km) Set 2	Loc ERR	Vzdálenost (km)	X_{faul} (Ω)	Pila rušení	Jen R_n
1	10:23:39.203	SLM 1	kovové	vyladěno	0,25	**0,25**	0,25	ne	27,00	14,64	ne	ano
2	10:36:10.674	SLM 1	kovové	podladěno -5A	1,04	**1,04**	0,63	ne/ano	26,21	13,85	ano	ano
3a	10:42	SLM 1	kovové	podladěno -12A	Nepřišel signál ZS - výpadek zdroje RIS							
3b	11:05:25.472	SLM 1	kovové	podladěno -12A	0,25	**0,25**	0,25	ne	27,00	14,64	ne	ano
4	11:13:39.310	SLM 1	kovové	přeladěno +5A	1,04	**1,04**	1,04	ne	26,21	13,85	ne	ano
5	11:24:21.790	SLM 1	kovové	přeladěno +12A	18,96	**0,01**	0,01	x	7,16	2,59	ne	ano
6	11:33:15.033	SLM 2	kovové	vyladěno	0,25	**0,25**	0,25	ne	27,00	12,11	ne	ano
7	12:13:07.662	SLM 2	obloukové	vyladěno	0,83	**0,83**	0,83	ne	27,98	12,42	ano	ano
8	12:20:45.904	SLM 2	obloukové	podladěno -10A	0,44	**0,44**	0,44	ne	26,80	11,92	ano	ano
9	12:28:48.580	SLM 1	obloukové	Vyladěno	0,63	**0,63**	0,63	ne	27,78	14,92	ne	ano
10a		SLM 1	odporové 1400 Ω	vyladěno	nesignalizováno vývodovou ochranou							
10b		SLM 1	odporové 1400 Ω	podladěno -10A	nesignalizováno vývodovou ochranou							
11		SLM 2	odporové 1400 Ω	podladěno - 5A	nesignalizováno vývodovou ochranou							
12	13:44:36.492	SLM 2	odporové 400 Ω	vyladěno	2,61	**2,61**	2,61	ne	24,64	9,75	ano	ano
13	13:51:43.533	SLM 1	odporové 400 Ω	vyladěno	8,52	**8,52**	8,03	x	24,66	13,66	ano	ano
14	14:07:46.010	SLM 1	odporové 200 Ω	vyladěno	0,44	**0,44**	0,44	ne/ano	26,80	14,45	ano	ano
15	14:14:52.213	SLM 2	odporové 200 Ω	vyladěno	0,25	**0,25**	0,25	ne	27,00	12,11	ano	ano
16	14:26:23.084	SLM 2	odporové 100 Ω	vyladěno	0,64	**0,64**	0,64	ne	26,61	11,72	ne	ano
17	14:32:34.933	SLM 1	odporové 100 Ω	vyladěno	0,64	**0,64**	0,64	ne	26,61	14,25	ne	ano

Evaluation of the accuracy of locating ground connections

As expected, the deviations in the location of the WS were up to about 1.5 km in most cases, while in a few cases (yellow in Tab. 3-1 and Tab. 3-2) the localization result jumped to another part of the DS. After a more detailed analysis, it was found that there is a significant source of flicker at the VN75 outlet, the value of which exceeds the permitted level by three times. The source of this interference is located in the area of Starý Hrozenkov (DTS Pila). Since this interference causes much more significant voltage events than the actual ground fault and the Vdip2 system is designed to localize the source of asymmetry, the localization results in the given source of interference in cases where the actual interference occurs at the time of the fault. Information whether interference occurred during the tests is provided in the Tab. 3-1 and Tab. 3-2 in the column *Saw Interference*.

An example of the effect of interference is shown in the figure below – the consumption currents at the affected outlet.



Giant. 3-3: Example of interference effect 13:51:43.533 - resistive 400 Ω SLM1

The influence of this source of interference on the voltage quality can be demonstrated and identified using the VQI card of the Vdip2 system.

<u>*Localization Accuracy*</u>

- **The average localization error over all faults was 2.16 km (1.8 km after adjusting the settings)**
- **localization was affected by a high level of flicker** (4 times exceeding the limit) – shifting the fault point to the location of the source of interference (the system locates the source of interference) – such a high level is undesirable in the HV/LV system
- **excluding extremes** (5x jump to the Starý Hrozenkov area due to interference), **the average localization error is 1km**

More detailed information about individual failure events is provided in the user interface of the Vdip2 system, below Giant. 3-4 and Giant. 3-5 summary localization results for the power supply status from UBR and SLM are given (green circle indicates the actual fault location).

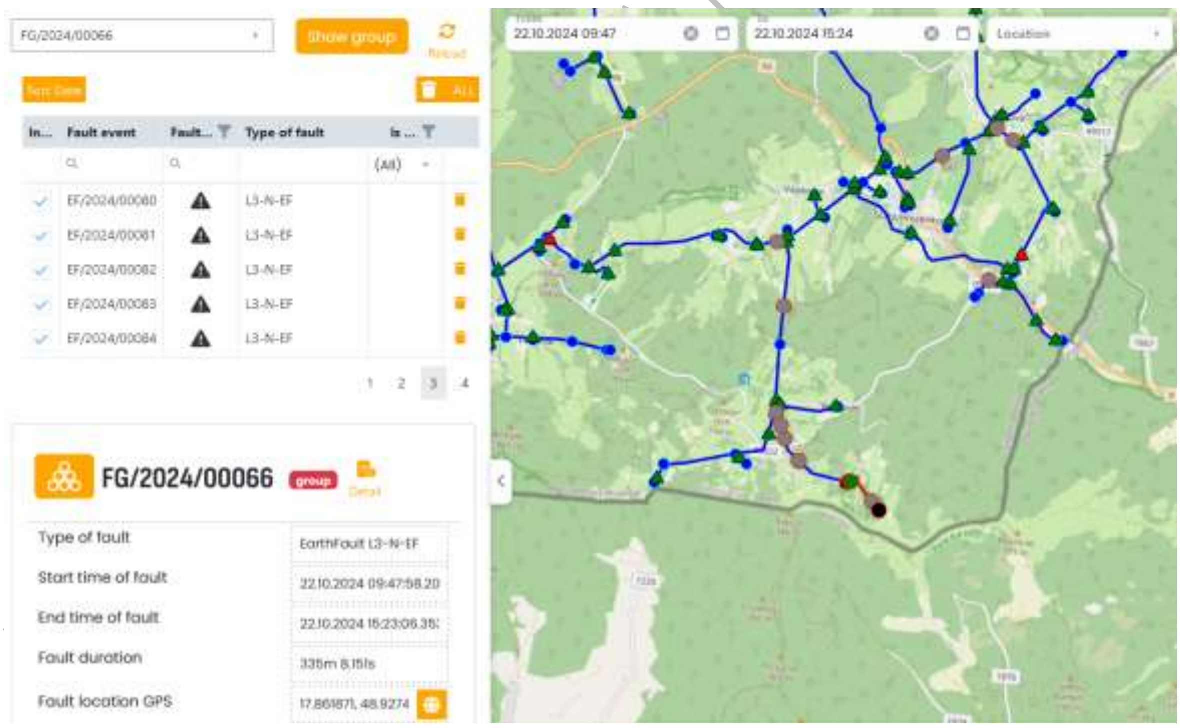
With regard to very good localization results, it is also necessary to take into account the extremely low penetration of DMU, which reduces the accuracy and sensitivity of localization:

- Number of line sections: 973 (424 HV 26 + 549 HV 75)
- Total length of line sections: 233 km
  (84 km VN26 + 149 km VN 75)

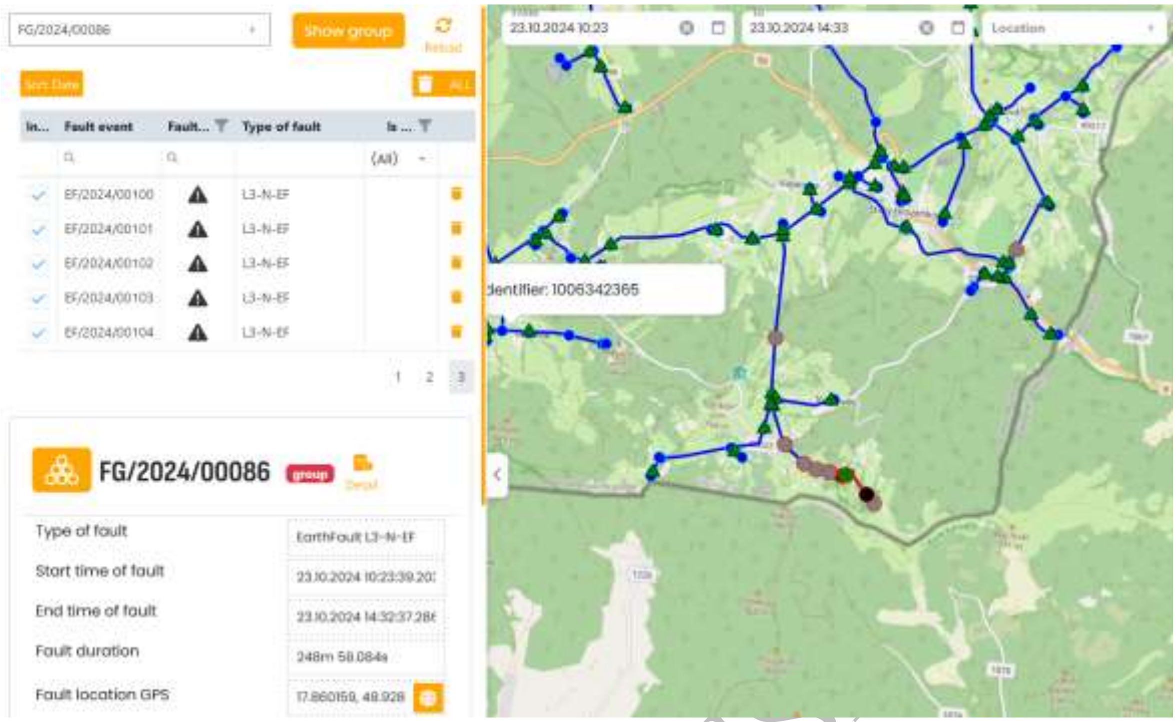
- Number of nodes (approx.) 968 of which 279 DTS
- 393 breakdown points
- topologically complex outlets VN75 and VN26 use only 18 DMUs – approx. 6.5 % of DMU penetration Vdip ready – 8 DMUs cover 233 km of lines

In the target deployment of the Vdip system, penetration by DMUs Vdip ready units can be expected to be about 60%, which is 10 times more than in the tests. Such a significant increase in DMU units will significantly increase the sensitivity and accuracy of fault localisation, **so much smaller deviations in fault localisation can be expected.**

With regard to these facts, it is recommended to perform more comprehensive tests at the target penetration of DMU units integrated into the Vdip system, and it would be appropriate to add these tests to the localization of non-congruent faults and short-circuit failures (significantly higher accuracy is expected in the case of short circuits – hundreds of meters)



Giant. 3-4: Fault localization results during the first day of testing – power supply from the UBR substation



Giant. 3-5: Fault localization results during the first day of testing – power supply from the SLM substation

CONCLUSION

Evaluation of the Vdip2 system

- **WS tests proved the full functionality of the deployed Vdip2 system** (centralization of fault records, communication infrastructure, HW components, HV outlet model, individual SW modules and the implemented Vdip method)

- During the test, only a few serious bugs were detected, which have already been mostly fixed in the respective modules

- numerical models of outlets outside VN75 and VN26 (Vdip system deployed) have not been validated and may show errors (affecting FRA localization on HV outlets) – localization on these outlets was not a priority of pilot operation

Localization accuracy with Vdip2

- **The average localization error over all faults was 2.16 km (1.8 km after adjusting the settings)**

- **localization was affected by a high level of flicker** (4 times exceeding the limit) – shifting the fault point to the location of the source of interference (the system locates the source of interference) – such a high level is undesirable in the HV/LV system

- **excluding extremes** (5x jump to the Starý Hrozenkov area due to interference), **the average localization error is 1km**

With regard to very good localization results, it is also necessary to take into account the extremely low penetration of DMU, which reduces the accuracy and sensitivity of localization:

- Number of line sections: 973 (424 HV 26 + 549 HV 75)
- Total length of line sections: 233 km
 (84 km VN26 + 149 km VN 75)
- Number of nodes (approx.) 968 of which 279 DTS
- 393 breakdown points
- topologically complex outlets VN75 and VN26 use only 18 DMUs – approx. 6.5 % of DMU penetration Vdip ready – 8 DMUs cover 233 km of lines

In the target deployment of the Vdip system, penetration by DMUs Vdip ready units can be expected to be about 60%, which is 10 times more than in the tests. Such a significant increase in DMU units will significantly increase the sensitivity and accuracy of fault localisation, **so much smaller deviations in fault localisation can be expected.**

With regard to these facts, it is recommended to perform more comprehensive tests at the target penetration of DMU units integrated into the Vdip system, and it would be appropriate to add these tests to the localization of non-congruent faults and short-circuit failures (significantly higher accuracy is expected in the case of short circuits – hundreds of meters)